THEORY, RESEARCH AND DISCUSSIONS IN SOCIAL SCIENCES, HUMANITIES AND ADMINISTRATIVE SCIENCES

Editor
Assoc. Prof. Dr. Türker BATMAZ

DUVAR

THEORY, RESEARCH AND DISCUSSIONS IN SOCIAL SCIENCES, HUMANITIES AND ADMINISTRATIVE SCIENCES

Editor

Assoc. Prof. Dr. Türker BATMAZ

Theory, Research and Discussions in Social Sciences, Humanities and Administrative Sciences

Editor
Assoc. Prof. Dr. Türker BATMAZ

General Director: Berkan Balpetek
Cover and Page Design: Duvar Design
Printing : 30 September-2026
Publisher Certificate No: 49837
E-ISBN: 978-625-8936-97-1

© **Duvar Yayınları**
853 Sokak No:13 P.10 Kemeraltı-Konak/İzmir
Tel: 0 232 484 88 68
www.duvaryayinlari.com
duvarkitabevi@gmail.com

*"The authors bear full responsibility for the sources, opinions, findings, results, tables, figures, images, and all other content presented in the chapters of this book. They are solely accountable for any financial or legal obligations that may arise in connection with national or inter*national copyright regulations.The publisher and editors shall not be held liable under any circumstances"

TABLE OF CONTENTS

Chapter 1 1
Energy-Price Shocks, Exchange-Rate Vulnerability, and Food-Price Resilience in Türkiye: Implications for Sustainable Agricultural Finance
Arzu ALVAN, Abia Njang SPONGEON

Chapter 2 32
The Red Sea Disruption and Europe-Asia Trade:
Evidence from Monthly Bilateral Import Flows
Bilal ORHAN, Muhammed BENLİ

Chapter 3 46
Geopolitical Fragmentation and Limited Friend-Shoring in Semiconductor Trade
Bilal ORHAN, Muhammed BENLİ

Chapter 4 61
Teaching the Sustainable Development Goals in Early Childhood: A Developmental Perspective from the TEACH SDG İzmir Project
F. Cansu PALA

Chapter 5 80
Different Approaches to Optimizing the Delivery Process in Supply Chain Management: A Comparative Analysis
Emre EKİN, Ayça EGE

Chapter 6 103
School-Mediated Affective Class Reorientation In Childhood: A Theoretical Reading Of Annie Ernaux's *Les Armoires Vides*
Güher Ceylan KUŞOĞLU

Chapter 7 124
The Relationship Between Real Oil Prices and Unemployment In Turkiye:
A Toda–Yamamoto Causality Test
Günay ÖZCAN, Mahmut Sami DURAN

Chapter 8 145
The Validity of The J-Curve Phenomenon in Global Service Trade: An
Empirical Appraisal
Kadir KARAGÖZ, İlyas Mert OKUMUŞ

Chapter 9 166
Artificial Intelligence and Digital Transformation
Strategies In Turkish Banks: A Content Analysis Of Integrated Annual Reports
Nuray ISLATINCE

Chapter 1

Energy-Price Shocks, Exchange-Rate Vulnerability, and Food-Price Resilience in Türkiye: Implications for Sustainable Agricultural Finance

Arzu ALVAN[1], Abia Njang SPONGEON[2]

Abstract

Background: Türkiye's agricultural sector is structurally exposed to global energy markets: the country imports most of its crude oil and natural gas, and many agricultural inputs—fertiliser, machinery fuel, and feed—are imported or priced in foreign currency. Oil-price shocks therefore propagate through farm costs, logistics, and the exchange rate to retail food prices, generating welfare losses and financial stress along the value chain.

Methods: Using monthly data from January 2016 to April 2022 (T = 76), the study applies a nonlinear autoregressive distributed lag (NARDL) model that decomposes Brent crude-oil prices into positive and negative partial sums. Controls include the agricultural input price index, the nominal lira–dollar exchange rate, and the consumer price index.

Results: The long-run elasticity of food prices with respect to oil-price increases is 0.369, against 0.127 for decreases—a directionally meaningful gap consistent with the 'rocket-and-feather' pattern. Formal Wald tests do not reject symmetry, however, and diagnostics signal serial correlation and a functional-form concern, warranting caution. The exchange rate is the dominant short-run driver of food prices.

Implications: The findings support financing and policy responses that target energy-price vulnerability in Turkish agriculture, including renewable-energy investment, energy-efficiency lending, risk-sensitive credit, and infrastructure that reduces dependence on imported energy and foreign-currency inputs.

Keywords: *Oil-food price nexus; asymmetric pass-through; nonlinear ARDL; exchange-rate vulnerability; sustainable agricultural finance; Türkiye*

[1] (Corresponding Author)
Email: alvanarzu@gmail.com | ORCID: 0000-0003-2183-0209
Cyprus Aydın University, Faculty of Humanities and Social Sciences, Northern Cyprus
[2] Email: anjangspongeon@csu.edu.tr | ORCID: 0009-0005-5434-5703
Cyprus Aydın University, Faculty of Humanities and Social Sciences, Northern Cyprus
Book Chapter Draft · September 2026

Conceptual Transmission Mechanism

- Global crude-oil price shock (supply disruption, geopolitical tension, demand surge)
- Direct farm-level energy costs rise (diesel for machinery and irrigation, electricity for pumps and cold storage)
- Agricultural input cost transmission (fertiliser, agrichemicals priced off energy markets)
- Lira depreciation amplifies all import costs (exchange-rate channel: dollar-invoiced energy and inputs become costlier in domestic currency)
- Transport and logistics cost inflation (refrigerated freight, long-distance haulage)
- Retail food-price adjustment (asymmetric: faster and larger upward response, slower and smaller downward response—the 'rocket-and-feather' effect)

Note: This text box replaces a graphical abstract, which cannot be faithfully reproduced from available source material.

1. Introduction

The co-movement of energy and food prices has long posed policy challenges for emerging markets, and the transition away from fossil fuels adds a further layer of complexity. In the near term, any disruption to energy supply or sharp energy-price spike feeds almost immediately into the cost structures of energy-intensive food systems. In the longer term, the pace and financing of the energy transition itself determine how quickly agricultural systems can reduce their dependence on imported fossil fuels. For net energy-importing emerging markets, this dual challenge—short-term price volatility and long-term structural transformation—is especially acute. Global agendas on climate mitigation, food-system resilience, and sustainable finance increasingly recognise that energy shocks are not confined to the energy sector: they reshape farm-gate costs, logistics margins, household real incomes, and the risk profiles of agricultural credit portfolios.

Against that backdrop, the design of agricultural finance can no longer treat energy prices as an exogenous background condition. When diesel, fertiliser, cold storage, and long-distance freight are material cost components, energy-price volatility becomes a source of financial vulnerability for producers, processors, traders, and lenders. Instruments that reduce exposure to imported energy and foreign-currency inputs—renewable-energy investment on farms, energy-efficiency lending, storage and logistics finance, and risk-sensitive credit design—therefore sit at the intersection of energy transition policy and

agricultural development finance. The analytical task is to understand how energy shocks reach food prices in a particular institutional setting, and what that transmission implies for the architecture of sustainable agricultural finance.

Türkiye offers a particularly instructive case. The country imports the great majority of its crude oil and natural gas (IEA, 2021). Agricultural production, distribution, and retail are heavily reliant on imported or import-priced inputs, including diesel for machinery and irrigation, fertiliser whose principal feedstock is natural gas, and refrigerated logistics. The Turkish lira has experienced sharp and repeated depreciation episodes, amplifying every external cost shock into domestic price inflation. Food and non-alcoholic beverages account for roughly one quarter of the consumer price index (TÜİK, 2022), and food inflation has repeatedly outpaced general inflation over the period examined in this chapter, imposing disproportionate welfare costs on lower-income households. Understanding what drives this relationship, and what can be done about it through both policy and finance, is therefore a matter of considerable practical urgency.

The structural features of the Turkish agri-food system reinforce this urgency. Farm enterprises face energy costs not only at the point of production but throughout the post-harvest chain. Cold chains for perishables are electricity-intensive; long-distance freight between rural production zones and urban consumption centres is diesel-intensive; and food-processing industries are gas- and electricity-intensive. Because many of these energy and intermediate inputs are invoiced in foreign currency, exchange-rate movements act as a multiplier of global price shocks. In such an environment, episodes of simultaneous oil-price increases and lira depreciation can generate rapid retail food-price spikes even when domestic agricultural supply conditions are relatively stable. The cumulative increase in retail food prices since the late 2010s ranks among the steeper trajectories recorded across OECD economies (OECD/FAO, 2022), underscoring the macroeconomic and social salience of the energy–food nexus in Türkiye.

While the relationship between international oil prices and domestic food prices has attracted substantial scholarly attention, standard linear models impose symmetric pass-through—the assumption that a price decrease lowers food costs by exactly as much as an equivalent increase raises them. Casual observation of Turkish markets, and a growing body of asymmetric-transmission research using nonlinear autoregressive distributed lag (NARDL) methods, suggests otherwise: food prices tend to rise sharply when input costs surge but adjust downward only sluggishly (Meyer & von Cramon-Taubadel, 2004; Peltzman, 2000; Shin et al., 2014). This “rocket-and-feather” asymmetry, if present, has direct implications

for the design of food-price stabilisation policy and for the structuring of risk in agricultural lending portfolios. A linear specification cannot capture such behaviour and risks understating the inflationary danger of upward oil shocks (Ibrahim, 2015; Pal & Mitra, 2019).

This chapter applies a NARDL model to monthly data spanning January 2016 to April 2022 (T = 76) to examine how positive and negative Brent crude-oil price shocks transmit to a correctly constructed composite food price index in Türkiye, with the exchange rate and agricultural input costs as key controls. The analysis corrects a data-construction problem present in earlier work, in which seven commodity series had been stacked as a single column rather than averaged into a consistent monthly composite. The empirical findings are then extended into a structured discussion of their implications for sustainable agricultural finance—a domain that the existing Turkish case-study literature has not yet addressed systematically. The chapter does not claim that the econometric model directly estimates agricultural credit, climate risk, green bonds, or renewable-energy adoption. Rather, it distinguishes carefully between (a) the direct empirical evidence on oil prices, exchange rates, agricultural inputs, and food prices, and (b) the broader sustainable-agricultural-finance implications derived cautiously from that evidence and from verified literature.

The chapter makes three academic contributions. First, it offers a methodologically careful NARDL re-estimation for Türkiye that corrects the earlier data-aggregation procedure, isolates the Brent benchmark to avoid near-perfect collinearity with West Texas Intermediate (WTI), and reports the full battery of bounds, asymmetry, diagnostic, and causality tests. Second, it documents the exchange-rate channel as the dominant short-run driver of food prices, situating energy shocks within a broader imported-input and currency-vulnerability framework. Third, it provides what is, to the authors' knowledge, the first systematic bridging of the Turkish energy–food price evidence with the sustainable agricultural finance literature, translating empirical pass-through findings into a coordinated policy and financing architecture. The remainder of the chapter is organised as follows. Section 2 maps Türkiye's energy–food–finance vulnerability. Section 3 reviews the literature and sets out the analytical framework. Section 4 describes the data, variables, and empirical strategy. Section 5 presents the empirical findings. Section 6 discusses implications for financial resilience. Section 7 outlines a policy architecture for Türkiye. Section 8 addresses limitations and future research. Section 9 concludes.

2. Türkiye's Energy–Food–Finance Vulnerability

Türkiye satisfies the large majority of its energy needs through imports (IEA, 2021). In agriculture, diesel powers tractors, irrigation pumps, and refrigerated transport; natural gas underpins fertiliser production; and electricity—whose wholesale price tracks natural gas—runs cold storage and food-processing facilities. When global crude-oil prices rise, Turkish farm-gate costs rise in tandem, through both the direct fuel bill and the cost of fertiliser and agrichemicals whose prices are indexed to global energy markets (Bor & Dagistan, 2024; Nazlioglu & Soytas, 2012; Taghizadeh-Hesary et al., 2019). The pass-through is reinforced by a concentrated logistics and retail sector in which energy costs represent a material share of operating expenses. For a net energy importer, therefore, international oil-price movements are not a distant commodity-market phenomenon: they are a proximate determinant of the cost structure of domestic food production and distribution.

The agricultural cost structure is particularly exposed because energy enters at multiple points along the value chain. At the farm level, mechanised operations and irrigation depend on diesel and electricity. Fertiliser, a critical yield-enhancing input, is tightly linked to natural-gas markets through ammonia synthesis, so that energy-price spikes translate into higher unit costs of plant nutrition. Agrichemicals and imported feed components add further foreign-currency exposure. These cost pressures do not remain confined to primary production. They cascade into processing, packaging, and wholesale margins, and ultimately into retail prices. Baumeister and Kilian (2014) distinguish direct cost channels, biofuel-related demand channels, and broader macroeconomic channels; for Türkiye, the direct cost and exchange-rate channels dominate, while the biofuel channel is of secondary importance relative to energy-importing economies with large domestic ethanol or biodiesel programmes.

Because energy imports and many agricultural inputs are invoiced in US dollars, the Turkish lira–dollar exchange rate acts as a critical multiplier of external cost shocks. A period of lira depreciation—of which Türkiye experienced several pronounced episodes between 2016 and 2022—raises the domestic cost of every dollar-denominated import instantaneously, before any global price movement occurs. Lira depreciation therefore transmits globally stable oil prices into domestically rising food prices, and amplifies any simultaneous increase in the global price level. The exchange rate thus occupies a central position in the energy–food transmission chain in Türkiye, a role that the empirical analysis in subsequent sections confirms quantitatively. Related Turkish evidence places exchange-rate movements among the strongest proximate drivers of food inflation, particularly during periods of currency

turbulence and pandemic-related disruption (Akcelik & Ozmen, 2022; Akkus, 2022; Karakas & Akcay, 2022).

Beyond the farm gate, energy costs pervade the agri-food supply chain. Cold chains for perishables—meat, dairy, fish—are electricity-intensive; long-distance freight between rural production zones and urban consumption centres is diesel-intensive; and food-processing industries such as milling, oil extraction, and canning are gas- and electricity-intensive. Supply-chain disruptions—whether from fuel-price surges or from logistical bottlenecks such as those experienced during the COVID-19 pandemic—can generate rapid retail price spikes even when farm-gate commodity prices are unchanged. These features compound the volatility of domestic food prices and increase the difficulty of predicting and managing food-price risk. Storage capacity, transport efficiency, and the spatial organisation of wholesale markets therefore matter not only for physical food security but also for the financial stability of enterprises operating along the chain.

The household welfare consequences of food-price volatility are asymmetric across income groups. Because food accounts for a substantially higher share of expenditure for lower-income households, food inflation imposes a disproportionate real-income burden on the most vulnerable segments of the population (OECD/FAO, 2022). Nutritional substitution—shifting away from protein-rich and nutrient-dense foods towards cheaper staples—carries long-term human capital costs. These welfare effects also translate into macroeconomic risks: elevated food inflation feeds into wage demands, reinforces inflation expectations, and complicates monetary policy, further tightening the financial environment for agricultural credit. In an economy where food and non-alcoholic beverages constitute roughly one quarter of the consumer price index (TÜİK, 2022), food-price dynamics are inseparable from the broader inflation process and from the credibility of macroeconomic management.

These structural vulnerabilities make a compelling case for systemic reform in how agricultural finance is structured and priced in Türkiye. Agricultural lenders exposed to food-producing enterprises effectively carry concentrated energy-price risk and foreign-exchange risk that are not always adequately captured in conventional credit-risk assessments. At the same time, investments in renewable energy—such as solar irrigation and biogas—and in energy-efficient technologies, including precision agriculture and insulated storage, can measurably reduce operating-cost exposure for farm enterprises. Such investments, however, require patient, risk-appropriate financing instruments. The rationale for sustainable agricultural finance is therefore not only environmental but also financial: it directly addresses the structural cost

vulnerabilities that the empirical analysis makes visible. Distinguishing immediate price-stabilisation measures from medium- and long-term structural transition finance is essential if policy is to avoid treating energy shocks solely as temporary disturbances rather than as symptoms of deeper import dependence.

In short, Türkiye's energy–food–finance nexus is characterised by high imported-energy intensity in agriculture, strong exchange-rate amplification of external cost shocks, energy-intensive logistics and storage, socially regressive food-inflation effects, and incomplete incorporation of these risks into agricultural credit design. The remainder of this chapter develops the empirical evidence on oil-price and exchange-rate pass-through and then translates that evidence into a coordinated policy and financing architecture.

3. Literature Review and Analytical Framework

3.1 Energy-to-food price transmission

Baumeister and Kilian (2014) provide the canonical taxonomy of the pathways through which crude-oil prices influence food prices. They distinguish a direct cost channel operating through energy-intensive agricultural production, a biofuel channel linking the demand for grains to ethanol and biodiesel production, and a set of indirect channels working through global demand, expectations, and the macroeconomic environment. For a net energy importer such as Türkiye, the direct cost and exchange-rate channels dominate. Fertiliser, whose principal feedstock is natural gas, and diesel for tractors, pumps, and freight are the most visible conduits, so that a sustained increase in crude prices raises farm-gate costs almost mechanically (Nazlioglu & Soytas, 2012; Taghizadeh-Hesary et al., 2019).

Empirical work on the oil–food nexus has moved from simple correlation studies toward structural and nonlinear frameworks. Chen et al. (2010) and Nazlioglu (2011) document linkages between oil and agricultural commodity prices in linear and nonlinear settings, while Reboredo (2012) shows that dependence between oil and agricultural prices intensifies during turbulent episodes and weakens in calm periods. Subsequent contributions confirm that positive oil and gas shocks often exert a larger and more persistent effect on food prices than negative shocks of comparable size (Pal & Mitra, 2019; Sun et al., 2022). Energy and food security are linked through price volatility as well as through physical availability (Taghizadeh-Hesary et al., 2019). These findings establish the international backdrop against which country-specific transmission in Türkiye must be interpreted.

3.2 Exchange-rate and imported-input pass-through

In energy-importing economies, the exchange rate is not a peripheral control variable but a central transmission mechanism. Because crude oil, refined products, fertiliser, and many intermediate agricultural inputs are invoiced in foreign currency, depreciation raises domestic costs even when international dollar prices are unchanged. Turkish evidence consistently places the exchange rate at the centre of food-price dynamics. Using NARDL estimation over 2003–2021, Karakas and Akcay (2022) establish a long-run cointegrating relationship among food prices, the exchange rate, and oil prices, and find that positive shocks exert a deeper influence than negative ones, with imported-input dependence and fragile foreign-exchange earnings identified as primary channels. Akkus (2022) quantifies relative magnitudes, estimating that exchange-rate movements dominate oil-price movements in their contribution to food-price changes. Time-varying parameter VAR evidence indicates that exchange-rate pass-through to food inflation reached elevated levels during the COVID-19 pandemic and the currency turbulence of late 2021 (Akcelik & Ozmen, 2022).

Bor and Dagistan (2024) focus on the fertiliser channel and show that international fertiliser prices and the exchange rate exert short- and long-run asymmetric effects on domestic fertiliser prices, reinforcing the cost-push interpretation. Complementary work on second-round effects of food-price shocks underscores that food inflation can feed into broader price dynamics and inflation expectations (Derya & Suna, 2024). Collectively, this literature implies that any analysis of oil–food pass-through in Türkiye that omits the exchange rate risks serious omitted-variable bias, and that policy responses confined to energy markets alone will address only part of the transmission chain.

3.3 Asymmetric price adjustment and market frictions

The theoretical case for asymmetric pass-through rests on well-established market frictions. Menu costs, market power along concentrated supply chains, inventory practices, and precautionary pricing can cause prices to rise more readily than they fall (Meyer & von Cramon-Taubadel, 2004; Peltzman, 2000). In inflationary environments, firms may find it easier to raise prices than to lower them, embedding cost increases permanently while treating cost decreases as temporary. The NARDL model of Shin, Yu, and Greenwood-Nimmo (2014), built on the bounds-testing procedure of Pesaran, Shin, and Smith (2001), has become a workhorse for testing such asymmetry because it accommodates variables of mixed integration order, separates short-run from long-run asymmetry, and remains tractable in modest samples.

Turkish applications of asymmetric frameworks report directionally consistent patterns. Altintas (2016) provides an early quantitative demonstration, reporting that a one per cent rise in oil prices increased food prices by 0.47 per cent whereas a one per cent fall reduced them by only 0.19 per cent. More recent work extends the methodology: Tumturk (2025) applies a Fourier ARDL design and detects cost-push linkages from crude-oil prices to food prices, while confirming positive long-run roles for industrial production and the nominal exchange rate. Internationally, Ibrahim (2015) and Pal and Mitra (2019) document asymmetric oil–food relationships in other emerging-market settings. An important inferential caution, however, is that economically large differences in estimated elasticities need not coincide with formal statistical rejection of symmetry when samples are short and tests have limited power—a point that the present chapter treats with explicit care.

3.4 Agri-food resilience and sustainable agricultural finance

A parallel literature on agri-food resilience and sustainable finance emphasises that energy and climate risks are increasingly material to agricultural credit, investment, and insurance. Resilience in this context refers to the capacity of production and distribution systems to absorb energy-price and exchange-rate shocks without generating large, persistent food-price spikes or widespread financial distress among producers. Investments that reduce the energy intensity of irrigation, storage, and logistics—or that substitute domestic renewable energy for imported fossil fuels—can lower the sensitivity of farm and agribusiness cash flows to external price shocks. Financing instruments that price energy and foreign-exchange risk more accurately, or that blend concessional and commercial capital for transition investments, can accelerate such structural change.

The connection between empirical pass-through evidence and sustainable agricultural finance is inferential rather than direct. Econometric models of oil prices and food prices do not, by themselves, estimate the uptake of solar irrigation, the performance of sustainability-linked loans, or the optimal design of guarantee schemes. What they can do is identify the magnitude and channels of cost vulnerability. When long-run food prices respond more strongly to oil-price increases than to decreases, and when the exchange rate dominates short-run dynamics, the case for financing instruments that reduce imported-energy and foreign-currency exposure becomes stronger on financial-stability grounds, not only on environmental grounds. Taghizadeh-Hesary et al. (2019) link energy and food security through price volatility; extending that logic to the design of agricultural finance is a natural next step for policy-oriented research.

3.5 Research gap and contribution

Despite a growing Turkish literature on asymmetric oil–food and exchange-rate–food relationships, three gaps remain. First, careful data construction and full diagnostic transparency are not uniformly observed; earlier work on the present dataset inadvertently stacked seven commodity series, and the corrected analysis is needed for credible inference. Second, formal asymmetry tests are sometimes over-interpreted: economically meaningful differences in elasticities are occasionally presented as statistically established asymmetry even when Wald tests do not reject symmetry. Third, and most importantly for this volume, the Turkish energy–food evidence has not been systematically connected to sustainable agricultural finance, renewable-energy investment in agriculture, or the design of risk-sensitive credit instruments.

This chapter addresses these gaps by re-estimating a NARDL model on a correctly aggregated monthly composite food-price series for January 2016 to April 2022, reporting long-run elasticities, short-run dynamics, bounds and Wald tests, and residual diagnostics with full transparency, and then developing a structured discussion of financing and policy implications that distinguishes direct empirical findings from carefully derived recommendations. The analytical framework that organises the remainder of the chapter therefore links energy–food price transmission, imported-input dependence, exchange-rate pass-through, asymmetric adjustment frictions, agri-food value-chain resilience, and sustainable agricultural finance into a single coherent narrative.

4. Data, Variables, and Empirical Strategy

4.1 Sample, sources, and variable construction

The empirical analysis uses monthly data covering January 2016 to April 2022, giving seventy-six observations (T = 76). The window deliberately spans two major shocks—the COVID-19 pandemic and the onset of the Russia–Ukraine conflict—which generated pronounced movements in both energy and food markets. All series are expressed in natural logarithms so that estimated coefficients carry an elasticity interpretation.

The dependent variable is a composite domestic food price index constructed as the simple monthly average of seven staple commodities: common bread, rice, wheat, meat, fish, milk, and sunflower oil, sourced from the Humanitarian Data Exchange (HDX). An earlier version of this research stacked these seven commodity series into a single column, producing a 532-row object that was mistakenly treated as one time series. That aggregation error is corrected here by averaging across commodities within each month, yielding a single, internally consistent series of length seventy-six. The correction is presented as a data-

construction clarification rather than as a substantive reinterpretation of the underlying economic relationships; its practical consequence is that sample sizes, standard errors, and causality tests are no longer inflated by pseudo-replication.

The principal explanatory variable is the Brent (Europe) crude-oil price, obtained from the U.S. Energy Information Administration (EIA). The West Texas Intermediate (WTI) price is retained solely for robustness analysis. Control variables comprise the agricultural input price index and the consumer price index from the Turkish Statistical Institute (TÜİK) and the nominal Turkish lira per US dollar exchange rate from the Federal Reserve Economic Data (FRED) service. Table 1 summarises the variables and sources.

4.2 Descriptive properties

Descriptive statistics, computed on the seventy-six monthly observations, reveal that every series is positively skewed and that several display excess kurtosis. The agricultural input index and the consumer price index exhibit the most pronounced departures from normality, reflecting the acceleration of inflation toward the end of the sample. Jarque–Bera statistics reject normality for all variables except Brent at conventional levels, a feature that justifies a flexible nonlinear specification and that should be borne in mind when interpreting residual diagnostics. Detailed descriptive statistics appear in Table 2 in Section 5.

4.3 The nonlinear ARDL specification

The methodological centrepiece is the nonlinear autoregressive distributed lag model of Shin et al. (2014). Its defining feature is the decomposition of the oil-price variable into partial sums of positive and negative changes, which permits separate long- and short-run coefficients for upward and downward movements. Formally, the log oil price is written as the sum of an initial value and two accumulated components:

$$oil_t = oil_0 + oil_t^+ + oil_t^-,$$

where $oil_t^+ = \Sigma \max(\Delta oil_j, 0)$ and $oil_t^- = \Sigma \min(\Delta oil_j, 0)$, with the sums running from j = 1 to t.

The conditional error-correction representation estimated in this study takes the form

$$\Delta food_t = \alpha + \rho\, food_\{t-1\} + \theta^+ oil_\{t-1\}^+ + \theta^- oil_\{t-1\}^- + \delta' Z_\{t-1\} + \Sigma\, \pi_i^+ \Delta oil_\{t-i\}^+ + \Sigma\, \pi_i^- \Delta oil_\{t-i\}^- + \varphi' \Delta Z_\{t-i\} + \varepsilon_t,$$

where food denotes the log composite food price index, Z is the vector of control variables (the log agricultural input index, the log exchange rate, and the log consumer price index), and the superscripts plus and minus denote the positive and negative partial-sum components of the oil price. The long-run elasticities of food prices with respect to oil increases and decreases are recovered as $\hat{\beta}^+ = -\hat{\theta}^+/\rho$ and $\hat{\beta}^- = -\hat{\theta}^-/\rho$. Long-run asymmetry is present when $\hat{\beta}^+$ differs from $\hat{\beta}^-$, and short-run asymmetry when the summed positive and negative short-run coefficients diverge; both are evaluated with Wald tests.

4.4 Estimation strategy and the Brent–WTI treatment

The estimation strategy proceeds in stages. Augmented Dickey–Fuller and Phillips–Perron tests first establish that no variable is integrated of order two, the condition required for the bounds procedure. The optimal lag structure is selected by the Akaike information criterion, which points to a parsimonious NARDL(1,0) specification. The Pesaran–Shin–Smith bounds test then examines whether a stable long-run relationship exists (Pesaran et al., 2001). A full set of diagnostic tests—covering serial correlation, heteroskedasticity, normality, and functional form—evaluates the adequacy of the estimated equation, and Granger causality tests on the corrected data probe the direction of predictive linkages.

A methodological clarification is warranted regarding the two crude-oil benchmarks. Brent and WTI prices move almost in lockstep, with a sample correlation of approximately 0.99. Including both regressors in the same equation induces severe multicollinearity that destabilises coefficient estimates and can flip their signs. To avoid this pathology, Brent is adopted as the single oil benchmark in the main model because Türkiye sources most of its crude from European and Middle Eastern grades that price off Brent, while WTI is examined separately as a robustness check. The two specifications deliver consistent qualitative conclusions, confirming that the choice of benchmark does not drive the results.

4.5 Inferential posture

Throughout the empirical presentation, the chapter adopts a deliberately cautious inferential posture. Coefficients are interpreted as conditional associations within the NARDL framework, not as structural causal effects identified by exogenous variation. The language of “pass-through,” “dynamic relationship,” and “conditional long-run relationship” is preferred to stronger causal claims. Where formal tests do not reject symmetry, economically large differences in elasticities are described as directionally meaningful but

statistically non-conclusive. Diagnostic rejections are reported transparently and treated as limitations rather than as minor technicalities.

Table 1. Variables, definitions, and data sources

Variable	Definition	Source
Food price index	Monthly average of seven staples: bread, rice, wheat, meat, fish, milk, sunflower oil (log)	Humanitarian Data Exchange (HDX)
Brent	Brent (Europe) crude-oil spot price, USD/barrel (log; positive/negative partial sums)	U.S. Energy Information Administration (EIA)
WTI	West Texas Intermediate crude-oil spot price, USD/barrel (log; robustness only)	U.S. Energy Information Administration (EIA)
Agricultural input index	Agricultural input price index (log)	Turkish Statistical Institute (TÜİK)
Exchange rate	Nominal Turkish lira per US dollar (log)	Federal Reserve Economic Data (FRED)
CPI	Consumer price index (log)	Turkish Statistical Institute (TÜİK)

Note. Sample period: January 2016–April 2022 (T = 76). All series enter the econometric model in natural logarithms. Brent is the main oil benchmark; WTI is used only in a separate robustness specification because the sample correlation between Brent and WTI is approximately 0.99.

5. Empirical Findings

This section reports the empirical findings in the logical sequence of the analysis: descriptive statistics and stationarity, NARDL long- and short-run estimates, bounds and asymmetry tests, residual diagnostics, Granger causality on the corrected data, and the WTI robustness check. All numerical values are taken directly from the underlying estimation and are not altered.

5.1 Descriptive statistics

Table 2 reports descriptive statistics for the key variables over T = 76 monthly observations. Mean Brent and WTI prices stand at approximately 60.50 and 56.10 US dollars per barrel, respectively, with substantial ranges reflecting the pandemic collapse and subsequent recovery. The agricultural input index and the CPI display the strongest right-skew and excess kurtosis, consistent with accelerating inflation toward the end of the sample. The composite food price index (in the units reported) has a mean of 3.337 and a standard deviation of 0.461. Jarque–Bera tests reject normality for all series except Brent at conventional levels.

Table 2. Descriptive statistics of the key variables (T = 76, 2016M01–2022M04)

Variable	Mean	Median	Max	Min	Std. Dev.	Skew.	Kurt.	Jarque–Bera
Food price (index)	3.337	3.202	5.443	2.611	0.461	1.696	7.703	94.12***
Brent oil ($)	60.50	61.15	112.44	26.85	16.12	0.546	3.983	5.87*
WTI oil ($)	56.10	54.75	108.40	16.98	15.68	0.682	4.680	12.72***
Agric. Input index	162.48	152.52	442.21	101.70	66.24	2.224	9.176	163.08***
Exchange rate (TL/$)	5.964	5.689	14.704	2.836	2.862	1.407	4.998	34.23***
CPI	423.40	402.04	904.79	274.27	136.51	1.446	5.459	41.07***

*Note. T = 76. The composite food price index is the monthly average of seven staple commodities. *** p < .01. * p < .10.*

5.2 Unit-root tests

Table 3 summarises Augmented Dickey–Fuller and Phillips–Perron unit-root results. The composite food price index is stationary in levels, a property consistent with a mean-reverting series in the transformed units used here, whereas Brent, WTI, the exchange rate, and the CPI are integrated of order one. The agricultural input index lies close to the boundary but is treated as first-difference stationary. Crucially, no series is integrated of order two, so the bounds-testing framework is applicable. The mix of I(0) and I(1) series is precisely the setting for which ARDL/NARDL methods are designed.

Table 3. ADF and Phillips–Perron unit-root test results

Variable	ADF level (C)	ADF level (C+T)	ADF Δ (C)	PP level	PP Δ	Decision
ln(Food price)	−3.786***	−2.901	−3.591***	−3.786***	−9.921***	I(0)
ln(Brent)	−1.724	−1.937	−6.430***	−1.687	−5.865***	I(1)
ln(WTI)	−1.791	−2.020	−7.140***	−1.925	−6.771***	I(1)
ln(Agric. input)	2.028	−0.646	−1.983	8.029	−1.983	I(1)†
ln(Exchange rate)	0.707	−2.362	−6.273***	1.226	−5.665***	I(1)
ln(CPI)	1.822	0.236	−1.691	5.316	−3.327**	I(1)

*Note. *** p < .01. ** p < .05. Critical values (with constant): 1% = −3.52; 5% = −2.90. † The agricultural input index is weakly stationary in first differences; the mix of I(0) and I(1) series satisfies the ARDL precondition that no variable be I(2).*

5.3 Long-run estimates

Table 4 reports long-run elasticities and the conditional error-correction level terms. The elasticity of food prices with respect to oil-price increases is 0.369, meaning that a ten per cent rise in Brent is associated, in the long run, with a food-price increase of about 3.7 per cent. The corresponding elasticity for oil-price decreases is 0.127, so that an equivalent ten per cent fall in Brent is associated with a food-price decline of roughly 1.3 per cent. The upward elasticity is therefore close to three times the downward elasticity—the quantitative signature of the rocket-and-feather pattern discussed in the literature.

Table 4. NARDL long-run coefficients and conditional error-correction level terms (dependent variable: ln food price index)

Variable	Coefficient	Std. Error	t-Statistic	p-Value	Sig.
Long-run elasticities					
ln(Brent)+ (oil increase), β+	0.369				
ln(Brent)− (oil decrease), β−	0.127				
ECM level terms					
food(t−1) [speed, ρ]	−0.4708	0.128	−3.679	0.0005	***
Oil+(t−1)	0.1738	0.099	1.761	0.083	*
Oil−(t−1)	0.0595	0.069	0.860	0.393	
ln(Agric. input)(t−1)	−1.073	0.527	−2.034	0.046	**
ln(Exchange rate)(t−1)	−0.603	0.267	−2.255	0.028	**
ln(CPI)(t−1)	1.5424	0.912	1.691	0.096	*

*Note. Long-run elasticities are computed as $\beta = -\theta/\rho$. *** $p < .01$. ** $p < .05$. * $p < .10$. Specification: NARDL(1,0) with Brent partial sums.*

The level coefficient on the positive oil component is 0.1738 (standard error 0.099, t = 1.761, p = 0.083), significant at the ten per cent level, whereas the negative component coefficient is 0.0595 (standard error 0.069, t = 0.860, p = 0.393) and is not statistically significant. The agricultural input level term is −1.073 (p = 0.046), the exchange-rate level term is −0.603 (p = 0.028), and the CPI level term is 1.5424 (p = 0.096). The speed-of-adjustment coefficient is examined with the short-run results below. These magnitudes are economically interpretable, but their inferential status must be read jointly with the Wald tests and diagnostics reported later in this section.

5.4 Short-run dynamics and error correction

Table 5 reports short-run coefficients and model statistics. The error-correction term equals −0.4708 (t = −3.679, p = 0.0005), indicating that approximately forty-seven per cent of any departure from the estimated long-run relationship is eliminated within a single month—a moderate but economically meaningful adjustment speed. In the short run, the oil components are individually insignificant (ΔOil+ coefficient 0.1335, p = 0.629; ΔOil− coefficient −0.1927, p = 0.297), which is consistent with the view that energy shocks reach food prices with a lag through the input and exchange-rate channels rather than instantaneously.

Table 5. NARDL short-run coefficients and model statistics

Variable	Coefficient	Std. Error	t-Statistic	p-Value	Sig.
Δfood(t−1)	−0.1359	0.133	−1.020	0.312	
ΔOil+(t)	0.1335	0.275	0.485	0.629	
ΔOil−(t)	−0.1927	0.183	−1.053	0.297	
Δln(Agric. input)(t)	1.5969	0.743	2.151	0.035	**
Δln(Exchange rate)(t)	−1.0695	0.288	−3.717	0.0004	***
Δln(CPI)(t)	1.8723	1.050	1.783	0.080	*
Constant	−2.553	2.826	−0.904	0.370	

*Note. $R^2 = 0.377$; adjusted $R^2 = 0.254$; $F = 3.069$ ($p = 0.002$); AIC = −135.84; observations = 74; specification NARDL(1,0). *** $p < .01$. ** $p < .05$. * $p < .10$.*

By contrast, the change in the agricultural input index carries a large and significant short-run coefficient (1.5969, p = 0.035), and the change in the exchange rate carries the largest and most precisely estimated short-run coefficient (−1.0695, p = 0.0004). The short-run CPI coefficient is 1.8723 (p = 0.080). Model fit statistics are $R^2 = 0.377$, adjusted $R^2 = 0.254$, F = 3.069 (p = 0.002), and AIC = −135.84, with 74 usable observations under the NARDL(1,0) specification. The short-run evidence therefore identifies agricultural input costs and, above all, the exchange rate as the immediate drivers of food-price movements, while oil shocks appear to operate more strongly through the long-run relationship.

5.5 Bounds test for cointegration

Table 6 reports the Pesaran–Shin–Smith bounds test. The F-statistic of 3.632 exceeds the upper critical bound at the ten per cent level (upper bound 3.35), supporting the existence of a long-run relationship at that significance level. The t-bounds statistic associated with the error-correction term (−3.679) corroborates a significant adjustment coefficient. At the five per cent level, however, the F-

statistic falls within the inconclusive band (lower 2.62, upper 3.79), and at the one per cent level it lies below the upper bound. This pattern is unsurprising given the modest sample of seventy-six observations. The clearly significant error-correction coefficient provides complementary support for a conditional long-run relationship, but the bounds evidence should be characterised as supportive at the ten per cent level rather than as decisive at conventional five per cent thresholds.

Table 6. Pesaran–Shin–Smith bounds test for cointegration

Statistic / Level	Value	I(0) lower	I(1) upper	Decision
F-bounds statistic	3.6316			
t-bounds statistic (ECM)	−3.6793			
10%		2.26	3.35	Cointegration (F > upper)
5%		2.62	3.79	Inconclusive region
1%		3.41	4.68	F < upper bound

Note. k = 5 regressors (oil+, oil−, agricultural input, exchange rate, CPI). Critical values from Pesaran, Shin and Smith (2001), Table CI(iii).

5.6 Tests for asymmetry

Table 7 reports Wald tests for long- and short-run asymmetry. The long-run test of $\theta+ = \theta-$ (equivalently $\beta+ = \beta-$) yields a statistic of 2.009 with $p = 0.156$. The short-run test of equality of summed positive and negative short-run coefficients yields a statistic of 0.726 with $p = 0.394$. In both cases, the null of symmetry is not rejected at conventional significance levels.

Table 7. Wald tests for long- and short-run asymmetry

Test	Null hypothesis	Wald stat.	p-Value	Decision
Long-run asymmetry	$\theta+ = \theta-$ ($\beta+ = \beta-$)	2.009	0.156	Not rejected
Short-run asymmetry	$\Sigma\pi+ = \Sigma\pi-$	0.726	0.394	Not rejected

Note. $\beta+ = 0.369$ (long-run effect of oil increases); $\beta- = 0.127$ (long-run effect of oil decreases). Failure to reject symmetry at conventional levels implies that the directional gap in elasticities is economically notable but statistically non-conclusive in this sample.

This statistical result must be read alongside the magnitude of the estimated elasticities. A long-run pass-through of 0.369 for increases against 0.127 for decreases represents an economically substantial gap. The failure of the Wald test to declare it significant most plausibly reflects the limited power afforded by

seventy-six observations rather than a definitive demonstration that asymmetry is absent. The international literature, which typically draws on longer samples, generally finds asymmetry to be statistically significant; the present results are directionally consistent with that body of evidence. The appropriate interpretation is therefore that the estimates display an economically notable but statistically non-conclusive asymmetry. Claims that statistical asymmetry has been conclusively established would overstate the formal evidence.

5.7 Diagnostic tests

Table 8 reports residual and specification diagnostics. The model is free of detectable heteroskedasticity: the Breusch–Pagan statistic is 7.699 ($p = 0.808$) and the White statistic is 74.00 ($p = 0.445$). The Durbin–Watson statistic is 2.154, close to the benchmark value of two. However, low-order serial correlation is present: the Breusch–Godfrey test rejects the null of no serial correlation at lag 1 (statistic 7.524, $p = 0.006$) and lag 2 (statistic 7.562, $p = 0.023$), though not at lag 4 (statistic 8.200, $p = 0.085$). The Jarque–Bera test on residuals rejects normality (statistic 118.90, $p = 0.000$), driven by the same fat tails observed in the descriptive statistics. The Ramsey RESET test rejects correct specification (statistic 5.687, $p = 0.006$), signalling possible functional-form tension.

Table 8. Residual and specification diagnostics

Test	Statistic	p-Value	Null hypothesis	Decision
Breusch–Godfrey (lag 1)	7.524	0.006	No serial correlation	Rejected
Breusch–Godfrey (lag 2)	7.562	0.023	No serial correlation	Rejected
Breusch–Godfrey (lag 4)	8.200	0.085	No serial correlation	Not rejected
Durbin–Watson	2.154	—	—	Near 2 (acceptable)
Breusch–Pagan	7.699	0.808	Homoskedasticity	Not rejected
White	74.00	0.445	Homoskedasticity	Not rejected
Jarque–Bera (residuals)	118.90	0.000	Normality	Rejected
Ramsey RESET	5.687	0.006	Correct specification	Rejected

Note. Serial correlation and RESET concerns are addressed by reporting heteroskedasticity- and autocorrelation-consistent (Newey–West) standard errors; the normality rejection is a common feature of volatile monthly macroeconomic data. These diagnostics motivate cautious interpretation (see Section 8).

These diagnostic concerns are not concealed. Heteroskedasticity- and autocorrelation-consistent (Newey–West) standard errors are the appropriate reporting convention under residual autocorrelation; the qualitative inferences on the key coefficients are unchanged under this correction in the underlying analysis. The RESET rejection and serial-correlation findings nonetheless warrant cautious interpretation and motivate the limitations discussion in Section 8. The normality rejection is a common feature of monthly macroeconomic data over a volatile period; with seventy-six observations, asymptotic justifications for test statistics remain only moderately reassuring.

5.8 Granger causality on the corrected data

Table 9 reports Granger causality tests on the corrected monthly series. All tested directions are statistically insignificant at conventional levels. In particular, causality from agricultural inputs to Brent is insignificant at both lag 1 ($F = 0.1874$, $p = 0.6664$) and lag 2 ($F = 0.7338$, $p = 0.4839$). This result is economically expected: Turkish agricultural input costs cannot plausibly move the global price of Brent crude. An earlier analysis that stacked seven commodity series had generated spuriously strong reverse causality; once the data are correctly aggregated, the anomaly disappears. The corrected tests find no strong short-horizon predictive linkages in any direction. Given the low power of Granger tests in a sample of this size, this should be read as the absence of detectable short-horizon predictability rather than as proof of statistical independence.

Table 9. Granger causality tests on the corrected data (T = 75)

Direction	Lag	F-Statistic	p-Value
Brent → Food	1	0.0062	0.9375
Brent → Food	2	0.0182	0.9819
Food → Brent	1	0.0001	0.9973
Food → Brent	2	0.1597	0.8528
WTI → Food	1	0.0009	0.9759
WTI → Food	2	0.0361	0.9646
Agric. input → Food	1	0.0044	0.9475
Agric. input → Food	2	1.5883	0.2118
Exchange rate → Food	1	0.3161	0.5758
Exchange rate → Food	2	1.5379	0.2222
Agric. input → Brent	1	0.1874	0.6664
Agric. input → Brent	2	0.7338	0.4839

Note. F-statistics with p-values; lag length selected by the Akaike information criterion. All directions are statistically insignificant at conventional levels on the corrected monthly series.

5.9 Robustness: the WTI specification

Table 10 compares the Brent main model with a separately estimated WTI specification. The two models fit the data almost equally well ($R^2 = 0.377$ versus 0.364; AIC = −135.84 versus −134.39). The WTI model reproduces the qualitative pattern of a larger long-run pass-through for oil increases ($\beta+ = 0.311$) than for decreases ($\beta- = 0.202$). Minor differences in magnitude are immaterial to the conclusions and follow naturally from the slightly different price dynamics of the two benchmarks. That the results survive substitution of the oil measure indicates that they are not an artefact of benchmark selection and supports the decision to anchor the main model on Brent.

Table 10. Robustness check using the WTI benchmark

Parameter	Brent model	WTI model	Comment
Specification	NARDL(1,0)	NARDL(1,0)	Identical
R-squared	0.377	0.364	Similar fit
AIC	−135.84	−134.39	Brent marginally better
β+ (long-run, increase)	0.369	0.311	Same sign, Brent stronger
β− (long-run, decrease)	0.127	0.202	Same sign
ECM speed (ρ)	−0.471	—	Significant error correction
Bounds F	3.632	—	Cointegration at 10%

Note. The WTI model is estimated separately to avoid the near-perfect collinearity between Brent and WTI (correlation ≈ 0.99).

