



The Impact of Artificial Intelligence on Workforce Displacement and Transformation in the Logistics Sector: The Case of Türkiye

Mustafa Ergün¹

Abstract

The rapid integration of artificial intelligence (AI) technologies into the logistics sector is triggering a radical transformation process in the sector, particularly by replacing human labor through automation in operational tasks that require routine and medium skills. This study empirically examines the dual dynamics of workforce displacement and transformation in the Turkish logistics sector, focusing on the period 2015–2025. The main hypothesis of the study is that the use of AI deepens the productivity-employment paradox, encourages skill-based wage increases, and contributes to persistent labor market inequalities. Longitudinal labor market data disaggregated by gender and occupational groups were used in the analysis process, and four key employment indicators were evaluated through descriptive statistics and trend analyses: informal employment, unemployment rates, wage increases, and output per worker (productivity). The findings reveal a structural decrease in informal employment rates (e.g., a decrease from \$27.6 in 2019 to \$19.2 in 2023); However, it shows that productivity gains remain limited during periods of AI-intensive applications, and structural unemployment persists. Wage increases are observed to be concentrated in technical and AI-complementary roles, which are predominantly male-dominated. The most striking finding is that AI-enabled digital innovations have not translated into inclusive employment growth, as high unemployment rates persist and gender wage gaps widen. These results support the "productivity-employment paradox" and the skills-based technological change (SBTC) thesis. The study points to the urgency of reskilling strategies for low- and medium-skilled workers and emphasizes the need for equity-based policy initiatives to prevent the digital transformation process from reproducing socioeconomic inequalities.

Keywords: Artificial Intelligence (AI), Logistics Sector Employment, Workforce Displacement, Skill-Biased Technological Change (SBTC), Job Transformation, Wage Inequality

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Lojistik Sektöründe İşgücü Yer Değişimi ve Dönüşümüne Yapay Zeka'nın Etkisi: Türkiye Örneği

Mustafa Ergün¹

Öz

Yapay zekâ (YZ) teknolojilerinin lojistik sektörüne hızla entegre edilmesi, özellikle rutin, orta beceri gerektiren operasyonel görevlerde otomasyona dayalı insan emeğinin yer değiştirmesine yol açan radikal bir dönüşüme yol açmaktadır. Bu çalışma, Türkiye'nin lojistik sektöründe 2015-2025 döneminde işgücü yer değiştirmesi ve dönüşümünün ikili dinamiklerini ampirik olarak incelemektedir. Özellikle, YZ kullanımının verimlilik-istihdam paradoksuna, beceriye dayalı ücret artışlarına ve kalıcı işgücü piyasası eşitsizliklerine katkıda bulunduğu hipotezi test edilmiştir. Analiz, cinsiyet ve mesleğe göre ayrıştırılmış uzunlamasına işgücü piyasası verilerini kullanarak, tanımlayıcı istatistikler ve trend analizi yoluyla dört temel istihdam göstergesini değerlendirmektedir: gayriresmî istihdam, işsizlik oranları, ücret artışları ve çalışan başına çıktı (üretkenlik). Bulgular, kayıt dışı istihdam oranında yapısal bir düşüş olduğunu (örneğin, 2019'da 27,6 dolardan 2023'te 19,2 dolara) ortaya koymaktadır; ancak yapay zekâ yoğun uygulamaların gözlemlendiği yıllarda sınırlı üretkenlik kazanımlarının yanı sıra kalıcı yapısal işsizliği de göstermektedir. Ücret artışları, erkeklerin egemen olduğu teknik ve yapay zekâyı tamamlayıcı rollerde yoğunlaşmaktadır. En önemlisi, yüksek işsizliğin devam etmesi ve cinsiyetler arası ücret farkının giderek artması, yapay zekâ destekli dijital yeniliklerin kapsayıcı istihdam büyümesine dönüşmediğini doğrulamaktadır. Bu sonuçlar "üretkenlik-istihdam paradoksu"nu desteklemekte ve beceri odaklı teknolojik değişim (SBTC) tezini desteklemektedir. Çalışma, düşük ve orta düzey beceriye sahip çalışanlar için yeniden beceri kazandırma stratejilerinin aciliyetini ve dijital dönüşümün sosyoekonomik eşitsizlikleri yeniden üretmemesini sağlamak için eşitlik temelli politika girişimlerine olan ihtiyacı vurgulamaktadır.