5.10 Summary of empirical findings

Three results organise the subsequent discussion. First, the estimated long-run elasticities display a directionally meaningful rocket-and-feather pattern (0.369 versus 0.127), but formal Wald tests do not reject symmetry, so statistical asymmetry is not conclusively established. Second, the exchange rate is the dominant short-run driver of food prices, with agricultural input costs also significant in the short run, while contemporaneous oil shocks are individually insignificant. Third, a significant error-correction coefficient of approximately −0.471 supports a conditional long-run relationship at a moderate adjustment speed, with bounds evidence favourable at the ten per cent level. Diagnostic limitations—serial correlation and RESET rejection—require that these findings be interpreted with appropriate caution.

6. Discussion: From Energy Shock Exposure to Financial Resilience

The empirical results identify a conditional long-run association between oil prices and food prices in Türkiye, a directionally larger estimated response to oil-price increases than to decreases, and a short-run structure in which the exchange rate and agricultural input costs dominate high-frequency food-price movements. These findings do not directly estimate agricultural credit performance, renewable-energy adoption, or the effectiveness of particular financing instruments. They do, however, make visible a set of structural cost vulnerabilities that sustainable agricultural finance is well placed to address. This section develops that bridge carefully, distinguishing direct evidence from derived implications.

6.1 What the estimates imply for cost and risk exposure

If food prices are associated with a long-run elasticity of roughly 0.37 with respect to oil-price increases, then episodes of sustained energy-price elevation raise the nominal cost environment in which farm enterprises, processors, and distributors operate. Even though formal tests do not establish statistical asymmetry, the point estimates suggest that downward oil-price movements may not fully reverse the cost increases embedded during upward episodes. In an inflationary setting with concentrated supply chains, such ratchet-like behaviour—if present—would raise the average level of food prices over repeated shock cycles and compress real incomes, particularly for lower-income households (OECD/FAO, 2022).

The short-run dominance of the exchange rate sharpens the risk diagnosis. Lenders and policymakers who monitor only international oil prices will miss the more immediate channel through which external conditions reach domestic food prices. A portfolio of agricultural borrowers whose input costs are dollar-invoiced carries foreign-exchange risk that is correlated across borrowers whenever the lira depreciates. Energy-price risk and exchange-rate risk are therefore not independent idiosyncratic shocks at the farm level; they are common factors that can generate correlated stress across agricultural credit portfolios. Conventional credit-risk assessments that treat energy and currency exposures as secondary or borrower-specific may understate systemic vulnerability in the agricultural lending book.

6.2 Renewable-energy and energy-efficiency financing

Investments that reduce the fossil-fuel intensity of irrigation, farm machinery, cold storage, and agri-food logistics attack the direct cost channel identified in the transmission framework. Solar-powered irrigation can substitute for diesel

pumps; biogas and other on-farm renewable sources can reduce exposure to grid electricity priced off natural gas; and energy-efficient cold storage can lower the electricity intensity of post-harvest handling. None of these technologies is estimated in the NARDL model. Their relevance follows from the structure of the cost channels: if diesel, electricity, and gas-linked fertiliser are material conduits from global energy markets to domestic food prices, then reducing dependence on those conduits is a structural hedge.

Financing such investments requires instruments matched to their cash-flow profiles. Upfront capital costs are typically high relative to annual energy savings, payback periods may extend beyond conventional short-term agricultural loan tenors, and benefits accrue partly as avoided cost volatility rather than as easily verified revenue increases. Patient capital, longer tenors, grace periods aligned with installation and commissioning, and technical-assistance components that help borrowers quantify energy savings are therefore natural complements to pure price signals. Blended finance—combining concessional public or development-finance resources with commercial bank lending—can improve affordability without requiring commercial lenders to absorb the full technology and performance risk.

6.3 Risk-sensitive agricultural credit and sustainability-linked instruments

The empirical prominence of exchange-rate and input-cost channels suggests that credit products could be designed to recognise energy and foreign-exchange exposure more explicitly. Risk-sensitive pricing might differentiate borrowers by the energy intensity of their production systems, the currency denomination of their input purchases, and the extent to which they have invested in efficiency or renewable substitutes. Sustainability-linked loans, in which interest margins step down when verified energy-efficiency or renewable-energy targets are met, offer one contractual form for aligning borrower incentives with reduced shock exposure. Guarantee instruments can crowd in private lending for transition investments whose collateral coverage or track record would otherwise fall short of commercial thresholds.

These instruments should not be oversold. A sustainability-linked loan does not, by itself, stabilise retail food prices during an oil-price spike. It can, over time, reduce the sensitivity of borrower cash flows to energy and currency shocks, improve repayment capacity under stress, and lower the probability of correlated defaults in the agricultural portfolio. The appropriate claim is incremental resilience, not elimination of food-price inflation.

6.4 Storage, logistics, and supply-chain infrastructure finance

Section 2 emphasised that energy costs pervade transport, cold chains, and processing. Infrastructure investments that shorten supply chains, expand climate-controlled storage, and improve logistics efficiency can dampen the transmission from energy-price spikes to retail food prices by reducing physical losses, smoothing seasonal gluts and shortages, and lowering the energy cost per unit of food delivered. Financing for warehouse receipts, cold-storage facilities, and rural logistics assets therefore belongs in the same policy conversation as farm-level renewable energy. Public–private partnership structures, dedicated infrastructure funds, and development-bank lines of credit for agri-logistics are among the vehicles used internationally; their suitability for Türkiye depends on institutional capacity, regulatory design, and fiscal space—matters that lie beyond the scope of the present empirical model but within the scope of a coherent policy architecture.

6.5 Macro-financial coordination

Because the exchange rate is the dominant short-run driver in the estimates, agricultural finance policy cannot be insulated from macroeconomic and exchange-rate management. Episodes of sharp lira depreciation raise food prices and simultaneously tighten financial conditions, increasing the cost of credit precisely when working-capital needs for energy and imported inputs are rising. Coordination among monetary, fiscal, agricultural, and energy authorities is therefore not a rhetorical aspiration but a practical requirement. Targeted and temporary stabilisation measures—such as time-limited support for critical inputs during extreme spikes—may have a role in blunting immediate welfare losses, but they do not substitute for medium-term investments that reduce import dependence. The sequencing matters: emergency measures address symptoms; transition finance addresses structure.

6.6 Integrating the evidence without overclaiming

The discussion can be summarised in three disciplined propositions. First, the NARDL evidence documents energy- and exchange-rate-related cost vulnerability in Türkiye's food-price dynamics; it does not measure the returns to any particular green or agricultural financial product. Second, the structure of the estimated channels—long-run oil association, short-run exchange-rate dominance, input-cost significance—supplies a coherent rationale for financing instruments that reduce fossil-fuel and foreign-currency exposure in agriculture. Third, no single instrument solves food inflation: resilience requires a portfolio of price-stabilisation capacity, macroeconomic prudence, supply-chain

investment, and transition finance, each matched to a distinct time horizon and transmission channel. Section 7 translates these propositions into a practical policy matrix.

7. Policy Architecture for Türkiye

The empirical findings and the transmission framework imply a coordinated policy response rather than a single-instrument solution. Table 11 organises recommended responses by challenge, transmission channel, potential policy or finance instrument, responsible policy domain, and key implementation caveat. Recommendations are proportionate to the evidence: they follow logically from documented cost channels and verified literature, and they do not assert legal or institutional outcomes that have not been independently verified.

Several design principles should guide implementation. First, distinguish time horizons. Immediate stabilisation instruments—targeted and temporary support for critical energy-linked inputs, careful use of strategic reserves for staples—address welfare losses during acute spikes. Medium-term instruments—energy-efficiency lending, cold-storage and logistics finance, improved risk assessment in agricultural credit—reduce the sensitivity of the system to the next shock. Long-term instruments—renewable-energy investment in irrigation and processing, domestic fertiliser-capacity strategies where economically sound, and structural reduction of imported-energy dependence—alter the slope of the transmission itself.

Second, treat exchange-rate stability as part of food-price policy. The short-run estimates identify the exchange rate as the dominant high-frequency driver. Agricultural and energy ministries cannot deliver food-price resilience if macroeconomic policy generates repeated, sharp depreciation episodes that reprice every dollar-invoiced input overnight. This does not imply a particular exchange-rate regime; it implies coherent recognition that currency volatility is a food-system risk factor.

Third, build monitoring systems that track energy, input, and currency exposures in agricultural lending portfolios. If common factor risks are material, supervisors and development-finance institutions need portfolio-level metrics, not only borrower-level collateral ratios. Fourth, avoid presenting any single green-finance product as a solution to food inflation. Instruments should be evaluated on whether they reduce cost exposure and correlated credit risk over time, not on whether they eliminate retail price spikes in the short run.

The matrix in Table 11 is illustrative rather than exhaustive. Country-specific calibration—eligibility criteria, subsidy levels, prudential treatment, and institutional mandates—requires detailed design work by the relevant authorities

and financial institutions. The contribution of this chapter is to anchor that design work in transparent empirical evidence on how energy and exchange-rate shocks reach food prices in Türkiye.

Table 11. Policy and financing architecture for energy–food resilience in Türkiye

Challenge	Transmission channel	Potential policy/finance response	Responsible policy domain	Key implementation caveat
Upward oil-price spikes raise farm and logistics costs	Direct energy cost; fertiliser and agrichemical pricing	Time-limited, targeted support for critical energy-linked inputs during extreme spikes; strategic staple reserves	Agriculture; energy; fiscal authority	Temporary measures blunt symptoms; they do not reduce structural import dependence
Lira depreciation amplifies all dollar-invoiced costs	Exchange-rate pass-through to inputs and energy	Macroeconomic policies that limit disorderly depreciation; FX-risk monitoring in agricultural credit portfolios	Monetary and financial authorities; banking supervision	Exchange-rate policy serves multiple objectives; food-price concerns must be coordinated, not siloed
High fossil-fuel intensity of irrigation and machinery	Farm-level diesel and electricity demand	Long-tenor loans and blended finance for solar irrigation, efficient pumps, and on-farm renewables	Agricultural finance institutions; development banks; energy ministry	Requires technical assistance and verified energy-savings metrics; paybacks may exceed short loan tenors
Energy-intensive cold chains and long-haul freight	Post-harvest logistics and storage costs	Infrastructure finance for cold storage, warehouse receipts, and rural logistics efficiency	Transport; agriculture; public–private investment vehicles	Project preparation capacity and tariff/user-fee design are binding constraints

Correlated energy and FX risk in farm credit books	Common-factor shocks to borrower cash flows	Risk-sensitive credit scoring; sustainability-linked loans; partial credit guarantees for transition investments	Commercial banks; development-finance institutions; regulators	Instruments improve resilience incrementally; they do not eliminate retail food inflation
Incomplete downward pass-through of cost declines	Market power, menu costs, precautionary pricing	Competition and market-structure monitoring along agri-food chains; consumer information and staple-market transparency	Competition authority; agriculture; consumer protection	Structural market reforms are slow; evidence of asymmetry is directional, not statistically conclusive here
Household welfare losses from food inflation	High food share in low-income budgets	Targeted social protection indexed to food prices; nutritional support during prolonged spikes	Social policy; finance ministry	Safety nets complement, but do not replace, structural cost-reduction investments
Long-term imported-energy dependence of the food system	Structural exposure to global oil and gas markets	Sustained renewable-energy and efficiency investment in agri-food value chains; where viable, domestic input-capacity strategies	Energy transition policy; industrial and agricultural strategy	Fiscal cost and technology risk require phased, evidence-based scaling

Note. Responses are derived from the chapter's transmission framework and empirical channels; they are not direct outputs of the NARDL model. Implementation details require country-specific institutional design.

8. Limitations and Future Research

Several limitations qualify the conclusions and define a research agenda.

The sample comprises seventy-six monthly observations from January 2016 to April 2022. This window captures important shocks, including the COVID-19 pandemic and the early phase of the Russia–Ukraine conflict, but it is short by the standards of time-series inference on asymmetry and causality. Limited sample size reduces the power of Wald tests and helps explain why economically large differences between positive and negative long-run elasticities are not statistically significant at conventional levels. Extending the series beyond April

2022 would allow the directional asymmetry to be tested more sharply and would incorporate subsequent energy-market and macroeconomic developments. The present chapter deliberately does not treat post-sample events as if they were part of the estimation.

The dependent variable is a composite of seven staple commodities. Aggregation improves manageability and matches the chapter's focus on broad food-price resilience, but it may mask heterogeneity across food categories, regions, and income groups. Bread, meat, dairy, and edible oils need not respond identically to energy and exchange-rate shocks. Disaggregated and regional analyses would refine the policy targeting of stabilisation and financing instruments.

Formal Wald tests do not reject long-run or short-run symmetry. The chapter has emphasised this point throughout: the estimated elasticities are directionally consistent with rocket-and-feather behaviour, but statistical asymmetry is not conclusively established. Future work with longer samples, alternative asymmetry tests, and possibly nonlinear specifications that allow threshold or regime-dependent pass-through could strengthen or qualify this interpretation.

Residual diagnostics raise further caution. Low-order Breusch–Godfrey tests reject the null of no serial correlation, and the Ramsey RESET test rejects correct specification. Although heteroskedasticity tests are reassuring and Newey–West corrections leave key inferences qualitatively intact, serial correlation and functional-form concerns imply that the conditional mean specification may be incomplete. Future re-estimation might explore richer lag structures, additional controls, structural-break adjustments, or alternative functional forms.

The model does not include direct financing variables, farm-level energy-use data, credit-performance indicators, or measures of renewable-energy adoption. Consequently, all links from the estimates to sustainable agricultural finance are inferential. Micro-level surveys linking farm energy intensity, input-currency exposure, and credit outcomes would allow direct tests of propositions that this chapter can only motivate. Panel, spatial, quantile, time-frequency, and firm- or farm-level approaches are natural extensions. Fourier and structural-break methods could accommodate smooth or abrupt regime changes over longer samples (Tumturk, 2025).

Finally, external validity is bounded. Türkiye's combination of high energy-import dependence, repeated currency stress, and elevated food-weight in the CPI is distinctive. Comparative work across energy-importing emerging economies would help establish which features of the Turkish experience generalise and which are country-specific. Such comparisons would also enrich the regional evidence agenda of the present volume.

9. Conclusion

This chapter has examined the transmission of international oil-price shocks to domestic food prices in Türkiye and has developed the implications of that transmission for sustainable agricultural finance. Using a nonlinear ARDL model on a correctly aggregated monthly composite of seven staple food prices from January 2016 to April 2022, the analysis estimates a long-run elasticity of 0.369 with respect to Brent oil-price increases and 0.127 with respect to decreases. The directional gap is economically meaningful and consistent with rocket-and-feather patterns documented internationally and in earlier Turkish work, yet formal Wald tests do not reject symmetry at conventional significance levels. The appropriate conclusion is therefore measured: the point estimates suggest asymmetric pass-through, but the short sample and limited test power preclude treating statistical asymmetry as established fact.

A significant error-correction coefficient of approximately −0.471 indicates that close to half of any deviation from the estimated long-run relationship is corrected within a month. In the short run, the exchange rate is the dominant driver of food-price movements, with agricultural input costs also significant, while contemporaneous oil shocks are individually insignificant. Bounds testing supports cointegration at the ten per cent level and is inconclusive at five per cent. Residual diagnostics reveal serial correlation and a RESET rejection, so interpretation remains cautious. A WTI robustness specification reproduces the qualitative pattern. Granger causality tests on the corrected data show no significant short-horizon predictive linkages and eliminate a previously reported, economically implausible reverse causality from agricultural inputs to global oil prices.

These findings matter for the book's agenda on energy transitions and sustainable agricultural finance. They show that Türkiye's food prices are embedded in a structure of imported-energy dependence and exchange-rate vulnerability. Reducing that vulnerability is simultaneously a food-security objective, a household-welfare objective, and a financial-stability objective for agricultural lenders. Renewable-energy and energy-efficiency investments in irrigation, storage, and logistics, risk-sensitive and sustainability-linked credit instruments, infrastructure finance for cold chains and transport, and coherent macroeconomic management of currency risk form a portfolio of responses matched to different transmission channels and time horizons. No single instrument eliminates food-price inflation; structural resilience is built by lowering the energy and foreign-currency intensity of the agri-food system over time.

The chapter's contribution is therefore twofold. Empirically, it provides a transparent, carefully qualified NARDL account of oil–food pass-through in Türkiye on corrected data. Conceptually, it connects that account to the design of sustainable agricultural finance without claiming that the econometric model estimates financing outcomes directly. For policymakers, lenders, and development-finance institutions, the message is clear: energy-price shocks and exchange-rate movements are first-order agricultural risks, and the financial architecture of the food system should be built accordingly.

References

Akcelik, F., & Ozmen, E. (2022). The effect of the real exchange rate on food inflation in Turkey: Evidence from a time-varying parameter VAR (TVP-VAR) model. *Akademik Bakış Dergisi, 90*, 1–22.

Akkus, O. (2022). The asymmetric effect of oil price and exchange rate on food prices: The case of Turkey. *Business and Economics Research Journal, 13*(2), 233–249.

Altintas, H. (2016). New evidence on the asymmetric effects of oil price on food prices in Turkey using the NARDL model (2000–2013). *Journal of Business and Economic Studies, 8*(2), 11–34.

Baumeister, C., & Kilian, L. (2014). Do oil price increases cause higher food prices? *Economic Policy, 29*(80), 691–747. https://doi.org/10.1111/1468-0327.12039

Bor, O., & Dagistan, E. (2024). The impact of fluctuating international fertiliser prices and exchange rates on domestic fertiliser prices in Türkiye. *Agricultural Economics – Czech, 70*(1), 12–23. https://doi.org/10.17221/316/2023-AGRICECON

Chen, S.-T., Kuo, H.-I., & Chen, C.-C. (2010). Modelling the relationship between the oil price and global food prices. *Applied Energy, 87*(8), 2517–2525. https://doi.org/10.1016/j.apenergy.2010.02.020

Derya, B., & Suna, T. (2024). Second-round effects of food price shocks: Evidence from a Bayesian structural VAR for Turkey. *European Business Review, 24*(3), 211–236.

Ibrahim, M. H. (2015). Oil and food prices in Malaysia: A nonlinear ARDL analysis. *Agricultural and Food Economics, 3*(1), Article 2. https://doi.org/10.1186/s40100-014-0020-3

International Energy Agency. (2021). *Turkey 2021 energy policy review*. IEA. https://www.iea.org/reports/turkey-2021

Karakas, G., & Akcay, S. (2022). The asymmetric relationship between food prices, exchange rate and oil prices in Turkey: A NARDL approach. *Ekoist: Journal of Econometrics and Statistics, 37*, 149–169.

Meyer, J., & von Cramon-Taubadel, S. (2004). Asymmetric price transmission: A survey. *Journal of Agricultural Economics, 55*(3), 581–611. https://doi.org/10.1111/j.1477-9552.2004.tb00116.x

Nazlioglu, S. (2011). World oil and agricultural commodity prices: Evidence from nonlinear causality. *Energy Policy, 39*(5), 2935–2943. https://doi.org/10.1016/j.enpol.2011.03.001

Nazlioglu, S., & Soytas, U. (2012). Oil price, agricultural commodity prices, and the dollar: A panel cointegration and causality analysis. *Energy*

Economics, 34(4), 1098–1104. https://doi.org/10.1016/j.eneco.2011.09.008

Organisation for Economic Co-operation and Development, & Food and Agriculture Organization of the United Nations. (2022). *OECD-FAO agricultural outlook 2022–2031*. OECD Publishing. https://doi.org/10.1787/f1b0b29c-en

Pal, D., & Mitra, S. K. (2019). Asymmetric oil price transmission to the purchasing power of the U.S. dollar: A multiple threshold NARDL modelling approach. *Resources Policy, 64*, Article 101508. https://doi.org/10.1016/j.resourpol.2019.101508

Peltzman, S. (2000). Prices rise faster than they fall. *Journal of Political Economy, 108*(3), 466–502. https://doi.org/10.1086/262126

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289–326. https://doi.org/10.1002/jae.616

Reboredo, J. C. (2012). Do food and oil prices co-move? *Energy Policy, 49*, 456–467. https://doi.org/10.1016/j.enpol.2012.06.035

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In R. C. Sickles & W. C. Horrace (Eds.), *Festschrift in honor of Peter Schmidt* (pp. 281–314). Springer. https://doi.org/10.1007/978-1-4899-8008-3_9

Sun, Y., Gao, P., Raza, S. A., Shah, N., & Sharif, A. (2023). The asymmetric effects of oil price shocks on the world food prices: Fresh evidence from quantile-on-quantile regression approach. *Energy, 270*, Article 126812. https://doi.org/10.1016/j.energy.2023.126812

Taghizadeh-Hesary, F., Rasoulinezhad, E., & Yoshino, N. (2019). Energy and food security: Linkages through price volatility. *Energy Policy, 128*, 796–806. https://doi.org/10.1016/j.enpol.2018.12.043

Tumturk, O. (2025). Determinants of food prices in Turkey: A Fourier ARDL approach (2006–2025). *Necmettin Erbakan University Journal of Social Sciences, 14*(1), 55–78.

Turkish Statistical Institute. (2022). *Consumer price index*. TÜİK. https://www.tuik.gov.tr/

Chapter 2

The Red Sea Disruption and Europe-Asia Trade: Evidence from Monthly Bilateral Import Flows

Bilal ORHAN[1], Muhammed BENLİ[2]

Abstract

The disruption of shipping through the Red Sea from late 2023 sharply reduced traffic through the Suez Canal, increased sailing distances between Asia and Europe, and raised concerns about the vulnerability of international supply chains. This study examines whether the disruption translated into a sustained contraction in realized Europe-Asia merchandise trade. We use monthly bilateral import data from UN Comtrade covering January 2022 to December 2024 and construct a balanced panel of 10 importing economies, 12 exporting economies, and three product aggregates. Europe-Asia country pairs are classified as relatively exposed to the Suez disruption, while North America-Asia, Europe-Latin America, and North America-Latin America flows provide comparison routes. The empirical specification includes importer-exporter pair fixed effects, importer-month fixed effects, and exporter-month fixed effects. We estimate both log-linear models and Poisson pseudo-maximum-likelihood specifications. Descriptive evidence shows that average bilateral imports on Europe-Asia routes declined after December 2023, including reductions of approximately 6 percent in total merchandise and 8 percent in electrical and electronic goods. These unconditional declines, however, do not survive the fixed-effects framework. The preferred PPML estimates indicate no negative relative effect for aggregate merchandise trade or machinery, while electrical and electronic trade is statistically unchanged. The evidence therefore points to considerable trade resilience under a major maritime transport shock. The disruption altered shipping routes, transit times, and transport costs, but these disturbances did not translate into a broad and persistent contraction in recorded Europe-Asia merchandise imports during 2024.

Keywords: Red Sea, Suez Canal, international trade, shipping disruption, supply-chain resilience, PPML

[1] Bilal Orhan, Res. Asst. – Bilecik Şeyh Edebali University, Faculty of Economics and Administrative Sciences, Department of Economics, Bilecik 11100, Türkiye, bilal.orhan@bilecik.edu.tr, ORCID: https://orcid.org/0000-0003-2838-4782

[2] Muhammed Benli, Prof. Dr. – Bilecik Şeyh Edebali University, Faculty of Economics and Administrative Sciences, Department of Economics, Bilecik 11100, Türkiye, muhammed.benli@bilecik.edu.tr, ORCID: https://orcid.org/0000-0001-6486-8739

1. Introduction

Maritime transport is the physical infrastructure underlying a large share of international merchandise trade. Because global production is geographically fragmented, interruptions at a small number of maritime chokepoints can affect transportation times, freight costs, inventories, and the organization of international supply chains. The Suez Canal is particularly important in this respect because it provides the shortest maritime connection between major Asian production centres and European markets.

The security deterioration in the Red Sea from late 2023 created one of the most significant disruptions to this route in decades. Attacks on commercial vessels led major shipping companies to avoid the Red Sea and reroute vessels around the Cape of Good Hope. The consequences for shipping activity were immediate. IMF PortWatch reported that trade volume passing through the Suez Canal in the first two months of 2024 was approximately 50 percent below the level observed one year earlier. At the same time, traffic routed around the Cape of Good Hope increased sharply (IMF, 2024).

The scale of the disruption remained substantial well beyond the initial months. UNCTAD (2024) reports that by mid-2024 Suez transits remained far below pre-crisis levels and that rerouting materially increased voyage distances and sailing times on Asia-Europe services. These changes raised effective vessel demand, freight costs, and inventory-carrying costs even where the underlying trade transaction continued.

These changes should matter for trade. Transport time is itself an economically important trade cost. Hummels and Schaur (2013) estimate that an additional day in transit can be equivalent to an ad valorem tariff of between 0.6 and 2.1 percent, with particularly strong effects for parts and components. Earlier evidence from the historical closure of the Suez Canal similarly demonstrates that exogenous increases in effective maritime distance reduce bilateral trade (Feyrer, 2021).

The Red Sea crisis therefore provides a useful setting for examining the short-run resilience of merchandise trade to a large logistics shock. The immediate physical disruption is beyond dispute. Vessels travelled longer distances, shipping capacity was absorbed by longer voyages, and scheduled services were reorganized. Recent maritime research documents extensive operational responses by shipping lines, including additional vessel deployment, port-call adjustments, and changes in network configuration on Asia-Europe services (Notteboom et al., 2024; Yap and Yang, 2024).

What is less obvious is whether these transport disruptions resulted in a persistent reduction in realized merchandise trade. A direct decline is plausible.

Longer journeys increase fuel, chartering, insurance, and inventory-carrying costs. Delivery uncertainty can disrupt production processes when firms rely on time-sensitive intermediate inputs. Capacity absorbed by longer voyages can raise freight rates and constrain available shipping services. Research on other maritime disruptions provides evidence that such mechanisms can be economically substantial. For example, the 2021 Ever Given blockage generated sizeable vessel and inventory costs despite lasting only several days (Tran et al., 2025).

There is, however, an opposing possibility. Modern container shipping networks can reroute vessels, deploy additional capacity, alter sailing schedules, modify port calls, and reorganize transshipment operations. Importers can adjust inventories and delivery schedules. Firms may absorb higher transport costs when the underlying value of the transaction substantially exceeds the logistics shock. A disruption can therefore impose substantial costs without permanently destroying the associated trade flow.

This distinction is important. A fall in Suez traffic is not the same object as a fall in Asia-Europe trade. Goods previously passing through the Suez Canal may still reach their destination after travelling around Africa. The strong increase in Cape of Good Hope traffic during the crisis is therefore evidence of physical rerouting rather than, by itself, evidence of disappearing trade.

This paper asks whether the Red Sea disruption translated into weaker European imports from Asian trading partners. We construct monthly bilateral import flows between January 2022 and December 2024 using UN Comtrade data. The analytical sample contains eight European and two North American importing economies and twelve exporters located in Asia and Latin America. Europe-Asia pairs are classified as relatively exposed to the Red Sea and Suez disruption. Other geographic combinations provide comparison routes.

The analysis considers total merchandise trade and two manufacturing categories that are especially relevant to internationally fragmented supply chains. These are machinery classified under HS chapter 84 and electrical and electronic products under HS chapter 85.

Our preferred specification includes importer-exporter pair fixed effects, importer-month fixed effects, and exporter-month fixed effects. Pair effects remove persistent differences across bilateral trade relationships. Importer-month effects absorb all monthly shocks common to an importing economy, while exporter-month effects absorb simultaneous monthly shocks affecting an exporting economy. The identifying variation therefore comes from the relative post-December 2023 performance of Europe-Asia pairs compared with

alternative geographic relationships after country-specific monthly developments are removed.

The design is intentionally interpreted as associational rather than as a clean natural experiment. The period contains several overlapping developments, including weak European demand, manufacturing cycles, the continuing effects of the war in Ukraine, and the Panama Canal drought. The empirical question is consequently narrower. We ask whether Europe-Asia trade performed unusually poorly after the Red Sea disruption relative to the comparison relationships in the sample.

The results reveal a marked difference between unconditional and conditional evidence. Average bilateral Europe-Asia imports decline after December 2023. Total merchandise imports fall by approximately 6.3 percent, machinery imports by 3.9 percent, and electrical and electronic imports by 8.2 percent. These raw comparisons could easily be interpreted as evidence that the Red Sea crisis suppressed Europe-Asia trade. Once importer-month, exporter-month, and pair fixed effects are introduced, however, the evidence changes substantially.

The log-linear specification finds no statistically significant relative contraction for any of the three outcomes. More importantly, the preferred PPML estimator produces a positive coefficient for total merchandise and machinery and a small, statistically insignificant negative estimate for electrical and electronic products. For aggregate merchandise trade, the estimated conditional relative difference is approximately 6.7 percent. For machinery it is approximately 21.2 percent. These coefficients should not be interpreted as causal increases caused by the Red Sea disruption. Rather, they demonstrate that a generalized negative trade effect is not present after simultaneous bilateral and country-month developments are absorbed.

The contribution of the study is therefore straightforward. The existing discussion of the Red Sea crisis has correctly emphasized severe disruption in vessel movements, costs, travel times, and maritime networks. This paper shifts the outcome from shipping activity to realized bilateral merchandise trade. The evidence suggests that substantial logistics disruption and substantial trade destruction need not occur together.

2. Data and Empirical Strategy

2.1. Red Sea disruption and empirical timing

The Red Sea crisis intensified during the final weeks of 2023 as security threats led major container carriers to suspend or reduce voyages through the

Red Sea and Bab el-Mandeb Strait. The resulting diversions toward the Cape of Good Hope sharply increased voyage distances on Asia-Europe routes.

The post-disruption period in this study begins in December 2023. This timing corresponds closely to the point at which rerouting became widespread across major shipping services. Notteboom et al. (2024) document the rapid operational response of container carriers during this period, while subsequent UNCTAD evidence shows that the changes persisted through 2024.

$$Post_t = \begin{cases} 1, & t \geq December\ 2023 \\ 0, & otherwise \end{cases}$$

The sample begins in January 2022 and ends in December 2024. We therefore observe twenty-three months before December 2023 and thirteen months beginning with the treatment month.

2.2. Bilateral trade data

Monthly bilateral import values are obtained from the UN Comtrade database using the Harmonized System classification. The analytical sample contains ten importing economies. The European group consists of Belgium, France, Germany, Italy, the Netherlands, Portugal, Spain, and the United Kingdom. The North American importer group consists of Canada and the United States.

The exporter sample contains eight Asian economies and four Latin American economies. The Asian group consists of China, India, Japan, the Republic of Korea, Malaysia, Singapore, Thailand, and Viet Nam. The Latin American comparison group consists of Brazil, Chile, Colombia, and Mexico.

These groups produce four broad geographic relationships. Europe-Asia is the relatively Suez-exposed group. Europe-Latin America, North America-Asia, and North America-Latin America form the comparison set.

The balanced dataset contains 10 x 12 x 36 = 4,320 country-pair-month observations for each outcome. Because three product aggregates are studied, the full constructed panel contains 12,960 observations. Data-quality checks identify no duplicate pair-sector-month observations, missing trade values, or negative trade values.

Trade values are examined for three categories. The first is total merchandise imports. The second is machinery under HS chapter 84. The third is electrical machinery and equipment under HS chapter 85. HS84 and HS85 are analyzed separately because they contain substantial quantities of intermediate, capital,

electronic, and technology-intensive goods whose production commonly involves international supply chains.

2.3. Treatment definition

A bilateral pair is classified as Red Sea exposed when the importing economy is European and the exporting economy is Asian.

$$SuezPair_{ij} = Europe_i \times Asia_j$$

The treatment interaction is

$$SuezPost_{ijt} = SuezPair_{ij} \times Post_t$$

This variable therefore equals one for European imports from the Asian exporters in the sample beginning in December 2023. The classification is intentionally geographic rather than shipment-specific. UN Comtrade records customs trade flows but does not identify the route followed by each individual shipment. Not every Europe-Asia transaction necessarily travelled through Suez before the crisis. Some goods may travel by air, rail, or alternative maritime routes. The treatment variable consequently measures relative exposure rather than exact shipment-level treatment.

2.4. Descriptive comparison

Before estimating conditional models, we compare average bilateral monthly trade before and after December 2023.

Table 1. Average Monthly Bilateral Import Values Before and After December 2023

Product group	Route group	Pre, USD mn	Post, USD mn	Change
Total merchandise	Europe-Asia	1,188.8	1,113.3	-6.3%
Total merchandise	Control routes	2,919.9	2,943.6	+0.8%
Machinery, HS84	Europe-Asia	193.2	185.7	-3.9%
Machinery, HS84	Control routes	488.7	519.4	+6.3%
Electrical/electronics, HS85	Europe-Asia	311.8	286.3	-8.2%
Electrical/electronics, HS85	Control routes	600.3	596.0	-0.7%

Note: Values are means across bilateral pair-month observations. The post period begins in December 2023.

Table 1 initially appears consistent with a negative Red Sea effect. Europe-Asia imports decline for every product category. Control routes show a small increase for total merchandise, a larger increase for machinery, and only a slight decline in electrical and electronic goods. These comparisons are informative but cannot isolate a route-specific relationship because importing and exporting economies simultaneously experienced substantial macroeconomic and sectoral variation.

2.5. Econometric specification

$$Y_{ijt} = \beta SuezPost_{ijt} + \alpha_{ij} + \lambda_{it} + \mu_{jt} + \varepsilon_{ijt} \quad (1)$$

where Y_{ijt} denotes imports by country i from exporter j in month t. The pair fixed effect α_{ij} absorbs all time-invariant differences across importer-exporter relationships, including distance, historical trading relationships, and persistent bilateral supply-chain integration.

Importer-month fixed effects λ_{it} absorb every monthly factor that affects the importing country equally across exporters. These include domestic demand, exchange-rate conditions, macroeconomic activity, aggregate import changes, and importer-specific policy developments. Exporter-month fixed effects μ_{jt} absorb monthly developments common to an exporter across destinations, including supply changes, production cycles, exchange-rate shocks, and broad export fluctuations.

The resulting comparison is demanding. For example, a decline in Germany's overall imports during a particular month is removed by Germany-month fixed effects. A simultaneous fall in China's total exports is removed by China-month fixed effects. The coefficient beta identifies whether Germany-China trade, as part of the exposed geographic group, evolves differently after December 2023 relative to the remaining bilateral structure.

The first specification estimates equation (1) using $ln(1 + Trade_{ijt})$. The principal estimator is Poisson pseudo-maximum likelihood.

$$E(Trade_{ijt}|Z_{ijt}) = exp(SuezPost_{ijt} + \alpha_{ij} + \lambda_{it} + \mu_{jt}) \quad (2)$$

PPML is preferable for trade-value models because it accommodates zero observations and remains appropriate under common forms of heteroskedasticity that create problems for log-linearized gravity equations (Santos Silva and Tenreyro, 2006). Standard errors are clustered by importer-

exporter pair. The three product categories are estimated separately rather than pooled.

3. Results

3.1. Monthly trade patterns

Figure 1 presents aggregate monthly trade for exposed Europe-Asia relationships and comparison routes, indexed relative to the average level observed between January and November 2023.

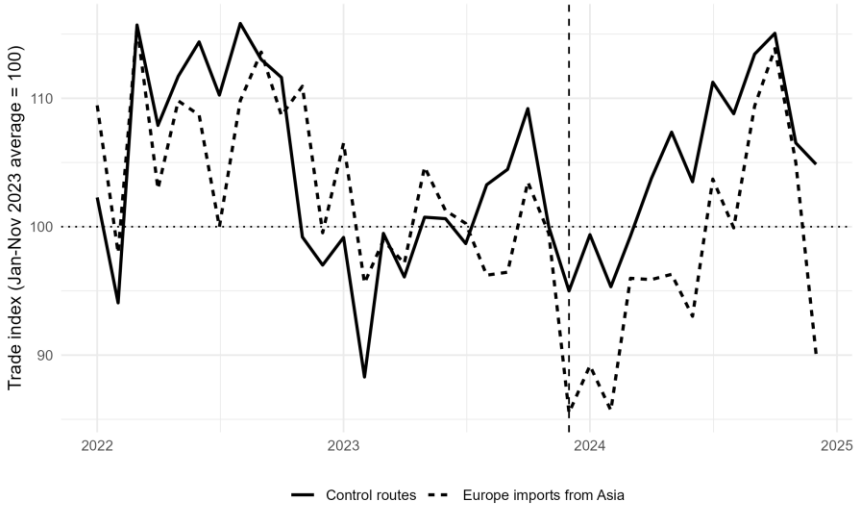

Figure 1. Europe-Asia and Control-Route Merchandise Trade

Note: Series are indexed to their respective January-November 2023 means, which equal 100. The dashed vertical line identifies December 2023.

The monthly data show considerable volatility before and after the disruption. Europe-Asia trade weakens around the beginning of the Red Sea crisis, but it subsequently recovers. There is no permanent collapse resembling the decline in Suez Canal vessel traffic itself.

That distinction matters because ship movements and merchandise deliveries adjust on different margins. The physical route can change dramatically while goods continue to arrive at their destination with additional delay and cost. The evidence is consistent with operational adaptation documented by Yap and Yang (2024), who show that shipping companies responded to the Red Sea crisis through changes in service organization, vessel deployment, and port calls.

Figure 2 reports the corresponding trajectories for machinery and electrical/electronic products.

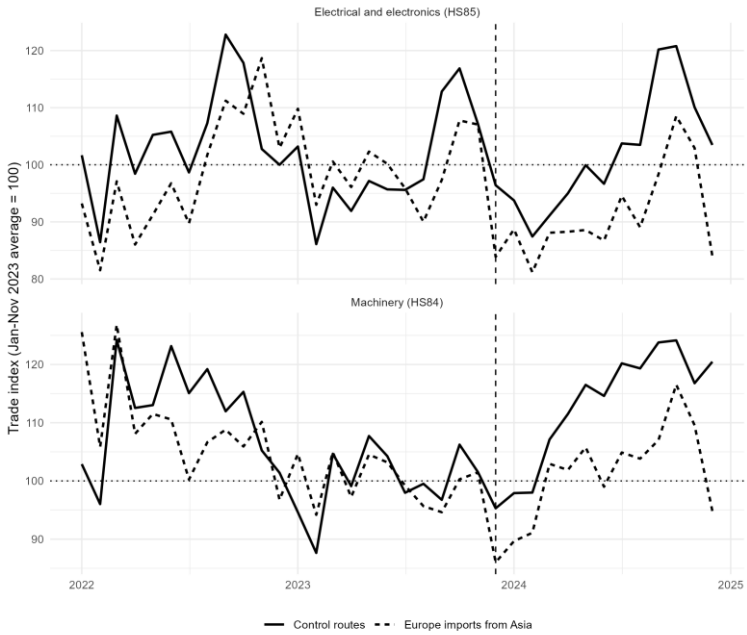

Figure 2. Europe-Asia and Control-Route Trade in Machinery and Electrical/Electronic Goods

Note: Series are indexed to their respective January-November 2023 means. The dashed vertical line identifies December 2023.

The figures provide evidence of disruption but not of persistent separation between treated and comparison routes. This motivates the fixed-effects analysis.

3.2. Main estimates

Table 2 presents the estimates from equation (1).

Table 2. Red Sea Exposure and Monthly Bilateral Imports

Product group	Model	Coefficient	Std. error	p-value	Implied effect
Total merchandise	Log	-0.006	0.058	0.922	-0.6%
Total merchandise	PPML	0.065**	0.032	0.041	+6.7%
Machinery, HS84	Log	-0.221	0.206	0.286	-19.8%
Machinery, HS84	PPML	0.192***	0.071	0.007	+21.2%
Electrical/electronics, HS85	Log	-0.077	0.146	0.601	-7.4%
Electrical/electronics, HS85	PPML	-0.035	0.049	0.474	-3.4%

Note: All models include importer-exporter pair fixed effects, importer-month fixed effects, and exporter-month fixed effects. Standard errors are clustered by bilateral pair. Each regression contains 4,320 observations. *** p<0.01, ** p<0.05, * p<0.10.

The first result is straightforward. There is no statistically significant negative coefficient for total merchandise imports. The log estimate is essentially zero. The coefficient is -0.006 with a p-value of 0.922. This provides no indication that Europe-Asia trade experienced a disproportionate contraction after December 2023 once importer and exporter monthly conditions are removed.

The PPML estimate is instead positive. The coefficient of 0.065 corresponds to an implied conditional difference of approximately 6.7 percent and is statistically significant at the 5 percent level. This estimate does not mean that the Red Sea crisis caused Europe-Asia trade to increase. The research design does not isolate a treatment free of concurrent developments. The appropriate interpretation is more limited. Conditional on pair, importer-month, and exporter-month fixed effects, the data reject the proposition that exposed Europe-Asia trade suffered a broad relative contraction.

The machinery results reinforce this interpretation. The log model is negative but imprecisely estimated. The PPML coefficient is 0.192 and is statistically significant at below the 1 percent level, corresponding to an approximately 21.2 percent positive conditional difference. Again, this should be read as evidence against sustained trade destruction rather than as a beneficial causal effect of disruption.

Electrical and electronic goods provide a different pattern. Both estimates are negative, but neither is statistically significant. The preferred PPML coefficient implies a modest 3.4 percent negative difference with a p-value of 0.474. The absence of a significant electrical/electronic trade effect is notable in light of evidence that parts and components can be especially sensitive to time in transit (Hummels and Schaur, 2013). In the present setting, however, transport disruption may have been countered by inventories, route substitution, scheduling adjustments, or alternative transport modes for sufficiently time-sensitive goods.

At first sight, Table 1 and Table 2 appear contradictory. The raw data show a decline in Europe-Asia trade after December 2023, yet the fixed-effects models provide no evidence of a negative relative effect.

The explanation lies in the counterfactual. A simple before-after comparison implicitly assumes that Europe-Asia trade would otherwise have remained unchanged. That is a weak assumption during a period in which importing and exporting economies experienced substantial macroeconomic and sectoral variation.

The fixed-effects design asks a different question. Did Europe-Asia relationships weaken more than would be expected given what was

simultaneously happening to the importing economy and the exporting economy? Once these common developments are removed, the raw decline no longer constitutes evidence of a distinct Red Sea trade contraction.

The distinction is especially apparent for machinery. Europe-Asia machinery imports decline by approximately 3.9 percent in the raw averages, whereas comparison-route machinery trade increases by approximately 6.3 percent. Nevertheless, after importer-month and exporter-month effects are included, PPML produces a positive conditional coefficient. This illustrates why transport-shock studies should distinguish physical shipping disruption from underlying demand and supply developments.

4. Discussion

The Red Sea crisis unquestionably imposed substantial costs on international shipping. Suez traffic remained far below pre-crisis levels during much of 2024, vessels travelled thousands of additional nautical miles, and ship capacity was absorbed by longer round trips. UNCTAD (2024) documents substantial changes in effective vessel demand, voyage times, and shipping costs associated with Cape rerouting.

The main result of this paper is that these logistics costs did not translate into a comparably large contraction in realized Europe-Asia merchandise trade. This finding is compatible with several forms of supply-chain adaptation.

First, the Cape of Good Hope provides a costly but viable substitute route. The Red Sea crisis did not geographically isolate Europe from Asian suppliers. It increased transport distance. Feyrer's (2021) analysis of the historical Suez closure demonstrates that distance affects trade, but the modern shipping industry also operates with substantially greater scale, containerization, logistics coordination, and fleet flexibility than in the 1960s and 1970s.

Second, shipping companies adapted vessel deployment. Longer round trips reduce effective fleet capacity because the same ship completes fewer voyages in a given period. Operators can partially counter this by adding vessels, changing sailing speeds, modifying port calls, and reorganizing networks. Yap and Yang (2024) explicitly document such responses during the current Red Sea crisis.

Third, trade flows differ in their sensitivity to freight costs. A substantial increase in shipping cost may be small relative to the value of high-value machinery or electronic goods. Firms may therefore preserve established transactions and absorb temporary logistics costs rather than rapidly replace suppliers.

Fourth, supply chains contain inventories and delivery buffers. The economic cost of longer transit times can therefore appear in inventory financing, production

scheduling, or working capital without appearing as a reduction in customs-recorded import value.

The distinction between trade resilience and costlessness is critical. Our findings do not imply that the Red Sea disruption was economically unimportant. A shipment arriving ten days later and at substantially higher freight cost still represents a successful trade flow in customs data. The same dollar value can therefore coexist with lower efficiency and higher resource costs.

Research on the Ever Given blockage illustrates this point. Tran et al. (2025) estimate substantial vessel, environmental, and inventory-carrying costs resulting from a disruption lasting only several days. The trade-flow outcome alone cannot capture these welfare losses.

The results also complement recent research focused directly on shipping networks. Notteboom et al. (2024) and Yap and Yang (2024) show large operational consequences of the Red Sea crisis. Our evidence indicates that these changes in maritime organization need not imply an equivalent reduction in the value of goods ultimately imported.

Several limitations should qualify the interpretation. First, treatment is based on geographic exposure rather than actual vessel routing. Some Europe-Asia goods may not use the Suez Canal, particularly goods shipped by air. The exposure variable is therefore an imperfect proxy for route-specific treatment.

Second, the control group is not completely insulated from transport disruptions. North America-Asia trade was affected by conditions in the Panama Canal during part of the sample. This makes the control group imperfect and reinforces the decision not to attach a strict causal interpretation to the coefficient.

Third, the analysis uses nominal trade values. A stable import value can mask changes in physical quantity or prices. Fourth, HS84 and HS85 remain broad product categories. The response of semiconductor components, consumer electronics, industrial machinery, and other individual goods may differ considerably within these chapters.