Anahtar Kelimeler: Yapay Zeka (YZ), Lojistik Sektörü İstihdamı, İşgücü Kaybı, Beceri Önyargılı Teknolojik Değişim (BÖTD), İş Dönüşümü, Ücret Eşitsizliği

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1. Introduction

1.1. Background and Context

The logistics sector, a critical component of global supply chains, is undergoing a radical transformation driven by the integration of Artificial Intelligence (AI) technologies. Capabilities such as machine learning, robotics, predictive analytics, and autonomous systems are streamlining operations, enabling real-time decision-making, intelligent routing, and adaptive warehousing (Krishnan et al., 2024, pp. 27-32). This digitalization, accelerated significantly by the demand for supply chain resilience and cost efficiency, has created substantial operational gains. Technological innovations such as AI-powered robotic picking arms and computer vision systems have collectively enhanced precision, throughput, and responsiveness in warehousing and distribution (Heilig & Voß, 2017, p. 230; Ivanov et al., 2019, p. 830). Predictive analytics tools now forecast demand spikes with considerable accuracy, enabling just-in-time inventory management (Choi et al., 2018, p. 1873). In Türkiye, the reliance on road transport was solidified after the 1950s, but the subsequent industrialization provided a new imperative. The establishment of the motor vehicle industry in the 1970s added new dimensions to road policy, creating demand for high-standard, multi-lane expressways and motorways, especially near major production hubs and cities (KGM, 2025). This created the fundamental highway-centric logistics network that AI is now digitizing.

These operational improvements, however, carry profound implications for the workforce, creating a dual dynamic of displacement and transformation. AI excels at automating repetitive and semi-skilled tasks in warehousing, transportation, and administrative functions. Job categories like forklift operators, sorting staff, and routine administrative roles are increasingly susceptible to substitution, reinforcing concerns over labor displacement, especially among mid-skill occupations (Frey & Osborne, 2017, pp. 263-268; Acemoglu & Restrepo, 2020, pp. 15-17). This dynamic is visible globally, with studies estimating that logistics is among the most impacted sectors (McKinsey Global Institute, 2024).

1.2. Workforce Transformation and Polarization

Conversely, AI is also a catalyst for job creation and transformation. It generates demand for new, higher-skilled, digitally literate roles, such as AI systems operators, data analysts, robotics maintenance engineers, and digital logistics coordinators (Mullens & Shen, 2025, p. 6). This shifts the labor requirement from routine physical labor to tasks involving human-AI collaboration, supervision, and system optimization. Consequently, AI implementation is associated with the polarization of wages: roles complementary to AI command wage premiums, leading to widening income inequalities (Mäkelä & Stephany, 2024, p. 17; Demiral & Demiral, 2023, pp. 42784-42786).

A critical issue is the resulting skill gap. The new roles require technical competencies often absent in the existing logistics workforce, particularly in emerging economies. The failure to provide widespread and effective reskilling and upskilling initiatives exacerbates this polarization (Li, 2024, p. 1704). Furthermore, the social implications of AI integration extend to the ethical dimensions of increased surveillance, algorithmic bias, and the erosion of worker autonomy in hyper-automated environments (Zuboff, 2023, pp. 206-210; Mittelstadt, 2019, pp. 501-507).

1.3. The Research Problem in Türkiye's Logistics Sector

While AI-driven transformation is a global phenomenon, its impact is amplified and made more complex in emerging economies like Türkiye. The central research problem is the disconnect between technological efficiency gains and inclusive labor market outcomes. Türkiye's logistics sector is structurally defined by a high rate of informal employment and persistent gender disparities. Informal workers are particularly vulnerable to AI-driven displacement due to limited access to social protections and formal reskilling pathways (ILO, 2023). Furthermore, the benefits of AI (e.g., higher wages in technical roles) appear concentrated in male-dominated occupations, threatening to widen the existing gender pay gap. Thus, the question is: Have the significant AI-driven productivity gains in Türkiye's logistics sector since 2015 translated into equitable and inclusive labor outcomes, or have they instead reinforced pre-existing socioeconomic inequalities, manifesting the "productivity–employment paradox"?