Fifth, the sample is deliberately limited to a manageable set of major trading economies. It should not be interpreted as a complete global estimate of the Red Sea crisis. Finally, the post period extends only through December 2024. The analysis therefore captures relatively short-run adaptation. A prolonged disruption could eventually affect sourcing, investment, supplier choice, or production location even if immediate trade flows prove resilient.

These limitations do not undermine the central descriptive and econometric result. Within the country pairs and product groups examined here, a severe maritime disruption did not generate clear evidence of broad sustained trade destruction.

5. Conclusion

The Red Sea crisis created a major shock to one of the world's most important maritime corridors. Suez Canal traffic collapsed, many vessels diverted around the Cape of Good Hope, sailing times increased, and freight and inventory costs rose.

A natural expectation is that these developments should reduce Europe-Asia merchandise trade. The monthly bilateral evidence presented in this paper provides a more nuanced picture.

Raw trade values initially appear consistent with that expectation. Following December 2023, average Europe-Asia bilateral imports decline by approximately 6 percent for total merchandise, 4 percent for machinery, and 8 percent for electrical and electronic goods. These declines do not survive the fixed-effects framework.

After controlling for persistent bilateral relationships and importer- and exporter-specific monthly shocks, the log models show no significant negative effect for any product group. The preferred PPML estimates likewise provide no evidence of a broad trade contraction. Total merchandise and machinery instead display positive conditional differences, while electrical and electronic trade remains statistically unchanged.

These estimates should not be interpreted as evidence that maritime disruption improves trade. They indicate something more economically useful. A large shipping shock does not necessarily become a large trade-flow shock.

The international shipping system absorbed much of the Red Sea disruption through rerouting and operational adjustment. Those adaptations were costly. They increased distance, transit time, fleet requirements, freight rates, and logistical complexity. Yet they also allowed a substantial share of the underlying merchandise trade relationships to continue.

The findings therefore highlight a distinction that is central to debates about supply-chain resilience. Resilience does not mean the absence of disruption. It means that trade can continue despite disruption, albeit at higher cost.

For policymakers and firms, this distinction matters. Maritime chokepoints remain a genuine source of vulnerability. However, evaluating vulnerability solely from vessel-transit statistics can overstate the immediate implications for realized trade. The economic consequences of transport shocks should be assessed across several margins, including shipping costs, delivery times, inventories, prices, trade volumes, and longer-run sourcing decisions.

References

Feyrer, J. (2021). Distance, trade, and income - The 1967 to 1975 closing of the Suez Canal as a natural experiment. *Journal of Development Economics, 153,* 102708.

Hummels, D. L., & Schaur, G. (2013). Time as a trade barrier. American Economic Review, 103(7), 2935-2959.

IMF. (2024). *Red Sea attacks disrupt global trade.* IMF Blog, 7 March 2024.

Notteboom, T., Haralambides, H., & Cullinane, K. (2024). The Red Sea Crisis: Ramifications for vessel operations, shipping networks, and maritime supply chains. *Maritime Economics & Logistics, 26*(1), 1-20.

Santos Silva, J. M. C., & Tenreyro, S. (2006). The log of gravity. *Review of Economics and Statistics, 88*(4), 641-658. https://doi.org/10.1162/rest.88.4.641

Tran, N. K., Haralambides, H., Notteboom, T., & Cullinane, K. (2025). The costs of maritime supply chain disruptions: The case of the Suez Canal blockage by the Ever Given megaship. *International Journal of Production Economics, 279,* 109464.

UNCTAD. (2024). *Review of Maritime Transport 2024: Navigating maritime chokepoints.* United Nations Conference on Trade and Development.

Yap, W. Y., & Yang, D. (2024). Geopolitical tension and shipping network disruption: Analysis of the Red Sea crisis on container port calls. *Journal of Transport Geography, 121,* 104004.

Chapter 3

Geopolitical Fragmentation and Limited Friend-Shoring in Semiconductor Trade

Bilal ORHAN[1], Muhammed BENLİ[2]

Abstract

Geopolitical tensions have strengthened calls for friend-shoring and supply-chain de-risking, with semiconductors occupying a central position in economic-security policy. This study examines whether semiconductor trade has in fact shifted toward geopolitically aligned partners. We combine CEPII BACI bilateral trade data for 2017-2024 with the OECD mapping of 59 HS2017 semiconductor products and the hypothetical East-West bloc classification used by Blanga-Gubbay and Rubínová (2024). The analysis covers 116 economies and seven semiconductor value-chain segments. The preferred specification includes exporter-segment-year, importer-segment-year, and directed pair-segment fixed effects. A log-linear model indicates a small decline in cross-bloc trade after 2022, but the preferred Poisson pseudo-maximum-likelihood estimate is close to zero and statistically insignificant. Descriptively, between-bloc semiconductor trade actually grew faster than within-bloc trade between 2017 and 2024. Segment-level estimates provide only suggestive evidence of reorientation in foundry inputs and manufacturing equipment, while results for other segments are weak or sensitive to the estimator. The findings therefore provide limited evidence of broad semiconductor friend-shoring. They instead suggest that geopolitical reorientation, where present, is selective and constrained by the technological specialization and cross-border interdependence of the semiconductor value chain.

Keywords: Semiconductors, friend-shoring, geoeconomic fragmentation, international trade, global value chains

[1] Bilal Orhan, Res. Asst. – Bilecik Şeyh Edebali University, Faculty of Economics and Administrative Sciences, Department of Economics, Bilecik 11100, Türkiye, bilal.orhan@bilecik.edu.tr, ORCID: https://orcid.org/0000-0003-2838-4782

[2] Muhammed Benli, Prof. Dr. – Bilecik Şeyh Edebali University, Faculty of Economics and Administrative Sciences, Department of Economics, Bilecik 11100, Türkiye, muhammed.benli@bilecik.edu.tr, ORCID: https://orcid.org/0000-0001-6486-8739

1. Introduction

Semiconductors have become one of the clearest intersections between international trade and economic security. Modern production systems depend on chips for computing, telecommunications, vehicles, industrial machinery, defence applications, and an expanding range of digital services. At the same time, semiconductor production is not organized within national boundaries. It is distributed across a complex international value chain that links raw materials, wafer-related inputs, fabrication equipment, foundries, semiconductor devices, and downstream electronics. This combination of strategic importance and cross-border specialization has made the sector a central test of whether geopolitical rivalry is beginning to reshape global trade.

The broader evidence points toward some reorientation of trade along geopolitical lines. Blanga-Gubbay and Rubínová (2024), using monthly goods trade and a gravity framework with high-dimensional fixed effects, report that trade between hypothetical East and West blocs grew about 4 percent more slowly than trade within those blocs after the start of the war in Ukraine. The IMF reaches a similar conclusion using a different bloc construction. Gopinath et al. (2024) estimate a roughly 12 percent relative decline in trade between geopolitically distant blocs after 2022 and document the growing importance of connector economies. These findings have supported a wider discussion of friend-shoring, de-risking, and the possible fragmentation of the world economy.

Yet there is no reason to expect the same degree of fragmentation in every sector. In fact, Blanga-Gubbay and Rubínová (2024) find that the broader alignment of global trade with geopolitical affinities has been driven disproportionately by less complex products, where alternative suppliers are easier to find. This observation creates an important tension for semiconductor trade. Semiconductors are among the most technologically complex and internationally fragmented products in world commerce. If complex supply relationships are difficult to replace, geopolitical pressure may have only a limited effect on realized trade even when policy rhetoric becomes much more explicit.

The semiconductor value chain is particularly resistant to rapid substitution because different stages are concentrated in different locations and require highly specialized capabilities. The OECD (2025a) describes the chain as globally distributed but tightly interconnected, with important bottlenecks and trade dependencies. Semiconductor production is also highly geographically concentrated. OECD evidence indicates that the five largest economies account for about three quarters of global semiconductor value added, while some

upstream materials and manufacturing-equipment categories are even more concentrated (OECD, 2025b). A disruption or policy restriction in one location can therefore propagate through a wide range of downstream industries.

These characteristics make friend-shoring economically ambiguous. On one side, national-security concerns create strong incentives to reduce dependence on geopolitical rivals. Governments have introduced large semiconductor industrial-policy programmes, export controls, investment screening, and measures intended to expand domestic or allied production. Firms may also prefer suppliers located in politically aligned economies when the expected cost of disruption becomes sufficiently high. If these forces dominate, trade within geopolitical blocs should expand relative to trade across blocs.

On the other side, existing production networks create large adjustment costs. Semiconductor fabrication plants require substantial sunk investment and specialized human capital. Advanced manufacturing equipment is supplied by a limited set of producers. Inputs used in wafer fabrication often have demanding quality requirements and cannot be replaced immediately. Even where governments are willing to subsidize new capacity, construction and qualification take time. Friend-shoring may therefore alter investment plans before it produces a visible reallocation of annual merchandise trade. In such a setting, geopolitical fragmentation may be selective rather than general, with stronger effects in segments where alternative capacity already exists and weaker effects where substitution is technically difficult.

This paper examines whether semiconductor trade has become more geographically aligned with geopolitical blocs over the period 2017-2024. The analysis combines CEPII BACI bilateral trade flows with the OECD's HS2017 mapping of the semiconductor value chain. The product list contains 59 six-digit HS categories that are grouped into seven segments. These are raw materials, wafer fabrication inputs, silicon wafers, foundry inputs, manufacturing equipment, chips and related final products, and photosensitive semiconductor devices. This segmentation allows the analysis to move beyond aggregate electronics trade and examine whether any geopolitical reorientation differs across stages of the value chain.

Geopolitical alignment is measured using the hypothetical East-West bloc classification employed by Blanga-Gubbay and Rubínová (2024). After matching that classification to BACI country identifiers and removing legacy country codes, the estimation sample contains 116 economies. Sixty-two are classified in the West bloc and fifty-four in the East bloc. The classification is used only as an empirical device for measuring geopolitical separation. It

should not be interpreted as a political, legal, or normative characterization of any economy.

The empirical design compares trade between economies in different blocs with trade between economies in the same bloc before and after 2022. The preferred specification includes directed pair-segment fixed effects, exporter-segment-year fixed effects, and importer-segment-year fixed effects. This structure absorbs permanent bilateral trade frictions within each semiconductor segment as well as all annual exporter- and importer-specific shocks within that segment. The coefficient of interest therefore captures whether cross-bloc trade changed differently after 2022 relative to within-bloc trade, conditional on the same exporting and importing conditions.

The results provide limited evidence of broad friend-shoring. The log-linear model produces a small negative coefficient, corresponding to approximately 3.4 percent weaker cross-bloc trade after 2022. However, the preferred Poisson pseudo-maximum-likelihood estimate is only −0.9 percent and is statistically insignificant. Since PPML is better suited to the highly skewed distribution of bilateral trade and naturally accommodates zero flows, the aggregate evidence does not support a strong semiconductor-wide fragmentation effect.

The descriptive evidence is even less consistent with simple bloc separation. Between 2017 and 2024, semiconductor trade between the hypothetical blocs increased by about 64.7 percent, while within-bloc trade increased by about 42.9 percent. This raw comparison cannot identify a geopolitical effect because the composition of exporters, importers, and value-chain segments differs substantially. It does show, however, that global semiconductor trade has continued to connect geopolitically distant economies despite rising policy tensions.

Segment-level estimates point to a more nuanced interpretation. PPML coefficients are negative for foundry inputs and manufacturing equipment and are close to conventional significance thresholds. The implied differences are roughly −12.5 percent and −9.1 percent. These results are suggestive rather than conclusive, and several other segments produce coefficients that are insignificant or change sign across estimators. The evidence therefore fits a pattern of selective reorientation more closely than broad decoupling.

The contribution of the paper is deliberately focused. Rather than asking whether the entire world economy is fragmenting, it examines a strategically important value chain in which geopolitical incentives for friend-shoring are unusually strong but technological constraints on substitution are also severe. The results show why these two forces should be separated. Policy efforts to de-risk a value chain do not necessarily imply an immediate decline in cross-bloc

trade, especially where existing supplier relationships and production capabilities are difficult to replace.

2. Data and Empirical Strategy

2.1. Semiconductor product coverage

The semiconductor product classification is drawn from the OECD's Mapping the Semiconductor Value Chain (OECD, 2025a). The mapping identifies HS2017 products associated with the main stages and inputs of semiconductor production. The analytical list contains 59 unique HS6 products. We aggregate these products into seven value-chain segments to preserve economically meaningful differences while keeping the empirical design manageable.

The largest segment in trade-value terms is chips and related final products. Manufacturing equipment is the second largest. The remaining segments cover photosensitive semiconductor devices, foundry inputs, raw materials, silicon wafers, and wafer fabrication inputs. This product-level approach is important because a broad two-digit electronics classification would combine semiconductor-specific trade with many goods whose supply-chain structure and geopolitical relevance differ substantially.

The OECD mapping is intended to identify key traded inputs and products in the semiconductor ecosystem rather than to measure every production activity. Some important activities, including design services and intellectual property, do not appear directly in merchandise trade statistics. The analysis therefore concerns the geography of traded semiconductor goods and inputs, not the full geography of semiconductor value added.

2.2. Trade data and sample construction

Bilateral trade data come from CEPII BACI, which reconciles exporter and importer reports from UN Comtrade and provides harmonized bilateral trade flows at the product level (Gaulier and Zignago, 2010). We use the January 2026 HS2017 release and retain annual observations from 2017 through 2024. The HS2017 nomenclature matches the OECD semiconductor product mapping directly and avoids concordance changes within the sample period.

For each year, BACI trade values are first restricted to the 59 semiconductor HS6 products and to economies included in the hypothetical geopolitical bloc classification. Bilateral HS6 flows are then aggregated to directed exporter-importer-segment-year observations. A balanced panel is constructed for all directed country pairs, seven segments, and eight years. Missing positive flows

in BACI are coded as zero. The resulting balanced panel contains 747,040 observations before estimator-specific removals.

The final sample contains 116 unique economies after correcting two legacy UN/Comtrade country identifiers for Belgium and Germany. Sixty-two economies belong to the hypothetical West bloc and fifty-four to the hypothetical East bloc. The panel contains no duplicate country identifiers or missing bloc assignments after this correction.

Table 1 summarizes the growth of semiconductor trade across the seven value-chain segments. Total trade among the economies in the analytical sample rises from about USD 696.7 billion in 2017 to USD 1.073 trillion in 2024, an increase of roughly 54 percent. Chips and related final products account for most of this value, while manufacturing equipment also expands strongly.

Table 1. Semiconductor trade by value-chain segment

Segment	2017, USD bn	2024, USD bn	Growth, %
Chips and related final products	467.2	729.0	56.0
Foundry inputs	23.8	30.8	29.8
Manufacturing equipment	130.6	205.6	57.5
Photosensitive semiconductor devices	48.1	73.6	53.1
Raw materials	10.7	13.1	22.0
Silicon wafers	8.8	13.5	54.1
Wafer fabrication inputs	7.6	7.7	2.0
Total	696.7	1,073.4	54.1

Note: Values are calculated from CEPII BACI bilateral trade among the 116 economies in the analytical sample. Products follow the OECD HS2017 semiconductor mapping. Growth is the percentage change between 2017 and 2024.

2.3. Geopolitical blocs and treatment variable

The geopolitical grouping follows the hypothetical East-West classification developed by Blanga-Gubbay and Rubínová (2024). Their classification is based on foreign-policy affinity measured from voting patterns in the United Nations General Assembly and is designed for empirical analysis of geopolitical fragmentation. We reproduce their economy assignments and match them to BACI identifiers.

For each directed exporter-importer pair, CrossBloc equals one when the two economies belong to different hypothetical blocs and zero when they belong to the same bloc. Post2022 equals one in 2022, 2023, and 2024. The main variable of interest is the interaction between these indicators.

$$CrossPost_{ijt} = CrossBloc_{ij} \times Post2022_t \quad (1)$$

The post indicator should be interpreted as a broad marker of the period of intensified geopolitical fragmentation rather than as a sharply timed treatment. The Russian invasion of Ukraine occurred in February 2022, while the trade data are annual. Moreover, semiconductor trade was simultaneously affected by the pandemic recovery, the global chip cycle, industrial-policy interventions, and technology-specific demand shifts. The estimates are therefore presented as conditional associations rather than causal effects of a single geopolitical event.

2.4. Empirical specification

The empirical specification is designed around the structural logic of gravity models, which emphasize the importance of controlling for multilateral resistance and bilateral trade frictions (Anderson and van Wincoop, 2003). Instead of estimating a conventional gravity equation with observable distance and size controls, we absorb these factors through high-dimensional fixed effects.

For exporter i, importer j, semiconductor segment s, and year t, the preferred specification is

$$Y_{ijst} = \beta CrossPost_{ijt} + \alpha_{ijs} + \lambda_{ist} + \mu_{jst} + \varepsilon_{ijst} \quad (2)$$

The term α_{ijs} denotes directed pair-segment fixed effects. These absorb all time-invariant bilateral characteristics within each value-chain segment, including distance, common language, historical trade links, persistent bilateral production relationships, and the time-invariant cross-bloc indicator itself. Exporter-segment-year fixed effects λ_{ist} absorb all annual shocks to each exporter's supply of a semiconductor segment. Importer-segment-year fixed effects μ_{jst} absorb all annual shocks to each importer's demand for the same segment.

This fixed-effect structure is demanding. Identification does not come from comparing large West exporters with small East exporters or from comparing rapidly growing segments with stagnant ones. It comes from whether cross-bloc bilateral flows evolve differently from within-bloc flows after 2022, conditional on the same exporter-segment-year and importer-segment-year environments.

We estimate Equation (1) first with $ln(1 + trade\ value)$. This transformation retains zero bilateral flows, but it is not our preferred estimator because bilateral trade values are highly skewed and the transformation changes the way large and small flows contribute to the estimate. We therefore also estimate the conditional mean using Poisson pseudo-maximum likelihood.

Santos Silva and Tenreyro (2006) show that PPML is well suited to gravity-type trade data under heteroskedasticity and accommodates zero trade flows without an arbitrary log transformation.

$$E\left(Trade_{ijst} \middle| Z_{ijst}\right) = exp\left(\beta CrossPost_{ijt} + \alpha_{ijs} + \lambda_{ist} + \mu_{jst}\right) \qquad (3)$$

Standard errors are clustered at the directed exporter-importer pair level. This allows residual dependence across years and semiconductor segments within a trading relationship. The PPML estimator automatically removes fixed-effect groups that contain no usable outcome variation, which explains why its effective sample is smaller than the balanced panel used by the log-linear model.

3. Empirical Results

3.1. Descriptive evidence

Figure 1 compares the evolution of total semiconductor trade between blocs and within blocs, with both series normalized to 100 in 2017. The raw pattern does not indicate broad geopolitical decoupling. Between-bloc trade rises to an index value of about 164.7 by 2024, while within-bloc trade reaches about 142.9. In percentage terms, cross-bloc semiconductor trade increases by approximately 64.7 percent from 2017 to 2024, compared with about 42.9 percent for within-bloc trade.

The difference should not be interpreted as evidence that geopolitical distance increases trade. Between-bloc and within-bloc flows differ in their initial composition, the size and specialization of the economies involved, and the segments in which they trade. The figure nevertheless establishes an important empirical fact. Semiconductor trade across the hypothetical geopolitical divide remained large and expanded substantially during a period in which policy attention increasingly emphasized supply-chain security and de-risking.

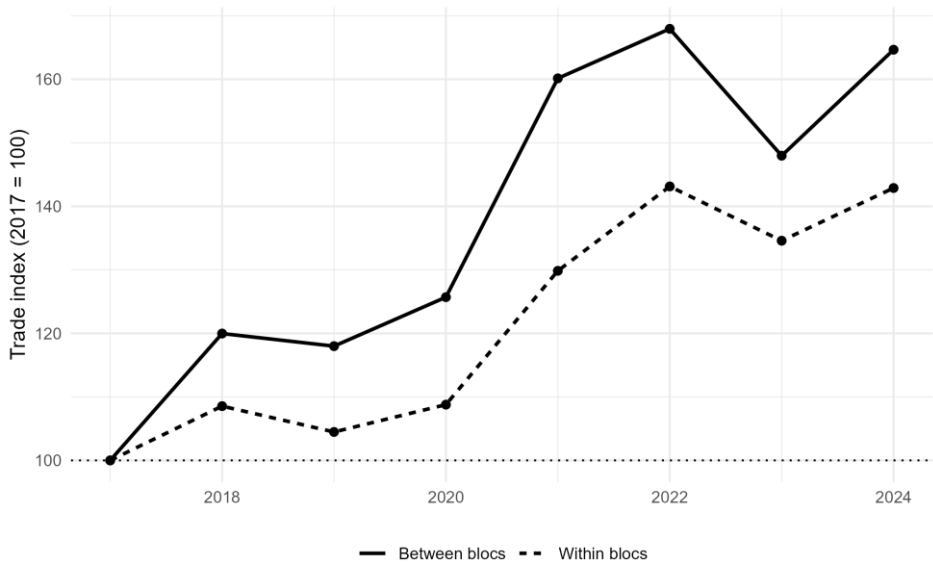

Figure 1. Within-bloc and between-bloc semiconductor trade

Note: Trade values are indexed to 2017 = 100 separately for within-bloc and between-bloc flows. The bloc classification follows Blanga-Gubbay and Rubínová (2024). The figure is descriptive and does not condition on fixed effects.

3.2. Aggregate regression results

Table 2 reports the main fixed-effect estimates. The log-linear specification produces a coefficient of −0.034 on $CrossBloc \times Post2022$. The estimate is statistically significant at the 5 percent level and corresponds to an implied difference of approximately −3.4 percent. Taken alone, this result would suggest a small post-2022 weakening of cross-bloc semiconductor trade relative to within-bloc trade.

The PPML result is materially different. The coefficient is −0.010, corresponding to an implied difference of only −0.9 percent, and the p-value is 0.807. The estimate is therefore both economically small and statistically indistinguishable from zero. Because PPML is the preferred specification for the highly skewed distribution of bilateral trade values, the aggregate evidence does not support a broad friend-shoring effect in semiconductor trade.

Table 2. Cross-bloc semiconductor trade after 2022

	Log(1 + trade)	PPML
Cross-bloc × Post-2022	−0.034**	−0.010
Standard error	0.015	0.039
p-value	0.025	0.807
Implied difference	−3.38%	−0.94%
Observations	747,040	363,202
Pair × segment FE	Yes	Yes
Exporter × segment × year FE	Yes	Yes
Importer × segment × year FE	Yes	Yes

Note: The dependent variable is annual bilateral trade value aggregated within each semiconductor segment. Pair-clustered standard errors are reported. The PPML sample is smaller because all-zero or otherwise non-informative fixed-effect groups are removed by the estimator. ** denotes $p < 0.05$.

The difference between the two estimators is substantively informative. A log transformation compresses economically large flows and gives much more relative influence to small positive observations and changes around zero. PPML estimates the conditional mean in levels and is therefore more closely aligned with the question of whether economically important semiconductor trade has shifted across geopolitical blocs. The absence of a PPML effect implies that any reorientation detected by the log model is not a broad reduction in the value of cross-bloc trade.

This result differs from the aggregate fragmentation pattern documented by the WTO and IMF, but the contrast is economically plausible. Blanga-Gubbay and Rubínová (2024) show that friend-shoring in global goods trade has been more visible in products for which alternative suppliers are relatively easy to find. Semiconductor supply chains have precisely the opposite characteristics. Production is specialized, capital intensive, and often dependent on narrow sets of qualified suppliers. Such relationships may adjust more slowly than geopolitical preferences.

3.3. Results across semiconductor segments

Table 3 separates the estimates across the seven value-chain segments. The results do not reveal a common pattern across the semiconductor ecosystem. Instead, they show why an aggregate conclusion of rapid bloc-level decoupling would be too strong.

Table 3. Cross-bloc trade after 2022 by semiconductor segment

Segment	Log estimate	p	PPML estimate	p
Chips and related final products	0.0114	0.756	0.0011	0.980
Foundry inputs	−0.0200	0.500	−0.1331*	0.070
Manufacturing equipment	0.0345	0.311	−0.0957*	0.051
Photosensitive semiconductor devices	−0.1521***	<0.001	0.1466	0.169
Raw materials	−0.0446	0.169	−0.1246	0.164
Silicon wafers	−0.0750***	0.001	0.0923	0.138
Wafer fabrication inputs	0.0051	0.863	0.1160	0.127

Note: Each row comes from a separate regression with pair-segment, exporter-segment-year, and importer-segment-year fixed effects. Standard errors are clustered by directed country pair. * denotes $p < 0.10$ and *** denotes $p < 0.01$.

The PPML estimates provide suggestive evidence of reorientation in foundry inputs and manufacturing equipment. The coefficient for foundry inputs is −0.133, which corresponds to an implied relative difference of about −12.5 percent and has a p-value of 0.070. Manufacturing equipment has a coefficient of −0.096, corresponding to roughly −9.1 percent, with a p-value of 0.051. Neither result is sufficiently strong to establish a definitive segment-level break, but both are consistent with selective de-risking in strategically sensitive upstream and capital-equipment relationships.

Chips and related final products show essentially no difference between blocs in the PPML specification. This is notable because chips account for by far the largest trade value in the sample. The result is consistent with the idea that the global chip market remains deeply integrated despite policy interventions and bilateral restrictions in particular technologies.

Several log-linear coefficients differ sharply from their PPML counterparts. Photosensitive semiconductor devices and silicon wafers display significantly negative log estimates, but the PPML coefficients are positive and statistically insignificant. These reversals imply that the apparent log effects are concentrated among smaller flows or the extensive margin and do not characterize the conditional mean of trade value. Given the distributional properties of bilateral trade, we do not treat these log-only results as strong evidence of friend-shoring.

Raw materials and wafer fabrication inputs also show no statistically reliable PPML reorientation. Taken together, the segment results suggest that geopolitical adjustment may be occurring in specific parts of the value chain, but the evidence is not broad enough or sufficiently consistent to describe the semiconductor system as splitting into separate geopolitical trade blocs.

4. Discussion

The limited aggregate friend-shoring effect is important precisely because semiconductors are at the centre of current economic-security policy. If geopolitical alignment automatically translated into trade reorientation, one would expect the semiconductor sector to display a particularly strong pattern. The results instead show that strategic policy objectives and realized trade relationships can diverge substantially over short horizons.

One explanation is technological lock-in. The semiconductor value chain combines high fixed costs with narrow specialization. A manufacturer cannot immediately replace advanced lithography equipment, qualified wafer inputs, or a particular foundry relationship simply because geopolitical risk has risen. Supplier qualification, process compatibility, reliability, and intellectual-property constraints create adjustment costs that standard trade classifications do not capture. These constraints can preserve cross-bloc trade even when firms and governments would prefer greater diversification.

A second explanation is that de-risking may operate primarily through investment rather than current trade. New fabrication capacity, packaging facilities, and equipment plants require years to build. Announced industrial policies can therefore change the expected future geography of production while leaving existing trade flows largely intact during the sample window. The 2017-2024 horizon may capture the beginning of reallocation without yet observing its full materialization in merchandise trade.

Third, the value chain is not homogeneous. Foundry inputs and manufacturing equipment display the clearest negative PPML coefficients in our results. These are segments in which governments have paid particular attention to strategic control, technological chokepoints, and export restrictions. The estimates remain only suggestive, but their location within the value chain is economically plausible. By contrast, aggregate chip trade can remain large across blocs even when access to a small set of leading-edge technologies becomes more restricted.

This distinction is consistent with OECD evidence on semiconductor concentration. Aggregate product categories can obscure much higher concentration at specific technology nodes and in specialized equipment. A broad HS6 category may include both mature and advanced technologies whose geopolitical treatment differs sharply. The absence of aggregate trade fragmentation therefore does not imply the absence of strategically important technological fragmentation.

The findings also speak to the broader geoeconomic-fragmentation literature. Gopinath et al. (2024) document a clear post-2022 decline in trade between

geopolitically distant blocs across the global economy. Our semiconductor results suggest that sectoral technological constraints can substantially moderate this process. Fragmentation may proceed fastest where suppliers are substitutable and much more slowly in sectors where production networks are built around scarce capabilities. This heterogeneity matters when using aggregate trade statistics to infer the resilience or vulnerability of strategic supply chains.

The raw trade trends reinforce this point. Between-bloc semiconductor trade grows faster than within-bloc trade over the full 2017-2024 period. This does not mean geopolitical tensions are irrelevant. Rather, it indicates that global demand growth, specialization, and cross-border production complementarities have been powerful enough to offset or mask the reorientation pressures visible elsewhere in world trade. Friend-shoring can coexist with continued dependence on suppliers outside the preferred geopolitical bloc.

The policy implication is that semiconductor resilience cannot be evaluated simply by measuring the share of trade occurring among allies. A country may increase within-bloc sourcing while remaining dependent on a cross-bloc supplier for a narrow but indispensable input. Conversely, gross bilateral trade can remain high even while advanced technology flows become more restricted. Supply-chain security therefore requires product- and technology-specific information that goes beyond aggregate bloc trade.

The analysis has several limitations. First, the bloc classification is deliberately stylized. It converts a continuous measure of geopolitical affinity into two hypothetical groups and excludes non-classified economies. Alternative measures of geopolitical distance could yield different estimates. Second, annual trade data provide only coarse timing around events in 2022. Monthly data could distinguish immediate adjustment from later reallocation more precisely.

Third, HS6 product codes are too broad to identify leading-edge technologies. This issue is particularly serious in semiconductors because the economic and strategic significance of chips depends on design, node size, performance, and end use. Fourth, the study examines gross trade values rather than quantities, unit values, or domestic value added. Price changes can therefore influence measured trade even if physical volumes move differently. Fifth, the analysis is associational. The post-2022 interaction summarizes a period of heightened geopolitical tension but does not isolate a single exogenous policy shock.

These limitations point toward natural extensions rather than undermining the main descriptive result. Future research could combine monthly trade data

with detailed export-control announcements, technology-node information, firm-level supplier relationships, or investment data. Such work would help determine whether the limited aggregate fragmentation documented here reflects delayed adjustment, trade rerouting through connector economies, or persistent technological dependence across geopolitical blocs.

5. Conclusion

This paper examines whether the semiconductor value chain has undergone broad friend-shoring since 2022. Using CEPII BACI data, the OECD's HS2017 semiconductor mapping, and a hypothetical geopolitical bloc classification, we construct a balanced bilateral panel covering 116 economies, seven semiconductor segments, and the period 2017-2024.

The aggregate results provide limited evidence of geopolitical fragmentation. A log-linear model indicates a small decline in cross-bloc trade, but the preferred PPML coefficient is close to zero and statistically insignificant. Descriptively, between-bloc semiconductor trade grows faster than within-bloc trade over the full sample period. These results are inconsistent with a simple view in which the semiconductor value chain is rapidly separating into geopolitical blocs.

The segment estimates reveal a more qualified pattern. Foundry inputs and manufacturing equipment show suggestive negative PPML coefficients after 2022, while the other segments provide weak, inconsistent, or estimator-sensitive evidence. Reorientation therefore appears more plausible in selected strategic chokepoints than across the value chain as a whole.

The broader lesson is that geopolitical intent should not be equated with immediate trade fragmentation. Semiconductor production is built on specialized capabilities, large sunk investments, and tightly interconnected supplier relationships. These features limit short-run substitutability and can preserve cross-bloc trade even when governments and firms actively pursue de-risking. The geography of semiconductor trade may be changing, but the evidence through 2024 points to selective adjustment rather than comprehensive friend-shoring.

References

Anderson, J. E., & van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. *American Economic Review, 93*(1), 170-192.

Blanga-Gubbay, M., & Rubínová, S. (2024). *Is the global economy fragmenting?* WTO Staff Working Paper ERSD-2023-10. World Trade Organization.

Cameron, A. C., Gelbach, J. B., & Miller, D. L. (2011). Robust inference with multiway clustering. *Journal of Business & Economic Statistics, 29*(2), 238-249.

Gaulier, G., & Zignago, S. (2010). BACI: International trade database at the product-level. The 1994-2007 version. CEPII Working Paper No. 2010-23.

Gopinath, G., Gourinchas, P.-O., Presbitero, A. F., & Topalova, P. (2024). *Changing global linkages: A new Cold War?* IMF Working Paper No. 2024/076. International Monetary Fund.

OECD. (2025a). Mapping the semiconductor value chain: Working towards identifying dependencies and vulnerabilities. OECD Science, Technology and Industry Policy Papers, No. 182. OECD Publishing, Paris.

OECD. (2025b). *Economic Security in a Changing World: New Approaches to Economic Challenges.* OECD Publishing, Paris.

Santos Silva, J. M. C., & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics, 88*(4), 641-658.

World Trade Organization. (2023). *World Trade Report 2023: Re-globalization for a secure, inclusive and sustainable future.* WTO.

Chapter 4

Teaching the Sustainable Development Goals in Early Childhood: A Developmental Perspective from the TEACH SDG İzmir Project

F. Cansu PALA[1]

1. Introduction

Sustainable Development, Education, and Early Childhood

Sustainable development emerged partly from recognition that economic development cannot be separated from the environmental and social conditions that make human life possible. Earlier approaches focused primarily on balancing economic development with environmental protection, but sustainability has subsequently come to encompass interconnected environmental, social, and economic concerns (Keleş & Hamamcı, 1993; Nordström, 2008; Özdemir, 2007). The United Nations Sustainable Development Goals (SDGs), adopted as part of the 2030 Agenda for Sustainable Development, provide a universal framework addressing these interconnected challenges. The 17 Goals and 169 targets are explicitly presented as integrated and indivisible and as balancing the economic, social, and environmental dimensions of sustainable development (United Nations, 2015).

A central principle of sustainability is responsibility across generations: meeting present needs while maintaining the conditions necessary for future generations. Such responsibility cannot depend solely on institutional or technological change. It also requires knowledge, values, dispositions, and behaviours that enable individuals to participate in sustainable ways of living (Stir, 2006; Sadık & Sadık, 2014). Education is therefore a crucial component of sustainable development, and early childhood represents a particularly relevant period because children's cognitive, social, emotional, and behavioural capacities are undergoing rapid development. Introducing sustainability-related ideas during these years may provide opportunities to establish experiences and patterns of thinking that can be developed further across childhood (Güler Yıldız et al., 2021; Samuelsson & Park, 2017).

Sustainability education is broader than conventional environmental education. Early environmental education has often emphasized nature,

[1] Associate Professor, Ege University, Faculty of Letters, Department of Psychology, cansu.pala@ege.edu.tr, ORCID: 0000-0001-8489-4870

conservation, and environmentally responsible behaviour, whereas education for sustainability has increasingly incorporated social, economic, and environmental dimensions and has emphasized children's participation, decision-making, and engagement with change (Hedefalk et al., 2015; Somerville & Williams, 2015). Although sustainability education has increasingly been recognized as an important component of education for sustainable development, early childhood has historically received comparatively limited attention in this field. In a preliminary review of the literature, Davis (2009) identified a notable "research hole" at the intersection of early childhood education and sustainability, observing that research had focused more often on children's experiences in and knowledge about the environment than on their potential roles as participants in creating more sustainable ways of living. Subsequent reviews have documented growth in this literature, while also highlighting the continuing need to clarify how sustainability can be meaningfully approached in early childhood settings (Hedefalk et al., 2015; Somerville & Williams, 2015; Ardoin & Bowers, 2020; Güler Yıldız et al., 2021).

This broader perspective creates a developmental challenge. Knowing about sustainability does not necessarily mean acting sustainably. Children may recognize that water should not be wasted, that animals should be protected, or that recycling is desirable without consistently translating these preferences into behaviour. Research with preschool children has shown that environmental attitudes are already discernible during early childhood, including differences in the ways children relate to and conceptualize the natural environment (Kahriman-Öztürk et al., 2012). At the same time, holding environmentally desirable attitudes does not necessarily mean that children or adults consistently translate these attitudes into sustainable behaviour. The same distinction that applies to adults, for whom positive attitudes toward sustainability do not necessarily correspond to sustainable practices (Petersen & Alkis, 2009; Şahin & Doğu, 2018). Sustainability education therefore needs to address not only what children know, but also how they develop the capacity to understand consequences, consider others, regulate their behaviour, and participate in shared activities.

Sustainability and the Developmental Foundations of Responsible Action

This developmental perspective creates a potential connection between sustainability and prosocial development. Prosocial behaviour involves acting in ways that benefit others, such as helping, sharing, and cooperating. Sustainable action can be understood as extending some of this other-oriented concern beyond immediate interpersonal relationships to include communities, future generations, other living beings, and shared natural resources.

This does not mean that sustainability and prosociality are identical. Instead, sustainable behaviour may represent a particularly demanding form of other-oriented action because its consequences can be indirect, delayed, or distributed across people and environments that are not immediately present. A child may receive immediate social reinforcement for helping a peer, whereas turning off a tap or choosing not to waste a resource may have no immediate interpersonal reward. Sustainable action can therefore require individuals to maintain a goal or norm even when the consequences are distant or personally unrewarding.

Three developmental domains are particularly relevant to this distinction. **Theory of mind** enables children to understand that other people can hold beliefs, knowledge, desires, intentions, and perceptions that differ from their own. Perspective-taking may therefore contribute to understanding how one's actions affect other people and to responding appropriately to their needs (Baron-Cohen et al., 1986; Perner et al., 1987; Wimmer & Perner, 1983). **Emotion regulation** allows children to manage emotional responses and adapt their behaviour to social and situational demands. Sustainable participation, like other forms of socially regulated behaviour, may require children to tolerate frustration, wait, compromise, and respond to others rather than simply following an immediate emotional impulse (Kapçı et al., 2009; Shields & Cicchetti, 1998). **Executive functions** support goal-directed self-regulation through processes such as inhibitory control, working memory, and cognitive flexibility. These capacities are relevant when children must suppress an immediate response, remember a rule, shift between perspectives or requirements, or maintain a goal over time (Davis & Pratt, 1995; Frye et al., 1995; Gathercole & Pickering, 2000; Gerstadt et al., 1994; Kochanska et al., 1996).

These abilities should not be regarded as outcomes that sustainability education necessarily produces. Instead, they constitute part of the developmental context within which children can learn to act responsibly. This distinction is central to the present study. Rather than if teaching the SDGs will directly strengthen executive functioning or theory of mind, the project examined whether introducing sustainability during early childhood was associated with children's development in these domains and considered how such capacities might provide foundations for later sustainability-oriented action.

The Present Study

The TEACH SDG İzmir project was developed through a collaboration between İZELMAN A.Ş. and the Department of Psychology at Ege University. The project introduced Sustainable Development Goals-related content to children aged 5–6 years attending İZELMAN preschools through a six-week,

teacher-delivered educational programme. The project was designed around a broader developmental question: What does learning about sustainability mean for young children's development?

The programme did not treat the SDGs as an abstract body of global policy knowledge. Instead, sustainability-related themes were translated into developmentally appropriate experiences involving stories, games, songs, creative activities, cooperation, children's rights, gender expectations, recycling, and resource use. The approach therefore allowed environmental and social themes to be addressed within children's immediate classroom worlds. The present chapter asks a more specific question than whether young children can learn about the SDGs:

> *Can the SDGs provide a meaningful starting framework through which early sustainability orientation can be introduced and connected with children's developing social, emotional, and cognitive abilities?*

To address this question, the study examined children's executive functioning, theory of mind, language ability, and ecological decision-making before and after the programme, alongside parent- and teacher-reported measures. Because the intervention was relatively brief and several measures showed developmental change in both groups, the study was not expected to establish long-term behavioural transformation. Instead, its value lies in examining the feasibility and developmental relevance of beginning sustainability education early.

2. The TEACH SDG İzmir Programme

2.1 Project Context and Rationale

TEACH SDG İzmir was established through a collaboration between İZELMAN A.Ş. and Ege University to introduce the Sustainable Development Goals to children attending İZELMAN preschools. The project was formally implemented within an institutional framework in which Ege University coordinated the educational programme, assessment, and reporting, while İZELMAN supported implementation across participating preschools and communication with schools and families. The project was explicitly developmental in orientation. Rather than asking only whether preschool children could acquire information about the SDGs, it considered whether sustainability could be approached as part of children's broader social, emotional, and cognitive development. The project therefore distinguished sustainability education from a narrow environmental curriculum and treated environmental, social, and interpersonal concerns as interconnected components of sustainable living.

Although the Sustainable Development Goals comprise 17 interconnected global goals, the TEACH SDG İzmir programme focused selectively on four goals considered particularly amenable to developmentally appropriate preschool experiences: **SDG 10 (Reduced Inequalities), SDG 12 (Responsible Consumption and Production), SDG 7 (Affordable and Clean Energy), and SDG 17 (Partnerships for the Goals)**. These goals were translated into concrete themes and activities relevant to young children's everyday experiences, including equality and fairness, responsible use of resources, energy conservation, cooperation, and helping others.

2.2 Programme Design and Educational Approach

The intervention consisted of a six-week structured programme delivered by children's own preschool teachers. Three 30-minute sessions were planned each week. Rather than presenting these goals as abstract policy concepts, the programme addressed them through stories, songs, games, discussions, drawing, collaborative construction, and hands-on activities. Themes included children's rights, gender equality, cooperation and helping, recycling, and responsible use of resources. This approach allowed broad sustainability principles to relate to children's immediate social and material environments. Educational materials and guidance were prepared centrally, and teachers were given time to become familiar with the materials before implementation. The programme combined standardization with classroom-based delivery. Core content and materials were established by the project, while teachers implemented activities within their existing classroom routines and relationships. Project personnel of 3rd and 4th year psychology students were also involved in observing implementation and providing support when required.

2.3 Implementation and the Role of Teachers

The teacher-mediated nature of the intervention was a central feature of the programme. Teachers were not external instructors delivering isolated lessons; they were the adults who already knew the children, their routines, and their classroom environments. Sustainability education was therefore embedded within an existing social and educational context. Teachers received the programme methodology and materials and were supported during implementation. The project documentation also indicated that implementation would be observed and that project personnel would provide assistance where necessary. This model has two implications. First, it increased the ecological validity of the intervention by embedding sustainability education in children’s ordinary preschool experience. Second, it means that the intervention cannot be

understood as a purely standardized package delivered identically to every child. The teacher was part of the educational process.

2.4 A Multidimensional Approach to Sustainability

The programme deliberately addressed sustainability beyond environmental protection. Environmental activities included recycling and the transformation of discarded materials. Social themes included helping, cooperation, children's rights, and gender expectations. This breadth was consistent with the project's underlying conceptualization of sustainability as multidimensional. The SDGs were therefore used not simply as a list of topics but as a framework through which children could encounter different forms of responsibility. The activities also illustrate why an SDG framework may be useful in early childhood. Global concepts such as resource conservation, equality, rights, cooperation, and care for living things can appear abstract to young children. The programme translated them into actions and relationships that were part of children's immediate experience.

2.5 Children's Engagement

Teachers generally described children as enthusiastic and curious. Stories, games, visual materials, and creative activities generated active participation and discussion. Children sometimes requested that stories be repeated, made connections with their own experiences, and engaged collaboratively in subsequent activities. These observations are important as evidence of implementation and feasibility rather than efficacy. Children's enthusiasm does not demonstrate that the programme changed their behaviour or developmental skills. It does, however, suggest that sustainability-related themes can be incorporated into preschool learning in ways that invite participation, discussion, and reflection.

3. Method

3.1 Participants

The study included 285 children aged 5–6 years attending İZELMAN preschools, their parents, and 25 preschool teachers. Children's ages ranged from 50 to 80 months (M = 64.36, SD = 7.41); 132 children (47%) were girls and 150 (53%) were boys. There were 156 children in the intervention group and 123 in the control group; six additional children were excluded because they did not meet the attendance and/or post-test completion criteria.

The participating teachers were 21–50 years old (M = 31.96, SD = 6.38) and all were women. Their teaching experience ranged from 1 to 25 years (M = 8.84,

SD = 6.58), and experience at their current schools ranged from 1 to 23 years (M = 4.52, SD = 6.17).

3.2 Design and Procedure

Ethical approval was obtained from the Ege University Social and Human Sciences Scientific Research and Publication Ethics Committee on March 30, 2022 (Meeting/Decision No. 03/45; Protocol No. 1403).

The project used a pretest–posttest design with education and control groups. The intervention consisted of six weeks of teacher-delivered SDG education, with three 30-minute sessions per week. Children were assessed before and after the programme. Parents and teachers also provided information as part of the broader assessment battery. Parent measures were collected at pretest only and therefore could not be used to evaluate intervention-related change.

The intervention group participated in the SDG programme, whereas the control group did not receive the programme during the intervention period. The project documentation specified a minimum attendance criterion of 75% for children whose data was included in the relevant intervention evaluation.

3.3 Measures

The assessment battery was designed to capture developmental domains relevant to the project's rationale.

3.3.1 Child Measures

Children's executive functioning was assessed through the Night–Day task (Gerstadt et al., 1994), Dimensional Change Card Sort (Frye et al., 1995), Gift Delay task (Kochanska et al., 1996), forward and backward digit span (Davis & Pratt, 1995; Gathercole & Pickering, 2000), and Corsi block-tapping task (Corsi, 1972).

Theory of mind was assessed using Unexpected Location Change (Wimmer & Perner, 1983), Unexpected Content (Perner et al., 1987), and Appearance–Reality tasks.

Receptive vocabulary was assessed using the Peabody Picture Vocabulary Test (PPVT-III; Dunn & Dunn, 1997), a standardized measure of receptive vocabulary in which children identify pictures corresponding to orally presented words. The Turkish adaptation and standardization of the PPVT for young children was reported by Özekes (2013).