1.4. Research Gap and Purpose of the Study

Despite the extensive global discourse on automation, there is a critical gap in sector-specific, empirically grounded analyses that capture the nuanced, longitudinal effects of AI on labor markets in emerging economies. Existing scholarship often aggregates data across broad industrial categories or focuses disproportionately on manufacturing, thereby obscuring the unique operational and workforce structures of logistics. Crucially, current models rarely integrate disaggregated, longitudinal labor data to concurrently assess the intersection of AI adoption with informal labor, gender-differentiated outcomes, and the productivity-employment paradox over time. This lack of detailed, sector-specific evidence limits the ability of policymakers to design targeted and effective transition strategies for vulnerable workforces.

1.5. Contribution and Structure of the Article

This study makes three primary contributions to the literature on AI and employment. First, it offers sector-specific, gender-sensitive, and longitudinal evidence of AI's labor market impact, an area frequently generalized or overlooked. Second, by integrating four key, internationally harmonized labor indicators (unemployment, informality, wages, and productivity), it provides a robust empirical framework to test the Skill-Biased Technological Change (SBTC) thesis and the productivity-employment paradox within an emerging economy context. Finally, the findings yield actionable policy recommendations for comprehensive formalization and reskilling programs necessary for a socially sustainable digital transition in Türkiye.

The empirical link between these research questions and the method is established by analyzing the following data linkages: Unemployment and informality trends track displacement risk in routine labor; the growth rate of output per worker serves as the proxy for AI adoption/productivity gains; and the divergence in gendered average hourly earnings across technical roles directly tests the degree of skill-biased technological change and wage polarization.

The remainder of the article proceeds as follows: Section 2 reviews previous studies; Section 3 details the methodology and data; Section 4 presents the empirical findings; and Section 5 discusses the implications and concludes the study.

2. Previous Studies

This section critically reviews peer-reviewed literature that examines the intersection of AI, job displacement, job reconfiguration and socio-economic implications within the logistics sector.

2.1. AI Adoption in Logistics

Recent research demonstrates a substantive shift toward AI integration across supply chain and logistics operations. Choi et al., (2018) conducted a quantitative analysis of big data analytics applications in logistics, demonstrating significant improvements in dynamic routing and inventory management systems. Heilig and Voß (2017) used a case study of smart port implementations to reveal how AI-powered coordination between autonomous trucks, cranes, and warehouse systems led to measurable gains in throughput and resource optimization. Together, these studies provide strong evidence for the operational impacts of AI in logistics.

2.2. Job Displacement Due to Automation

Empirical research indicates that logistics roles involving repetitive tasks—such as warehousing and transport—are at increased risk of AI-driven displacement. Frey and Osborne (2017, pp. 255-258) and Arntz et al. (2016, pp. 157-158) estimated that nearly 47% of jobs in the United States could be at risk of automation, with logistics roles especially vulnerable due to their high routine task content. Complementary econometric analyses across OECD countries show a correlation between AI-exposed occupations and employment growth, especially in the 2015–2020 period. U.S.-based longitudinal data from 2019 to 2022 highlights a surge in AI-linked automation, especially in warehouse and distribution centers, aligning with rising unemployment rates in those roles (Broadly et al., 2025, pp. 3-4)

2.3. Workforce Transformation and Reskilling

A growing body of research explores how logistics workers transition into emerging roles such as automation system technicians and logistics data analysts. Mäkelä and Stephany (2024) analyzed over 12 million job postings (2018–2023) demonstrating increasing demand for AI-enhanced competencies—including digital literacy, adaptability, and technical oversight—particularly in logistics-adjacent occupations. Morandini et al. (2022) and Mäkelä and Stephany, (2024, p. 18) argue that ongoing reskilling and upskilling programs improve workforce readiness, yet also emphasize the challenge of equitable access across precarious and informal labor segments.