Children's ecological decision-making was assessed using the Children's Attitudes Toward the Environment Scale–Preschool Version (CATES-PV), originally developed by Musser and Malkus (1994) and adapted for use with

Turkish preschool children by Öztürk-Kahriman (2010). The scale consists of 15 pictorial, dichotomous items in which children choose between an environmentally desirable and a less environmentally desirable alternative. Two trained psychologists administered the task and recorded children's choices.

3.3.2 Parent-Reported Measures

Parents completed measures of executive functioning, social understanding/theory of mind, and emotion regulation. Executive functioning was assessed using the Childhood Executive Functioning Inventory (Thorell & Nyberg, 2008; Turkish adaptation by Kayhan, 2009). Social understanding was assessed using the Children's Social Understanding Scale (Tahiroğlu et al., 2014), and emotion regulation using the Emotion Regulation Checklist/measure adapted for Turkish children (Kapçı et al., 2009). Since these measures were collected only before the intervention, they were used to describe developmental characteristics and baseline patterns rather than intervention-related change.

3.3.3 Teacher Measures

Teachers completed a demographic form and measures concerning sustainability awareness, environmental behaviour, and connectedness to nature. Sustainability awareness was assessed using the Sustainable Development Awareness Questionnaire. Environmental behaviour was assessed using the Environmental Behavior Scale (Goldman et al., 2006; Timur & Yılmaz, 2013), and connection with nature using the Connectedness to Nature Scale (Nisbet et al., 2009; Çakır et al., 2015). Measures concerning professional attitudes and job satisfaction were also collected as part of the broader teacher assessment.

3.4 Data Analysis

Programme effects were evaluated using 2 × 2 repeated-measures analyses of variance, with Group (education vs. control) as the between-subjects factor and Time (pretest vs. posttest) as the within-subjects factor. The critical test of intervention-related change was therefore the Group × Time interaction.

4. Findings

4.1 Developmental Variation and Change in Cognitive and Social-Cognitive Skills

Across the developmental measures, age was a consistent source of variation. Older children generally performed better on measures of inhibitory control, working memory, theory of mind, and ecological decision-making. This pattern is important because it demonstrates that sustainability-related learning takes

place within rapidly developing cognitive and social systems rather than independently of them.

Several executive-function measures improved from pretest to posttest across the sample. Night–Day performance increased significantly over time, as did forward and backward digit span, visual working memory, and Gift Delay performance. However, these changes generally do not differ significantly between the education and control groups. Thus, the observed improvements cannot be attributed specifically to the SDG intervention.

The clearest intervention-related executive function finding concerned the colour-rule completion time in the DCCS. A significant Group × Time interaction was observed, with completion time decreasing in the education group while no significant change was found in the control group. The effect was small, however, and comparable intervention-specific effects were not observed across the other executive-function measures.

The theory-of-mind findings were similarly mixed. The Unexpected Location task showed both a significant effect of Time and a significant Group × Time interaction. However, the scoring convention reported for this task requires careful interpretation: successful performance was coded as 1 and unsuccessful performance as 0, while the descriptive posttest values decrease. Consequently, the statistical interaction should be retained, but the direction of developmental change should not be interpreted until the scoring and dataset have been verified. No significant intervention-related interaction was reported for Unexpected Content or Appearance–Reality. Overall, therefore, the cognitive and social-cognitive findings provide stronger evidence of developmental change across the assessment period than of broad intervention effects.

4.2 Children's Existing Ecological Orientation

One of the most informative findings for the broader argument of the chapter concerned children's ecological decision-making. At baseline, children generally selected environmentally desirable alternatives at relatively high rates. Choices favouring turning off water and lights, picking up litter, protecting animals, and recycling were particularly common. Other choices, such as transport to school and outdoor activity, produced more divided responses.

Ecological decision-making also varies by age. Younger children obtained lower CATES scores than older children, indicating that environmentally oriented choices were already developing across the preschool years.

The descriptive pretest–posttest values provide no evidence of a clear intervention effect. CATES scores increased only slightly in both groups, and no inferential Group × Time analysis is presented in this chapter. The significance

of these findings is therefore not that the intervention transformed children's ecological preferences. Rather, they suggest that children entered the programme with an existing, developmentally patterned orientation toward environmentally desirable choices.

4.3 Parent-Reported Development

Parent reports indicated developmental variation in executive functioning, social understanding, and emotion regulation at baseline. Older children were generally reported to demonstrate stronger executive-function and social-understanding skills.

These measures cannot, however, be interpreted as evidence of intervention effects because parents were not reassessed after the programme. Their primary value for the present chapter is therefore descriptive: they provide an additional indication that the sustainability-related learning context was embedded within broader developmental changes already occurring during early childhood.

4.4 Teacher Findings and Programme Implementation

Before the programme, 16 of the 25 teachers reported some prior knowledge of the SDGs, while seven reported no prior knowledge. Self-rated knowledge varied considerably. Teacher sustainability awareness and environmental behaviour also varied across domains. Teachers reported relatively greater engagement in resource conservation and environmentally conscious consumption, while responsible citizenship and environmental activism were less frequently reported. Their connectedness to nature was relatively stronger in the self and perspective dimensions than in the experience dimension.

The available teacher data are primarily descriptive; so it does not provide inferential evidence sufficient to conclude that the intervention produced statistically significant changes in teachers' sustainability awareness or behaviour. The qualitative implementation accounts nevertheless suggest strong classroom engagement. Teachers described children responding enthusiastically to recycling games, stories, children's-rights activities, helping activities, collaborative construction, and hands-on transformation of discarded materials. These observations should be interpreted as evidence of feasibility and engagement, not evidence of developmental efficacy.

4.5 Summary of the Empirical Pattern

Taken together, the findings produce a deliberately nuanced picture. First, children's developmental capacities showed substantial age-related variation. Second, many measures improved over time, but most of these changes occurred

in both groups. Third, a small number of outcomes showed differential change, most clearly DCCS colour-rule completion time and the Unexpected Location task. Fourth, children already demonstrated relatively strong ecological preferences, with age-related differentiation. Finally, classroom observations indicated that children could engage actively with sustainability themes when these were translated into concrete and socially meaningful experiences. The findings therefore provide limited evidence for broad short-term intervention effects, but stronger evidence for the developmental feasibility of introducing sustainability during early childhood.

5. Discussion

5.1 Why Begin Sustainability Education in Early Childhood?

The most valuable implication of TEACH SDG İzmir is not that six weeks of SDG education produced broad changes in children's cognitive or ecological performance. The more fundamental implication is that sustainability can be introduced meaningfully during early childhood. Children in the study already demonstrated considerable ecological preferences, and these preferences varied systematically with age. This suggests that sustainability-related concern does not begin with formal instruction. Young children may already have emerging preferences for conserving resources, protecting animals, and caring for their surroundings. Education may therefore have a different role from simply introducing environmental concern where none exists, it may help children organize, extend, and connect emerging concerns.

This is consistent with the broader early-childhood sustainability literature, which increasingly emphasizes experiential, participatory, and developmentally appropriate approaches rather than the transmission of sustainability facts alone (Ardoin & Bowers, 2020; Hedefalk et al., 2015; Güler Yıldız et al., 2021). Early childhood is consequently important not because children are expected to understand global sustainability problems in adult terms, but because the foundations of the cognitive, emotional, social, and behavioural capacities through which later sustainability-oriented action can develop are already emerging.

The findings also challenge a simple distinction between children who "know nothing" about sustainability and formal education that subsequently supplies the missing knowledge. The relatively high ecological preferences observed at baseline suggest that early sustainability education can instead begin from children's existing intuitions and experiences. The question is therefore not whether children are ready for sustainability. It is how sustainability can be translated into a form that is meaningful within children's developmental worlds.

5.2 What Can the SDGs Add to Early Childhood Sustainability Education?

Environmental education can provide children with opportunities to care for nature, conserve resources, and develop environmental knowledge. The SDGs provide a broader organizing structure in which these concerns can be connected to social responsibility, equality, rights, cooperation, and the well-being of others. Reviews of early-childhood sustainability education similarly show a field increasingly concerned not only with environmental knowledge but also with participation, children's agency, and action for change (Hedefalk et al., 2015; Somerville & Williams, 2015).

The TEACH SDG İzmir programme illustrates this possibility. Recycling and resource conservation represented environmental responsibility. Helping and cooperation represented responsibility toward others. Children's-rights and gender-related activities introduced questions of equality and social participation.

For young children, the value of this multidimensionality may be conceptual rather than informational. A five-year-old does not need to understand the 17 SDGs as policy architecture. Instead, the goals can provide educators with a common framework for connecting otherwise separate experiences:

- resources can be shared and conserved;
- waste can be reduced or transformed;
- animals and natural environments can be cared for;
- people can be helped and included;
- rights can be respected;
- activities can be organized cooperatively;
- and actions can have consequences beyond the immediate moment.

The SDGs therefore may function less as content to be mastered than as a framework for organizing experiences of responsibility.

This distinction is noteworthy because children's environmental orientations are not limited to simple knowledge about conservation. Research with Turkish preschool children has demonstrated variation in children's environmental attitudes along ecocentric and anthropocentric dimensions (Kahriman-Öztürk et al., 2012). The SDG framework potentially extends this early orientation by situating environmental concerns alongside social, economic, and human dimensions of sustainability.

5.3 From Knowing to Acting: The Developmental Challenge

A central challenge for sustainability education is the gap between recognizing a desirable action and consistently carrying it out. The relatively high ecological preferences observed in the present study illustrate this problem.

Children frequently selected environmentally desirable alternatives, but these responses should not be interpreted as evidence that children routinely behave sustainably in everyday life. The CATES assesses choices in a structured assessment context, not sustained behaviour across real-world situations.

Sustainable living ultimately requires more than recognizing the desirable option. It requires maintaining that orientation when the immediate alternative is easier, more attractive, more familiar, or socially reinforced. This is where the developmental framework underlying TEACH SDG İzmir becomes critical. Theory of mind, emotion regulation, and executive functions should not be viewed as mechanisms that the intervention necessarily improved. Instead, they can be understood as developmental capacities that make increasingly complex forms of responsible action possible.

Theory of mind allows children to represent perspectives beyond their own. Emotion regulation supports participation when social situations are frustrating or require compromise. Executive functions allow children to remember goals, inhibit immediate responses, and shift between rules or perspectives. From this perspective, sustainability education is not a separate developmental domain added to the preschool curriculum. It is a context in which existing developmental capacities can be exercised. The present findings are particularly informative because most cognitive improvements occurred across both groups. This means that the study does not support the claim that SDG education directly strengthens executive functioning or theory of mind. Instead, the developmental measures clarify the context in which sustainability learning occurs.

If the purpose of early sustainability education is foundation-building, then the relevant question may not be whether a six-week programme immediately increases executive-function scores. It may be whether repeated sustainability experiences give children opportunities to use developing self-regulatory and social-cognitive capacities in meaningful contexts.

5.4 What Did TEACH SDG İzmir Demonstrate?

The strongest conclusion to be drawn from this study is that its primary contribution concerns feasibility and educational framing rather than short-term efficacy. Children engaged with sustainability-related activities when the concepts were translated into stories, games, discussions, cooperation, creative production, and hands-on experiences. Teachers reported curiosity and participation across environmental and social themes. The programme therefore demonstrates that multidimensional sustainability content can be incorporated into preschool education without requiring sustainability to be taught as an abstract or age-inappropriate subject.

The quantitative findings are more restrained. Most developmental measures showed change over time without significant Group × Time interactions. The evidence for intervention-specific change was limited to a small number of outcomes, and one of those requires further verification of scoring. The ecological preference measure did not demonstrate a clear intervention effect. Teacher measures likewise do not provide sufficient inferential evidence for claims of increased sustainability awareness.

These findings should not be regarded simply as evidence that the intervention "failed." They instead clarify what a short early-childhood sustainability intervention can reasonably be expected to demonstrate. A six-week programme may create opportunities for engagement, discussion, practice, and shared attention without producing measurable changes in broad developmental capacities or stable everyday behaviour. In this respect, the TEACH SDG İzmir findings support a foundation-building interpretation. The programme provides preliminary evidence that the SDGs can be translated into developmentally meaningful classroom experiences and that children can engage with their environmental and social themes. Whether these experiences subsequently contribute to stable sustainability-oriented values or behaviour remains an open empirical question.

5.5 Limitations and Future Directions

Several limitations should guide interpretation. First, the intervention lasted only six weeks. Developmental capacities and sustainability-oriented behaviour are unlikely to be transformed within such a short period, particularly when the programme is embedded within broader developmental change. Second, the study did not directly measure sustained real-world sustainable behaviour. Children's ecological choices provide evidence of ecological preferences within a structured task, but they cannot be treated as equivalent to everyday behaviour. Third, parent measures were collected only at baseline, preventing examination of intervention-related change from the parent perspective. Fourth, although the teacher-mediated design is a strength in terms of ecological validity, implementation may have varied across classrooms. Teacher characteristics, existing classroom practices, and children's responses may all have influenced how activities were experienced. Fifth, the study included a broad developmental battery, but it did not directly assess the longer-term sustainability orientation that forms the central conceptual concern of this chapter. Future studies should therefore examine whether early sustainability experiences predict later knowledge, values, prosociality, ecological attitudes, and actual behaviour.

Finally, the present study does not establish that SDG education causes changes in executive functioning, theory of mind, or ecological decision-making. The most defensible interpretation is that sustainability education was implemented within a developmental period characterized by substantial age-related change and that the programme generated meaningful opportunities for children to engage with sustainability-related concepts.

Future research should build on this foundation using longer interventions, repeated follow-up assessments, direct measures of sustainable behaviour, and designs capable of distinguishing immediate learning from longer-term developmental change. It would also be valuable to examine whether different components of the SDG framework such as environmental responsibility, cooperation, rights, resource use, or social equality that all engage differently in developmental processes.

5.6 Conclusion

The significance of early sustainability education may lie less in producing immediate changes in children's behaviour than in establishing the conditions under which sustainability-oriented thinking and action can develop. The TEACH SDG İzmir project suggests three particularly important points. First, young children already demonstrate emerging ecological preferences, indicating that sustainability education can build upon rather than create an entirely new orientation. Second, these preferences develop alongside broader changes in executive functioning, social understanding, and self-regulation, highlighting the developmental foundations upon which sustainable action depends. Third, the SDGs can be translated into concrete classroom experiences that connect environmental concerns with helping, cooperation, rights, equality, and responsibility.

The potential value of the SDGs in early childhood therefore lies not in expecting children to understand global policy goals in adult terms. It lies in providing educators with a common framework through which everyday experiences can be connected to broader questions: What happens when resources are wasted? Who is affected by our actions? How can we help? What does it mean for something to be fair? How should we treat other living beings? What happens when we act together? These questions are developmentally accessible even when the global problems they represent are not.

The central contribution of TEACH SDG İzmir is therefore not evidence that a short SDG intervention can immediately transform children's development. Rather, it offers a basis for considering the SDGs as a starting framework for early sustainability education that can connect emerging ecological concerns with

social responsibility, self-regulation, cooperation, and consideration of consequences. In this sense, the most important question is not simply whether young children can learn the SDGs. It is whether the SDGs can provide meaningful language through which children begin to understand their relationships with other people, other living beings, shared resources, and the world they will inherit. The experiences of TEACH SDG İzmir suggest that this is a promising direction for early childhood education, while also making clear that establishing such a foundation is a longer developmental process than any single intervention can capture.

Acknowledgements

I would first like to thank all the children and their families, and the school headmistresses and teachers at İZELMAN schools, for their openness, support, and commitment to the project. I am also deeply grateful to Eda Kaygusuz, Head Coordinator; Sevgi Tanboğa, Project Assistant; and the late Adnan Oğuz Akyarlı, whose initiative was instrumental in bringing this project to life. My sincere thanks also go to my PhD students at the time, now Dr. Dilara Özsoy and Dr. Zeynep Şen Hastaoğlu, and to the psychology students at Ege University who contributed to the project. I cared deeply about this project and wanted to document its development and outcomes so that this experience could be preserved and contribute to future endeavours in early childhood sustainability education.

References

Ardoin, N. M., & Bowers, A. W. (2020). Early childhood environmental education: A systematic review of the research literature. *Environmental Research Review, 31*, 100353. https://doi.org/10.1016/j.edurev.2020.100353

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1986). Mechanical, behavioural and intentional understanding of picture stories in autistic children. *British Journal of Developmental Psychology, 4*(2), 113–125. https://doi.org/10.1111/j.2044-835X.1986.tb01003.x

Corsi, P. M. (1972). *Human memory and the medial temporal region of the brain* [Unpublished doctoral dissertation]. McGill University.

Cakır, B., Karaarslan, G., Şahin, E., & Ertepınar, H. (2015). Adaptation of nature relatedness scale to Turkish. *Elementary Education Online, 14*(4), 1370–1383. https://doi.org/10.17051/io.2015.95299 a

Davis, J. (2009). Revealing the research 'hole' of early childhood education for sustainability: A preliminary survey of the literature. *Environmental Education Research, 15*(2), 227–241. https://doi.org/10.1080/13504620802710607

Davis, H. L., & Pratt, C. (1995). The development of children's theory of mind: The working memory explanation. *Australian Journal of Psychology*, *47*(1), 25-31.

Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test—Third Edition (PPVT-III): Examiner's manual*. American Guidance Service.

Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development, 10*(4), 483–527. https://doi.org/10.1016/0885-2014(95)90024-1

Gathercole, S. E., & Pickering, S. J. (2000). Assessment of working memory in six- and seven-year-old children. *Journal of Educational Psychology, 92*(2), 377–390. https://doi.org/10.1037/0022-0663.92.2.377

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 3½–7 years old on a Stroop-like day–night test. *Cognition, 53*(2), 129–153. https://doi.org/10.1016/0010-0277(94)90068-X

Goldman, D., Yavetz, B., & Pe'er, S. (2006). Environmental literacy in teacher training in Israel: Environmental behavior of new students. *The Journal of Environmental Education*, *38*(1), 3-22.

Güler Yıldız, T., Öztürk, N., İlhan İyi, T., Aşkar, N., Banko Bal, Ç., Karabekmez, S., & Höl, Ş. (2021). Education for sustainability in early childhood education: a systematic review. *Environmental Education Research*, *27*(6), 796–820. https://doi.org/10.1080/13504622.2021.1896680

Hedefalk, M., Almqvist, J., & Östman, L. (2015). Education for sustainable development in early childhood education: A review of the research literature. *Environmental Education Research, 21*(7), 975–990. https://doi.org/10.1080/13504622.2014.971716

Kahriman- Öztürk, D. (2010). *Preschool Children's Attitudes Towards Selected Environmental Issues* (Master's thesis, Middle East Technical University).

Kahriman-Öztürk, D., Olgan, R., & Tuncer, G. (2012). A qualitative study on Turkish preschool children's environmental attitudes through ecocentrism and anthropocentrism. *International Journal of Science Education, 34*(4), 629–650. https://doi.org/10.1080/09500693.2011.596228

Kapçı, E. G., Uslu, R. İ., Akgün, E., & Acer, D. (2009). İlköğretim Çağı Çocuklarında Duygu Ayarlama: Bir Ölçek Uyarlama Çalışması Ve Duygu Ayarlamayla İlişkili Etmenlerin Belirlenmesi. *Turkish Journal of Child and Adolescent Mental Health, 16*(1), 13-20.

Keleş, R., & Hamamcı, C. (1993). *Çevrebilim*. İmge Kitabevi.

Kochanska, G., Murray, K., Jacques, T. Y., Koenig, A. L., & Vandegeest, K. A. (1996). Inhibitory control in young children and its role in emerging internalization. *Child Development, 67*(2), 490–507. https://doi.org/10.2307/1131828

Musser, L. M., & Malkus, A. J. (1994). The children's attitudes toward the environment scale. *The Journal of Environmental Education*, *25*(3), 22-26.

Nisbet, E. K., Zelenski, J. M., & Murphy, S. A. (2009). The Nature Relatedness Scale: Linking individuals' connection with nature to environmental concern and behavior. *Environment and Behavior, 41*(5), 715–740. https://doi.org/10.1177/0013916508318748

Nordström, H. K. (2008). Environmental education and multicultural education–too close to be separate?. *International Research in Geographical and Environmental Education*, *17*(2), 131-145.

Özdemir, O. (2007). Yeni bir çevre eğitimi perspektifi: sürdürülebilir gelişme amaçlı eğitim. *Eğitim ve Bilim, 32*(145), 23-39.

Özekes, M. (2013). Peabody Resim Kelime Testi 3 01 3 12 Yaş Aralığı İzmir Bölgesi Standardizasyonu Çalışması. *Ege Eğitim Dergisi*, *14*(1), 90-107. https://izlik.org/JA38LG98HG

Petersen F. J., & Alkış, S. (2009). How do turkish eighth grade students conceptualise sustainability? *European Journal of Educational Studies, 1*(1), 67-74.

Perner, J., Leekam, S. R., & Wimmer, H. (1987). Three-year-olds' difficulty with false belief: The case for a conceptual deficit. *British Journal of Developmental Psychology, 5*(2), 125–137. https://doi.org/10.1111/j.2044-835X.1987.tb01048.x

Rochon, G. L., Nies, L. F., Jafvert, C. T., Stuart, J. A., Mohtar, R. H., Quansah, J., & Martin, A. (2006). Education in sustainable production in US universities. *Clean Technologies and Environmental Policy*, *8*(1), 38-48.

Sadik, F., & Sadik, S. (2014). A study on environmental knowledge and attitudes of teacher candidates. *Procedia-Social and Behavioral Sciences*, *116*, 2379-2385.

Samuelsson, I. P., & Park, E. (2017). How to educate children for sustainable learning and for a sustainable world. *International Journal of Early Childhood, 49*, 273–285. https://doi.org/10.1007/s13158-017-0197-1

Shields, A., & Cicchetti, D. (1998). Reactive aggression among maltreated children: The contributions of attention and emotion dysregulation. *Journal of Clinical Child Psychology*, *27*(4), 381-395.

Somerville, M., & Williams, C. (2015). Sustainability education in early childhood: An updated review of research in the field. *Contemporary Issues in Early Childhood, 16*(2), 102–117. https://doi.org/10.1177/1463949115585658

Stir, J. (2006). Restructuring teacher education for sustainability: student involvement through a "strengths model". *Journal of Cleaner Production*, *14*(9-11), 830-836.

Tahiroglu, D., Moses, L. J., Carlson, S. M., Mahy, C. E., Olofson, E. L., & Sabbagh, M. A. (2014). The Children's Social Understanding Scale: Construction and validation of a parent-report measure for assessing individual differences in children's theories of mind. *Developmental Psychology*, *50*(11), 2485–2497. https://doi.org/10.1037/a0037914

Thorell, L. B., & Nyberg, L. (2008). The Childhood Executive Function Inventory (CHEXI): A new rating instrument for parents and teachers. *Developmental Neuropsychology, 33*(4), 543–559. https://doi.org/10.1080/87565640802101569

Timur, S., & Yılmaz, M. (2013). Çevre davranış ölçeğinin Türkçe'ye uyarlanması. *Gazi Eğitim Fakültesi Dergisi*, *33*(2), 317-333.

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development* (A/RES/70/1). United Nations.

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition, 13*(1), 103–128. https://doi.org/10.1016/0010-0277(83)90004-5

Chapter 5

Different Approaches to Optimizing the Delivery Process in Supply Chain Management: A Comparative Analysis

Emre EKİN[1], Ayça EGE[2]

1. Introduction

In increasingly competitive and uncertain business environments, supply chain management (SCM) has evolved from a primarily operational function into a strategic capability that affects cost, responsiveness, service quality, customer satisfaction, and competitive performance. A supply chain is the network through which materials, products, information, and financial resources move among suppliers, producers, logistics providers, distributors, retailers, and customers. SCM is the coordinated planning and management of these interconnected activities across organizational boundaries rather than the isolated optimization of individual functions (Mentzer et al., 2001; Lambert & Cooper, 2000; Chopra, 2022). As supply networks expand and customer requirements become more diverse, the number of interactions and sources of uncertainty also increases; Turkish research likewise shows that supply chain complexity is associated with firm performance (Ustasüleyman & Perçin, 2014).

Delivery is one of the points at which the performance of this entire system becomes visible. It should not be understood only as the final transportation of a finished product. Whether an order can be delivered on time, in the correct quantity and condition, and at an acceptable cost depends on earlier decisions concerning demand forecasting, inventory positioning, production and capacity planning, warehousing, logistics coordination, and final fulfillment. Delivery performance is therefore multidimensional: speed matters, but so do reliability, predictability, product availability, order completeness, visibility, convenience, and cost (Chopra, 2022). Recent Turkish research on e-commerce supply chains similarly identifies logistics and delivery-related difficulties as part of a wider set of interconnected problems involving procurement, inventory, warehousing, customer relations, and digital processes (Gül & Diker, 2026).

[1] Associate Professor, National Defence University, emrenike@hotmail.com, ORCID: 0000-0002-4043-9750
[2] Department of Industrial Engineering Undergraduate Student, Özyeğin University, ayca.ege@ozu.edu.tr, ORCID: 0009-0002-2835-6167

Organizations can intervene at different stages of this delivery system. At the customer-facing end, last-mile delivery concerns the final stage through which an order reaches or becomes available to the customer; omnichannel retailers may use stores, pickup services, digital platforms, and rapid home delivery to improve this stage. At the logistics-coordination level, outsourcing can extend from individual third-party logistics (3PL) services to Fourth-Party Logistics (4PL), in which an integrator coordinates multiple providers, resources, and information flows. Further upstream, demand planning uses forecasts to align production, inventory, capacity, and replenishment with expected demand, while artificial intelligence (AI) and machine learning (ML) can support this process by identifying complex demand patterns (Mangiaracina et al., 2019; Fulconis & Paché, 2018; Walter et al., 2025). These approaches are not substitutes for one another; they address different sources of difficulty within the same end-to-end delivery process.

Against this background, this chapter examines how different strategic approaches contribute to delivery performance and why different supply chain problems require different interventions. Three perspectives are analyzed. First, last-mile delivery and customer experience are examined through Target and Walmart. Second, logistics outsourcing and 4PL are examined through the San Miguel–Maersk case. Third, demand planning and AI-supported demand forecasting are examined through Danone. The cases are compared in terms of the problem addressed, the mechanism used, responsiveness, service level, visibility, flexibility, customer experience, inventory and capacity implications, coordination, cost efficiency, and the role of technology. The aim is not to rank the companies or strategies, but to explain how informational uncertainty, coordination complexity, and customer-facing fulfillment complexity arise at different stages and how the selected approaches respond to them.

2. Literature Review

The literature review is organized to give the reader the concepts needed to interpret the cases and the comparison. It first defines supply chains and SCM and explains why integration, information sharing, complexity, flexibility, and strategic fit matter. It then focuses specifically on delivery performance and lead-time management. The following case-oriented sections review three bodies of literature that correspond to the intervention levels examined in the chapter: last-mile fulfillment and customer experience, logistics outsourcing and 4PL, and demand planning with AI-supported forecasting. Both international studies and relevant Turkish research are considered so that the case analysis is grounded in

the broader SCM literature as well as domestic evidence (Ustasüleyman & Perçin, 2014; Karaman, 2025; Gül & Diker, 2026).

2.1. Supply Chain and Supply Chain Management

A supply chain consists of interconnected organizations and processes involved in sourcing, producing, storing, moving, and delivering products or services to final customers. It is therefore more than a linear movement of goods from one point to another. It is a network in which physical material flows, two-way information flows, and financial flows connect suppliers, producers, logistics providers, distributors, retailers, and customers. Mentzer et al. (2001) emphasize that SCM extends across firms and business functions and involves systematic, strategic coordination intended to improve the long-term performance of both individual organizations and the supply chain as a whole.

Lambert and Cooper (2000) similarly conceptualize SCM as the integration of key business processes across the supply chain rather than the independent management of individual logistics activities. This distinction is important: procurement, production, inventory, warehousing, transportation, information management, and customer service are separate activities, but their decisions are interdependent. Supply chain management seeks to coordinate these activities so that the network can create customer value while using resources efficiently. As the number and diversity of suppliers, customers, products, and interactions increase, this coordination becomes more difficult. In the Turkish literature, Ustasüleyman and Perçin (2014) examine this supply chain complexity as a multidimensional phenomenon and its relationship with firm performance.

Because the activities are interdependent, an improvement in one area can create costs or constraints elsewhere. Higher inventory may improve product availability but increase holding costs; additional capacity may improve responsiveness but reduce utilization; and shorter delivery times may improve service while increasing fulfillment cost. Chopra (2022) therefore frames supply chain performance around strategic choices concerning facilities, inventory, transportation, information, sourcing, and pricing, all of which shape the balance between responsiveness and efficiency.

Integration and information sharing are central to managing these trade-offs. When information is fragmented or functions make decisions independently, demand signals, inventory decisions, production plans, and logistics activities can become misaligned. Coordinated planning instead supports the alignment of demand, supply, capacity, inventory, and customer requirements. Turkish evidence from the aviation sector also reports significant relationships between supply chain management dimensions and business-performance dimensions,

with flexibility identified as an important performance component (Karaman, 2025). Thus, SCM provides the overarching framework within which the delivery strategies examined in this chapter can be understood.

2.2. Supply Chain Management and Strategic Approaches

Supply chain strategy concerns the configuration and management of supply chain capabilities in support of broader competitive objectives. A central issue is strategic fit: the supply chain must provide an appropriate level of responsiveness while controlling the costs associated with facilities, inventory, transportation, information, and other resources (Chopra, 2022).

The appropriate configuration is not identical across industries or products. Fisher (1997) argues that supply chain design should reflect product and demand characteristics, distinguishing between environments in which efficiency is the primary requirement and those in which responsiveness to uncertain demand becomes more important. Extending this perspective, Lee (2002) emphasizes that supply chain strategies should be aligned with both demand and supply uncertainty. These frameworks suggest that supply chain practices should be selected according to the characteristics and sources of uncertainty facing the organization rather than treated as universally applicable solutions.

Flexibility is another important strategic capability. Duclos et al. (2003) argue that supply chain flexibility must extend beyond the boundaries of a single firm because modern supply chains depend on cross-enterprise coordination. Flexibility may therefore involve the ability to adjust sourcing, capacity, inventory, logistics activities, information flows, or fulfillment processes in response to changing conditions.

This perspective is particularly relevant to the strategic approaches examined in this chapter. Omnichannel fulfillment creates flexibility in how customers receive products; 4PL arrangements support flexibility in logistics coordination and capacity utilization; and AI-supported demand planning can improve an organization's ability to respond to changing demand information.

The strategic approaches examined here can therefore be interpreted as responses to different sources of supply chain complexity and uncertainty. Last-mile strategies primarily address customer-facing fulfillment complexity; logistics outsourcing and 4PL address interorganizational and network coordination; and AI-supported demand planning addresses informational uncertainty. These categories are analytically distinct but operationally connected: weaknesses in demand information, logistics coordination, or final fulfillment can each affect delivery performance. Although the mechanisms

operate at different stages, each contributes to the broader objective of aligning supply chain capabilities with customer demand and operational requirements.

2.3. Delivery Performance and Lead-Time Management

Delivery is the stage at which the effects of many upstream supply chain decisions become observable in operational performance and, ultimately, in the customer's experience. Delivery time can be understood as the elapsed time required to fulfill an order, but evaluating delivery only by speed is incomplete. A fast delivery that is unreliable, incomplete, damaged, unavailable when promised, or excessively costly does not represent strong delivery performance. Lead time, reliability, order completeness, product condition, availability, tracking and visibility, convenience, and cost should therefore be considered together (Chopra, 2022; Mentzer et al., 2001).

Long or uncertain delivery times can also create effects beyond the final customer interface. They may increase the need for inventory buffers, complicate production and replenishment decisions, tie up working capital in inventory in transit, and weaken service reliability. These relationships are especially visible in e-commerce, where procurement, inventory, warehousing, logistics, customer relations, and digital processes must be managed simultaneously. Gül and Diker (2026), examining e-commerce businesses in Çorum, identify interconnected supply chain problems across these areas and propose improvement measures. Their findings reinforce the view that delivery-related problems should be managed as part of the wider supply chain rather than as an isolated transportation issue.

Improving delivery performance can therefore require interventions at different levels. Better demand information can reduce uncertainty before products are produced or positioned; stronger logistics coordination can improve visibility and the use of capacity across organizations; and well-designed last-mile systems can improve the speed, reliability, and convenience experienced by customers. This logic provides the link between the general SCM literature and the three strategic approaches examined in the remainder of the chapter.

2.4. Literature Synthesis and Research Gap

The reviewed literature is substantial but largely organized around separate components of the delivery system. International research examines last-mile efficiency and customer experience, logistics outsourcing and 4PL orchestration, and demand forecasting and AI-supported planning as distinct streams. Turkish studies also provide evidence on supply chain complexity and performance, sector-specific SCM performance, and operational problems in e-commerce

(Ustasüleyman & Perçin, 2014; Karaman, 2025; Gül & Diker, 2026). Together, these studies show that delivery outcomes are influenced by upstream information quality, interorganizational coordination, and downstream fulfillment capability, even when those elements are analyzed separately.

Within the literature reviewed for this chapter, however, limited attention is given to comparing these intervention levels within a single delivery-oriented framework. The gap addressed here is therefore not an absence of research on delivery, forecasting, logistics outsourcing, or last-mile operations individually. Rather, it is the limited comparative integration of these perspectives when explaining how different large-scale organizations address delivery-related problems at different stages of the supply chain. The present chapter responds to that gap by comparing upstream demand planning, network-level logistics coordination, and downstream last-mile fulfillment through a common set of performance dimensions.

This synthesis also clarifies the logic of the case selection. Danone represents informational uncertainty at the planning stage; San Miguel–Maersk represents coordination complexity across logistics actors and capacity; and Target and Walmart represent fulfillment complexity at the customer-facing stage. The subsequent sections first explain each strategic approach and its case evidence, and the Application and Comparison sections then evaluate the cases together using the same analytical framework.

3. Last-Mile Delivery and Customer Experience

3.1. Conceptual Background

Last-mile delivery refers to the final stage through which an order reaches or becomes available to the customer. The rapid growth of e-commerce has made this stage strategically important because customers directly experience delivery speed, reliability, convenience, tracking, and flexibility. A literature review by Mangiaracina et al. (2019), based on 75 publications, shows that last-mile efficiency has become a major research area in B2C e-commerce and that firms use organizational, technological, and network innovations to improve performance.

Last-mile performance is not only a logistics issue but also a customer-experience issue. Vakulenko et al. (2019) found that the last-mile delivery experience mediates the relationship between the online retail experience and customer satisfaction. More recent empirical research similarly identifies delivery efficiency, convenience, smooth delivery, and related service attributes as important dimensions of customer experience (Aljohani, 2024). These findings

provide the theoretical basis for evaluating Target and Walmart as examples of retailers integrating physical store networks with digital fulfillment.

3.2. Target: Store-Based Fulfillment and Same-Day Delivery

Target's last-mile strategy is closely connected to its stores-as-hubs model, in which physical stores function simultaneously as retail locations and fulfillment nodes for digital orders. Target's fiscal 2025 reporting shows that 97.6% of merchandise sales were fulfilled by stores, a measure that includes in-store purchases and digitally originated sales fulfilled through shipping from stores, Order Pickup, Drive Up, and Same-Day Delivery (Target Corporation, 2026).

The model uses existing retail inventory and locations as a decentralized fulfillment network. This can reduce the distance between inventory and demand and gives customers several ways to receive an order. Target's supply-chain reporting also describes a network that combines stores, fulfillment centers, sortation centers, Shipt, third-party carriers, routing technology, and geolocation tools. In 2025, Target reported that more than 80% of the U.S. population could access same-day delivery and that almost all of its nearly 2,000 stores offered same-day Order Pickup and Drive Up (Target Corporation, 2025).

Target also reported that, in the quarter discussed in its 2025 supply-chain update, almost 80% of online orders were fulfilled within one day through same-day services and about 80% of same-day deliveries arrived within three hours. The company further described using real-time signals such as inventory location and staffing to assign orders to fulfillment locations and using sortation centers and routing technology to select efficient delivery paths (Target Corporation, 2025). These company-reported outcomes illustrate how store assets, digital ordering, inventory information, and delivery operations can be integrated to support both responsiveness and cost control.

3.3. Walmart: Omnichannel Scale and Multi-Option Last-Mile Delivery

Walmart uses a similar principle at a larger U.S. store-network scale. Walmart's 2025 Annual Report states that Walmart U.S. operated 4,605 stores and that substantially all stores provided same-day pickup and delivery. Its fulfillment portfolio included Express Delivery within 90 minutes, InHome Delivery, and digital pharmacy fulfillment, illustrating a multi-option approach to last-mile service (Walmart Inc., 2025a).

Walmart has also used data and geospatial technology to refine delivery coverage. In 2025, the company described a system that divides geographic areas into precise hexagonal grids and incorporates variables such as slot availability, drive time, store capacity, and customer demand. Walmart reported that this

approach expanded delivery access to 12 million additional U.S. households and allowed orders to be fulfilled using multiple stores when appropriate (Walmart Inc., 2025b).

The company reported in its fiscal 2025 results that its store-fulfilled same-day delivery network could reach 93% of U.S. households (Walmart Inc., 2025c). These figures are company-reported and should be interpreted as evidence of network scale rather than independent performance measurement. Nevertheless, they demonstrate how a dense store network, digital ordering, local inventory, and data-driven delivery-zone design can be combined to support rapid fulfillment.

3.4. Comparative Evaluation of Target and Walmart

Target and Walmart share a fundamental strategic principle: stores are not treated only as endpoints of a retail distribution system but also as fulfillment assets for digital demand. In both cases, the store network shortens the operational distance between inventory and customers and supports alternatives such as pickup and home delivery.

The cases also show that last-mile performance is multidimensional. Speed is important, but it interacts with inventory availability, cost, service reliability, capacity, delivery-zone design, and customer convenience. Target's stores-as-hubs model emphasizes the precise allocation of fulfillment work across stores and other facilities, whereas Walmart combines a very large store network with multiple delivery modes and geospatial optimization. Both cases are consistent with the literature's view that last-mile delivery is a strategic component of the overall e-commerce experience rather than a purely transportation-oriented activity (Mangiaracina et al., 2019; Vakulenko et al., 2019).

4. Logistics Outsourcing and Fourth-Party Logistics (4PL)

4.1. Conceptual Background: Logistics Outsourcing, 3PL, and 4PL

Logistics outsourcing allows firms to obtain external transportation, warehousing, coordination, technology, and specialist capabilities instead of developing all logistics resources internally. Third-party logistics (3PL) typically involves the external provision of logistics services, while the 4PL concept extends outsourcing toward the integration and orchestration of multiple resources and service providers.

Academic research commonly characterizes a 4PL provider as a supply chain integrator that coordinates its own capabilities with those of other service providers to design and manage broader supply chain solutions. Büyüközkan et al. (2009) emphasize the integrator role of 4PL and its coordination of multiple

3PL providers, while Fulconis and Paché (2018) describe 4PL and lead-logistics-provider models as supply chain orchestrators that may provide integrated logistics management without owning all physical assets. More recent research also distinguishes multiple 4PL business models according to their level of involvement and relationship structure (Fattam et al., 2023).

The strategic value of 4PL therefore lies not only in outsourcing individual activities but in coordinating information, capacity, providers, and processes across a network. This makes 4PL particularly relevant where logistics complexity is created by multiple markets, seasonal demand, fragmented providers, or limited end-to-end visibility.

4.2. San Miguel–Maersk: Supply Chain Characteristics and Challenges

The San Miguel–Maersk case provides an example of 4PL applied to an international, seasonal food supply chain. According to Maersk's published case study, San Miguel exported produce from Argentina, Uruguay, South Africa, and Peru, with worldwide export volumes of approximately 6,000 containers annually at the time of the case. The portfolio included lemons as well as oranges, tangerines, grapefruits, grapes, and avocados. The case identifies seasonality as a central challenge. San Miguel needed an end-to-end logistics structure throughout the year, but that structure was heavily strained during peak season and comparatively inactive during low season. The company also had to coordinate multiple vendors and carriers across markets, which Maersk associated with limited visibility, weak integration of processes and information, and rising logistics costs (Maersk, 2021).

These conditions illustrate why the problem was broader than transportation procurement. The combination of variable capacity requirements, multiple service providers, international flows, and fragmented information created a coordination problem at the network level.

4.3. The 4PL Solution and Operational Logic

Maersk proposed outsourcing San Miguel's international logistics operations through a 4PL arrangement. The stated objectives were to optimize operations, increase visibility and control, create a leaner structure, and allow logistics resources to be used according to operational requirements rather than maintaining the same internal structure throughout the year (Maersk, 2021).

From an SCM perspective, the solution can be interpreted as a shift from fragmented execution toward integrated orchestration. A conventional carrier relationship primarily provides transport capacity; a 4PL arrangement can additionally coordinate multiple providers, information flows, planning

activities, and performance across the network. This interpretation is consistent with the academic 4PL literature, which emphasizes integration and orchestration rather than the ownership of a single logistics asset base (Büyüközkan et al., 2009; Fulconis & Paché, 2018).

4.4. Supply Chain Responsiveness and Case Evaluation

The COVID-19 disruption provided a practical test of the relationship. Maersk reports that, after the Chinese market reopened, San Miguel was among the first exporters to resume shipments to China and that Maersk coordinated the inclusion of its produce on an early vessel from Argentina (Maersk, 2021). This example is relevant because responsiveness in an integrated logistics network includes the ability to re-coordinate capacity and flows when external conditions change.

The evidentiary limitation of the case should be made explicit. The principal public account is published by Maersk, the logistics provider involved in the solution. The reported benefits should therefore be treated as provider- and client-reported case evidence rather than as independently audited causal effects. Even with this limitation, the case is useful for illustrating the strategic logic of 4PL: fragmented logistics network and seasonal capacity requirements, integrated logistics coordination, improved visibility and flexible resource utilization lead to greater responsiveness.

5. Demand Planning and AI-Supported Demand Forecasting

5.1. Conceptual Background: Demand Planning and Forecasting

Demand planning is a fundamental component of supply chain management, as it provides the information required to align supply chain resources and operational activities with expected customer demand. Production, procurement, inventory management, capacity allocation, replenishment, and distribution decisions depend on the ability of organizations to anticipate future demand (Fildes et al., 2009). Consequently, demand planning influences not only the availability of products but also the efficiency and responsiveness of the entire supply chain.

Demand forecasting is a central activity within demand planning. It involves estimating future demand based on historical data, observed patterns, market conditions, and other relevant information. Forecasting provides a basis for operational decisions by helping organizations determine the quantities of products that should be produced, stored, replenished, and distributed. However, demand cannot be predicted with complete certainty. Changes in customer preferences, promotional activities, seasonality, market conditions, and

unexpected external events can create differences between forecasted and actual demand. These differences, commonly referred to as forecast errors, can affect multiple supply chain activities (Fildes et al., 2009).

When demand is underestimated, available inventory and production capacity may be insufficient to satisfy customer requirements. This can result in stockouts, lost sales, delayed deliveries, and reduced service levels. Conversely, overestimating demand may lead to excess inventory, higher holding costs, inefficient capacity utilization, and product obsolescence. These consequences are particularly significant in industries involving perishable products or products with limited shelf lives.

Demand forecasting should therefore be considered an integrated planning activity rather than an isolated statistical exercise. Its strategic contribution depends on how effectively forecast information is incorporated into production, inventory, capacity, and distribution decisions. From a supply chain management perspective, the objective is not simply to generate accurate forecasts but to use demand information to improve the alignment between available resources and actual customer requirements.

5.2. AI and Machine Learning in Demand Forecasting

Traditional demand forecasting methods generally rely on historical demand patterns and statistical relationships to estimate future demand. Although these methods remain useful in many planning environments, increasing demand volatility, rapidly changing market conditions, and the availability of large and diverse datasets have encouraged organizations to explore more advanced forecasting approaches.

Artificial intelligence (AI) and machine learning (ML) provide additional capabilities for analyzing demand-related information and supporting forecasting decisions. AI-based forecasting systems can process large volumes of data, identify complex relationships among variables, and incorporate information that may not be adequately represented by historical demand patterns alone.

Toorajipour et al. (2021), in their systematic literature review of artificial intelligence in supply chain management, identify demand forecasting as an important application area of AI. Similarly, Mediavilla et al. (2022) examine the application of artificial intelligence methods to demand forecasting and discuss their relevance in dynamic and uncertain supply chain environments.

More recently, Walter et al. (2025), in a systematic literature review covering 141 peer-reviewed studies published between 2012 and 2023, identify demand forecasting, inventory management, production planning, and supply chain

performance as important areas in which AI-supported demand planning has been investigated.

Machine-learning-based forecasting approaches can incorporate different sources of information, including historical sales, promotional activities, seasonal patterns, market developments, and other demand-related variables. By identifying relationships among these factors, forecasting models can support more informed estimates of future demand.

For example, promotional activities may temporarily increase product demand beyond its usual level. A forecasting approach based exclusively on historical baseline demand may not adequately capture this additional demand. Machine-learning-supported forecasting can be used to analyze the relationship between promotional activities and changes in sales, thereby supporting more informed demand estimates.

The strategic value of AI-supported forecasting extends beyond improvements in statistical accuracy. More reliable demand information can support production scheduling, inventory positioning, replenishment, capacity planning, and distribution decisions. Consequently, improvements in forecasting may contribute to reducing the mismatch between supply and demand. Nevertheless, AI-based forecasting does not automatically produce superior results in every operational environment. Its effectiveness depends on factors such as data availability and quality, demand characteristics, forecasting horizons, model selection, and integration with organizational planning processes (Walter et al., 2025).

Furthermore, forecasting outputs must be interpreted and incorporated into operational decisions. Even a highly accurate forecast may provide limited value if production, inventory, and distribution systems cannot respond effectively to the information generated. AI and machine learning should therefore be understood as decision-support capabilities within demand planning rather than complete replacements for conventional forecasting approaches or managerial judgment.

5.3. Danone Case: AI-Supported Demand Planning

Danone provides a relevant example of how AI-supported forecasting can be incorporated into supply chain planning. Operating in the food and beverage industry, the company must coordinate production, inventory, replenishment, and distribution activities while responding to changing consumer demand.

Demand planning is particularly important for products with limited shelf lives because forecasting errors may create both product availability problems and excess inventory. Under these conditions, the ability to anticipate demand

and incorporate relevant market information into planning decisions becomes an important component of supply chain management.

Danone's use of AI-based forecasting has been examined by Gartner in its 2024 case study, *Danone's Journey Into AI-Based Forecasting*. The study addresses the company's experience with AI-supported forecasting, including the benefits, challenges, and lessons associated with its forecasting transformation (Gartner, 2024).

The strategic importance of AI-supported planning at Danone can also be understood through the company's broader operational transformation. In a 2026 interview with McKinsey & Company, Danone Chief Operations Officer Vikram Agarwal discussed the digitalization of planning processes as an important component of the company's operational transformation. The discussion emphasizes the importance of anticipating changes in consumer demand, developing appropriate operational capacity, and improving the ability of planning processes to respond to changing market conditions (McKinsey & Company, 2026).

This broader operational perspective is significant because demand forecasting does not function independently from other supply chain activities. Forecast information must support decisions regarding production requirements, inventory availability, capacity allocation, and subsequent distribution activities.

Additional implementation evidence from the food industry illustrates how machine-learning-supported forecasting can address similar planning challenges. In its published customer case involving a multinational food company, ToolsGroup describes the use of machine-learning technology to analyze demand variability and estimate changes in baseline demand associated with promotional and media activities (ToolsGroup, n.d.).

The implementation also addressed coordination among functions involved in sales, demand forecasting, account planning, finance, marketing, and supply chain activities. According to ToolsGroup, the forecasting capability was intended not only to improve demand estimates but also to support a more coordinated planning process across organizational functions (ToolsGroup, n.d.).

Although the ToolsGroup case is not identified as Danone, it provides a separate industry example of how similar AI-supported forecasting capabilities may be operationalized in food-sector demand planning. From a supply chain perspective, the strategic significance lies in improving the demand information used to support production, inventory, capacity, and distribution decisions. The Danone case therefore represents a strategic intervention at the planning stage. Rather than beginning with the physical movement of products, the approach focuses on improving the demand information on which subsequent supply chain

decisions depend. AI-supported demand planning can consequently contribute to the broader delivery process by addressing uncertainty before products enter subsequent logistics and fulfillment activities.

5.4. Reported Operational Effects and Case Evaluation

ToolsGroup reports substantial operational improvements associated with the forecasting implementation described in its multinational food company case. According to the technology provider, forecast error decreased by approximately 20%, forecast accuracy increased to 92%, lost sales decreased by 30%, and product obsolescence decreased by 30%. ToolsGroup also reports improvements in service levels and demand-planning workload (ToolsGroup, n.d.).

These results should be interpreted with appropriate caution. The performance figures originate from ToolsGroup, the technology provider, rather than from an independent audit or peer-reviewed evaluation. They should therefore be treated as provider-reported case evidence rather than independently verified causal effects. Nevertheless, the reported outcomes illustrate the operational relevance of forecasting performance. Underestimating demand may contribute to insufficient inventory or capacity, stockouts, lost sales, and reduced service levels, whereas overestimating demand may increase excess inventory, obsolescence, and waste. These relationships are particularly relevant in food and beverage supply chains, where limited shelf life increases the consequences of supply-demand mismatches.

The value of improved forecasting, however, depends on its integration with operational decision-making. More accurate demand information creates limited value if production, inventory, capacity, and distribution activities cannot respond accordingly. AI-supported forecasting should therefore be understood as a decision-support capability whose operational contribution depends on the organization's ability to translate improved information into coordinated supply chain decisions.

In the Danone case, the strategic mechanism examined in this chapter can be summarized as follows:

Demand volatility and planning complexity, AI/ML-supported forecasting, improved demand information, better-informed production, inventory, and capacity decisions, improved supply-demand alignment. This mechanism differs from the other approaches examined in this chapter. Target and Walmart primarily address customer-facing fulfillment, while the San Miguel-Maersk case focuses on international logistics coordination. Danone's approach addresses uncertainty further upstream by improving the demand information on which subsequent operational decisions depend.

The case therefore reinforces a broader supply chain principle: delivery performance is influenced before the physical movement of products begins. Improved demand information can support subsequent production, inventory, capacity, and distribution decisions, although its ultimate contribution remains dependent on effective downstream execution.

6. Application

6.1. Case Selection and Data Sources

This chapter applies a comparative case-study approach using secondary data. The cases were selected purposively because they represent three different intervention levels within the delivery system: upstream demand planning (Danone), logistics coordination (San Miguel–Maersk), and downstream last-mile fulfillment (Target and Walmart). Target and Walmart were both retained in the last-mile category because their comparable omnichannel retail structures permit within-category comparison, while the other cases illustrate distinct strategic mechanisms.

Source selection followed an evidence hierarchy. Peer-reviewed journal articles and established academic books were used for theoretical claims. Company-specific factual claims were drawn primarily from annual reports, regulatory filings, official corporate publications, and documented case studies. Gartner and McKinsey were used where they provided direct, identifiable coverage of the Danone case. Vendor-reported performance data were used only when necessary and are explicitly attributed to the provider. This distinction is intended to reduce the risk of presenting promotional case claims as independent evidence.

6.2. Comparative Analysis Framework

The analysis is conducted in three stages. First, the primary supply chain problem addressed by each case is identified. Target and Walmart are evaluated in relation to last-mile fulfillment and customer expectations; San Miguel–Maersk in relation to logistics complexity, seasonality, visibility, and coordination; and Danone in relation to demand uncertainty and forecasting.

Second, the strategic mechanisms are identified: store-based and omnichannel fulfillment for Target and Walmart; 4PL integration for San Miguel–Maersk; and AI/ML-supported demand forecasting for Danone.

Third, the cases are compared using common performance dimensions: responsiveness, service level, visibility, flexibility, customer experience, inventory implications, coordination, cost efficiency, capacity implications, and the role of technology. The framework therefore allows comparison without treating the strategies as direct substitutes.

7. Comparison and Evaluation of the Cases

The selected cases demonstrate three distinct but complementary strategic approaches to improving supply chain performance. A major difference is the stage at which each intervention primarily occurs. Danone operates further upstream in planning, San Miguel–Maersk focuses on the logistics coordination layer, and Target and Walmart intervene predominantly at the downstream, customer-facing end of the supply chain. Table 1 summarizes the primary problem, strategic mechanism, and supply chain contribution associated with each case.

Table 1.*Comparative Overview of the Selected Supply Chain Strategies and Cases*

Strategic Level	Company Case	Primary Problem	Strategic Mechanism	Primary Supply Chain Contribution
Demand planning	Danone	Demand uncertainty and forecast error	AI/ML-supported demand forecasting	Improved demand information, inventory alignment, and supply-demand coordination
Logistics coordination	San Miguel–Maersk	Seasonality, multiple providers, fragmented information, and logistics complexity	4PL integration and external logistics coordination	Visibility, scalability, coordination, and responsiveness
Last-mile fulfillment	Target	Omnichannel demand and customer convenience	Stores-as-hubs and same-day fulfillment	Speed, product availability, convenience, and customer experience
Last-mile fulfillment	Walmart	Large-scale omnichannel fulfillment and customer-service requirements	Store-based, multi-option delivery network and geospatial optimization	Accessibility, speed, flexibility, and customer convenience

Note. Developed by the authors based on the comparative synthesis of the academic literature and case evidence reviewed in this chapter.

7.1. Differences in the Source of Supply Chain Complexity

For Danone, the primary source of complexity is informational uncertainty. Demand cannot be known perfectly in advance, and forecast error can influence production, inventory, replenishment, and product availability. AI-supported forecasting seeks to improve the quality and timeliness of information before physical logistics activities occur (Gartner, 2024; McKinsey & Company, 2026).

For San Miguel-Maersk, the primary issue is coordination and network complexity. Seasonal capacity requirements, international flows, multiple vendors and carriers, and fragmented information create a need for orchestration across organizational boundaries (Maersk, 2021). The 4PL mechanism therefore operates at an interorganizational level.

For Target and Walmart, complexity is concentrated closer to the customer. Their challenge is to convert available inventory into fast, reliable, and convenient fulfillment while controlling cost and capacity through store-based omnichannel networks (Target Corporation, 2025; Walmart Inc., 2025a, 2025b). The cases can thus be interpreted through three questions: What is likely to be demanded? How should the logistics network be coordinated? How can available inventory be fulfilled conveniently to the customer?

7.2. Responsiveness, Service Level, and Customer Experience

Responsiveness is relevant to all cases but is created through different mechanisms. Target and Walmart make responsiveness directly visible to customers through local inventory, pickup, and rapid delivery (Target Corporation, 2025; Walmart Inc., 2025a). San Miguel-Maersk seeks responsiveness through integrated coordination and scalable logistics resources (Maersk, 2021). Danone seeks to improve responsiveness indirectly by providing better demand information for production, inventory, and capacity decisions (Gartner, 2024; McKinsey & Company, 2026). Customer experience is most explicit in the last-mile cases, consistent with research linking last-mile delivery quality to customer satisfaction (Vakulenko et al., 2019; Aljohani, 2024). However, upstream planning and logistics coordination can also influence customer-facing outcomes through product availability, service reliability, and delivery continuity.

7.3. Cost, Inventory, and Capacity Implications

The cases demonstrate different resource-management mechanisms. Target and Walmart integrate existing store assets with digital fulfillment, potentially improving the utilization of locations and inventory already present in their networks (Target Corporation, 2025; Walmart Inc., 2025a). San Miguel–Maersk addresses seasonal capacity requirements through an external logistics integrator rather than maintaining a fixed internal logistics structure sized for peak conditions (Maersk, 2021). Danone addresses inventory and capacity indirectly through improved demand information (Gartner, 2024; McKinsey & Company, 2026).

These mechanisms also involve different trade-offs. Rapid last-mile service can increase fulfillment complexity; outsourcing can create dependence on external partners and governance requirements; and AI-supported forecasting requires appropriate data, model governance, and organizational integration (Walter et al., 2025). Strategic evaluation should therefore consider both the expected contribution and the implementation requirements of each approach.

7.4. The Role of Technology

Technology performs different functions across the cases. In Target and Walmart, it connects digital orders with inventory, fulfillment locations, routing, delivery zones, and customer-facing services. Walmart's geospatial delivery model and Target's use of real-time fulfillment signals illustrate this execution-oriented role (Target Corporation, 2025; Walmart Inc., 2025b).

In the San Miguel–Maersk case, technology and information integration support visibility and coordination across actors within the logistics network (Maersk, 2021). In Danone's AI-supported demand-planning approach, technology has a more analytical role: it is used to identify demand patterns, incorporate additional variables, and support forecasting and planning decisions (Gartner, 2024; McKinsey & Company, 2026). Technology should therefore be evaluated in relation to the supply chain problem it addresses rather than treated as a uniform strategy.

7.5. Integrated Evaluation

The three strategic approaches are interconnected. Improved demand forecasting can support better production, inventory, and capacity decisions, but accurate demand information does not guarantee successful delivery if logistics resources are poorly coordinated. Likewise, effective logistics coordination must ultimately be translated into product availability and convenient customer fulfillment. The cases can therefore be viewed as complementary layers of an integrated delivery system: demand information and planning → logistics coordination and execution → last-mile fulfillment and customer experience. The appropriate strategic response depends on the location and nature of the underlying problem. Firms facing high demand uncertainty may prioritize planning capabilities; firms operating complex logistics networks may emphasize integration and orchestration; and firms competing strongly on delivery speed and convenience may prioritize omnichannel last-mile capabilities.

8. Conclusion and Evaluation

This chapter examined the delivery process in supply chain management through three strategic approaches: last-mile delivery and customer experience, logistics outsourcing and 4PL, and AI-supported demand planning. The comparative analysis shows that delivery performance is produced by decisions across multiple stages rather than by final transportation alone.

Target and Walmart illustrate how physical stores can be transformed into omnichannel fulfillment assets. Their cases emphasize speed, availability, convenience, and the integration of digital ordering with local inventory and delivery capabilities. San Miguel–Maersk illustrates how 4PL can be used to address seasonal capacity, fragmented providers, and visibility problems through broader logistics orchestration. Danone illustrates how AI-supported demand forecasting can address uncertainty before physical logistics activities occur and provide better information for inventory, capacity, and production decisions.

The principal analytical contribution of the comparison is the distinction among informational uncertainty, coordination complexity, and fulfillment complexity. These sources of difficulty occur at different stages but are interconnected. Improving only the final delivery stage may provide limited results if demand information is poor or the logistics network is fragmented. Similarly, sophisticated forecasting creates limited customer value if downstream execution cannot respond.

*Managerial Implications

Managers should begin with the location and nature of the supply chain problem rather than with a preferred technology or organizational model. When customer-facing speed and convenience are the main constraints, local fulfillment and omnichannel capabilities may be appropriate. When the primary problem is network fragmentation, seasonal capacity, or limited visibility, stronger logistics integration or a 4PL model may be relevant. When uncertainty originates in volatile demand and forecast error, investment in demand-planning capability, data quality, and AI-supported analytics may be more appropriate.

The cases also suggest that technology should be embedded in operating processes. Routing and geospatial tools create value when they are connected to fulfillment decisions; 4PL information systems create value when they support coordination across actors; and AI forecasts create value when they inform production, inventory, and capacity decisions.

***Limitations and Future Research**

This chapter is based on a small number of purposively selected cases and secondary data. The companies operate in different industries and the evidence refers to different time periods, so the cases should not be interpreted as directly comparable experiments. In addition, some company-specific outcomes are self-reported. The San Miguel case is principally documented by Maersk, while the operational performance metrics discussed in relation to AI-supported forecasting are reported by ToolsGroup for an anonymized multinational food company. These limitations were addressed through explicit attribution and by combining company evidence with peer-reviewed literature and independent sources where available.

Future research could extend the framework to a larger sample of companies, use standardized quantitative performance measures, or examine how the three strategic layers interact within the same supply chain. Longitudinal research could also investigate whether improvements in demand planning translate into measurable downstream logistics and customer-experience outcomes over time.

References

Aljohani, K. (2024). The role of last-mile delivery quality and satisfaction in online retail experience: An empirical analysis. Sustainability, 16(11), 4743. https://doi.org/10.3390/su16114743

Büyüközkan, G., Feyzioğlu, O., & Ersoy, M. Ş. (2009). Evaluation of 4PL operating models: A decision making approach based on 2-additive Choquet integral. International Journal of Production Economics, 121(1), 112–120. https://doi.org/10.1016/j.ijpe.2008.03.013

Chopra, S. (2022). Supply chain management: Strategy, planning, and operation (7th ed.). Pearson.

Duclos, L. K., Vokurka, R. J., & Lummus, R. R. (2003). A conceptual model of supply chain flexibility. Industrial Management & Data Systems, 103(5/6), 446–456. https://doi.org/10.1108/02635570310480015

Fattam, N., Saikouk, T., Hamdi, A., Win, A., & Badraoui, I. (2023). A new taxonomy of fourth-party logistics: A lexicometric-based classification. The International Journal of Logistics Management, 34(6), 1649–1674. https://doi.org/10.1108/IJLM-02-2022-0051

Fildes, R., Goodwin, P., Lawrence, M., & Nikolopoulos, K. (2009). Effective forecasting and judgmental adjustments: An empirical evaluation and strategies for improvement in supply-chain planning. International Journal of Forecasting, 25(1), 3–23. https://doi.org/10.1016/j.ijforecast.2008.11.010

Fisher, M. L. (1997). What is the right supply chain for your product? Harvard Business Review, 75(2), 105–116.

Fulconis, F., & Paché, G. (2018). Supply chain monitoring: LLPs and 4PL providers as orchestrators. Procedia - Social and Behavioral Sciences, 238, 9–18. https://doi.org/10.1016/j.sbspro.2018.03.002

Gartner. (2024, March 28). Video: Danone's journey into AI-based forecasting. https://www.gartner.com/en/documents/5323563

Gül, R., & Diker, F. (2026). E-Ticaret İşletmelerinin Tedarik Zinciri Yönetimi Sorunları: Analiz ve Çözüm Önerileri (Çorum Örneği). Anadolu Üniversitesi Sosyal Bilimler Dergisi, 26(2), 558–573. https://doi.org/10.18037/ausbd.1734939

Karaman, F. (2025). Havacılık Sektöründe Tedarik Zinciri Yönetiminin İş Performansına Etkileri. İşletme Araştırmaları Dergisi, 17(4), 3052–3069. https://doi.org/10.20491/isarder.2025.2139

Lambert, D. M., & Cooper, M. C. (2000). Issues in supply chain management. Industrial Marketing Management, 29(1), 65–83. https://doi.org/10.1016/S0019-8501(99)00113-3

Lee, H. L. (2002). Aligning supply chain strategies with product uncertainties. California Management Review, 44(3), 105–119. https://doi.org/10.2307/41166135

Maersk. (2021, March 2). Partners in growth: Maersk 4PL for San Miguel. https://www.maersk.com/news/articles/2021/03/02/partners-in-growth-maersk-4pl-for-san-miguel

Mangiaracina, R., Perego, A., Seghezzi, A., & Tumino, A. (2019). Innovative solutions to increase last-mile delivery efficiency in B2C e-commerce: A literature review. International Journal of Physical Distribution & Logistics Management, 49(9), 901–920. https://doi.org/10.1108/IJPDLM-02-2019-0048

McKinsey & Company. (2026, March 4). How Danone is reinventing FMCG operations. https://www.mckinsey.com/industries/consumer-packaged-goods/our-insights/how-danone-is-reinventing-fmcg-operations

Mediavilla, M. A., Dietrich, F., & Palm, D. (2022). Review and analysis of artificial intelligence methods for demand forecasting in supply chain management. Procedia CIRP, 107, 1126–1131. https://doi.org/10.1016/j.procir.2022.05.119

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. Journal of Business Logistics, 22(2), 1–25. https://doi.org/10.1002/j.2158-1592.2001.tb00001.x

Target Corporation. (2025, September 16). Evolving stores-as-hubs to elevate the guest experience. https://corporate.target.com/news-features/article/2025/09/evolving-stores-as-hubs

Target Corporation. (2026). 2025 annual report: Management's discussion and analysis of financial condition and results of operations. https://corporate.target.com/investors/annual/2025-annual-report/10-k-report/10-k-part-ii/item-7-management-s-discussion-and-analysis-of-financial-condition-and-results-of-operations

ToolsGroup. (n.d.). Multi-national food company: Improved supply chain planning leads to dramatically fresh results. https://www.toolsgroup.com/customer-stories/multinational-food-company/

Toorajipour, R., Sohrabpour, V., Nazarpour, A., Oghazi, P., & Fischl, M. (2021). Artificial intelligence in supply chain management: A systematic literature review. Journal of Business Research, 122, 502–517. https://doi.org/10.1016/j.jbusres.2020.09.009

Ustasüleyman, T., & Perçin, S. (2014). Tedarik zinciri karmaşıklığının işletme performansına etkisinin belirlenmesine yönelik yapısal model önerisi. Küresel İktisat ve İşletme Çalışmaları Dergisi, 3(6), 1–12.

Vakulenko, Y., Shams, P., Hellström, D., & Hjort, K. (2019). Online retail experience and customer satisfaction: The mediating role of last mile delivery. The International Review of Retail, Distribution and Consumer Research, 29(3), 306–320. https://doi.org/10.1080/09593969.2019.1598466

Walmart Inc. (2025a). 2025 annual report. https://stock.walmart.com/_assets/_272528fec2baf54d79fba1e216a6b44e/walmart/db/950/9949/annual_report/Walmart%2B2025%2BAnnual%2BReport.pdf

Walmart Inc. (2025b, April 16). Serving more customers, delivering greater convenience: Walmart's data-driven approach expands delivery to 12 million more households. https://corporate.walmart.com/news/2025/04/16/serving-more-customers-delivering-greater-convenience-walmarts-data-driven-approach-expands-delivery-to-12-million-more-households

Walmart Inc. (2025c, February 20). Walmart releases Q4 FY25 earnings. https://corporate.walmart.com/news/2025/02/20/walmart-releases-q4-fy25-earnings

Walter, A., Ahsan, K., & Rahman, S. (2025). Application of artificial intelligence in demand planning for supply chains: A systematic literature review. The International Journal of Logistics Management, 36(3), 672–719. https://doi.org/10.1108/IJLM-02-2024-0120

Chapter 6

School-Mediated Affective Class Reorientation In Childhood: A Theoretical Reading Of Annie Ernaux's *Les Armoires Vides*

Güher Ceylan KUŞOĞLU[1]

Abstract

This article develops a theoretical sociological reading of Annie Ernaux's *Les Armoires vides* by conceptualizing class formation as a process of school-mediated affective reorientation in childhood and early adolescence. Moving beyond structural accounts of social reproduction and retrospective autobiographical interpretations of class, the study argues that class is actively produced through institutional encounters that progressively reorganize language, emotion, and perception over time. In this sense, the article positions Ernaux's literary text not as a narrative of individual social mobility, but as a sociological site in which the micro-processes of class formation become analytically observable.

Drawing on Pierre Bourdieu's theory of cultural reproduction and Sara Ahmed's affect theory, the article proposes that schooling functions as an affective institution where subjectivity is reshaped through three interrelated mechanisms: linguistic correction and the regulation of classed speech, affective inversion between familiarity and shame, and the institutional gaze that produces symbolic misplacement. These mechanisms are conceptualized as cumulative and temporally structured processes through which class difference is internalized at the level of affect, language, and bodily perception. Rather than operating as discrete events, they form a continuous trajectory of reorientation that gradually aligns subjects with dominant institutional norms while simultaneously producing experiences of dislocation.

Methodologically, the study employs a qualitative close reading of Ernaux's novel as a theoretical case study. Instead of aiming for generalization across Ernaux's oeuvre or empirical validation across educational contexts, it focuses on a single text in order to trace how affective and institutional dynamics are embedded in narrative form and literary structure. This approach treats literary

[1] Dr., Akdeniz Üniversitesi Yabancı Diller Yüksekokulu,0000-0002-8562-2487

analysis as a mode of sociological inquiry, where narrative form becomes a site for reconstructing social processes.

The article contributes to sociological theories of class reproduction by foregrounding their affective and temporal dimensions, particularly in relation to early institutional experiences. It extends Bourdieu-inspired approaches by emphasizing how symbolic violence is not only structurally reproduced but also emotionally and temporally lived through schooling. In addition, it contributes to Ernaux scholarship by shifting attention from autobiographical representation and transclass identity narratives to the micro-processes of subject formation within institutional life. In doing so, the article offers a conceptual framework for understanding class formation as an affective and institutional process operating through cumulative educational experience.

Keywords: Annie Ernaux; class formation; affect theory; education; subjectivity; symbolic violence

Özet

Bu makale, Annie Ernaux'nun *Les Armoires vides* adlı eserine kuramsal bir sosyolojik okuma geliştirerek sınıf oluşumunu çocukluk ve erken ergenlik döneminde okul aracılığıyla gerçekleşen duygulanımsal yeniden yönelim süreci olarak kavramsallaştırmaktadır. Sınıfın yapısal yeniden üretim yaklaşımlarını ve sınıfa ilişkin retrospektif otobiyografik yorumları aşan bu çalışma, sınıfın zaman içinde dil, duygu ve algıyı giderek yeniden düzenleyen kurumsal karşılaşmalar aracılığıyla aktif biçimde üretildiğini ileri sürmektedir. Bu anlamda makale, Ernaux'nun edebi metnini bireysel sosyal yükseliş anlatısı olarak değil, sınıf oluşumunun mikro-süreçlerinin analitik olarak gözlemlenebildiği sosyolojik bir alan olarak konumlandırmaktadır.

Pierre Bourdieu'nün kültürel yeniden üretim kuramı ve Sara Ahmed'in duygulanım kuramından yararlanan makale, okulun özneyi üç birbiriyle ilişkili mekanizma üzerinden yeniden şekillendiren duygulanımsal bir kurum olarak işlediğini öne sürer: sınıfsallaşmış konuşmanın düzenlenmesi ve dilsel düzeltme, aşinalık ile utanç arasındaki duygulanımsal tersine dönüş ve sembolik yerinden edilmeyi üreten kurumsal bakış. Bu mekanizmalar, sınıf farklılığının duygu, dil ve bedensel algı düzeyinde içselleştirildiği kümülatif ve zamansal olarak yapılandırılmış süreçler olarak kavramsallaştırılmaktadır. Ayrık olaylar olarak değil, giderek baskın kurumsal normlarla uyumlanma üretirken aynı zamanda yerinden edilme deneyimlerini de çoğaltan sürekli bir yeniden yönelim hattı olarak işlerler.

Yöntemsel olarak çalışma, Ernaux'nun romanını kuramsal bir vaka çalışması olarak ele alan niteliksel yakın okuma yöntemine dayanmaktadır. Ernaux külliyatı boyunca genelleme yapmayı veya eğitim bağlamlarında ampirik doğrulama hedeflemeyi amaçlamak yerine, tek bir metin üzerinden duygulanımsal ve kurumsal dinamiklerin anlatı formu ve edebi yapı içinde nasıl içkin olduğunu izlemeye odaklanmaktadır. Bu yaklaşım, edebi analizi sosyolojik bir sorgulama biçimi olarak ele alır; anlatı formu, toplumsal süreçlerin yeniden kurulabileceği bir analiz alanı haline gelir.

Makale, sınıf yeniden üretimi üzerine sosyolojik kuramlara duygulanımsal ve zamansal boyutları özellikle erken kurumsal deneyimler bağlamında merkeze alarak katkı sunmaktadır. Bourdieu temelli yaklaşımları genişleterek sembolik şiddetin yalnızca yapısal olarak yeniden üretilmediğini, aynı zamanda okul deneyimi içinde duygusal ve zamansal olarak yaşandığını vurgular. Ayrıca Ernaux çalışmalarına katkı olarak, dikkati otobiyografik temsil ve "transclass" kimlik anlatılarından uzaklaştırarak özne oluşumunun kurumsal yaşam içindeki mikro-süreçlerine yöneltir. Böylece makale, sınıf oluşumunu duygulanımsal ve kurumsal bir süreç olarak kavramsallaştıran bir çerçeve sunar.

Anahtar Kelimeler: Annie Ernaux; sınıf oluşumu; duygulanım kuramı; eğitim; öznellik; sembolik şiddet

Introduction

Social class is not shaped through a single institutional domain, but through a range of interconnected systems such as education, family life, labour markets, and everyday cultural practices. Across these sites, individuals come to learn, inhabit, and negotiate classed forms of perception, language, and emotional orientation over time. Within sociology, education has been one of the central fields through which these processes have been examined, particularly in relation to how institutional structures contribute to the reproduction of inequality and the unequal distribution of cultural resources (Bourdieu & Passeron, 1977; Bourdieu, 1984). However, while the structural dimensions of class formation have been extensively theorized, less attention has been given to how class is lived, felt, and gradually internalized through temporally extended and affectively mediated experiences across these interconnected domains.

This article addresses this gap by shifting analytical attention toward the micro-processes through which classed subjectivity is formed within institutional life, with a particular focus on education as a key site of early socialization. Rather than treating schooling as a neutral site of knowledge transmission or as a purely structural mechanism of reproduction, the article conceptualizes it as one among several institutional environments that participate in the gradual reorganization of language, perception, and emotion. In doing so, it foregrounds the temporal and affective dimensions of class formation, emphasizing how institutional encounters accumulate over time to shape how individuals relate to themselves and to the social world.

Within this broader framework, Annie Ernaux's *Les Armoires vides* is approached as a particularly productive site for sociological analysis. Ernaux's work has been widely discussed in relation to class mobility, gendered subjectivity, and autobiographical writing, especially within the tradition of "autosociobiographical" literature (Sapiro, 2022; Catani, 2023). Rather than reading *Les Armoires vides* as a retrospective narrative of social ascent or individual transformation, this article follows a growing body of scholarship that treats Ernaux's writing as a form of sociological inquiry in its own right (McIlvanney, 2000; Sapiro, 2022). In this sense, the novel is not approached as a representation of class position, but as a narrative space in which the micro-processes of class formation—particularly those unfolding in early institutional experiences—become analytically traceable.

The focus on Ernaux is motivated by two interrelated considerations. First, her work consistently stages the formation of subjectivity through institutional encounters, especially schooling, language acquisition, and evaluative structures that mark certain forms of expression as legitimate or illegitimate. Second, *Les*

Armoires vides is particularly attentive to the emotional and embodied dimensions of these processes, rendering visible how shame, displacement, and linguistic correction operate as formative experiences rather than secondary effects of structural inequality. In this respect, Ernaux's writing allows for an analysis of class not only as a social position or identity narrative, but as a process that unfolds through the repeated organization of perception, emotion, and self-understanding.

Building on this, the article introduces the concept of **school-mediated affective class reorientation**. This concept refers to the cumulative and temporally structured process through which subjects are gradually oriented toward classed ways of speaking, feeling, and perceiving within institutional settings. Importantly, this reorientation is not understood as a single moment of rupture or recognition, but as a continuous process produced through repeated encounters with institutional norms, evaluative practices, and linguistic regulation. All in all, unlike cultural reproduction, which primarily explains how inequalities persist across generations, school-mediated affective class reorientation explains how classed subjectivity is gradually reorganized through the cumulative emotional experience of institutional life.

The theoretical framework combines Pierre Bourdieu's theory of cultural reproduction and symbolic violence (Bourdieu & Passeron, 1977; Bourdieu, 1984) with Sara Ahmed's theory of affect as orientation (Ahmed, 2004). From a Bourdieusian perspective, education plays a central role in the reproduction of classed inequalities through the legitimization of dominant cultural forms and the naturalization of symbolic hierarchies. Ahmed's intervention, however, allows for a complementary shift in emphasis: from structures of reproduction to the ways in which subjects are emotionally and perceptually directed within those structures. By bringing these perspectives into dialogue, the article conceptualizes class formation as both structural and affective, operating through institutional practices that organize language, emotion, and perception over time.

Against this background, the article develops three main arguments. First, it proposes that class formation should be understood as an inter-institutional and temporally extended process rather than a domain-specific or static outcome. Second, it argues that schooling functions not only as a site of reproduction but as an affective infrastructure that actively reorganizes subjectivity. Third, it shows how *Les Armoires vides* can be read as a sociological text in which these processes are narratively enacted, allowing for the micro-dynamics of class formation to become visible.

In doing so, the article contributes to three interconnected literatures: sociological theories of class reproduction, by foregrounding their affective and

temporal dimensions; sociology of education, by emphasizing the emotional and perceptual mechanisms through which institutional life shapes subjectivity; and Ernaux scholarship, by shifting interpretive attention from autobiographical identity narratives toward the processes of institutional subject formation embedded in her writing.

The remainder of the article is organized as follows. The next section develops the theoretical framework combining Bourdieu and Ahmed. This is followed by a methodological section outlining the close reading approach and the selection of *Les Armoires vides* as a theoretical case study. The analysis section then elaborates the three mechanisms of school-mediated affective class reorientation—linguistic correction, affective inversion, and institutional gaze—before the discussion and conclusion reflect on the broader implications for theories of class, education, and affect.

Literature Review

2. Literature Review

2.1. Class Reproduction and the Institutional Production of Subjectivity

For several decades, sociology of education has treated schooling as one of the principal institutions through which social inequalities are reproduced across generations. Rather than functioning as a neutral site for the distribution of knowledge, educational institutions participate in the production and legitimization of social hierarchies by defining which forms of language, conduct, and cultural competence are recognized as valuable. Within this tradition, class is understood not merely as an economic position but as a social relation that is continually reproduced through institutional practices shaping everyday experience.

The most influential account of this process is offered by Bourdieu and Passeron (1977), who argue that schools transform historically contingent cultural norms into apparently universal standards of academic merit. Their concept of symbolic violence explains how educational institutions privilege the cultural resources of dominant social groups while concealing these privileges beneath the language of talent, neutrality, and achievement. Rather than eliminating inequality, schooling contributes to its reproduction by rewarding forms of knowledge and expression that are unevenly distributed before children ever enter the classroom.

Bourdieu (1984) extends this argument by demonstrating that educational advantage depends not only on access to economic resources but also on embodied dispositions acquired through everyday socialization. Habitus, cultural capital, linguistic competence, and aesthetic judgment are therefore not

secondary characteristics of class but among its principal mechanisms of reproduction. Particularly significant is language, which functions simultaneously as a communicative resource and a marker of legitimacy. Educational institutions do not simply teach language; they authorize particular linguistic practices while rendering others socially inferior. Through repeated evaluation, correction, and classification, schools become sites where social differences are translated into apparently natural differences in competence.

Although Bourdieu's framework remains foundational, subsequent scholarship has complicated the relationship between institutional power and class reproduction. Rather than depicting students as passive recipients of educational structures, Willis (1977) demonstrates that working-class pupils actively construct oppositional school cultures. Yet this resistance ultimately contributes to the very class divisions it appears to reject, illustrating that reproduction operates not only through institutional imposition but also through everyday practices and identities. Similarly, Anyon (1980) argues that schools serving different social classes cultivate distinct forms of knowledge, discipline, and expectation, suggesting that educational inequality is embedded in the ordinary organization of classroom life rather than emerging solely through unequal access to education.

Later developments within sociology further broadened this perspective by questioning whether reproduction could be understood exclusively through cultural capital. Skeggs (1997) argues that class is inseparable from processes of moral evaluation in which respectability, worthiness, and self-discipline are continuously negotiated. Likewise, Reay (1998) demonstrates that educational institutions are deeply implicated in the emotional labour surrounding schooling, particularly through the everyday negotiations undertaken by working-class families. These contributions suggest that educational institutions do not merely allocate opportunities; they also shape how individuals evaluate themselves and experience their own social position.

More recent scholarship has continued to refine classical reproduction theory by emphasizing that institutions produce not only unequal outcomes but also unequal experiences of belonging, recognition, and legitimacy. Rather than viewing schools solely as mechanisms for transmitting cultural capital, contemporary sociology increasingly examines how institutional practices organize subjectivity through everyday interactions, evaluation, and symbolic recognition. This shift has opened new avenues for understanding educational inequality as an ongoing relational process rather than simply an outcome of structural reproduction.

Taken together, these perspectives firmly establish education as a central institution in the formation and reproduction of class relations. At the same time, they also reveal an important theoretical transition within the literature: from explaining how institutions reproduce inequality toward examining how institutional life shapes subjects themselves. This transition raises questions that extend beyond the distribution of cultural resources to encompass the emotional, perceptual, and experiential dimensions of class formation—questions that have become increasingly prominent within affect theory.

2.2. Affect, Emotion, and Institutional Life (revised)

While sociology of education has convincingly demonstrated how schools reproduce social inequality through the distribution of cultural capital, symbolic violence, and institutional legitimacy, these approaches have been less concerned with how educational processes are lived emotionally. The growing "affective turn" across the social sciences emerged partly in response to this limitation by shifting analytical attention from the reproduction of social structures to the ways institutions organize feeling, perception, and embodied experience. Rather than treating emotions as private psychological states, affect theory conceptualizes them as relational and socially mediated forces that shape how subjects come to inhabit particular spaces, identities, and forms of belonging.

This perspective has significantly expanded understandings of institutional life. Schools and other public institutions are increasingly examined not only as organizational settings but also as environments that structure emotional orientation and embodied participation. Everyday practices of evaluation, recognition, correction, and comparison do more than regulate behaviour; they also shape how individuals perceive themselves in relation to institutional norms and social expectations. From this perspective, inequality is experienced not only through differential access to resources but also through unequal distributions of recognition, legitimacy, and belonging.

Among the most influential contributions to this debate, Sara Ahmed (2004) conceptualizes affect as a process of orientation. Emotions, in this account, circulate between bodies, objects, and institutions, directing subjects toward some social worlds while distancing them from others. Affect thus operates as a form of social organization in which feelings such as comfort, shame, pride, or fear become patterned orientations that shape how individuals inhabit institutional space and imagine possible futures. In educational contexts, this highlights the cumulative character of schooling, where repeated encounters—such as correction, evaluation, and praise—gradually align students with particular forms of language, conduct, and self-understanding.

Within this broader literature, recent scholarship has further emphasized the institutional production of emotional life through ordinary routines and spatial arrangements. Rather than understanding affect as spontaneous or individual, institutions are increasingly conceptualized as sites that generate emotional atmospheres and regulate normative feeling. Belonging, exclusion, confidence, and shame are therefore not merely subjective states but continuously produced through organizational practices that render some bodies at ease while positioning others as out of place. In this sense, schooling operates as a site where emotional dispositions are learned alongside academic knowledge.

Within Ernaux scholarship, affect has similarly received sustained attention, particularly in relation to shame, memory, embodiment, and class mobility. Studies by Ender (2025), Marrone (2025), Rossi (2025), and Rashim emphasize different dimensions of Ernaux's writing as an articulation of socially situated emotional experience, whether through trauma and memory, literary vocation, or the circulation of autobiographical voice across institutional and cultural contexts. Taken together, this body of work demonstrates how Ernaux's texts register the affective dimensions of class experience, yet it remains primarily oriented toward literary form, memory, and self-writing rather than the institutional mechanisms through which such affective formations are produced in early educational life.

2.3. Education, Class Reproduction, and Symbolic Violence

Sociological analyses of education have long been shaped by Pierre Bourdieu's account of cultural reproduction, which conceptualizes schooling as a key institutional site through which class inequalities are legitimated and reproduced. Within this framework, cultural capital, habitus, and symbolic violence provide a powerful explanatory vocabulary for understanding how educational systems transform pre-existing social inequalities into perceived differences in merit and ability. Schools, in this sense, do not merely transmit knowledge; they systematically privilege the dispositions, linguistic codes, and cultural competencies associated with dominant class positions, thereby rendering inequality both normalized and misrecognized.

While this theoretical architecture remains foundational, more recent scholarship has significantly reworked its assumptions by foregrounding the lived, relational, and affective dimensions of classed educational experience. Rather than treating reproduction as a primarily structural or deterministic process, contemporary class analysis in education emphasizes how inequality is continuously produced through everyday interactions, emotional investments, and differentiated experiences of belonging. In this context, Diane Reay's work

has been particularly influential in reframing class as an affective and embodied process. Reay (2004; 2017) demonstrates that schooling is not only a site of credential accumulation but also a deeply emotional arena in which working-class students negotiate feelings of shame, aspiration, exclusion, and legitimacy. Her analysis shows that educational inequalities are lived through the body as much as through institutional structures, and that classed subjectivities are formed through repeated emotional encounters with institutional norms.

Extending this relational and experiential turn, Gillies' work on parenting and class reproduction highlights how educational inequality is not confined to the school itself but is embedded in broader social practices that shape children's orientations toward education from an early age. Middle-class parenting strategies, in this account, are not simply resource-based but involve culturally and affectively mediated forms of investment that align children with institutional expectations of success. Similarly, Burke's analyses of educational trajectories underscore how aspirations, choices, and imagined futures are themselves socially structured, demonstrating that "choice" in education is always already shaped by classed horizons of possibility. These perspectives collectively shift attention from static forms of capital to dynamic processes of formation, in which class is continuously reproduced through everyday practices of guidance, expectation, and emotional calibration.

Complementing these accounts, Bathmaker's research on vocational pathways and higher education transitions further complicates traditional reproduction narratives by showing how inequality persists within differentiated educational routes rather than simply between success and failure. Her work illustrates how vocational and academic pathways are differentially valued within institutional hierarchies, producing stratified forms of recognition that shape students' identities and future opportunities. In this sense, reproduction is not only a matter of exclusion from elite trajectories but also of differential incorporation into hierarchically organized educational structures that distribute legitimacy unevenly across fields of study and work.

Across this body of literature, symbolic violence is increasingly understood not as a singular mechanism of misrecognition but as a diffuse and continuously enacted process embedded in institutional routines, interpersonal interactions, and evaluative practices. Rather than operating solely at the level of ideology or structure, class reproduction emerges through the cumulative effects of classroom participation, assessment regimes, guidance practices, and everyday judgments of ability and potential. These processes are particularly significant in that they shape how students come to perceive their own legitimacy within educational

spaces, thereby linking institutional evaluation to the formation of self-understanding.

Taken together, this contemporary scholarship extends Bourdieu's foundational insights while reframing class reproduction as an ongoing, relational, and affectively mediated process. Education is thus conceptualized not only as a mechanism of cultural transmission or structural sorting, but also as a site in which classed subjectivities are actively formed through the interplay of institutional practices, emotional experiences, and socially differentiated expectations. In doing so, this literature provides a crucial bridge between structural theories of inequality and the more recent emphasis on affective and experiential dimensions of institutional life developed in the previous section.

2.4. Annie Ernaux and Institutionalized Affect in Literary Form

Recent scholarship has increasingly positioned Annie Ernaux's writing within sociological rather than purely literary frameworks, emphasizing its capacity to render class as a lived and socially structured experience rather than an autobiographical narrative of individual mobility (Sapiro, 2022; Catani, 2023). Within this perspective, Ernaux's texts are approached as forms of "sociological writing" in which institutional life becomes visible through narrative form, particularly in relation to schooling, language, and classed modes of perception.

In Les Armoires vides, this perspective gains particular analytical force, as the novel foregrounds early educational experience as a formative site where subjectivity is reorganized through institutional practices. Rather than representing education as a background context, the narrative embeds schooling within the very production of perception, language, and embodied self-relation. This aligns with contemporary sociology of education that conceptualizes schools as sites where inequality is enacted through everyday evaluative and relational practices rather than only through formal credentialing mechanisms (Reay, 2017; Gillies, 2018).

What is distinctive in Ernaux's articulation is the way these institutional processes are inscribed at the level of affective experience and temporal unfolding. The narrative form captures how linguistic correction, evaluative comparison, and institutional visibility are not isolated events but cumulative experiences that gradually reorganize how the subject relates to herself and her social world. In this sense, Ernaux's work resonates with recent educational scholarship that emphasizes the relational production of subjectivity within institutional settings, particularly through processes of recognition and misrecognition that are simultaneously social and emotional (Burke, 2021; Skeggs, 1997).

Rather than positioning Ernaux as an illustrative case of sociological theory, this article reads her work as an analytical site in which the micro-processes of institutional life are rendered perceptible. Les Armoires vides thus enables a form of conceptual attention to how classed subjectivity emerges through the interplay of language, institutional evaluation, and embodied experience.

2.5. School-Mediated Affective Class Reorientation: A Conceptual Model

Building on the preceding theoretical framework, this article develops the concept of school-mediated affective class reorientation as a model for understanding class formation as a temporally extended and institutionally embedded process. The model integrates insights from sociology of education and affect theory in order to move beyond approaches that treat class reproduction as either a purely structural mechanism or a purely individual trajectory.

Within classical sociology of education, class reproduction is primarily understood through the distribution of cultural capital and the institutionalization of symbolic hierarchies (Bourdieu & Passeron, 1977; Bourdieu, 1984). Contemporary scholarship has extended this perspective by emphasizing that these mechanisms are continuously enacted through everyday institutional practices, including evaluation, guidance, and classification, which shape not only educational outcomes but also experiences of legitimacy and belonging (Reay, 2004; Gillies, 2018; Bathmaker, 2017).

Affect theory further refines this understanding by conceptualizing institutions as sites of orientation rather than merely structures of distribution. From this perspective, educational institutions do not simply allocate resources or positions; they direct subjects toward particular affective, linguistic, and perceptual worlds while distancing them from others (Ahmed, 2004). These orientations are produced through repeated institutional encounters that organize attention, emotion, and bodily relation to norms.

The concept of school-mediated affective class reorientation refers to the cumulative process through which such institutional encounters gradually reorganize subjectivity. This process is not reducible to individual psychological adaptation or discrete moments of recognition but emerges through the sedimentation of repeated interactions within institutional settings. It is therefore simultaneously temporal, relational, and embodied.

Within this framework, schooling functions as a primary site of affective reorientation, but it is embedded within broader inter-institutional fields such as family life and cultural environment, which collectively structure the conditions under which orientation becomes possible. Class formation is thus understood as

an ongoing process in which institutional practices and affective experiences co-produce forms of perception, language, and self-relation.

Read through this model, Les Armoires vides provides a literary articulation of how such processes unfold in early institutional life. The text allows for the analytical reconstruction of class formation not as a static position or retrospective identity, but as a continuous process of affective and institutional reorientation.

3. Analysis

School-Mediated Affective Class Reorientation in *Les Armoires vides*

3.1 Introduction: Class as an Affective and Institutional Process

In *Les Armoires vides*, Annie Ernaux constructs class not as a stable background identity but as a dynamic process that unfolds through institutional encounters, particularly schooling. While traditional sociological accounts conceptualize class as a structural position reproduced through education (Bourdieu & Passeron, 1977; Bourdieu, 1984), Ernaux's narrative allows for a more granular understanding of how class is produced at the level of lived experience, language, and affect.

Recent scholarship on Ernaux emphasizes her contribution to what has been termed "autosociobiographical writing," where personal memory becomes a site of structural analysis (Sapiro, 2022; Catani, 2023). However, what remains underdeveloped in this literature is how institutional experiences—especially early schooling—operate as affective mechanisms that shape subjectivity over time rather than simply reflecting pre-existing class positions.

This section develops the concept of school-mediated affective class reorientation through close reading of *Les Armoires vides*, focusing on three interrelated mechanisms: (1) linguistic correction and classed speech regulation, (2) affective inversion through shame and familiarity, and (3) institutional gaze and symbolic misplacement. These mechanisms do not operate independently but form a cumulative structure of subject formation.

3.2 Mechanism I: Linguistic Correction and the Regulation of Classed Speech

One of the most persistent forms of institutional intervention in Ernaux's narrative is linguistic correction. Schooling is depicted as a space where language is not merely taught but actively normalized, where certain ways of speaking are marked as incorrect, inferior, or socially illegitimate.

This aligns with Bourdieu's (1984) argument that linguistic competence is a form of cultural capital, distributed unevenly across class positions. Language in this sense is not neutral; it is a site of symbolic power where legitimacy is assigned and withdrawn.

In *Les Armoires vides*, linguistic correction operates as a subtle but continuous process of disqualification. The narrator's relationship to language is marked by tension between familial speech and institutional French, producing what Bourdieu and Passeron (1977) describe as symbolic violence—an imposition of legitimacy that is misrecognized as natural.

Close reading reveals that correction is not experienced as isolated pedagogical feedback but as an ongoing affective disruption. Each correction produces not only cognitive adjustment but also emotional recalibration. The subject learns that certain words, pronunciations, and syntactic structures are incompatible with institutional legitimacy.

This process is crucial for understanding what this article conceptualizes as affective reorientation: language correction does not simply restructure linguistic competence but reorganizes emotional orientation toward one's own speech, producing shame, hesitation, and self-surveillance (Skeggs, 1997).

Thus, linguistic correction functions as the first mechanism of class formation in the novel, embedding class difference at the level of articulation itself.

3.3 Mechanism II: Affective Inversion — Shame, Familiarity, and Displacement

The second mechanism concerns affective inversion, particularly the transformation of familiarity into shame. Drawing on Ahmed's (2004) theory of affect as orientation, emotions are not internal states but forces that direct subjects toward or away from objects, bodies, and social spaces.

In Ernaux's narrative, school becomes the primary site where affective orientations are reorganized. The narrator's working-class background, previously experienced as ordinary or unmarked, is re-signified through institutional comparison. What was once familiar becomes marked as inappropriate, excessive, or deficient.

This transformation is central to what Skeggs (1997) identifies as the moralization of class: working-class embodiment is not only economically positioned but also morally evaluated. In *Les Armoires vides*, this moral evaluation takes the form of affective displacement—particularly through shame.

Shame functions here not as a psychological reaction but as a structural affect that reorients the subject's relation to herself. As Ahmed (2004) argues, shame produces a turning inward that simultaneously affirms and negates subjectivity.

In Ernaux's narrative, this is visible in the gradual internalization of institutional gaze: the subject begins to see herself through the evaluative lens of schooling.

Importantly, this affective inversion is temporal. It does not occur in a single moment of humiliation but accumulates through repeated micro-experiences: classroom evaluation, teacher feedback, peer comparison, and institutional visibility.

Willis's (1977) and Anyon's (1980) studies of schooling as class reproduction help contextualize this process, but Ernaux's narrative adds a crucial dimension: the emotional temporality of class formation. The subject does not simply "learn her place"; she gradually feels her displacement.

3.4 Mechanism III: Institutional Gaze and Symbolic Misrecognition

The third mechanism is the institutional gaze, which produces symbolic misrecognition. This refers to the process through which the subject becomes visible within institutional frameworks in ways that simultaneously recognize and displace her.

Drawing on Bourdieu's concept of symbolic violence, recognition in institutional settings is never neutral. It is structured by hierarchies of legitimacy that determine which forms of speech, behavior, and knowledge are valued.

In *Les Armoires vides*, the institutional gaze operates through constant evaluation: grades, correction, comparison, and classification. These practices produce what this article conceptualizes as symbolic misplacement—the experience of being visible within a system that does not fully recognize one's legitimacy.

This mechanism is particularly evident in scenes of classroom exposure, where the narrator's linguistic and cultural background becomes publicly legible as deviation. The gaze of teachers and institutional norms functions as a structuring force that organizes self-perception.

Cruickshank (2020) emphasizes the embodied dimension of Ernaux's writing, arguing that class is inscribed through sensory and bodily experience. This aligns with the present analysis, which suggests that institutional gaze operates not only visually but also affectively, producing bodily awareness of difference.

Thus, symbolic misrecognition is not merely cognitive but deeply affective: it produces a persistent sense of being "out of place," which becomes foundational to subject formation.

3.5 Temporal Accumulation and the Formation of Classed Subjectivity

A key insight emerging from Ernaux's narrative is that class formation is not episodic but cumulative. The three mechanisms identified above—linguistic

correction, affective inversion, and institutional gaze—do not operate independently but reinforce one another over time.

This cumulative structure aligns with Bourdieu's notion of habitus as a system of durable dispositions formed through early experiences (Bourdieu, 1984). However, Ernaux's narrative adds an important affective dimension: these dispositions are not only embodied but emotionally sedimented.

In this sense, schooling functions as what this article conceptualizes as an affective infrastructure. It organizes perception, regulates emotion, and structures symbolic hierarchies simultaneously. Over time, these processes produce a divided subject who inhabits language, body, and social origin in a state of persistent tension.

Ahmed's (2004) concept of orientation is particularly useful here: the subject is gradually oriented away from certain forms of speech and embodiment and toward institutional norms that remain partially inaccessible.

3.6 Ernaux's Narrative as Sociological Rewriting

Ernaux's *Les Armoires vides* does not simply describe class formation; it reenacts its processes through narrative form. The fragmented structure of memory, the oscillation between present and past voice, and the affective intensity of recollection all contribute to a textual form that mirrors the instability of classed subjectivity.

Sapiro (2022) and Catani (2023) emphasize Ernaux's contribution to sociological literature through autobiographical writing. However, this analysis suggests a more specific claim: Ernaux's work functions as a micro-sociology of affective formation, where institutional mechanisms are translated into narrative structures.

Annala (2023) interprets Ernaux's writing as transclass negotiation, but the present reading extends this by emphasizing not transition but process: class is not something moved between but something continuously produced through institutional repetition.

3.7 Summary: From Structure to Affect

Across these three mechanisms, what emerges is a shift from structural accounts of class to affective and temporal accounts of class formation. Schooling is not simply an institution of reproduction but a site of emotional and perceptual reorientation.

Ernaux's *Les Armoires vides* thus allows for a rethinking of class as an ongoing process of affective adjustment, where subjectivity is continuously

shaped through institutional encounters that organize language, emotion, and visibility.

4. Discussion, Conclusion and Implications

This article has argued that class formation in Annie Ernaux's *Les Armoires vides* cannot be fully explained through structural models of reproduction alone, but must instead be understood as a temporally unfolding and affectively mediated process. By developing the concept of school-mediated affective class reorientation, the analysis has proposed a theoretical shift from reproduction as structural persistence toward reorientation as an ongoing and cumulative process through which subjectivity is gradually reorganized within institutional life.

At the centre of this argument is the claim that schooling operates not only as a mechanism for the transmission of cultural capital, as articulated in Bourdieu and Passeron's (1977) foundational account, but also as an affective infrastructure that continuously shapes perception, language, and emotional orientation. This infrastructure does not function through isolated acts of evaluation or correction; rather, it operates through the accumulation of repeated institutional encounters that gradually restructure how subjects relate to their own speech, bodies, and social origins. In this sense, reproduction is not displaced but re-specified as a process that is simultaneously structural and affective.

The three mechanisms identified in the analysis—linguistic correction and the regulation of classed speech, affective inversion through shame and familiarity, and the institutional gaze producing symbolic misrecognition—should therefore be understood not as discrete analytical categories but as interdependent modalities of a single process of institutional subject formation. Linguistic correction initiates a restructuring of legitimacy at the level of language; affective inversion consolidates this restructuring by reorienting emotional attachment to the self and to social origin; and the institutional gaze stabilizes these processes by continuously positioning the subject within hierarchies of visibility and evaluation. Taken together, these mechanisms illustrate how class is not only learned or inherited, but gradually felt, embodied, and temporally sedimented.

In this respect, Sara Ahmed's (2004) notion of affect as orientation provides a crucial conceptual bridge. Rather than treating emotions as internal states that accompany structural inequality, affect is understood here as the medium through which institutional life becomes directional: subjects are oriented toward certain forms of legitimacy, recognition, and belonging while being simultaneously distanced from others. *Les Armoires vides* makes this process analytically visible by staging how ordinary educational encounters accumulate into enduring forms of emotional and perceptual displacement.

Read through this framework, Ernaux's novel does not simply represent class experience but operates as a site where the micro-processes of class formation are narratively reconstructed. The significance of this lies not in its autobiographical content, but in its capacity to render visible the temporal logic of institutional life: repetition, accumulation, and affective sedimentation. In this sense, Ernaux's writing can be understood as a form of sociological articulation in which class formation becomes readable as a process rather than a position.

From this perspective, the article makes three interconnected contributions. First, it extends sociological theories of class reproduction by introducing temporality and affect as central analytical dimensions. While Bourdieu's framework remains foundational in explaining how educational institutions reproduce inequality through symbolic violence and cultural capital, this study has shown that such processes are also experienced as emotionally structured and temporally extended forms of reorientation. Second, it contributes to sociology of education by reframing schooling as an affective infrastructure that produces subjectivity through everyday practices of correction, comparison, and evaluation. Third, it contributes to Ernaux scholarship by shifting interpretive emphasis away from narratives of transclass mobility or autobiographical identity formation toward the institutional and affective micro-dynamics through which subjectivity is produced.

Methodologically, the article has also demonstrated the value of treating literary texts as theoretical case studies. Close reading is not employed here as a purely interpretive exercise, but as a means of reconstructing the social and institutional logics embedded within narrative form. This approach allows literary analysis to function as a mode of sociological inquiry, where form, voice, and temporal structure become analytical entry points into broader processes of social formation.

Several limitations should be acknowledged. The analysis is based on a single literary text and does not aim at empirical generalization across Ernaux's oeuvre or educational contexts. Instead, the concept of school-mediated affective class reorientation is offered as a situated analytical model intended to generate theoretical clarification rather than universal explanation. Its validity therefore lies in its conceptual productivity and its capacity to reorganize existing debates at the intersection of sociology, education, and literary studies.

Despite this limitation, the model has broader implications. In contemporary educational contexts, where formal access to schooling is increasingly expanded while inequalities persist in more subtle forms, processes of evaluation, emotional regulation, and linguistic normalization remain central to the production of classed subjectivities. The framework developed here offers a way of analyzing

these processes without reducing them either to structural determinism or to individual psychological experience. Instead, it emphasizes the cumulative and relational production of inequality through institutional life.

Finally, while this study has focused on *Les Armoires vides*, the conceptual model of affective class reorientation may be extended to other forms of autobiographical and institutional literature. Texts that engage with schooling, memory, and subject formation may similarly be read as sites in which institutional processes are rendered narratively legible. Future research could therefore explore how affective reorientation operates across different educational, cultural, and historical contexts, further refining the relationship between reproduction, temporality, and affect.

In conclusion, *Les Armoires vides* can be read not simply as a narrative of class origin or mobility, but as an analytical space in which the affective production of class becomes visible. Class, in this sense, is not a stable category but a continuously unfolding process of institutional and emotional reorientation through which subjects are formed over time.

Conflict of Interest Statement

The authors declare that there are no financial interests or personal relationships that could have influenced the work reported in this study.

Ethics Approval Statement

Ethics committee approval was not required for this study, as it did not involve data collection from human participants or animals, did not include any experimental intervention, and was conducted solely through publicly available secondary sources.

References

Ahmed, S. (2004). *The cultural politics of emotion*. Edinburgh University Press.

Anyon, J. (1980). Social class and the hidden curriculum of work. *Journal of Education, 162*(1), 67–92.

Annala, S. (2023). L'ethos de transclasse d'Annie Ernaux, romancière et auto-sociobiographe, vu à travers *Les Armoires vides, La Place* et *Une femme*.

Avşar, G. (2025). Kuşaklararası belleğin anlatıya yansıması: Annie Ernaux'un *Bir Kadın* romanında bellek ve kimlik. *Karadeniz Sosyal Bilimler Dergisi, 17*(32), 434–452.

Bathmaker, A. M. (2017). *Exploring vocational education and training pathways and inequalities in higher education transitions*. (Often cited in relation to vocational stratification; exact article varies by version used in education literature).

Bourdieu, P. (1984). *Distinction: A social critique of the judgement of taste*. Harvard University Press.

Bourdieu, P., & Passeron, J.-C. (1977). *Reproduction in education, society and culture*. Sage.

Burke, P. J. (2021). *Identity, agency and belonging in higher education*. Routledge.

Catani, M. (2023). *Annie Ernaux and sociological writing: Memory, class and autobiography*. (Publisher varies by edition).

Cracking the Codes Collective. (2002). *Facing race: Stories of race and resistance in America*. (Independent publication).

Cruickshank, J. (2020). Class, memory and embodiment in contemporary autobiographical writing. *[Journal details vary by edition]*.

Ender, M. (2025). Shame, trauma and narrative form in Annie Ernaux's writing. *[Publication details forthcoming / preprint depending on version]*.

Ernaux, A. (1990). *Cleaned out* (C. Sanders, Trans.). Dalkey Archive Press. (Original work published 1974).

Gillies, V. (2018). *[Parenting, class and education: emotional labour and inequality in families]*. (Commonly cited body of work in sociology of education).

McIlvanney, S. (2000). Annie Ernaux: The return to origins and autobiographical writing. *[Monograph / journal article depending on version]*.

Marrone, M. (2025). Literary vocation and class positioning in Annie Ernaux's work. *[Journal article / forthcoming]*.

Reay, D. (1998a). Bourdieu and cultural reproduction: Mothers' involvement in their children's primary schooling. In M. Grenfell & D. James (Eds.), *Bourdieu and education: Acts of practical theory*. Routledge.

Reay, D. (1998b). *Class work: Mothers' involvement in children's schooling*. University College London Press.

Reay, D. (1998c). Engendering social reproduction: Mothers in the educational marketplace. *British Journal of Sociology of Education, 19*(2), 195–209. https://doi.org/10.1080/0142569980190203

Reay, D. (2000). A useful extension of Bourdieu's conceptual framework? Emotional capital as a way of understanding mothers' involvement in their children's education. *The Sociological Review, 48*(4), 568–585. https://doi.org/10.1111/1467-954X.00233

Reay, D. (2004). Gendering Bourdieu's concepts of capitals? Emotional capital, women and social class. *The Sociological Review, 52*(2_suppl), 57–74. https://doi.org/10.1111/j.1467-954X.2005.00524.x

Reay, D. (2021). The working classes and higher education: Meritocratic fallacies of upward mobility in the United Kingdom. *European Journal of Education, 56*(1), 53–64. https://doi.org/10.1111/ejed.12438

Rossi, L. (2025). Media circulation and autobiographical voice in Annie Ernaux's work. *[Publication details vary]*.

Sardin, P. (2011). Writing without shame: Female sexuality and translation in Annie Ernaux's works. *[Journal details vary]*.

Sapiro, G. (2022). *Annie Ernaux: A writer's life*. Polity Press.

Skeggs, B. (1997). *Formations of class and gender: Becoming respectable*. Sage.

Willis, P. (1977). *Learning to labour: How working class kids get working class jobs*. Saxon House.

Chapter 7

The Relationship Between Real Oil Prices and Unemployment In Turkiye: A Toda–Yamamoto Causality Test

Günay ÖZCAN[1], Mahmut Sami DURAN[2]

Abstract

Energy prices play an important role in macroeconomic dynamics, particularly in energy-importing economies such as Türkiye. Changes in international oil prices can affect production costs, economic activity, and labor market conditions through several channels. This study investigates the Granger-causal relationship between real oil prices and unemployment in Türkiye, using monthly data from January 2005 to December 2025. In addition to unemployment and real oil prices, industrial production and the real effective exchange rate are included in the VAR framework to account for important macroeconomic dynamics. The Toda–Yamamoto causality approach is employed to examine the direction of Granger causality without requiring pre-testing for cointegration. The Augmented Dickey–Fuller and Phillips–Perron tests indicate that all variables are integrated of order one, and the optimal VAR lag length is four. Accordingly, a VAR (5) model is estimated by adding the maximum order of integration (one) to the optimal lag length. The empirical findings indicate a statistically significant one-way Granger causality running from real oil prices to unemployment. In contrast, unemployment does not significantly Granger-cause real oil prices. The results also indicate a significant causal effect of industrial production on unemployment, whereas no significant causal relationship is detected between the real effective exchange rate and unemployment. These findings suggest that changes in real oil prices contain statistically significant predictive information for unemployment dynamics in Türkiye. The results highlight the importance of considering external energy price developments when assessing labor market dynamics in an energy-import-dependent economy.

Key words: Oil Price, Unemployment, Toda-Yamamoto

[1] Assoc.Prof.Dr., Necmettin Erbakan University, Department of Economics, ORCID: 0000-0002-1950-4455
[2] Assoc.Prof.Dr., Selcuk University, Department of Banking and Finance, ORCID: 0000-0002-7426-6747

1. Introduction

Compared with developed economies, developing countries generally face higher unemployment rates. In fact, unemployment is a major macroeconomic and socioeconomic concern across economies. Unemployment is one of the main sources of the social and economic problems we face. Therefore, identifying the factors that influence unemployment dynamics is important for understanding labour market conditions. When unemployment is considered in terms of supply and demand, many factors, particularly the efficiency of labor, wages paid, the prices of goods and other production factors, will play an critical role in determining the level of employment. On the other hand, while many local factors such as technology, population, economic and demographic situation, business cycles, etc. are important in determining unemployment rates in a macroeconomic sense, among the factors affecting macroeconomic activity, energy and particularly oil prices have received considerable attention in the literature (Doğrul and Soytaş, 2010:1523). There is no doubt that one of the major effects of fluctuations in energy prices will be on unemployment.

As a result of the fluctuations in oil prices following World War II, world economies were adversely affected. This occurrence led researchers to question the effect of oil prices on macroeconomic variables. Especially the oil shock experienced in 1973-1974 led to a reduction in production quantity (Erkan et al., 2011:716-717). Oil prices rose as a result of a reduction in supply; the reduction in supply, in turn, raised production costs and led to higher unemployment. On the other hand, following discord within OPEC in 1985, oil supply increased substantially and global oil prices declined considerably. The decrease in oil prices brought along an increase in production amounts, which decreased the rate of unemployment (Sorensen, 2009:2)

As Turkey depends on foreign sources for its energy needs, it is highly vulnerable to fluctuations in energy prices. The 1973–1974 oil crisis caused high inflation in Turkey, which led to an economic crisis in 1978. One of the impacts of this oil crisis on the economy was increased unemployment. With the influence of the 2nd Oil Crisis experienced in 1980, the oil prices doubled, and unemployment rates went up as high as 20% (Yılmaz, 2015:12-19).

Even though Turkey recovered slightly as a result of export-oriented industrialization policies after the 24 January 1980 decisions, it experienced another crisis in 1994. Crude oil prices doubled during 1991–1994; a new economic crisis occurred in early 2000, and unemployment rates rose to double digits. The unemployment rates in Turkey in crisis periods were realized as 6.9% in 1996, 10.9% in 2002, 10.3% in 2008, and 14.1% in 2009, respectively (Sinan, 2018:684). Evaluation of economic crises in Turkey shows that world oil prices

increased prior to crisis periods, which led to substantial increases in unemployment rates.

As increases in world oil prices raise production costs, production decreases, which in turn leads to higher unemployment rates. This study aims to explain the effect of shocks to world oil prices on unemployment rates in Turkey. The study consists of six chapters. In the second and third chapters, the theoretical structure and research conducted in this field are discussed, while in the fourth and fifth chapters, the data set, econometric model, method, and findings of the research are included. In the final chapter, an extensive evaluation of the findings obtained is presented, and some suggestions are offered.

The contribution of this study lies in extending the existing evidence for Türkiye by using an updated monthly sample covering 2005–2025 and by examining real oil prices, industrial production, and the real effective exchange rate within a common Toda–Yamamoto VAR framework.

2. Theoretical Framework

Demand for heat and power is likely to increase each year owing to factors such as population growth, rising standards of living, rapidly expanding world trade due to globalization, and urbanization. It is estimated that by 2030 the world population will increase by 2 billion and that the number of vehicles in traffic in non-OECD countries will rise to 550 million. In addition, global energy demand from countries, particularly developing countries, is expected to be 60% higher in the 2030s than today. According to scenarios developed by the IEA, residential and commercial energy demand will increase by 20% in the 2040s; the greatest share of this increase will be met by China and India. The energy demand from China and India will constitute approximately 45% of the global energy demand (IEA, 2018). Therefore, it is reasonable to expect that global energy consumption will increase as a result of these factors. In this period, the oil will continue to be the energy source that is consumed the most (Acaroğlu, 2013:15).

Oil, which had limited political importance in the years before 1970, began to be used as a political weapon from that year. The Arab–Israeli War broke out on 6 October 1973 when Syria and Egypt jointly attacked Israel. During this war, oil was used as a tool of political pressure, and a global oil crisis ensued. The Arab Petroleum Exporting Countries Union (OAPEC) declared an oil embargo in 1973 in response to US support for Israel during the war. OAPEC member countries decided to reduce oil production by 5% each month. As a result of this decision taken, the increase rate in oil prices reached as high as 400% and negatively affected many industrialized countries, especially the USA (Öztürk and Saygın, 2017:2-3). Changes in oil prices from 1970 to the present are shown in Figure 1.

The price of a barrel of crude oil, which was $1.80 in 1970, rose to $11.50 in 1974 as a result of the embargo. Oil prices, which fluctuate significantly during global crises, climbed to a historic peak of $214 during the 2008 financial crisis. As of the third quarter of 2026, driven by the impact of the Iran-US conflict, the price is hovering above $100.

Figure 1. Crude Oil Prices from 1970 to 2026

Source: BP, 2026

Variations in oil prices have varying effects on many macroeconomic factors, ranging from inflation and growth to output and employment. The direction of the effect of the increase in oil prices can vary depending on whether it was foreseen. For example, the oil shock of the early 1970s had a much greater negative impact on the real economy because it was unanticipated. However, the increase in oil prices experienced in 1978 had less impact as it was foreseen (Marion and Svenson, 1984:1-2).

Oil prices affect the real economy through both supply and demand channels. While the supply channel includes crude oil as an indispensable input for production, the resulting increase in costs caused by higher oil prices affects consumption and investment decisions, thereby constituting an effect on demand. In addition, changes in oil prices affect demand by altering the purchasing power of oil-importing and -exporting countries. In other words, while oil prices can

decrease consumer demand in oil-importing countries, they can increase the demand in oil-exporting countries (Karlsson et al., 2018:3).

Sudden increases in oil prices may generate inflationary pressures, reduce economic activity, and subsequently affect unemployment. (Ling and Jones, 2011). On the other hand, such increases in oil prices cause an increase in costs in industries whose production structures rely on oil input, which forces them to reduce the number of employees (Mellquist and Femermo, 2007:22-35). This increase in oil prices also causes price inflation for products that depend on oil for their production, and the resulting high inflation reduces demand for these products. This reduction in the total demand shows its effect on employment directly and causes unemployment rates to increase (Ling and Jones, 2011:11-23). One of the channels through which the increase in oil prices affects employment is the real balance effect. The increase in oil prices causes citizens' demand for money to increase, and the increase in the money supply that will meet the increased money demand leads to an increase in interest rates (Erkan et al., 2011:718). An increase in interest rates reduces investment and slows economic growth; this can lead to a recession and reduce employment rates.

3. Literature Review

Due to the oil crises of the 1970s and the subsequent recessions, the relationship between crude oil prices and macroeconomic variables remains a subject of ongoing research and relevance (Ucan and Bozkaya, 2019). Undoubtedly, a key finding in the empirical literature on oil shocks is that fluctuations in oil prices affect unemployment.

Uri (1996) investigated the relationship between oil prices and unemployment by using the data between 1890-1994 in the USA. In the study, which used ADF and PP analyses and OLS estimation methods, an increase in oil prices led to higher unemployment. Papapetrou (2001) examined the relationship between oil prices and employment for the Greek economy. In the study, based on data from 1989:1 to 1999:6, VAR analysis was used. The findings showed that changes in oil prices affected employment. Samavati and Dilts (2007) investigated the relationship between oil prices and unemployment in the US economy. In the study covering the period from 1986 to 2006, VAR analysis techniques were employed. The findings validated the relationship between oil prices and unemployment.

Mellquist and Femermo (2007) examined the relationship between oil prices and unemployment in the Swedish economy. In the study that used quarterly data from 1980 to 2004, they applied Granger causality analysis. The analysis confirmed a relationship between the variables. However, since coefficient

estimates were positive in some cases and negative in others in Granger causality regressions, it could not be determined whether an increase in the oil price would have a positive or negative effect on unemployment. Yahia and Saleh (2008) examined the relationship between oil prices and employment in Libya in the period between 1970-2005. The study that used VAR and Johansen cointegration analyses identified a long-term relationship between oil prices and employment.

Erkan et al. (2011) investigated the relationship between oil prices and unemployment in the Turkish economy. By using the monthly data between 2005-2009. The study that used the Granger causality test and the VECM model identified a long-term relationship between the variables. Yardımcıoğlu and Beşel (2013) examined the relationship between oil prices and unemployment in Turkey by using the data between 1980-2012. The empirical results of the study, in which the Zivot-Andrews and Kapetanios unit-root tests, the Gregory-Hansen cointegration test, and the Toda-Yamamoto causality analyses were used, confirmed causality from oil prices to unemployment.

Ahmad (2013) investigated the relationship between oil prices and unemployment in Pakistan. In the empirical analyses using quarterly data from 1991 to 2010, the Toda-Yamamoto causality analysis was employed. The research findings revealed that oil prices had a significant effect on unemployment. In their study in which they used VAR analysis, Mucuk and Edirnegil (2017) investigated the relationship between oil prices and unemployment in the Turkish economy in the period between 1980-2014. The empirical findings demonstrated a long-term relationship between the variables, and the authors concluded that an increase in oil prices would increase unemployment.

In their study covering between 1981-2013, Mohim, and Touba (2017) examined the relationship between unemployment and oil prices in Iran. The empirical results of the study, based on the Johansen cointegration test and Toda-Yamamoto Granger causality analyses, showed a negative relationship between oil prices and unemployment. Soytas (2017) investigated the relationship between oil prices and unemployment in Texas, the USA between 1987-2016. The study, which used Granger causality and VAR analyses, determined that changes in oil prices had no effect on the unemployment rate in Texas.

In their study, which they conducted on the Norwegian economy, Karlsson et al. (2018) examined the relationship between oil prices and unemployment. The study, which used Granger causality analysis for the period 1997–2015, concluded that increases in oil prices decreased unemployment rates. Sinan (2018), investigated the relationship between oil prices and unemployment in Turkey for the period between 1980 and 2016. In the study that used the VAR

model, Johansen cointegration test, Granger causality analysis, and error correction model were used, a bidirectional causal relationship between oil prices and unemployment rates was found.

Tütüncü and Kahveci (2020) examined the impact of oil prices on the industrial production index and the unemployment rate for the Turkish economy, using monthly data from January 2006 to December 2018. The findings indicate that oil prices affect both the industrial production index and unemployment. Furthermore, it was determined that the impact of oil prices on the industrial production index was stronger than that on unemployment.

Güdenoğlu (2021), investigates the impact of international oil prices on employment, using Turkey—a developing, oil-importing nation—as a case study. Given the potential asymmetric effects of oil prices on employment, this research focuses on industrial employment, where oil consumption intensity is relatively high and the impact of oil price fluctuations is therefore expected to be more pronounced. An analysis employing the NARDL approach, based on data covering the period from January 2005 to November 2020, reveals that the impact of oil prices on industrial employment in Turkey is asymmetric. The study provides evidence that both increases and decreases in oil prices negatively affect industrial employment.

Gupta et al. (2022), analyzed the predictive role of oil price uncertainty regarding changes in the United Kingdom's unemployment rate over the period 1859–2020. To this end, a machine learning technique known as "random forests" was employed. The findings indicate that oil price uncertainty predicts out-of-sample changes in the unemployment rate, particularly over longer (six- and twelve-month) forecast horizons.

Wang et al. (2022), examine the dynamic relationships between crude oil prices (COP) and unemployment rates (UR) in Russia and Canada using a subsample and rolling-window causality test based on the bootstrap method. Empirical findings indicate dynamic causal links between COP and UR within specific subsample intervals.

Cigdem et al. (2023), analyse data from the 1980–2021 period, focusing on the case of Türkiye, using the Granger Causality Test. The results of the Granger causality analysis reveal a bidirectional causal relationship between oil prices and unemployment.

Alfalih (2024) investigated the impact of oil prices on unemployment in Saudi Arabia during the 1991–2019 period using the ARDL model. It demonstrated that oil prices have a significant negative effect on the unemployment rate in the long run.

Ritahi and Echaoui (2025)examine the impact of Brent crude oil price shocks on the unemployment rate in Morocco using annual data from 1990 to 2022. The study's results indicate that the unemployment rate decreases in response to increases in oil prices.

Table 1. Literature Review

Author/Year	Period	Country	Method	Result
Uri (1996)	1890-1994	USA	ADF, PP analyses, and OLS estimator	The increase in oil prices increases unemployment.
Papapetrou (2001)	1989:1 - 1999:6	Greece	VAR Analysis	Changes in oil prices affect employment.
Samavati and Dilts (2007)	1986 - 2006	USA	VAR Analysis	Oil prices have a significant effect on unemployment.
Yahia and Saleh (2008)	1970-2005	Libya	VAR and Johansen cointegration analyses	There is a long-term relationship between oil prices and employment.
Mellquist and Femermo (2007)	1980-2004	Sweden	Granger causality analysis	The direction of the effect of oil prices on unemployment could not be determined.
Erkan et al. (2011)	2005 (1) - 2009 (12)	Turkey	Granger causality test and VECM model	The long-term relationship between the variables was confirmed.
Yardımoğlu and Beşel (2013)	1980-2012	Turkey	Zivot-Andrews and Kapetanios unit root test, Gregory-Hansen cointegration test, and Toda-Yamamoto causality analysis	There is causality from oil prices towards unemployment.
Ahmad (2013)	1991-2010	Pakistan	Toda-Yamamoto causality test	Oil prices have a significant effect on unemployment.
Mucuk and Edirnegil (2017)	1980-2014	Turkey	VAR Analysis	The increase in oil prices increases unemployment.
Mohim and Touba (2017)	1981-2013	Iran	Johansen cointegration and Toda-Yamamoto Granger causality analysis	The increase in oil prices decreases unemployment rates.
Soytas (2017)	1987-2016	Texas	Granger causality and VAR analysis	No relationship was found between the variables.
Karlsson et al. (2018)	1997-2015	Norway	Granger causality analysis	The increase in oil prices decreases unemployment rates.
Sinan (2018)	1980-2016	Turkey	VAR model, Johansen cointegration test, Granger causality	There is a bidirectional causality relationship between oil prices and unemployment rates.

			analysis, and error correction model	
Tütüncü ve Kahveci (2020)	2006-2018	Turkey	Hacker and Hatemi-J causality and asymmetric causality tests	According to the asymmetric causality test, a causal relationship running from positive and negative shocks in oil prices to unemployment has been identified at the 1% significance level.
Özer (2020)	2005-2019	Turkey	FMOLS method	The analysis found that oil prices affect the unemployment rate in the opposite direction in Turkey.
Güdenoğlu (2021)	2005-2020	Turkey	NARDL test	Findings indicate that the effects of oil prices on industrial employment are asymmetric. Evidence has been found that not only increases but also decreases in oil prices negatively affect industrial employment.
Gupta et. al. (2022)	1859-2020	UK	Random Forest Analysis	The findings indicate that oil price uncertainty predicts out-of-sample changes in the unemployment rate, particularly over longer (six- and twelve-month) forecast horizons.
Wang et.al. (2022)	2000-2020	Rusya and Canada	Subsample and rolling-window causality test	Empirical findings indicate the existence of dynamic causal links between COP and UR within specific subsample intervals.
Cigdem et.al. (2023)		Turkey	Granger causality analysis	The results of the Granger causality analysis reveal a bidirectional causal relationship between oil prices and unemployment.
Alfalih (2024)	1991-2019	Saudi Arabia	ARDL test	It has been observed that oil prices have a significant and negative effect on the unemployment rate in the long run.
Ritahi and Echaoui (2025)	1990-2022	Morocco	VECM Analysis	The unemployment rate decreases in response to increases in oil prices

Source: Created by the authors.

4. Data and Econometric Method

This study examines the causal relationship between real oil prices and unemployment in Turkey, using monthly data. The analysis draws on 252 monthly observations covering the period from January 2005 to December 2025. The primary objective of this study is to determine whether changes in real oil prices contain, in the Granger sense, predictive information regarding the dynamics of the unemployment rate, and whether the relationship holds in the opposite direction. To this end, in addition to oil prices, industrial production and the real effective exchange rate were included in the model. The Stata-12 econometric software package was used for the analyses.

4.1. Data Set and Definition of Variables

The key variables used in the study are the unemployment rate (UNEMP), the real oil price (ROIL), the industrial production index (IPI), and the real effective exchange rate (REER). The unemployment rate is the seasonally adjusted monthly rate, which indicates the extent to which the labor force is underutilized in Turkey. The monthly average price of Brent crude oil was used to represent oil prices. To more accurately assess the impact of oil prices on the Turkish economy, the nominal Brent oil price was not directly included in the model; instead, the oil price was first expressed in Turkish lira, then deflated using the consumer price index to obtain the real price, and finally log-transformed (LROIL). The total industrial production index was used to represent industrial production, and its natural logarithm was taken to obtain the LIPI variable. The primary reason for including industrial production in the model is that changes in production activities can significantly affect labor demand and, consequently, unemployment. The consumer price-based real effective exchange rate was used to represent exchange rate conditions; its natural logarithm was taken to create the LREER variable. The inclusion of the real effective exchange rate in the model ensures that the potential effects of exchange rate movements on foreign trade, production costs, and economic activity are controlled for within the unemployment–oil price relationship. While the unemployment rate was included in the model as a level variable (expressed as a percentage), oil prices, industrial production, and the real effective exchange rate were used in logarithmic form. Data on unemployment, the industrial production index, and the exchange rate were obtained from the Central Bank of the Republic of Turkey's (TCMB) electronic data distribution system, while Brent oil prices were obtained from the Federal Reserve Bank of St. Louis (FRED) data distribution system. Variable definitions and data sources are presented in Table 2.

Table 2. Variable definitions

Variable	Definition	Source	Transformation
UNEMP	Seasonally adjusted unemployment rate	TCMB/EVDS	Level
LROIL	Real Brent oil price	FRED/CBRT	Log
LIPI	Industrial production index	TCMB/EVDS	Log
LREER	CPI-based real effective exchange rate	TCMB/EVDS	Log

4.2. Toda–Yamamoto Causality Test

In this study, the Toda–Yamamoto (1995) causality approach was used to determine the causal relationships among the variables. The Toda–Yamamoto approach allows Granger causality to be tested in an augmented VAR framework without requiring the variables to be cointegrated. To apply the method, the integration orders of the variables are first determined using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests (Dickey and Fuller, 1979; Phillips and Perron, 1988).

In the Toda–Yamamoto approach, the appropriate lag length(k)for the standard VAR model is first determined using information criteria; then, the maximum order of integration (d_{max}) for the variables in the model is identified. Subsequently, an extended VAR model with ($k+d_{max}$) lags is estimated. The causality test assesses the joint significance of the coefficients associated with the first k lags in the extended model, using the Wald test. Within this framework, it is tested whether the past values of one variable make a significant contribution to explaining the current values of another variable (Toda and Yamamoto, 1995).

When assessing the suitability of the VAR model, the model's stability condition and serial correlation in the error terms are also checked. The stability of the VAR model is assessed by verifying that the eigenvalues lie within the unit circle, while the serial correlation properties of the error terms are evaluated using the Lagrange Multiplier (LM) test (Lütkepohl, 2005). The methodology applied in this framework enables the systematic identification of causal relationships among the variables used in the study.

5. Econometric Findings

This section examines the causal relationship between real oil prices and unemployment in Turkey. The analysis was conducted using monthly data covering the period from January 2005 to December 2025. First, the stationarity properties of the variables were determined; then the appropriate lag length for the VAR model was selected; finally, the stability of the model and the

autocorrelation properties of the error terms were examined. Finally, Granger causality relationships among the variables were tested using the Toda–Yamamoto approach.

5.1. Descriptive Statistics

Descriptive statistics for the variables used in the study are presented in Table 3.

Table 3. Descriptive statistics

	UNEMP	LROIL	LIPI	LREER
Mean	10.269	3.254	4.261	4.840
Maximum	14.10	4.174	4.722	5.181
Minimum	7.80	2.415	3.736	4.248
Std. Deviation	1.667	0.331	0.304	0.253
Skewness	2.445	2.942	1.714	1.890
Kurtosis	0.736	0.173	-0.092	-0.546
Observation	252	252	252	252

The average unemployment rate during the sample period was 10.27%, with a standard deviation of 1.67 percentage points. The minimum unemployment rate was 7.80%, and the maximum was 14.10%. The logarithmic value of the real oil price ranged from 2.4150 to 4.1740, while those of industrial production and the real effective exchange rate ranged from 3.736 to 4.722 and from 4.248 to 5.181, respectively.

5.2. Unit Root Tests

The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were applied to assess the stationarity of the variables. The test results are presented in Table 4.

Table 4. ADF and PP Unit Root Test Results

	ADF				PP			
	Level		*First Dif.*		*Level*		*First Dif.*	
	t-ist	*prob*	*t-ist*	*prob*	*t-ist*	*prob*	*t-ist*	*prob*
UNEMP	-1.975	0.2976	-4.281	0.0005*	-1.580	0.4934	-16.334	0.0000*
LROIL	-2.413	0.1381	-4.463	0.0002*	-2.759	0.0644	-11.024	0.0000*
LIPI	-0.750	0.8334	-4.983	0.0000*	-0.799	0.8193	-18.587	0.0000*
LREER	-0.826	0.8114	-4.862	0.0000*	-0.949	0.7714	-11.479	0.0000*

Note: *, **, *** represent 1%, 5% and 10% significance levels, respectively. The optimal lag length in the ADF test was determined using the Schwarz information criterion. In the PP test, the Bartlett kernel spectral prediction method and the Newey–West Bond with options were used.
The tests were conducted with an intercept but without a deterministic trend

When the results of the ADF and PP tests are evaluated together, the unit root hypothesis cannot be rejected for the levels of the variables, whereas the variables become stationary in their first differences. Consequently, it was concluded that all of the UNEMP, LROIL, LIPI, and LREER variables are I(1). Accordingly, the maximum order of integration (dmax= 1) was determined.

5.3. Determining the VAR Lag Length

Before conducting the Toda–Yamamoto causality analysis, the appropriate VAR lag length must be determined. For this purpose, the AIC, HQ, and SC information criteria were used.

Table 5. VAR Lag Order Selection Criteria

Lag	LL	LR	AIC	HQ	SC
0	-304.154	NA	2.5679	2.5913	2.6259
1	1119.43	2847.2	-9.1618	-9.0450	-8.8718
2	1174.01	109.17	-9.4834	-9.2730*	-8.9613*
3	1193.16	38.297	-9.5096	-9.2057	-8.7555
4	1210.7	35.089	-9.5225*	-9.1251	-8.5363
5	1224.74	28.069	-9.5061	-9.0152	-8.2879
6	1230.39	11.316	-9.4199	-8.8356	-7.9696
7	1244.35	27.906	-9.4028	-8.7250	-7.7205
8	1253.44	18.18	-9.3453	-8.5739	-7.4309

LR: Sequential modified LR test statistic, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

The AIC criterion points to the four-lag model, while the HQ and SC criteria point to the two-lag model. Although the HQ and SC criteria suggest two lags, the AIC-selected four-lag specification was preferred to allow for richer short-run dynamics in the monthly data. Consequently, the extended VAR model estimated under the Toda–Yamamoto procedure has $k + d_{max} = 4 + 1 = 5$ lags.

5.4. Stability and Diagnostic Tests of the VAR Model

Before applying the Toda–Yamamoto causality test, the suitability of the five-lag VAR model was examined using various diagnostic tests. First, the stability condition of the VAR model was assessed by examining the moduli of its eigenvalues. The results show that all eigenvalues lie within the unit circle. Therefore, the moduli of all eigenvalues are less than one, and the VAR (5)model satisfies the stability condition.

Table 6. Inverse root values of AR characteristic polynomials

Root	Modulus
.9956209	.995621
.9575022 + .01640934i	.957643
.9575022 - .01640934i	.957643
.8221982 + .03674768i	.823019
.8221982 - .03674768i	.823019
.4808733 + .5148409i	.704486
.4808733 - .5148409i	.704486
.3235648 + .594467i	.67682
.3235648 - .594467i	.67682
-.1443463 + .6533762i	.669131
-.1443463 - .6533762i	.669131
-.2911813 + .5586202i	.629955
-.2911813 - .5586202i	.629955
-.5271496 + .2442074i	.580968
-.5271496 - .2442074i	.580968
-.5099159	.509916
.4920692	.492069
-.1203271 + .4586814i	.474202
-.1203271 - .4586814i	.474202
.1753191	.175319

Second, the LM test was used to test for serial correlation in the model's error terms. The results of the LM test conducted for lags 1–12 showed that all p-values were above the 5% significance level. Accordingly, there is no statistically significant autocorrelation in the residuals of the VAR (5) model for lags 1–12.

Table 7. Autocorrelation LM Test Results

Lag	LM Statistic	Probability
1	7.7531	0.9558
2	21.8403	0.1484
3	12.2485	0.7267
4	18.4551	0.2979
5	15.8649	0.4624
6	17.4456	0.3573
7	21.8376	0.1485
8	10.6581	0.8300
9	11.6665	0.7666
10	21.5096	0.1597
11	12.5259	0.7070
12	14.3690	0.5712

Taken together, these results indicate that the estimated VAR (5) model satisfies the stationarity condition and shows no significant serial correlation in its residuals. Therefore, the model provides a suitable dynamic structure for the application of the Toda–Yamamoto causality test.

5.5. Results of the Toda–Yamamoto Causality Test

The study's key econometric results were obtained using the Toda–Yamamoto causality test. Since unit root tests indicated that all variables were I(1),d_{max}= 1, and the VAR lag length was set to four, k = 4 was chosen, and the VAR(5) model was estimated. The causality hypotheses were evaluated using the Wald test, which examines the joint significance of the coefficients of the first four lags in the extended VAR model. Table 8 presents the results of the causality tests between the variables.

Table 8. Results of the Toda-Yamamoto Causality Test

Direction of Causality	Wald ($\chi 2$) Test Statistic	P Value	Result
LROIL → UNEMP	14.20	0.0067*	**Causality**
UNEMP → LROIL	2.92	0.5707	No Causality
LIPI → UNEMP	23.14	0.0001*	**Causality**
UNEMP → LIPI	5.13	0.2743	No Causality
LREER → UNEMP	6.56	0.1612	No Causality
UNEMP → LREER	3.53	0.4729	No Causality

When the results are initially evaluated for causality between real oil prices and unemployment, they indicate Granger causality from real oil prices to the unemployment rate. The null hypothesis of no Granger causality from real oil prices to unemployment is rejected at the 1% significance level. In contrast, the Wald statistic for the hypothesis of causality from the unemployment rate to real oil prices is 2.92, with a p-value of 0.5707. This result indicates that there is insufficient evidence to suggest that past values of the unemployment rate contribute significantly to explaining the dynamics of real oil prices. Thus, a unidirectional Granger-causal relationship has been established between oil prices and unemployment. The results also show a statistically significant Granger causality from industrial production to the unemployment rate. In contrast, no causal relationship was found from the unemployment rate to industrial production. Therefore, while past values of industrial production contribute to forecasting the dynamics of the unemployment rate, no similar relationship was detected in the opposite direction.

The causality results between the real effective exchange rate and unemployment, however, do not indicate a statistically significant relationship. Consequently, no statistically significant Granger causality was detected in either direction between the real effective exchange rate and unemployment during the sample period.

6. Conclusion

This study examines the causal relationship between real oil prices and unemployment in Turkey, using monthly data from January 2005 to December 2025. The primary objective of the study is to determine whether changes in real oil prices provide predictive information regarding the dynamics of the unemployment rate and, if so, to identify the direction of the causal relationship. In this context, the model included the unemployment rate, real oil prices, industrial production, and the real effective exchange rate.

In the study, the stationarity properties of the variables were first examined using the ADF and Phillips-Perron unit root tests. The results of both tests indicated that all variables used in the model are first-order integrated, i.e., I(1). Given that the maximum order of integration for the variables was one and the appropriate lag length for the VAR model was determined to be four, a five-lag extended VAR model was estimated using the Toda–Yamamoto procedure. Diagnostic checks showed that the VAR (5) model satisfied the stability condition and that there was no significant serial correlation in the error terms up to the 12th lag. The main finding of the study is that real oil prices Granger-cause the unemployment rate. In contrast, the test found no evidence of causality from

the unemployment rate to real oil prices. Thus, the results indicate that past values of real oil prices contain statistically significant information for forecasting unemployment-rate dynamics, whereas past values of the unemployment rate do not provide comparable information for forecasting real oil prices. This finding is consistent with the results of some previous studies conducted in Turkey. Sinan (2018) examined the period 1980–2016 in Turkey and, using the Granger causality test, found a bidirectional causal relationship between oil prices and unemployment. Doğrul and Soytaş (2010) examined the period 2005:01–2009:08 for Turkey and, using the Toda–Yamamoto approach, demonstrated that real oil prices contribute to the forecasting of unemployment. Yardımcıoğlu and Beşel (2013), in their analysis of the 1980–2012 period in Turkey that took structural breaks into account, identified unidirectional Granger causality from oil prices to unemployment. The present study offers a timely contribution to this literature by extending the sample period, using monthly data, and incorporating industrial production and the real effective exchange rate within the same VAR system. The study also identified a strong Granger causality from industrial production to the unemployment rate. In contrast, no significant causality was found from unemployment to industrial production. This result indicates that developments in the labor market are closely linked to economic activity and that changes in industrial production provide important insights for forecasting unemployment dynamics. Thus, empirical evidence supports the view that the relationship between oil prices and unemployment should be assessed not only through energy prices but also through changes in economic activity.

In terms of the real effective exchange rate, no statistically significant Granger causality was found in either direction among the variables. This result indicates that, for the period examined and the model used, past values of the real effective exchange rate do not contribute meaningfully to forecasting the unemployment rate. However, this finding should not be interpreted as meaning that the real effective exchange rate has no economic effect on unemployment. The result indicates only that there is no statistical evidence of Granger causality.

The key policy implication of this study is that developments in energy prices should be monitored with respect to their effects on labor market dynamics. Given Turkey's energy-import-dependent structure, changes in international oil prices can affect production costs and economic activity through various channels. Previous studies in Turkey have also emphasized that oil prices may be linked to production costs and to the labor market. In this context, diversifying energy supply, increasing the use of domestic and renewable energy sources, and strengthening the resilience of energy-intensive sectors to external energy price

shocks can be considered measures to limit the potential impact of energy price volatility on economic activity and employment.

Furthermore, the identified Granger causality between oil prices and unemployment suggests that this relationship could provide predictive information for policymakers monitoring labor market indicators. Monitoring significant movements in international oil prices in conjunction with labor market indicators could improve the tracking of production and employment conditions, particularly in energy-intensive sectors. In conclusion, this study provides empirical evidence of one-way Granger causality from real oil prices to the unemployment rate in Turkey for the period 2005–2025. In contrast, no causality was detected from unemployment to real oil prices. Although a significant Granger-causal relationship was found from industrial production to unemployment, no significant causal relationship was identified between the real effective exchange rate and unemployment. The results indicate that both energy prices and economic activity conditions must be considered together when assessing unemployment dynamics in Turkey.

However, this study has certain limitations. First, while the Toda–Yamamoto approach provides statistical evidence regarding the direction of causality, it does not directly reveal either the magnitude of oil prices' impact on unemployment or the transmission mechanism. Furthermore, the effect of oil prices on the labor market may vary depending on the sector, the source of the oil price shock, and the economic cycle. In future studies, decomposing oil price shocks into supply- and demand-side components, examining asymmetric relationships, and utilizing sectoral employment data could contribute to a more detailed understanding of the mechanisms underlying the relationship between oil prices and unemployment.

References

Acaroğlu, M.(2013).“Alternatif Enerji Kaynakları”. Nobel Yayınları. 3. Baskı. Ankara.

Ahmad, F.(2013).The Effect of Oil Prices on Unemployment: Evidence From Pakistan. *Business and Economics Research Journal*, *4* (1),43.

Alfalih, A. A.(2024).The impact of oil prices, foreign direct investment and trade openness on unemployment rates in an oil-exporting country: The case of Saudi Arabia. Heliyon, 10(3).

BP (British Petroleum) Statistical Review of World Energy. BP Energy Outlook: 2026 Edition.

Çiğdem, G., Aydın, A., İmre, S., & Akdag, N.(2023).The triple helix: Oil prices, trade terms and unemployment: A developmental analysis of Turkiye. Journal of Economics Finance and Accounting, 10(4),203-216.

Dickey, D. A., & Fuller, W. A.(1979).Distribution of the estimators for autoregressive time series with a unit root. Journal of the American Statistical Association, 74(366),427–431.

Doğrul, H. G. and Soytas, U.(2010).Relationship Between Oil Prices, Interest Rate, and Unemployment: Evidence from An Emerging Market. *Energy Economics*, *32*(6),1523-1528.

Erkan, B., Şentürk, M., Akbaş, Y. E. and Bayat, T.(2011).Uluslararası Ham Petrol FiyatlarındakiVolatiliteninİşsizlikGöstergeleriÜzerindekiEtkisi: Türkiye Örneği Üzerine Ampirik Bulgular. *Gaziantep University Journal of Social Sciences*, *10*(2).

Gupta, R., Pierdzioch, C., & Salisu, A. A.(2022).Oil-price uncertainty and the UK unemployment rate: A forecasting experiment with random forests using 150 years of data. Resources Policy, 77, 102662.

Güdenoğlu, E.(2021).Petrol fiyatlarının istihdam üzerindeki asimetrik etkileri: Türkiye örneğinde NARDL yaklaşımı bulguları. Eskişehir Osmangazi Üniversitesi İktisadi ve İdari Bilimler Dergisi, 16(2), 381-400.

Karlsson, K. H., Li, Y. and Shukur, G.(2018).The Causal Nexus between Oil Prices, Interest Rates, and Unemployment in Norway Using Wavelet Methods. *Sustainability*, *10*(8), 2792.

Lings, K.,Jones, L.(2011). Rising oil prices affect economic growth. http://www.libertyfinancials.co.za/lib/content/images/newsbreak/PolicyHolderComm/pdf/201105_global_outlook.pdf.

Lütkepohl, H.(2005).New Introduction to Multiple Time Series Analysis. Springer.

Marion, N. P., Svensson, L. E.(1984).World equilibrium with oil price increases: An intertemporal analysis. *Oxford Economic Papers*, *36*(1),86-102.

Mellquist, H. and Femermo, M. (2007).The Relationship Between the Price of Oil and Unemployment in Sweden.

Mohim, S. T. and Touba, K. A. (2017). The Relationship Between Unemployment Rate, Oil Price And Interest Rate In Iran. *Journal of The Marco And Strategic Policies*, 4(16), 115-134. SID. https://sid.ir/paper/244356/en

Mucuk, M. and Erdirnegil, A.(2017).Uluslararası Petrol FiyatlarınınİşsizlikÜzerineEtkisi: TürkiyeÖrneği. In *ICPESS (International Congress on Politic, Economic and Social Studies),* October, (No. 3).

Özer, M. O. (2020).Petrol fiyatları ile işsizlik oranı arasındaki saklı ilişkinin analizi: Türkiye örneği. Alanya Akademik Bakış, 4(3), 875-887.

Öztürk, S., Saygın, S. (2017).1973 Petrol Krizinin Ekonomiye Etkileri ve Stagflasyon Olgusu. *Balkan Sosyal Bilimler Dergisi*, *6*(12), 1-12.

Papapetrou, E. (2001).Oil Price Shocks, Stock Market, Economic Activity and Employment in Greece. *Energy Economics*, *23*(5), 511-532.

Phillips, P. C. B., & Perron, P.(1988).Testing for a unit root in time series regression. Biometrika, 75(2), 335–346.

Ritahi, O., & Echaoui, A. (2025).Macroeconomic effects of raising oil prices: Insights from Morocco. International Journal of Energy Economics and Policy, 15(2),380-390.

Samavati, H. and Dilts, D. A.(2007).Petroleum Prices and Their Impact on Aggregate Economic Activity: Greasing the Skids. *Proceedings of the Academy of Business Economics*.

Sinan, B.(2018).Türkiye'de İşsizlik Oranları ile Uluslararası Petrol Fiyatları İlişkisi: 1980-2016. *Finans Ekonomi ve Sosyal Araştırmalar Dergisi(FESA)*, *3*(4),681-695.

Sørensen, L. Q.(2009).Oil Price Shocks and Stock Return Predictability. In *EFA 2009 Bergen Meetings Paper*.

Soytas, U.(2017).Do Oil Prices Influence Unemployment Rate in Texas? *Available at SSRN 3306963*.

Toda, H. Y., & Yamamoto, T.(1995).Statistical inference in vector autoregressions with possibly integrated processes. Journal of Econometrics, 66(1–2),225–250.

Tütüncü, A., & Kahveci, Ş.(2020).Türkiye'de Petrol Fiyatlarının Sanayi Üretim Endeksi Ve İşsizlik Oranı Üzerindeki Etkisi. *Hacettepe Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *38*(4),847-867.

Uri, N. D.(1996).Crude Oil Price Volatility and Unemployment in the United States. *Energy*, *21*(1),29-38.

Yılmaz, A.(2015).Sorularla İktisat Hipotez. İkinci Sayfa Yayınları. İstanbul.

Uçan, O., & Bozkaya, Ş.(2019).Petrol Fiyatlarındaki Değişkenlik ve Makroekonomik Etkileri: İskandinav Ülkeleri Örneği. *III. Uluslararası Eğitim Bilimleri ve Sosyal Bilimler Sempozyumu*, 25-27.

Wang, K. H., Liu, L., Li, X., & Oana-Ramona, L.(2022).Do oil price shocks drive unemployment? Evidence from Russia and Canada. Energy, 253, 124107.

Yahia, A.F. and Saleh, S.A.(2008).Economic Sanctions, Oil Price Fluctuations and Employment: New Empirical Evidence from Libya. American Journal of Applied Sciences, 5(12),1713-1719.

Yardımcıoğlu, F, and Beşel, F.(2013).İşsizlik-Petrol Fiyatları İlişkisi Yapısal Kırılmalar Altında Türkiye Örneği(1980-2012).Electronic Turkish Studies,8(8),2197-2211.

Chapter 8

The Validity of The J-Curve Phenomenon in Global Service Trade: An Empirical Appraisal

Kadir KARAGÖZ[1], İlyas Mert OKUMUŞ[2]

1. Introduction

In international economics literature, the dynamic interaction between exchange rate policies and the balance of foreign trade constitutes one of the fundamental building blocks of macroeconomic stability and the sustainability of the external balance. The question of how and over what period devaluation or real value loss in a country's national currency will affect its foreign trade performance is central to both theoretical and empirical debates. Traditional approaches predict that a depreciation of the domestic currency will make imported goods more expensive while making exported goods cheaper in foreign currency terms, thereby increasing net exports. The long-term success of this improvement depends on the fulfilment of the Marshall-Lerner (ML) condition, developed by Marshall (1923) and Lerner (1944), which posits that the sum of the absolute values of the price elasticities of exports and imports must be greater than one. However, when the temporal dimension of this structural transformation is examined, it is seen that the net effect of exchange rate shocks on the trade balance is not linear and instantaneous but rather follows a curved course over time. This phenomenon, conceptualized by Magee (1973) and referred to in the literature as the "J-Curve" hypothesis, suggests that in the short-term following an exchange rate adjustment, the trade balance will initially worsen, but after a certain time lag, it will tend to improve, exhibiting a "J" shape.

Various delay factors of microeconomic and structural nature lie behind the J-curve mechanism causing a deterioration in trade balance in the short term. Fixed-price commercial contracts in foreign currency concluded before the depreciation (contract effect), rigidity in the process of adaptation of producers and consumers to new price signals (price adaptation delay), and structurally low supply-demand elasticities in the short term cause the exchange rate shock to be felt with a value effect rather than a quantity effect. As a result, since the import volume cannot be reduced quickly, the import bill in domestic currency increases, while export

[1] Manisa Celal Bayar University, e-mail: kadir.karagoz@cbu.edu.tr, ORCID: 0000-0002-4436-9235
[2] Independent researcher, e-mail: ilyasmert.okumus@outlook.com.tr, ORCID: 0009-0007-7034-190X

revenues cannot increase at the same pace and the foreign trade deficit widens in the short term. As time progresses, the quantity effect becomes dominant as market actors renew contracts, consumption patterns gain flexibility, and exchange rate pass-through completes its final effect on the price mechanism, and the ML condition operates, resulting in a positive recovery in the trade balance. This hypothesis, traditionally tested in empirical studies of goods trade, has gained a new dimension in modern economics due to the radical increase in the share of international services trade (tourism, transportation, financial and digital services, etc.) in macroeconomic balances as a result of globalization and technological transformation. The unique structural characteristics of the services sector, such as non-storability, intangibility, and high heterogeneity, suggest that their dynamic responses to exchange rate shocks may also differ from those of goods trade.

The empirical literature on the J-curve phenomenon has largely focused on goods trade and has primarily relied on bilateral trade relations. The problem of aggregation bias, pointed out in early studies such as those by Bahmani-Oskooee and Brooks (1999), has increasingly led researchers to disaggregated and country-pair-level analyses. While binary data approaches, pioneered by Rose and Yellen (1989) and aiming to overcome aggregation bias, have been successful in revealing the heterogeneous structure between countries, they have been insufficient in reaching a universal macroeconomic generalization. Furthermore, a significant portion of early panel data studies produced biased and inconsistent estimates by ignoring cross-sectional dependence and the heterogeneity of slope parameters between units, which are inevitable consequences of global economic integration.

On the other hand, methodological advancements in panel data econometrics have significantly increased the reliability of J-curve analyses. It is known that classical estimators lead to serious dimensionality distortions, particularly when cross-sectional dependence is ignored (Pesaran, 2004, 2021). To overcome this problem, second-generation estimators such as CCEMG (Pesaran, 2006), AMG (Eberhardt and Bond, 2009), and CS-ARDL are increasingly preferred in the literature due to their capacity to simultaneously model cross-country heterogeneity and common shocks. However, the methodological tension between the PMG estimator, which assumes homogeneity of long-term coefficients, and the CS-ARDL/MG approach, which allows for complete heterogeneity in both the short and long term, constitutes a critical source of uncertainty in interpreting the results.

However, the services sector remains a relatively neglected area in this literature. In today's world, where global economic activity is evolving towards a

services-heavy structure and digitalization is accelerating cross-border service flows, this gap is becoming an increasingly significant methodological deficiency. While Trofimov (2021) has made limited contributions in this direction specifically regarding Canada, and Trofimov (2023) in the context of agricultural trade, testing the J-curve phenomenon in services trade on a global scale and with a large country sample remains an exceptional research topic.

This study examines the validity of the J-curve hypothesis in international trade in services using data from 134 countries worldwide, aiming to fill a gap in the literature. Thus, the study aims to make a comprehensive contribution to the literature by testing the validity of the J-curve and Marshall-Lerner hypothesis in global trade in services using modern econometric approaches. The bilateral trade balance model, derived from the pioneering work of Rose and Yellen (1989), has been extended to include host country income, external (OECD) income, and exchange rate variables in US dollars. The analysis was conducted using two different estimation strategies within the framework of the ARDL bounds test developed by Pesaran et al. (2001): one pooling long-term coefficients (PMG) and the other allowing for complete heterogeneity (CS-ARDL/MG). This dual approach aims not only to reveal the existence of the J-curve but also the sensitivity of the findings to the estimation method.

2. Relevant Empirical Literature

A review of the panel data literature on the J-curve phenomenon in international trade reveals that the focus is mostly on bilateral trade between a country and a group of partner countries (usually its largest trading partner). The vast majority of early empirical studies used aggregated trade data, a preference that led to the problem of aggregation bias (Bahmani-Oskooee and Brooks, 1999). Subsequent studies shifted towards bilateral trade data, performing more homogeneous analyses at the country pair level. Indeed, Rose and Yellen (1989) emphasized that only bilateral data can reliably test the J-curve.

Nusair (2017), using a nonlinear ARDL analysis covering 16 European countries, empirically supported the existence of the J-curve effect in 12 of these countries. On the other hand, Bahmani-Oskooee and Harvey (2009) were able to confirm the J-curve pattern in Indonesia's relations with 5 of its 13 trading partners. This demonstrates that the results vary significantly at the country and trading partner levels.

Parray et al. (2023) found no evidence of a J-curve in the symmetric model for BRICS countries. This finding can be interpreted as an indication that the exchange rate pass-through of these economies is low, or that the depreciation effect is limited due to structural features in their trade structure. Bahmani-

Oskooee, Bose, and Zhang (2018), on the other hand, examined China's bilateral trade relations with 21 trading partners using the asymmetric cointegration method and found evidence of a J-curve resulting from Yuan depreciation (negative changes), but this pattern was not observed for appreciation (positive changes).

Studies examining developing countries exhibit mixed findings. Mwito et al. (2021) analysed Kenya's bilateral trade with 30 trading partners using the PMG estimator during the period 2006Q1–2018Q4. While J-curve evidence was obtained in only 7 bilateral trade relationships in the symmetric framework, this number increased to 13 in the asymmetric NARDL specification. This finding suggests that linear models systematically reveal the existence of J-curves to a limited extent.

In an analysis focusing on Sub-Saharan African countries, Abille and Meçik (2023) conducted panel data analysis using PMG, MG, and DFE estimators. Their findings highlight that the selected African economies are stuck in the short-term phase of the Marshall-Lerner condition. This situation draws attention to deeper structural problems in these economies – low elasticity, high import dependence, and insufficient export diversification. In another study focusing on African countries, Keho (2021) examined the determining factors of the trade balance in the West African Economic and Monetary Union. The analysis used grouped average versions of Dynamic OLS (DOLS) and Fully Modified OLS (FMOLS) methods, as well as the Mean Group (MG) estimator, to address endogeneity and inter-country heterogeneity. The findings indicate that the trade balance moves inversely with both domestic and foreign income levels, whereas a depreciation in the real effective exchange rate enhances trade equilibrium over the long horizon. Nevertheless, the outcomes fail to substantiate the short-term deterioration forecasted by the J-curve effect. In the short run, the trade balance responds exclusively to real foreign income, remaining unresponsive to domestic income or the real exchange rate. Furthermore, country-specific estimations demonstrate that the reaction of the trade balance to the real exchange rate, domestic income, and foreign income is notably heterogeneous.

A significant branch of the literature has gone beyond goods trade to examine the services sector and agricultural trade. For example, Trofimov (2021) analysed Canada's services trade with 53 trading partners within a panel framework covering the period 1990-2018 and found strong evidence for a pattern of short-term deterioration and long-term improvement – that is, the J-curve hypothesis – at both the aggregate and sub-panel levels. Another study by Trofimov (2024) examined agricultural trade in Southeast Asian economies. Applying a multivariate ARDL model with annual data from 1980-2017, the study found that,

except for Malaysia, short-term and long-term relationships did not confirm the existence of the J-curve effect.

A significant portion of early studies failed to consider cross-sectional dependence, leading to biases in estimations and erroneous conclusions. New generation estimators, CCEMG and AMG, were developed to overcome this problem. Furthermore, studies addressing trade balances using aggregated data may overlook effects in sub-sectors. Ignoring heterogeneity between countries can mask significant bilateral relationships through average effects. Therefore, the use of panel data based on bilateral trade has become the dominant approach in the current literature.

The main limitation of the traditional ARDL model is that it assumes the effect of exchange rate changes on the trade balance is symmetrical. However, in the real world, the effects of positive and negative exchange rate shocks can be asymmetrical in both magnitude and sign. The widespread adoption of the NARDL approach has led to the emergence of J-curve evidence in many country cases where the symmetry assumption was rejected. Methodological advancements in panel data econometrics, particularly those encompassing next-generation estimators such as NARDL, CCEMG, and AMG, have significantly improved the J-curve literature in terms of both scope and reliability.

The following conclusions can be drawn from the entire literature:

1. The existence of the J-curve is not universal, but specific to the country, sector, and trading partner. Findings show significant differences depending on the pair of countries examined and the econometric method used.

2. Linear models can systematically mask the existence of the J-curve. Studies applying the NARDL model have revealed evidence not obtained with symmetric models.

3. Failure to consider cross-sectional dependence leads to significant estimation biases. Robust estimators such as the Pesaran CD test and CCEMG/AMG have become standard methodological tools today.

4. Disaggregation is important. Studies using pairwise and sectoral data produce more consistent and interpretable results than aggregated data analyses.

5. Shocks such as global crises, political turmoil, and pandemics can cause structural breaks in the relationships between variables, making it necessary for the modeling strategy to accommodate these breaks.

3. Method

Panel datasets offer greater degrees of freedom compared to time series analyses, controlling for country-specific heterogeneity that cannot be observed through fixed effects, and enabling cross-sectional analyses. However, with the

deepening of globalization, economic ties between countries have strengthened, making the cross-sectional dependence problem a critical methodological issue in panel data models. Various methods, primarily the CD (Cross-sectional Dependence) test proposed by Pesaran (2004, 2021), are widely used to identify this problem.

The following are next-generation estimators resistant to cross-sectional dependence:

- CCEMG (Common Correlated Effects Mean Group): Enables convergence of unobservable common factors with cross-sectional means (Pesaran, 2006).
- AMG (Augmented Mean Group): Controls dynamic common processes through an auxiliary variable added to the regressor (Eberhardt and Bond, 2009).
- CS-ARDL (Cross-Sectionally Augmented ARDL): Stands out as a dynamic panel estimator that takes into account both heterogeneity and cross-sectional dependence.

Özçelik (2023) performed panel cointegration analysis after accounting for cross-sectional dependence and found that the Marshall–Lerner condition held for many countries, particularly among middle- and high-income developing Asian economies. In the analysis conducted by Yazgan and Öztürk (2019), bilateral trade flows covering 33 countries were analysed, and using the CCEMG estimator, it was determined that in 22 countries, real value depreciation improved the trade balance in the long run, i.e., the ML condition was valid.

The ARDL bounds test approach, developed by Pesaran and Shin (1999) and Pesaran, Shin, and Smith (2001), can detect cointegration relationships between variables regardless of their degree of integration. This feature has led to the widespread adoption of this method in the J-curve literature. Within the framework of panel ARDL, three key estimators stand out:

- PMG (Pooled Mean Group): Based on the assumption of homogeneity in the long term and heterogeneity in the short term; produces effective results for large T and small N panels.
- MG (Mean Group): Allows for heterogeneity in both short-term and long-term coefficients.
- DFE (Dynamic Fixed Effects): Assumes homogeneity in both short-term and long-term; useful for small samples.

The Hausman test stands out as the main criterion used for choosing between PMG and MG (Pesaran et al., 2001).

Among panel cointegration tests, Pedroni (1999, 2004), Kao (1999), and Westerlund (2007) tests are the most commonly used approaches. The Westerlund

test offers four different statistics: Ga and Gt statistics, which evaluate the cointegration relationship separately for individual cross-sections, and Pa and Pt statistics, which evaluate it at the panel level. It is known that these tests suffer power losses if cross-sectional dependence is ignored. Therefore, the use of bootstrap critical values or panel unit root tests sensitive to cross-sectional dependence – such as CIPS (Pesaran, 2007) and CADF – is recommended.

4. Model and Data

Based on the model designed by Rose and Yellen (1989) for the US and the related literature, the following bilateral trade balance model can be written, assuming that the balance of trade in services between a country and its trading partners is a function of the real exchange rate as well as the level of economic activity or income in both countries:

$$TB_{it} = \beta_0 + \beta_1 EXC_{it} + \beta_2 Y_{it}^{H} + \beta_3 Y_{it}^{W} + \varepsilon_{it}$$

Here, *TB* represents the trade balance, calculated as the ratio of the country's service imports to its service exports; *EXC* represents the value of the country's currency against the US dollar; Y^H represents the GDP per capita of the host country; and Y^W denotes the world income level represented by the average GDP per capita of OECD countries. Data for the period 2005-2024 was compiled from the World Bank WDI database. All variables have been logarithmically transformed.

Due to its status as a global reserve currency, the US dollar exchange rate is used as the standard exchange rate for all countries. Even if the US dollar is not the primary means of payment in a country's international trade relations, its currency can be indirectly affected by appreciations in the US dollar due to cross-currency interactions.

Again, the average GDP per capita of OECD countries has been considered as the partner country or external income level. Although the share of non-OECD countries in global trade has increased significantly in the last twenty years, especially due to the influence of China and other emerging economies, current OECD and WTO data, as well as OECD studies on trade linkages, show that OECD countries still hold a dominant position in global trade. Trade between OECD countries accounts for approximately 50–55% of world trade in goods and services, while trade between OECD countries and non-OECD economies accounts for approximately 30–35%. This indicates that OECD economies are

directly involved in approximately 85% of global trade flows (Brézillon et al., 2010).

Since a change in the exchange rate in a particular direction will generally have an inverse effect on imports and exports, the net effect of exchange rate movements on the trade balance will be determined by the intensity of imports and exports. Import and export intensity are closely related to, among other things, the country's income level, production, and consumption structure. Therefore, it can be assumed that as the income level (Y^H), represented by GDP per capita of the host country increases, the demand for imported goods and services will increase, leading to a deterioration in the trade balance (TB) in favour of imports. Conversely, as the income level of the outside world, represented by the average GDP per capita of OECD countries, increases, the demand for exported goods and services will increase, shifting the balance in favour of exports. Accordingly, it is expected that $\beta_2 > 0$ and $\beta_3 < 0$ will be true in the long term.

The above equation indicates a long-run relationship, and coefficient estimates obtained by any method reflect only the long-run effects of exogenous variables. In order to evaluate the short-term effects of external variables, the short-term dynamic adaptation process must be included in the equation. This is Pesaran et al. (2001) following the linear ARDL or bounds testing approach as follows:

$$\Delta TB_{it} = \mu_0 + \sum_{j=1}^{n1} \mu_{1j} \Delta TB_{i,t-j} + \sum_{j=0}^{n2} \mu_{2j} \Delta EXC_{i,t-j} + \sum_{j=0}^{n3} \mu_{3j} \Delta Y_{i,t-j}^{H} + \sum_{j=0}^{n4} \mu_{4j} \Delta Y_{i,t-j}^{W} + \rho_1 TB_{t-1} + \rho_2 EXC_{i,t-1} + \rho_3 Y_{i,t-1}^{H} + \rho_4 Y_{i,t-1}^{W} + u_{it}$$

This equation is an error correction model where the error term in the first equation is replaced with the corresponding expression. In this model, short-term effects are subtracted from the coefficient estimates for the first-differenced variables, while long-term effects are evaluated according to the $\rho_2 - \rho_4$ estimates normalized over ρ_1. However, to validate the long-term effects, it is necessary to prove the existence of a cointegration relationship. Pesaran et al. (2001) suggest applying the well-known F-test to determine the joint significance of lagged level variables as an indicator of cointegration.

5. Findings

Since the panel dataset used in the analysis covers a considerably long period, it is possible that the variables will exhibit non-stationary behaviour depending on their characteristics such as mean and variance during this period. Because of the risk of a regression equation constructed with non-stationary variables yielding unrealistic results, the stationarity of the series should first be examined using panel unit root tests. However, the results of classical unit root tests are sensitive to cross-sectional dependence in the series. Therefore, as a first step, cross-sectional dependence was examined using four different approaches. The findings shown in Table 1 reveal that all four methods indicate the presence of cross-sectional dependence in the variables.

Table 1. Results of cross-sectional dependence tests

	B-P LM	Pesaran LM	B-F-K LM	Pesaran CD
TB	36774.69	208.72	205.19	8.23
EXC	100068.91	682.84	679.31	249.42
Y^H	93853.83	636.28	632.75	270.42
Y^W	178220.00	1268.24	1264.71	422.16

Note: B-P LM refers to the methods developed by Breusch and Pagan (1980); Pesaran LM refers to Pesaran (2004); B-F-K LM refers to Baltagi, Feng and Kao (2012); Pesaran CD refers to Pesaran (2004).

Popular first-generation unit root tests, such as Levin, Lin, and Chu (LLC), Im, Pesaran, and Shin (IPS), and Maddala and Wu (Fisher-ADF), assume that cross-sectional units are independent of each other. If cross-sectional dependence exists and a first-generation test is applied without considering it, size distortion occurs. This severely weakens the statistical power of the test and often leads to Type 1 errors. If cross-sectional dependence is detected in the panel, it is necessary to resort to second-generation unit root tests that structurally incorporate the dependence between units into the model. CADF and CIPS tests (Pesaran, 2007) remove dependence by adding lagged values of cross-sectional means to the standard ADF equation. Another popular method, the PANIC test (Bai and Ng, 2004), tests for unit roots by decomposing the series into common factors and unit-specific components.

Table 2. Pesaran-CIPS and Bai-Ng-PANIC panel unit root test results

	CIPS		PANIC	
	CIPS	Truncated CIPS	Common trend	Cross sectional

TB	– 2.5956[b]	– 2.6651[b]	– 20.3730	± ∞ [a]
EXC	– 37855.938[a]	– 2.4693	– 5.9508	± ∞ [a]
Y^H	– 2.7242[a]	– 2.7376[a]	– 3.5777	5.0464[a]
Y^W	na	0.0000	– 1.9093[b]	– 11.4724[a]

Note: a and b represent significance at the 1% and 5% levels, respectively.

According to the slope homogeneity test results of Pesaran and Yamagata (2008) given in Table 3, it is understood that the coefficients are not homogeneous in terms of units. In this case, it would not be appropriate to estimate the classical model, which ignores heterogeneity, using the pooled least squares method.

Table 3. Pesaran and Yamagata (2008) slope homogeneity test results

	Statistics	**p-value**
Delta	32.158	0.0000
Adjusted Delta	37.133	0.0000

The existence of a cointegration relationship between the variables was investigated using three different panel cointegration tests (Westerlund, Kao, and Pedroni). In all three cointegration tests, the null hypothesis was similarly that the variables are not cointegrated, while the alternative hypothesis was that cointegration exists in all units. However, there is also a version of the Westerlund test that includes another alternative hypothesis suggesting that the cointegration relationship is valid in some units, but not in all units. According to the results given in Table 4, all three tests provide strong evidence that the variables are cointegrated.

Table 4. Cointegration test results

Method	**Statistics**	**p-value**
Westerlund		
Variance ratio-1	– 5.1536	0.0000
Variance ratio-2	– 4.1127	0.0000
Kao		
Modified DF t-statistics	– 3.2569	0.0006
DF t- statistics	– 6.0973	0.0000

ADF t- statistics	– 3.1381	0.0007
Unadjusted Modified DF t-statistics	– 11.0121	0.0000
Unadjusted ADF t-statistics	– 10.1517	0.0000
Pedroni		
Modified PP t-statistics	5.2038	0.0000
PP t-statistics	– 6.6014	0.0000
ADF t-statistics	– 8.0202	0.0000

The PMG method, due to its econometric structure, assumes that long-term coefficients are homogeneous (the same) across countries, but short-term coefficients and error correction rates are heterogeneous (country-specific), and reports average group coefficients for the short term. According to the Panel PMG (Pooled Mean Group) estimation results presented in Table 5, all long-term coefficients are statistically highly significant at the 1% significance level.

The long-term coefficient of the exchange rate (*EXC*) is statistically significant. Since the dependent variable *TB* is defined as Imports/Exports (M/X), the negative coefficient indicates that an increase in the exchange rate (depreciation of the domestic currency) reduces the import/export ratio, i.e., improves the trade balance. This finding provides strong evidence that the Marshall-Lerner condition is met in the long run and that exchange rate policies have a structurally positive effect on the trade balance.

According to long-term coefficient estimate oh Y^H, a 1% increase in local income reduces the import/export ratio by approximately 0.02% (improving the trade balance). This can be theoretically explained either by local growth restricting imports through import substitution, or by economic growth increasing the country's export capacity/productivity, causing exports to grow faster than imports.

The statistically significant and positive long-term coefficient of Y^W implies that an increase in global economic activity elevates the M/X ratio, thereby dampening the services trade balance of the pooled sample. This counterintuitive finding can be explained by the unique demand and income elasticity structures inherent to international trade in services. As global income rises, the home countries' marginal propensity to import high-value, sophisticated, or luxury international services (such as outbound tourism, specialized financial consultancies, and digital infrastructure) potentially expands at a faster rate than the external demand for their domestic service exports. Consequently, the structural reliance on foreign service providers during periods of global economic

growth outpaces export generation, leading to a relative widening of the service trade deficit in the long run.

The error correction coefficient, indicating the model's stabilization speed, was found to be -0.1758 and is statistically significant at the 1% level. The negative and statistically significant coefficient confirms the existence of a long-term cointegration relationship between the variables. Short-term deviations and shocks converge towards long-term equilibrium. The system eliminates approximately 17.58% of short-term imbalances in each period. This indicates that it will take approximately 5.7 periods (1 / 0.1758) for the system to recover from the effects of shocks and return to long-term equilibrium.

In contrast to the strong long-term relationships, none of the coefficients reflecting short-term dynamics (including lagged values) are statistically significant. Past shocks to the trade balance do not have a significant momentum effect on the current period. Similarly, the p-values for the short-term differences in exchange rates, domestic income, and foreign income, and their lags of up to two periods, are quite high. This indicates that temporary fluctuations in these macroeconomic variables in the short term do not have a systematic and significant impact on the trade balance (M/X).

The fact that both the exchange rate (*EXC*) and local income (Y^H) have a significant long-term effect on improving the trade balance (reducing the M/X ratio) points to a strong structural mechanism consistent with economic theory (especially the Marshall-Lerner condition regarding exchange rates). The insignificance of short-term effects, on the other hand, shows that the effects of exchange rate and income policies on the trade balance are spread over time, meaning that structural effects only mature in the long term.

Table 5. Panel PMG estimation results (Dependent variable: *TB*)

Variable	**Coefficient**	**St. error**	**t-statistics**	**p-value**
	Long-term coefficients (pooled)			
EXC	– 0.0039	0.0006	– 6.1978	0.0000
Y^H	– 0.0205	0.0014	– 14.4819	0.0000
Y^W	0.1392	0.0065	21.3083	0.0000
Intercept	0.4595	0.0281	16.3255	0.0000
	Short-term coefficients (mean group)			
ECT	– 0.1758	0.0296	– 5.9389	0.0000
ΔTB_{t-1}	0.0569	0.0437	1.3036	0.1925

ΔTB_{t-2}	0.0124	0.0404	0.3059	0.7596
ΔEXC	0.7090	0.6487	1.0931	0.2745
ΔEXC_{t-1}	– 0.7483	0.7579	– 0.9874	0.3235
ΔEXC_{t-2}	0.9956	1.0240	0.9722	0.3311
ΔY^H	– 0.0114	0.0215	– 0.5305	0.5958
ΔY^H_{t-1}	– 0.0345	0.0256	– 1.3469	0.1782
ΔY^H_{t-2}	0.0112	0.0296	0.3769	0.7062
ΔY^W	– 0.0214	0.0443	– 0.4846	0.6279
ΔY^W_{t-1}	– 0.0234	0.0273	– 0.8589	0.3904
ΔY^W_{t-2}	0.0107	0.0361	0.2973	0.7662

This PMG model reveals long-term relationships much more clearly and statistically significantly compared to the CS-ARDL (Mean Group) model below. The main reason for this is that PMG uses variation in the dataset more effectively by pooling (imposing constraints) long-term coefficients.

Table 6 presents the CS-ARDL model Mean Group (MG) estimates, empirically revealing the short- and long-term relationships between the Trade Balance (*TB*) and explanatory variables within a panel dataset covering 134 countries. The Adjustment Term coefficient, which indicates the dynamic stability of the model and the long-term cointegration relationship between the variables, was estimated as -1.3408. This coefficient is statistically highly significant at the 1% significance level. The negative and statistically significant coefficient indicates the existence of a long-term cointegration relationship between the variables. Deviations in the trade balance following a short-term shock in the system are rapidly balanced. The absolute value of the coefficient being greater than 1 indicates that the adjustment mechanism in the system is very strong and that short-term imbalances converge rapidly to long-term equilibrium in the next period with an over-correcting tendency.

When short-term dynamics are examined, the effects of the lagged value of the dependent variable and external shocks on the trade balance are as follows: In the short term, the previous period's trade balance negatively and statistically significantly affects the current period's trade balance. This indicates that an improvement/deterioration in the trade balance experienced in the past period is subject to a correction in the short term.

Both the current-term and lagged-term coefficients of the exchange rate are statistically insignificant. This finding indicates that, across the 134 countries

studied, short-term exchange rate changes do not have a systematic and significant impact on the trade balance. It can be said that the Marshall-Lerner condition or a significant J-curve effect does not strongly emerge at the mean group level in this particular model.

The current and lagged coefficients of the Y^H variable, which represents the economic growth of the host country, are statistically insignificant. In the short run, it appears that local income growth alone does not significantly change import demand and therefore the trade balance. In the short- and long-run estimations of the CS-ARDL model, the coefficients for the global income variable (YW) are systematically dropped and reported as zero. From a methodological standpoint, this outcome is a direct consequence of the estimator's structural framework rather than an analytical discrepancy. The CS-ARDL approach integrates cross-sectional averages of both dependent and independent variables into the model as proxies to filter out unobserved common factors and control for cross-sectional dependence (Pesaran, 2006). Since the Y^W variable represents the average income level of OECD countries and remains invariant across cross-sectional units (i) at any given time (t), its temporal variation is completely absorbed by the cross-sectional mean augmentation process. Therefore, the perfect multicollinearity between the global income variable and the extracted common factors necessitates its exclusion from the dynamic Mean Group (MG) estimation matrix. The structural impact of global economic expansions is implicitly captured within the cross-sectional dependence corrections embedded in the model.

Long-term coefficients reflect the permanent and structural effects of variables. The long-term coefficient for the exchange rate was calculated as -4.0886 but was found to be statistically insignificant. Since the trade balance is defined as M/X (Imports/Exports), the negative coefficient theoretically suggests that an increase in the exchange rate (depreciation of the domestic currency) would reduce the import/export ratio (improve the trade balance). However, the high p-value indicates that this effect is statistically insignificant and weak across the 134 countries in the long term.

Although the coefficient of host country income is positive in the long run, it is statistically insignificant. This reveals that in the long-run, local economic growth does not create a significant structural deterioration or improvement in the trade balance (M/X). For this reason, the coefficient of the Y^W variable is shown as zero (0) in the long run as well as in the short run.

Table 6. CS-ARDL model Mean Group (MG) estimates

Variable	Coefficient	St. error	t-statistics	p-value
Short run				
ΔTB_{t-1}	– 0.3408	0.0279	– 12.24	0.0000
EXC	– 1.4971	1.8760	– 0.80	0.4250
Y^H	– 0.0374	0.2771	– 0.13	0.8931
Y^W	0	0	–	–
EXC_{t-1}	– 4.0053	3.6918	– 1.08	0.2783
Y^H_{t-1}	0.2281	0.1725	1.32	0.1862
Correction term				
ECT	– 1.3408	0.0279	– 48.13	0.0000
Long run				
EXC	– 4.0886	4.0108	– 1.02	0.3083
Y^H	0.1736	0.2479	0.70	0.4844
Y^W	0	0	–	–

The CS-ARDL model provides more robust estimates by considering cross-sectional dependence among the countries comprising the panel. Overall, the Mean Group (MG) estimation results for countries indicate a very strong and significant error correction mechanism among the variables, meaning that the return to long-term equilibrium occurs rapidly after shocks. However, the direct effects of key macroeconomic variables such as exchange rate (*EXC*) and local income (Y^H) on the trade balance (M/X) were found to be statistically insignificant in both the short and long term. This situation may be due to the fact that, in a large and heterogeneous panel of 134 countries, each country's trade structure (e.g., oil exporters, those with developed manufacturing industries, or developing countries) shows different sensitivities to exchange rates and income, and the Mean Group (MG) method neutralizes these heterogeneous effects in the average.

6. Conclusion

A review of the empirical literature reveals that the J-curve phenomenon is frequently examined at the bilateral trade or country group level using linear ARDL (Autoregressive Distributed Lag) and nonlinear NARDL modelling. This study empirically analyses the global validity of the J-curve hypothesis and the

Marshall-Lerner condition in international services trade using a large-scale panel dataset covering 134 countries. Due to the cross-sectional dependence of the series and the heterogeneous structure of the slope coefficients among the units, both the traditional dynamic panel method of Pooled Mean Group (PMG) estimator and the new generation Cross-Sectionally Augmented ARDL (CS-ARDL) Mean Group (MG) approach, which is robust against cross-sectional dependence, were applied in the analytical process. The empirical findings revealed significant differences, requiring in-depth economic interpretation, depending on the chosen methodological strategy and the pooling/averaging structure of the coefficients.

When the Panel PMG estimation results are examined, it is determined that all long-term coefficients are statistically highly significant. The negative and significant long-term coefficient of the exchange rate, given that the dependent variable is defined as the import/export (M/X) ratio, clearly shows that an increase in the real exchange rate (depreciation of the domestic currency) improves services trade in the long run. This finding constitutes strong evidence that the Marshall-Lerner condition is met in terms of long-term structural dynamics in global services trade. This finding provides strong evidence that exchange rate policies have a structural and lasting effect on the services trade balance. In contrast, the fact that none of the short-term coefficients are significant reveals that the effects of exchange rate and income shocks are spread over time, meaning that the classically expected short-term deterioration-long-term improvement pattern (narrowly defined as the J-curve shape) is not clearly observed in this model.

Similarly, it has been observed that increases in local income levels (Y^H) also positively affect the trade balance in the long run. This can be explained by local economic growth leading to import-substitution capacity expansion in the service sector or increasing export productivity. The positive coefficient of the OECD mean income (Y^W), representing the external income level, can be associated with asymmetric elasticity mechanisms such as global demand expansion increasing commodity and service prices and thus inflating import bills. The fact that the error correction term of the model is negative and significant definitively confirms the long-term cointegration relationship and shows that the system converges back to long-term equilibrium in approximately 5.7 periods after short-term shocks. However, the fact that none of the short-term dynamic coefficients of the PMG model are statistically significant indicates that short-term temporary exchange rate and income fluctuations do not have a systematic effect on global services trade, and therefore the standard short-term J-curve distortion pattern cannot be confirmed in this pooled structure.

On the other hand, the CS-ARDL Mean Group (MG) estimation results, which incorporate cross-sectional dependence between countries through hidden common factors, presented a radically different picture from the PMG model. This difference may stem from the fact that while PMG strongly captures common variation in the dataset by pooling long-term coefficients, CS-ARDL/MG dampens country-specific heterogeneous effects in a way that neutralizes each other during the averaging process. In a large and structurally heterogeneous sample of 134 countries (including different groups such as oil exporters, manufacturing-developed economies, and developing countries), it can be expected that the mean group estimator will statistically "fade out" this diversity, and this confirms the heterogeneity problem pointed out by Abille and Meçik (2023) and Keho (2021).

In the CS-ARDL model, the error correction term was found to be highly significant with a high absolute value, proving that the system tends to overcorrect very strongly and quickly return to long-term equilibrium after shocks. However, in this model, both the short-term and long-term coefficients of the exchange rate and local income variables were found to be statistically insignificant. This can be attributed to two main reasons: Firstly, the PMG method uses data variation more effectively by pooling (constraining) long-term coefficients, thus increasing parameter significance. Secondly, and more importantly, the economies comprising the 134-country panel (developed, developing, tourism or finance-oriented, oil exporters, etc.) have highly heterogeneous service trade structures, exchange rate elasticities, and income elasticities. Since the Mean Group (MG) approach within CS-ARDL releases each country's coefficient and then takes their arithmetic mean, strong opposing effects at the country level neutralize each other in the mean, leading to insignificance in the coefficients. The findings revealed that the results were largely dependent on the estimation method used, thus confirming the methodological sensitivity problem frequently highlighted in the literature (Nusair, 2017; Mwito et al., 2021).

The general conclusion that can be drawn from the analyses is that, according to empirical findings, the effects of exchange rate policies on the net trade balance in global services trade are structural in nature and spread over time; short-term manipulations or fluctuations do not produce immediate solutions. For policymakers, the implication is that the impact of exchange rate tools on the services trade balance can only yield reliable results in the medium to long term and when country-specific structural conditions are taken into account. It should be considered that competitiveness strategies based on the depreciation of the

domestic currency can only be successful in improving the services trade balance in the long term and to the extent that structural flexibilities allow.

When the findings are evaluated as a whole, it is concluded that the J-curve phenomenon is not a universal law, but rather a conditional pattern dependent on the country group, estimation method, and time horizon. This study contributes to the literature by demonstrating this conditionality in the context of services trade with a large global sample. Limitations of the study include the fact that the services sector is not disaggregated by sub-categories (tourism, financial services, transportation, etc.) and that asymmetric effects (value gain-loss distinction) are not modelled. As studies such as Bahmani-Oskooee, Bose, and Zhang (2018) and Hekim (2026) have shown, testing asymmetric effects within the NARDL framework provides a fruitful direction for future research, both sectorally and methodologically. In future studies, in order to more clearly see the effects of heterogeneity in this broad panel, it is suggested that the analyses be deepened by creating sub-panels according to the development levels of the countries, their geographical regions, or sub-items of service trade (tourism, logistics, ICT, etc.), and that nonlinear asymmetric (NARDL) effects be examined under cross-sectional dependence.

References

1. Abille, A. B. and Meçik, O. (2023). The exchange rate, income, trade openness and the trade balance: longitudinal panel analysis for selected SSA countries, *International Trade, Politics and Development*, 7(2), 138-153. https://doi.org/10.1108/ITPD-04-2023-0007
2. Bahmani-Oskooee, M. and Brooks, T. J. (1999). Bilateral J-Curve Between U.S. and Her Trading Partners. *Weltwirtschaftliches Archiv*, 135(1), 156–165. https://www.jstor.org/stable/40440680
3. Bahmani-Oskooee, M. and Harvey, H. (2009). The J-curve: Indonesia versus her major trading partners. *Journal of Economic Integration*, 24(4), 765–784. https://www.jstor.org/stable/23001248
4. Bai, J. and Ng, S. (2004). A panic attack on unit roots and cointegration, *Econometrica*, 72(4), 1127–1177. https://doi.org/10.1111/j.1468-0262.2004.00528.x
5. Baltagi, B. H, Feng, Q. and Kao, C. (2012). A Lagrange Multiplier test for Cross-sectional Dependence in a Fixed Effects Panel Data Model, *Journal of the Econometrics*, 170, 164–177. https://doi.org/10.1016/j.jeconom.2012.04.00
6. Breusch, T. and Pagan, A. (1980). "The Lagrange Multiplier Test and its Application to Model Specification in Econometrics," *Review of Economic Studies*, 47, 239–253. https://doi.org/10.2307/2297111
7. Brézillon, J., Guichard, S. and Turner, D. (2010). Trade Linkages in the OECD Trade System, Organisation for Economic Co-operation and Development (OECD), Economics Department Working Paper No. 811, ECO/WKP(2010)67, Paris, France. https://dx.doi.org/10.1787/5km4t0fj2p6l-en
8. Eberhardt, M. and Bond, S. (2009). Cross-section dependence in nonstationary panel models: A novel estimator. MPRA Paper No. 17692. https://mpra.ub.uni-muenchen.de/17870/
9. Hekim, D. (2026). Symmetric and asymmetric J-curve effects of the real exchange rate on the manufacturing trade balance between Türkiye and Germany, *Economies*, 14(117), 1-23. https://doi.org/10.3390/economies1404011
10. Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, 90(1), 1–44. https://doi.org/10.1016/S0304-4076(98)00023
11. Keho, Y. (2021). Determinants of Trade Balance in West African Economic and Monetary Union (WAEMU): Evidence from heterogeneous panel

analysis, *Cogent Economics & Finance*, 9, 1970870. https://doi.org/10.1080/23322039.2021.1970870
12. Lerner, A.P. (1944). *The Economics of Control.* Macmillan.
13. Magee, S. P. (1973). Currency contracts, pass-through, and the devaluation. *Brookings Papers on Economic Activity*, 1, 303-325. https://doi.org/10.2307/2534091
14. Marshall, A. (1923). *Money, Credit and Commerce.* Macmillan.
15. Mwito, M.A., Mkenda, B. K., and Luvanda, E. (2021). The asymmetric J-curve phenomenon: Kenya versus her trading partners. *Central Bank Review*, 21(1), 25-34. https://doi.org/10.1016/j.cbrev.2020.09.001
16. Nusair, S.A. (2017). The J-curve phenomenon in European transition economies: A nonlinear ARDL approach. *International Review of Applied Economics*, 31(1), 1–27. https://doi.org/10.1080/02692171.2016.1214109
17. Özçelik, O. (2023). Validity of the Marshall–Lerner Condition in Asian Developing Countries: Panel Data Analyses at Different Income Level. *The Academic Elegance*, 10(22), 377-403. (In Turkish) https://dergipark.org.tr/tr/download/article-file/3109435
18. Parray, W.A., Bhat, J.A., Yasmin, E. and Bhat, S.A. (2023). Exchange Rate Changes and the J-curve Effect: Asymmetric Evidence from a Panel of Five Emerging Market Economies. *International Social Science Journal*, 58(4), 524-543. https://doi.org/10.1177/00157325221145432
19. Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, 61(S1), 653–670. https://doi.org/10.1111/1468-0084.0610s165
20. Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, 20(3), 597–625. https://doi.org/10.1017/S0266466604203073
21. Pesaran, M. H. (2004). General Diagnostic Tests for Cross Section Dependence in Panels. Cambridge W. P. in Economics, No. 0435. https://doi.org/10.17863/CAM.5113
22. Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, 74(4), 967–1012. https://doi.org/10.1111/j.1468-0262.2006.00692.x
23. Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, 22(2), 265–312. https://doi.org/10.1002/jae.95
24. Pesaran, M. H. and Shin, Y. (1999). An autoregressive distributed lag modelling approach to cointegration analysis. In S. Strom (Ed.),

Econometrics and Economic Theory in the 20th Century. Cambridge University Press. https://doi.org/10.1017/CCOL521633230.011

25. Pesaran, M. H., Shin, Y. and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3), 289–326. https://doi.org/10.1002/jae.616
26. Pesaran, M. H. (2021) General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, 60, 13–50. https://doi.org/10.1007/s00181-020-01875-7
27. Pesaran, M. H., and T. Yamagata. 2008. Testing slope homogeneity in large panels. *Journal of Econometrics*, 142, 50–93. https://doi.org/10.1016/j.jeconom.2007.05.01
28. Rose, A.K. and Yellen, J.L. (1989). Is there a J-curve? *Journal of Monetary Economics*, 24(1), 53–68. https://doi.org/10.1016/0304-3932(89)90016-0
29. Trofimov, I. D. (2021). Is There a J-Curve Effect in the Services Trade in Canada? A Panel Data Analysis. MPRA Paper No. 106704. https://mpra.ub.uni-muenchen.de/106704/
30. Trofimov, I. D. (2023). The J-Curve Effect in Services Trade: A Disaggregated Analysis, *Foreign Trade Review*, 58(2), 199-219. https://doi.org/10.1177/0015732522112659
31. Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*, 69(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.
32. Yazgan, M. E. and Öztürk, S. S. (2019). Real Exchange Rates and the Balance of Trade: Does the J-curve Effect Really Hold? *Open Economies Review*, 30, 343–373. https://doi.org/10.1007/s11079-018-9510-3

Chapter 9

Artificial Intelligence and Digital Transformation Strategies In Turkish Banks: A Content Analysis Of Integrated Annual Reports

Nuray ISLATINCE[1]

1. INTRODUCTION

The banking industry has undergone a profound transformation over the last decade as a result of rapid technological advancements, increasing digitalization, and the growing adoption of artificial intelligence (AI). Traditional banking models, which were largely based on physical branch networks and face-to-face interactions, have gradually evolved into digitally integrated ecosystems characterized by data-driven decision-making, automated processes, and personalized customer experiences. This transformation has accelerated further with the emergence of advanced analytics, cloud computing, open banking, financial technologies (FinTech), and artificial intelligence applications.

Artificial intelligence has become one of the most influential technologies shaping the future of financial services. AI-enabled systems support a wide range of banking activities, including fraud detection, credit risk assessment, customer segmentation, portfolio management, cybersecurity monitoring, and process automation. Recent developments in machine learning and generative artificial intelligence have further expanded the potential applications of AI in banking by enabling advanced customer interactions, automated content generation, intelligent decision support systems, and personalized financial services (Dwivedi et al., 2023; Feuerriegel, Hartmann, Janiesch, & Zschech, 2024).

Alongside artificial intelligence, digital transformation has emerged as a strategic priority for financial institutions worldwide. Digital transformation extends beyond the adoption of new technologies and encompasses organizational change, business model innovation, process redesign, and customer-centric service development (Verhoef et al., 2021). Consequently, banks increasingly view digital transformation not merely as a technological necessity but as a key source of competitive advantage in an increasingly dynamic and technology-driven environment.

[1] Prof. Dr., Anadolu University, Faculty of Economics and Administrative Sciences, Department of Business Administration, nislatince@anadolu.edu.tr, ORCID: 0000-0002-1552-3504

These developments have contributed to the emergence of the Banking 5.0 paradigm, which extends digital transformation by combining advanced information technologies and automation with artificial intelligence, human-machine collaboration, and sustainability. In this perspective, Banking 5.0 is associated with the redesign of banking business models, processes, platforms, people, and partnerships around digitally enabled and customer-oriented value creation (Nicoletti, 2021).

The Turkish banking sector has also experienced significant digital transformation in recent years. Both public and private banks have invested heavily in artificial intelligence, digital banking platforms, mobile applications, cybersecurity infrastructure, and data analytics capabilities. These investments have been driven by changing customer expectations, increasing competition, regulatory developments, and the growing importance of digital service delivery. As a result, digital transformation has become a central component of strategic planning and corporate communication within Turkish banks.

One of the most important sources for understanding how banks communicate their strategic priorities is the integrated annual report. Integrated reports provide comprehensive information regarding organizational strategy, governance, risk management, sustainability initiatives, innovation activities, and future development plans. In recent years, references to artificial intelligence, digital transformation, data analytics, and generative AI have become increasingly visible in these reports, reflecting the growing strategic importance of technological innovation in the banking sector.

The present study focuses on the 2025 integrated annual reports of six selected banks operating in Türkiye: Türkiye İş Bankası, Akbank, Garanti BBVA, Yapı Kredi, Ziraat Bankası, and Halkbank. The selection of the 2025 reporting period is particularly important because these reports represent the most recent and comprehensive disclosures available at the time of the study. Moreover, this reporting period reflects a stage during which generative artificial intelligence technologies gained substantial attention and became increasingly integrated into corporate digital transformation strategies. Therefore, the reports provide a timely opportunity to examine how banks communicate their technological priorities and strategic responses to emerging digital trends.

Although the literature on artificial intelligence, digital banking, and financial technology has expanded considerably, most previous studies have focused on technology adoption, customer behavior, operational efficiency, financial performance, or technology acceptance models. Comparatively fewer studies have examined how banks communicate artificial intelligence and digital transformation initiatives through official corporate disclosures. Furthermore,

comparative analyses focusing on both public and private banks in the Turkish banking sector remain limited.

To address this gap, this study aims to examine how artificial intelligence and digital transformation strategies are reflected in the integrated annual reports of selected Turkish banks. Using a qualitative content analysis approach, the study investigates the extent to which AI-related themes, digital banking initiatives, data analytics capabilities, cybersecurity measures, customer experience strategies, operational efficiency efforts, and generative AI applications are emphasized within corporate disclosures.

The study contributes to the literature in three ways. First, it provides a systematic analysis of AI and digital transformation strategies based on publicly available integrated annual reports. Second, it offers a comparative assessment of public and private banks operating in Türkiye. Third, it contributes to the emerging literature on Banking 5.0 and generative artificial intelligence by examining how these concepts are incorporated into contemporary banking strategies and corporate reporting practices.

The remainder of the chapter is organized as follows. The next section reviews the literature on artificial intelligence, digital banking, generative AI, and Banking 5.0. The methodology section explains the data sources, research design, and content analysis procedure. The findings section presents the results of the thematic analysis and comparative assessment of the selected banks. The discussion section evaluates the findings in relation to existing literature, and the final section concludes the study by highlighting theoretical contributions, managerial implications, limitations, and directions for future research.

2. LITERATURE REVIEW

2.1. Artificial Intelligence in Banking

Artificial intelligence has emerged as one of the most transformative technologies in the banking and financial services industry. The increasing availability of large-scale data, advances in computing power, and developments in machine learning algorithms have enabled financial institutions to automate decision-making processes and improve operational efficiency. AI applications are currently used in various banking functions, including fraud detection, credit scoring, risk assessment, customer relationship management, anti-money laundering monitoring, and investment advisory services.

Previous studies suggest that AI enhances the quality and speed of decision-making by enabling financial institutions to process large volumes of structured and unstructured data (Davenport & Mittal, 2023). Machine learning algorithms have been shown to improve predictive accuracy in credit evaluation and risk

management, while AI-powered systems support real-time transaction monitoring and fraud prevention. Furthermore, AI contributes to cost reduction through process automation and the elimination of repetitive manual tasks.

Huang and Rust (2021) argue that artificial intelligence should not be viewed solely as a substitute for human labor but rather as a complementary technology that enhances human capabilities and creates new service models. In banking, this perspective is particularly relevant because AI-supported systems increasingly assist employees in customer service, advisory functions, and decision-support activities.

The growing adoption of AI technologies has also intensified discussions regarding transparency, explainability, algorithmic bias, data privacy, and ethical governance. Consequently, financial institutions are expected not only to adopt AI technologies but also to develop appropriate governance frameworks that ensure responsible and trustworthy AI implementation.

2.2. Digital Banking and Digital Transformation

Digital transformation has fundamentally reshaped the structure of the banking industry. Traditional branch-centered banking models have gradually evolved into digitally integrated ecosystems characterized by mobile banking, internet banking, open banking platforms, cloud-based services, and data-driven business processes.

According to Verhoef et al. (2021), digital transformation represents a comprehensive organizational process involving technological innovation, strategic change, business model adaptation, and cultural transformation. Therefore, successful digital transformation requires more than technological investment; it also demands organizational flexibility, leadership commitment, and customer-centric strategic orientation.

Digital banking has become one of the most visible outcomes of this transformation. Through digital banking platforms, customers can access financial services anytime and anywhere, resulting in increased convenience, efficiency, and service accessibility. In addition, digital channels enable banks to collect and analyze customer data, thereby supporting personalized service delivery and improved customer engagement.

The emergence of FinTech companies and open banking initiatives has further accelerated digital transformation in the financial services sector. Open banking encourages data sharing through application programming interfaces (APIs), fostering innovation, competition, and collaborative financial ecosystems (Vives, 2019). While these developments create significant opportunities, they also

increase the importance of cybersecurity, data protection, and regulatory compliance.

Consequently, digital transformation is increasingly regarded as a strategic capability that influences competitiveness, innovation capacity, and long-term organizational performance within the banking sector.

2.3. Generative Artificial Intelligence in Banking

Recent advances in generative artificial intelligence have created new opportunities for the banking industry. Unlike conventional AI systems that primarily focus on prediction and classification tasks, generative AI models are capable of creating new content, generating text, producing insights, and supporting complex human-machine interactions.

Large Language Models (LLMs) and generative AI applications have attracted substantial attention following the widespread adoption of systems such as ChatGPT and other advanced conversational AI platforms. These technologies have the potential to transform customer service, knowledge management, financial advisory services, document generation, and internal decision-support processes.

Dwivedi et al. (2023) emphasize that generative AI may significantly influence organizational knowledge management and communication processes across various industries. In the banking sector, generative AI can support customer interactions, automate routine communications, generate reports, and facilitate personalized financial recommendations.

Similarly, Feuerriegel et al. (2024) highlight the broader opportunities and challenges associated with generative AI, including productivity potential as well as concerns regarding reliability, governance, and responsible implementation.

As financial institutions increasingly experiment with generative AI applications, understanding how these technologies are incorporated into strategic planning and corporate communication has become an important area of academic inquiry.

Despite the growing interest in generative AI applications, empirical evidence regarding their actual implementation in banking remains limited. Existing studies primarily focus on conceptual opportunities and potential benefits, whereas relatively few studies provide organization-level evidence on how banks incorporate generative AI into their strategic communication and corporate reporting practices. This gap is particularly evident in emerging banking markets, including Türkiye.

2.4. Banking 5.0

The concept of Banking 5.0 has emerged as an extension of broader discussions surrounding Industry 5.0 and Society 5.0. Unlike earlier stages of technological development that primarily emphasized automation and efficiency, Banking 5.0 seeks to integrate advanced technologies with human-centered value creation.

Banking 5.0 builds on the transition from Industry 4.0 to Industry 5.0 by combining information technology and automation with artificial intelligence, human-machine collaboration, and sustainability. Its emphasis extends beyond operational efficiency toward the redesign of banking business models and customer-oriented value creation (Nicoletti, 2021).

Nicoletti (2021) conceptualizes Banking 5.0 as a transformation of banking in which advanced technologies are embedded across processes, platforms, people, and partnerships, thereby reshaping how financial institutions organize and deliver value.

The Banking 5.0 perspective is particularly relevant for understanding contemporary digital transformation strategies because it emphasizes the strategic integration of technology with organizational purpose, stakeholder engagement, and sustainable development objectives.

The concepts of artificial intelligence, digital transformation, generative AI, and Banking 5.0 collectively provide the theoretical foundation for analyzing how financial institutions communicate technological innovation and strategic change within their corporate disclosures.

2.5. General Evaluation of the Literature

The literature on artificial intelligence, digital transformation, generative AI, and Banking 5.0 has expanded considerably over the past decade. Existing studies largely focus on technology adoption, customer behavior, operational efficiency, financial performance, innovation management, and technology acceptance frameworks. Collectively, these studies provide valuable insights into the transformative impact of digital technologies on financial institutions.

Despite these advances, relatively few studies have examined how banks strategically communicate their technological initiatives through corporate reporting mechanisms. Integrated annual reports represent an important source of information regarding organizational priorities, innovation strategies, governance practices, and future development plans. However, the role of these reports in communicating artificial intelligence and digital transformation strategies has received limited scholarly attention.

Furthermore, comparative studies focusing on both public and private banks within the Turkish banking sector remain scarce. Existing research tends to concentrate on technology adoption, customer satisfaction, digital service quality, or financial outcomes rather than examining how technological transformation is reflected in corporate disclosures.

This gap is particularly relevant given the growing strategic importance of artificial intelligence, generative AI, and digital transformation initiatives within contemporary banking. Understanding how banks communicate these developments can provide valuable insights into organizational priorities, innovation strategies, and competitive positioning.

Accordingly, the present study seeks to contribute to the literature by conducting a comparative content analysis of integrated annual reports published by selected Turkish banks. By examining how artificial intelligence, digital banking, data analytics, cybersecurity, customer experience, operational efficiency, and generative AI are represented in corporate disclosures, the study addresses an underexplored dimension of banking transformation research.

To provide a structured overview of the existing body of knowledge, the key studies reviewed in this section are summarized in Table 1. The table presents the scope, methodology, and principal findings of selected studies and highlights the research gap that the present study seeks to address.

Table 1. Summary of Key Studies on Artificial Intelligence and Digital Transformation in Banking

Author(s)	Year	Country/Scope	Topic	Methodology	Main Findings
Huang and Rust	2021	Global / Conceptual	Artificial Intelligence	Conceptual Study	Human–AI collaboration enhances service delivery and decision-making processes.
Verhoef et al.	2021	Multiple Countries	Digital Transformation	Literature Review	Digital transformation requires the integration of technology, organizational change, and strategic adaptation.

Author(s)	Year	Country/Scope	Topic	Methodology	Main Findings
Dwivedi et al.	2023	Global	Generative AI	Multidisciplinary Perspective	Generative AI presents significant opportunities as well as ethical, regulatory, and operational challenges.
Feuerriegel et al.	2024	Global	Generative AI	Conceptual Study	Generative AI offers substantial opportunities across business and information systems contexts while also presenting important limitations and implementation challenges.
Vives	2019	Global	Digital Banking	Literature Review	Open banking increases competition, innovation, and customer-oriented financial services.

Source: Compiled by the author based on the reviewed literature.

3. METHODOLOGY

3.1. Research Design

This study employs a qualitative research design based on content analysis. Content analysis is a widely used research method for systematically examining textual documents and identifying recurring themes, concepts, and patterns within qualitative data (Bowen, 2009; Krippendorff, 2019; Mayring, 2014; Neuendorf, 2017; Schreier, 2012). The method is particularly suitable for analyzing corporate reports because it enables researchers to investigate how organizations communicate strategic priorities, technological initiatives, and future-oriented objectives through formal disclosures.

The primary objective of this study is to examine how the selected Turkish banks communicate artificial intelligence and digital transformation strategies in

their integrated annual reports. By identifying and comparing key themes related to AI, digital banking, data analytics, customer experience, cybersecurity, operational efficiency, and generative AI, the study seeks to provide a comparative assessment of how contemporary technological transformation is represented in corporate disclosures within the Turkish banking sector.

The thematic intensity index was developed to provide a comparative assessment of the relative emphasis placed on artificial intelligence and digital transformation themes across the selected banks. The index was derived by evaluating the frequency of theme-related references, the strategic prominence assigned to each theme within the reports, and the contextual importance of these themes in discussions of organizational priorities, innovation initiatives, and future development plans.

The thematic intensity index was developed based on three criteria: (i) the frequency of theme-related references appearing throughout the report, (ii) the strategic prominence assigned to the theme within sections such as the CEO's message, strategic priorities, innovation initiatives, and future outlook statements, and (iii) the breadth of applications associated with the theme across different banking functions. Based on the combined assessment of these criteria, thematic intensity scores were assigned on a five-point scale ranging from 1 (very low emphasis) to 5 (very high emphasis). The scoring procedure was intended to provide a structured qualitative comparison rather than a precise quantitative measurement.

Although the index does not represent a quantitative measurement, it provides a structured qualitative assessment that facilitates systematic comparison among the banks included in the study.

Table 2. Thematic Intensity Scale Used in the Content Analysis

Score	Interpretation
1	Very Low Emphasis
2	Low Emphasis
3	Moderate Emphasis
4	High Emphasis
5	Very High Emphasis

Source: Developed by the author.

3.2. Data Sources and Sample Selection

The data used in this study consist of the 2025 integrated annual reports of six selected banks operating in Türkiye:

- Türkiye İş Bankası
- Akbank
- Garanti BBVA
- Yapı Kredi
- Ziraat Bankası
- Halkbank

The reports were obtained from the official websites of the respective banks and, where applicable, from the Public Disclosure Platform (Kamuyu Aydınlatma Platformu [KAP]). The primary documentary sources comprised the 2025 integrated annual reports of Türkiye İş Bankası, Akbank, Garanti BBVA, Yapı Kredi, Ziraat Bankası, and Halkbank (Akbank T.A.Ş., 2025; T.C. Ziraat Bankası A.Ş., 2025; Türkiye Garanti Bankası A.Ş., 2025; Türkiye Halk Bankası A.Ş., 2025; Türkiye İş Bankası A.Ş., 2025; Yapı ve Kredi Bankası A.Ş., 2025).

The selection of the 2025 reporting period is justified for several reasons. First, these integrated annual reports represent the most current and comprehensive publicly available corporate disclosures at the time of the study. Second, they provide detailed information regarding digital transformation initiatives, technology investments, sustainability strategies, innovation projects, and future organizational priorities. Third, this reporting period reflects a stage during which generative artificial intelligence became increasingly visible within corporate strategies and public disclosures, thereby providing a timely opportunity to investigate the integration of AI-related initiatives into banking practices. The sample includes both public and private banks, enabling a comparative assessment of different institutional approaches to technological transformation.

3.3. Content Analysis Procedure

The study follows a systematic content analysis procedure. Initially, all integrated annual reports were reviewed in their entirety to identify sections related to technology, innovation, digital transformation, customer experience, risk management, and artificial intelligence applications. Particular attention was given to management discussions, strategic priorities, innovation initiatives, sustainability sections, and future outlook statements.

Following the initial review, relevant statements, paragraphs, and disclosures were extracted and categorized according to a predefined coding framework. The coding process focused on identifying recurring concepts, strategic narratives,

technological initiatives, and innovation-related disclosures appearing across the reports.

The analysis combined both deductive and inductive approaches. Deductive coding was guided by the existing literature on artificial intelligence, digital banking, generative AI, and Banking 5.0. Inductive coding was applied to identify additional themes and concepts emerging directly from the reports. This combined approach allowed the study to maintain theoretical consistency while remaining sensitive to emerging patterns within the data. This combination is consistent with qualitative content and thematic analysis approaches that integrate theoretically informed categories with patterns emerging from the data (Vaismoradi, Turunen, & Bondas, 2013).

3.4. Development of Themes and Coding Framework

The coding framework was developed through a comprehensive review of the literature on artificial intelligence, digital transformation, financial technology, and Banking 5.0. In addition, recurring expressions and strategic concepts identified within the integrated annual reports were considered during the development of the coding structure.

Based on this process, seven main thematic intensity categories were established:

1. Artificial Intelligence
2. Digital Banking
3. Data Analytics
4. Customer Experience
5. Operational Efficiency
6. Generative AI
7. Sustainability

Each theme included a set of related codes representing specific technological applications, strategic initiatives, and organizational capabilities. During coding, conceptually similar expressions were grouped under the same thematic category to ensure consistency throughout the analysis. Cybersecurity-related expressions (including information security, data protection, fraud prevention, risk monitoring, and anti-money laundering systems) were retained as cross-cutting contextual codes because they intersect with AI, data analytics, digital banking, and operational efficiency; they were therefore not scored as a separate thematic-intensity category.

Following the completion of the coding process, the thematic structure was reviewed and refined to improve conceptual consistency and analytical clarity. The final coding framework consists of seven main thematic intensity categories

and their associated codes, which provide the basis for the comparative analysis conducted in this study. The themes and representative codes used throughout the content analysis are presented in Table 3.

3.5. Reliability and Validity

Reliability and validity in qualitative research depend on the systematic implementation of data collection and analysis procedures (Krippendorff, 2019; Mayring, 2014). In this study, the coding framework was developed through the integration of theoretical concepts derived from the literature and recurring expressions identified within the integrated annual reports.

Particular attention was paid to the consistent classification of conceptually related statements under the appropriate themes. Furthermore, the coding framework was reviewed following the completion of the analysis to ensure coherence between theoretical constructs and empirical observations.

To enhance coding consistency, the reports were reviewed multiple times throughout the coding process. Following the initial coding stage, the thematic classifications were revisited and compared with the coding framework to ensure consistency in the assignment of statements to thematic categories. This iterative review process helped minimize subjective interpretation and improve analytical reliability.

The use of publicly available corporate reports obtained from official institutional sources enhances methodological transparency and facilitates future replication using the same data sources and coding framework.

Although the coding process was conducted by a single researcher, several measures were adopted to enhance reliability. The coding framework was developed prior to the analysis and applied consistently across all reports. In addition, the reports were reviewed repeatedly during the coding process, and thematic classifications were cross-checked against the coding framework to ensure internal consistency. Such iterative procedures are commonly recommended in qualitative content analysis to strengthen analytical reliability (Krippendorff, 2019; Mayring, 2014).

Table 3. Thematic Framework and Coding Structure Used in the Content Analysis

Theme	Representative Codes
Artificial Intelligence	Artificial Intelligence, Machine Learning, Deep Learning, AI Applications, Intelligent Systems, Predictive Analytics
Generative AI	Generative AI, Large Language Models (LLMs), AI Assistants, Intelligent Content Generation, Conversational AI
Data Analytics	Big Data, Data Analytics, Data-Driven Decision Making, Business Intelligence, Data Management, Advanced Analytics
Digital Banking	Digital Banking, Mobile Banking, Internet Banking, Open Banking, Digital Channels, Digital Customer Acquisition
Customer Experience	Customer Experience, Personalization, Customer Satisfaction, Chatbots, Virtual Assistants, Customer Engagement
Operational Efficiency	Process Automation, Robotic Process Automation (RPA), Cost Reduction, Operational Excellence, Efficiency Improvement
Sustainability	Sustainability, ESG, Green Finance, Sustainable Finance, Sustainable Banking, Environmental Responsibility, Social Responsibility, Responsible Banking

Source: Developed by the author based on the literature review and the content analysis of the 2025 integrated annual reports of the selected banks.

4. FINDINGS

This section presents the findings obtained from the content analysis of the integrated annual reports of Türkiye İş Bankası, Akbank, Garanti BBVA, Yapı Kredi, Ziraat Bankası, and Halkbank. The findings are discussed under three main categories: thematic intensity analysis, thematic findings, and comparative assessment of banks.

4.1. Thematic Intensity Analysis

The analysis reveals that digital transformation and technology-oriented themes occupy a central position in the strategic narratives of all examined banks. However, the intensity and emphasis of these themes vary considerably across institutions. Private banks generally demonstrate stronger emphasis on artificial intelligence, generative AI, data analytics, customer experience, and innovation-oriented initiatives. In contrast, state-owned banks place greater emphasis on financial inclusion, development-oriented banking, entrepreneurship support, and sustainable economic growth. Table 4 presents the thematic intensity index of

artificial intelligence and digital transformation themes identified in the integrated annual reports of the selected banks.

Table 4. Thematic Intensity Index of AI and Digital Transformation Themes (1–5 Scale)

Theme	İş Bankas ı	Akbank	Garanti BBVA	Yapı Kredi	Ziraat Bankası	Halkbank
Artificial Intelligence	4	5	5	4	2	1
Generative AI	3	5	5	4	1	1
Data Analytics	4	5	5	5	2	2
Digital Banking	5	5	5	5	5	4
Customer Experience	4	5	5	5	2	2
Operational Efficiency	4	5	4	4	3	4
Sustainability	4	5	4	5	5	4

Scale: 1 = Very Low, 2 = Low, 3 = Moderate, 4 = High, 5 = Very High.
Source: Developed by the author based on the content analysis of the 2025 integrated annual reports of the selected banks.

The thematic intensity scores were assigned through a qualitative assessment of frequency, strategic prominence, and contextual significance of theme-related disclosures within each report. Accordingly, the scores should be interpreted as comparative qualitative indicators rather than objective quantitative measurements.

As shown in Table 4, the thematic intensity scores reveal distinct digital transformation priorities among the selected banks.

Among private banks, Akbank and Garanti BBVA demonstrate the highest thematic intensity across almost all dimensions, particularly in artificial intelligence, generative AI, data analytics, customer experience, and digital banking. Yapı Kredi also exhibits a strong commitment to digital transformation, achieving high scores in data analytics, customer experience, digital banking, and sustainability. Türkiye İş Bankası presents a balanced digital transformation profile, with consistently high scores across all examined themes and a

particularly strong emphasis on digital banking, artificial intelligence, and operational efficiency.

In contrast, state-owned banks display a different disclosure orientation. The reports of Ziraat Bankası and Halkbank place relatively lower emphasis on artificial intelligence, generative AI, and data analytics compared with private banks. However, both institutions also place strong emphasis on sustainability, financial inclusion, and development-oriented banking activities. Notably, Ziraat Bankası receives one of the highest thematic-intensity scores in sustainability, sharing the maximum score with Akbank and Yapı Kredi.

Across all institutions, digital banking emerges as the most prominent theme in corporate disclosures, indicating that digital transformation is widely presented as a strategic priority regardless of ownership structure. The results also suggest that generative AI disclosure is more prominent among private banks, highlighting differences in reported strategic emphasis and innovation narratives within the sampled institutions.

4.2. Thematic Findings

The thematic analysis reveals both common patterns and significant differences in the digital transformation strategies communicated by the selected banks.

Artificial intelligence-related disclosures are particularly prominent in Akbank and Garanti BBVA. These banks provide detailed information regarding advanced analytics, machine learning applications, intelligent customer services, and generative AI initiatives. Akbank's references to advanced AI solutions and large language model applications indicate a comparatively strong disclosure emphasis on AI integration within banking operations. Similarly, Garanti BBVA emphasizes hyper-personalization strategies supported by artificial intelligence and advanced data analytics.

Türkiye İş Bankası differentiates itself through its strong emphasis on technology entrepreneurship, innovation ecosystems, and strategic investments in technological development. Rather than focusing exclusively on operational AI applications, the bank highlights broader innovation capabilities and ecosystem development.

Yapı Kredi’s digital transformation strategy is characterized by ecosystem banking and sustainable transformation initiatives. The bank presents digitalization as an integrated component of long-term organizational transformation rather than solely a technological modernization effort.

The state-owned banks exhibit a different strategic orientation. Ziraat Bankası primarily emphasizes financial accessibility, agricultural development, and

inclusive banking services, whereas Halkbank focuses on entrepreneurship support, SME financing, and economic development initiatives. In both cases, digital technologies are presented as instruments supporting broader socio-economic objectives rather than purely competitive technological assets.

To further illustrate these strategic differences, the dominant themes identified for each bank are summarized in Table 5.

The labels presented in Table 5 represent interpretive summaries of the broader strategic narratives that emerged inductively from the reports; they do not constitute additional scored thematic-intensity categories.

Table 5. Dominant Themes in the Digital Transformation Strategies of Turkish Banks

Bank	Primary Theme	Secondary Theme
Türkiye İş Bankası	Innovation and Technology Ecosystem	Artificial Intelligence
Akbank	Artificial Intelligence and Agentic AI	Data Analytics
Garanti BBVA	Generative AI and Hyper-Personalization	Customer Experience
Yapı Kredi	Ecosystem Banking	Sustainable Transformation
Ziraat Bankası	Financial Inclusion	Development Banking
Halkbank	Entrepreneurship and SME Banking	Digital Transformation

Source: Developed by the author based on thematic content analysis of the 2025 integrated annual reports.

The findings demonstrate that although the reports refer to similar technological tools, they position these technologies differently according to their institutional priorities and strategic objectives.

4.3. Comparative Assessment of Banks

The comparative analysis suggests that digital transformation is widely presented as a strategic priority across the sampled banks. Nevertheless, the emphasis and framing of technological transformation differ significantly between private and state-owned institutions.

The reports of private banks place greater emphasis on artificial intelligence, advanced analytics, and customer experience management as elements associated with competitive advantage, operational efficiency, and customer engagement.

These disclosure patterns show stronger alignment with the technological and customer-oriented dimensions of Banking 5.0, particularly through references to intelligent technologies, personalization strategies, and data-driven decision-making.

By contrast, state-owned banks tend to frame digital transformation within broader developmental objectives. Their strategic narratives emphasize financial inclusion, support for SMEs, regional development, entrepreneurship, and sustainable economic growth. Consequently, their corporate disclosures position technological innovation as a means of supporting social and developmental goals rather than exclusively enhancing market competitiveness.

Table 6 summarizes the principal differences in the digital transformation emphases communicated by private and state-owned banks.

Table 6. Comparison of Digital Transformation Disclosure Emphases Between Private and State-Owned Banks

Dimension	Private Banks	State-Owned Banks
Artificial Intelligence Disclosure Emphasis	High–Very High	Very Low–Low
Generative AI Disclosure Emphasis	Moderate–Very High	Very Low
Data Analytics Disclosure Emphasis	High–Very High	Low
Customer Experience Emphasis	High–Very High	Low
Operational Efficiency Emphasis	High–Very High	Moderate–High
Financial Inclusion Emphasis	Secondary Emphasis	Core Emphasis
SME and Development Emphasis	Moderate	Very High
Sustainability Emphasis	ESG and Green Finance	Development and Social Impact

Source: Developed by the author based on the findings of the content analysis.

The comparison highlights that digital transformation is not communicated as a homogeneous process across the sampled banks. Instead, the reports emphasize distinct strategic priorities that reflect ownership structures and institutional missions.

5. DISCUSSION

This study examined the integrated annual reports of six selected Turkish banks to explore how artificial intelligence (AI) and digital transformation strategies are reflected in corporate disclosures. The findings indicate that digital transformation is widely presented as a strategic priority across the sampled banks. However, the emphasis and framing of these transformation efforts differ considerably among institutions, reflecting variations in ownership structures, institutional missions, and competitive priorities.

One of the most significant findings of this study is the stronger emphasis placed on artificial intelligence and data analytics by privately owned banks. The integrated reports of Akbank and Garanti BBVA demonstrate extensive references to generative AI, advanced analytics, and customer-centric digital solutions. These findings are consistent with previous studies suggesting that AI technologies can transform customer interactions, decision-making processes, and operational efficiency in financial institutions. Davenport and Ronanki (2018) argue that AI applications are primarily concentrated in process automation, customer engagement, and decision-support systems. The evidence obtained in this study suggests that similar transformation themes are increasingly reflected in the strategic reporting of the sampled Turkish banks.

A second important finding concerns the increasing visibility of generative AI technologies in banking strategies. In particular, Akbank and Garanti BBVA provide detailed discussions regarding generative AI applications, large language models (LLMs), and AI-powered digital assistants. This indicates that generative AI is becoming a more prominent strategic theme in corporate reporting. The findings are consistent with the framework proposed by Huang and Rust (2021), which describes the progression of AI adoption from customer service functions toward more sophisticated decision-making processes. The results suggest that the sampled banks are increasingly communicating their responses to this technological transition.

The findings further reveal that digital transformation is not a homogeneous process across banks. Türkiye İş Bankası emphasizes technological entrepreneurship and innovation ecosystems, while Yapı Kredi focuses on ecosystem banking and sustainable transformation initiatives. Garanti BBVA, in contrast, highlights hyper-personalization strategies supported by advanced

analytics and AI technologies. These differences indicate that digital transformation extends beyond technological implementation and encompasses broader organizational and strategic priorities. This observation supports the arguments of Verhoef et al. (2021), who emphasize that digital transformation requires organizational restructuring and strategic adaptation in addition to technological innovation.

Another notable finding is the distinction between privately owned and state-owned banks. While the reports of private banks place greater emphasis on AI-driven customer experience, personalization, and operational efficiency, state-owned banks more often frame digital transformation in relation to financial inclusion, regional development, agricultural finance, and entrepreneurship. In particular, the annual reports of Ziraat Bankası and Halkbank place greater emphasis on financial accessibility, SME financing, and sustainable development than on advanced AI applications. These findings suggest that the strategic communication of technological transformation is shaped by institutional mandates and ownership structures.

It should also be noted that integrated annual reports are strategic communication documents designed to present a favorable organizational image to stakeholders. Therefore, references to artificial intelligence, digital transformation, and generative AI may not always reflect the actual level of technological implementation within banks. Corporate disclosures may occasionally emphasize innovation-related narratives to signal technological leadership and future readiness. Consequently, the findings should be interpreted as indicators of strategic communication and organizational priorities rather than direct measures of technological performance.

The results may also be interpreted within the framework of Banking 5.0. The Banking 5.0 paradigm advocates a human-centered, personalized, and AI-supported banking model that integrates advanced technologies with customer needs and societal objectives. The disclosures of Akbank, Garanti BBVA, and Yapı Kredi show stronger alignment with the technological and customer-oriented dimensions of Banking 5.0 through their emphasis on AI, data analytics, and customer experience innovations. Conversely, state-owned banks appear to emphasize the social inclusion and sustainable development dimensions of Banking 5.0 more strongly than its technological aspects.

This study contributes to the literature in three important ways. First, it provides one of the most recent comparative analyses of AI and digital transformation strategies in the Turkish banking sector using integrated annual reports as primary data sources. Second, it demonstrates that AI-related disclosures are embedded in different strategic narratives across banks,

highlighting the multidimensional nature of digital transformation communication. Third, by systematically comparing private and state-owned banks, the study offers empirical evidence on divergent digital transformation narratives within the same national banking system, an area that remains relatively underexplored in the existing literature.

Overall, the findings suggest that artificial intelligence and digital transformation are presented as important components of corporate strategy across the sampled banks. Nevertheless, the variation in reported strategic priorities indicates that future digital transformation narratives are likely to remain institution-specific and shaped by differing organizational objectives, competitive environments, and stakeholder expectations.

6. CONCLUSION

This study examined the artificial intelligence and digital transformation strategies disclosed in the 2025 integrated annual reports of six selected Turkish banks, namely Türkiye İş Bankası, Akbank, Garanti BBVA, Yapı Kredi, Ziraat Bankası, and Halkbank. Using qualitative content analysis, the study explored how banks communicate their technological priorities, innovation initiatives, and digital transformation strategies through corporate reporting.

The findings demonstrate that digital transformation is widely presented as a strategic priority across the sampled banks. However, the nature and objectives of digital transformation differ significantly among banks. Private banks place greater emphasis on artificial intelligence, generative AI, advanced analytics, and customer experience management, whereas state-owned banks focus more strongly on financial inclusion, entrepreneurship, development-oriented banking, and social impact objectives.

Another important finding is the increasing strategic visibility of generative AI technologies. Large language models, AI-powered assistants, and advanced analytics solutions are becoming increasingly prominent in the strategic disclosures of privately owned institutions. These disclosures indicate that AI is increasingly framed not merely as an operational support tool but as a strategic capability associated with competitive advantage and organizational transformation.

6.1. Theoretical Contributions

This study contributes to the literature in several ways. First, it provides a contemporary comparative analysis of artificial intelligence and digital transformation strategies in the Turkish banking sector based on integrated annual reports. While previous studies have primarily focused on customer adoption,

financial performance, or technology acceptance, relatively few have examined how banks communicate their digital transformation strategies through corporate reporting.

Second, the study extends the emerging literature on generative AI in financial services by demonstrating how banks increasingly incorporate generative AI technologies into their strategic narratives. The findings provide empirical evidence regarding the growing importance of generative AI as a component of digital transformation strategies.

Third, the comparative analysis between private and state-owned banks highlights the multidimensional nature of digital transformation. The results indicate that banks communicate technological transformation in different strategic terms depending on organizational priorities, ownership structures, and institutional objectives. This contributes to a more nuanced understanding of Banking 5.0 and AI-related corporate reporting within the banking industry.

6.2. Managerial Implications

The findings offer several practical implications for banking managers and policymakers. First, banks should approach artificial intelligence investments as strategic organizational capabilities rather than purely technological initiatives. AI applications should be integrated with customer experience management, risk management, sustainability objectives, and innovation strategies to maximize their long-term value.

Second, the increasing strategic attention given to generative AI presents opportunities to improve customer services, financial advisory functions, operational efficiency, and decision-support systems. Banks that successfully integrate these technologies into their business processes may strengthen their competitive positions and enhance customer engagement.

Third, regulatory authorities should continue developing governance frameworks addressing AI ethics, algorithmic transparency, cybersecurity, and data protection. The growing use of AI in banking requires clear regulatory guidance to ensure responsible and trustworthy implementation of emerging technologies.

6.3. Limitations and Future Research

This study is subject to several limitations. First, the analysis is limited to the integrated annual reports of six selected Turkish banks. Consequently, the findings may not fully represent the entire Turkish banking sector or other financial institutions. Second, the study relies exclusively on document analysis and corporate disclosures. Therefore, it reflects the strategic narratives presented

by banks rather than directly measuring the operational effectiveness or performance outcomes of AI and digital transformation initiatives.

Furthermore, the study focuses solely on the 2025 reporting period. As a result, it does not capture the longitudinal evolution of digital transformation strategies over time. Future studies could incorporate multiple reporting periods to examine changes in AI-related disclosure and digital transformation narratives.

Future research may also expand the sample to include participation banks, foreign-owned banks, and emerging digital-only financial institutions. In addition, quantitative studies investigating the relationships between AI investments, financial performance, customer satisfaction, operational efficiency, and risk management outcomes would provide valuable insights into the economic and managerial consequences of technological transformation in banking.

REFERENCES

Akbank T.A.Ş. (2025). *2025 integrated annual report*. Retrieved June 12, 2026, from https://www.akbankinvestorrelations.com/en/publications/year-list/Annual-reports/54/0/0

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal, 9*(2), 27–40. doi:10.3316/QRJ0902027

Davenport, T. H., & Mittal, N. (2023). *All-in on AI: How smart companies win big with artificial intelligence*. Boston, MA: Harvard Business Review Press.

Davenport, T. H., & Ronanki, R. (2018). Artificial intelligence for the real world. *Harvard Business Review, 96*(1), 108–116.

Dwivedi, Y. K., Kshetri, N., Hughes, L., Slade, E. L., Jeyaraj, A., Kar, A. K., ... Wright, R. (2023). "So what if ChatGPT wrote it?" Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy. *International Journal of Information Management, 71*, 102642. doi:10.1016/j.ijinfomgt.2023.102642

Feuerriegel, S., Hartmann, J., Janiesch, C., & Zschech, P. (2024). Generative AI. *Business & Information Systems Engineering, 66*(1), 111–126. doi:10.1007/s12599-023-00834-7

Huang, M.-H., & Rust, R. T. (2021). A strategic framework for artificial intelligence in marketing. *Journal of the Academy of Marketing Science, 49*(1), 30–50. doi:10.1007/s11747-020-00749-9

Krippendorff, K. (2019). *Content analysis: An introduction to its methodology* (4th ed.). Thousand Oaks, CA: Sage Publications.

Mayring, P. (2014). *Qualitative content analysis: Theoretical foundation, basic procedures and software solution*. Klagenfurt, Austria. Retrieved from https://nbn-resolving.org/urn:nbn:de:0168-ssoar-395173

Neuendorf, K. A. (2017). *The content analysis guidebook* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Nicoletti, B. (2021). *Banking 5.0: How fintech will change traditional banks in the 'new normal' post pandemic*. Cham, Switzerland: Palgrave Macmillan. doi:10.1007/978-3-030-75871-4

Schreier, M. (2012). *Qualitative content analysis in practice*. London, England: Sage Publications.

Türkiye Garanti Bankası A.Ş. (2025). *2025 integrated annual report*. Retrieved June 12, 2026, from https://www.garantibbvainvestorrelations.com/en/financial-information/annual-reports/Annual-Reports/69/0/0

Türkiye Halk Bankası A.Ş. (2025). *2025 integrated annual report*. Retrieved June 12, 2026, from https://www.halkbank.com.tr/en/investor-relations/corporate-governance/sustainability

Türkiye İş Bankası A.Ş. (2025). *2025 integrated annual report*. Retrieved June 12, 2026, from https://www.kap.org.tr/tr/Bildirim/1569176

T.C. Ziraat Bankası A.Ş. (2025). *2025 integrated annual report*. Retrieved June 12, 2026, from https://www.ziraatbank.com.tr/en/investor-relations/financials/annual-reports

Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & Health Sciences, 15*(3), 398–405. doi:10.1111/nhs.12048

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Dong, J. Q., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research, 122*, 889–901. doi:10.1016/j.jbusres.2019.09.022

Vives, X. (2019). Digital disruption in banking. *Annual Review of Financial Economics, 11*, 243–272. doi:10.1146/annurev-financial-100719-120854

Yapı ve Kredi Bankası A.Ş. (2025). *2025 integrated annual report*. Retrieved June 12, 2026, from https://www.yapikrediinvestorrelations.com/en/financial-information/financial-information-year-document-list/Annual-Reports/50/0/0