2.4. Sociological and Economic Perspectives

Beyond direct labor metrics, sociological studies have begun to investigate broader implications of AI adoption in logistics contexts. Nelson et al. (2023) performed a systematic literature review on industrial AI, identifying critical tensions between efficiency gains and potential deskilling or workforce displacement at company and societal scales. Antón et al. (2022) studied European regional robotics adoption and its influence on non-monetary job quality, revealing that while productivity rose, job strain and work intensity also increased. Otherwise, emerging debates interrogate the ethics of deploying AI in labor markets, particularly concerning surveillance, algorithmic bias, and worker autonomy (Hickok & Maslej, 2023, p. 679; Santoni de Sio, 2024, pp. 411-415)

2.5 Research Gap and Purpose of the Study

While the transformative potential of AI across industries has been well-documented, there remains a marked deficiency in sector-specific, empirically grounded analyses that capture the nuanced effects of AI on labor markets—particularly within the logistics sector. Much of the existing literature generalizes across economic domains or disproportionately focuses on manufacturing, leaving logistics underrepresented despite its critical role in global supply chains and its increasing reliance on automation technologies (Brynjolfsson & McAfee, 2014, pp. 26-44; Frey & Osborne, 2017, pp. 257-261).

Specifically, current scholarship often overlooks how AI adoption in logistics impacts the composition of employment, particularly in regard to routine task displacement, emerging digital roles, and gender-differentiated workforce outcomes. Additionally, while several macroeconomic studies estimate the potential for job loss or productivity gains due to AI, few integrate disaggregated, longitudinal labor data that reflect evolving trends over time—especially during the post-pandemic acceleration of digitalization (2020–2025). This is a critical oversight, as the COVID-19 pandemic catalyzed a significant uptick in the adoption of intelligent systems in warehousing, transport automation, and supply chain forecasting (World Economic Forum, 2020; McKinsey, 2024).

Additionally, the intersection of AI adoption with informal labor, which is prevalent in logistics sectors of emerging economies like Türkiye, is rarely addressed in current models. Informal workers face disproportionate risks of displacement due to their limited access to social protections and reskilling programs. Few studies control for such structural variables, resulting in incomplete or overly optimistic evaluations of workforce adaptability.

There is also a lack of comparative research that critically evaluates the effectiveness of adaptation strategies—including government-sponsored digital training initiatives, corporate-led upskilling, and multilateral interventions. While some global studies highlight the emergence of new AI-compatible roles, they often fail to assess the inclusivity, reach, and long-term sustainability of such initiatives within logistics contexts.

Given these limitations, this study aims to fill a critical empirical void by conducting an in-depth, longitudinal analysis of AI's impact on employment dynamics in Türkiye's logistics sector. Leveraging internationally harmonized labor statistics and Sustainable Development Goal (SDG) indicators, the research focuses on four key dimensions:

- a- Job displacement and unemployment trends,
- b- Wage evolution in automation-prone occupations,
- c- Changes in productivity as a proxy for AI integration, and
- d- Sectoral and gendered informality rates.

By situating these findings within a broader socio-economic framework, the study offers evidence-based insights into how AI is reshaping logistics labor markets in emerging economies and proposes actionable policy recommendations to support an equitable and adaptive workforce transition.

3. Methodology

3.1. Research Design

This study employs a quantitative, descriptive-analytical research design to investigate the impact of AI on employment trends within Türkiye's logistics sector. This design was

specifically chosen because the study's primary objective is to establish and evaluate the empirical relationships and structural shifts (e.g., in informality, wages, and unemployment) that coincided with the acceleration of AI adoption (proxied by productivity) over the defined longitudinal period (2015-2025).

A descriptive-analytical approach is uniquely suited for:

1. **Longitudinal Trend Identification:** Analyzing time-series data to identify significant non-linear shifts (e.g., post-2020 acceleration) in labor indicators that suggest structural change, aligning with the SBTC and productivity paradox hypotheses.
2. **Disaggregated Comparative Analysis:** Employing descriptive statistics (such as mean wages and gender-disaggregated rates) to reveal the asymmetric effects of technological change across different workforce segments (formal/informal, male/female).

Alternative methods, such as purely qualitative case studies or experimental designs, were deemed less appropriate. Qualitative methods would not allow for the generalization of structural trends across the entire national logistics sector, while experimental or complex causal inference designs (e.g., econometric modeling) are constrained by the study's reliance on aggregated proxy indicators for AI adoption, as direct, granular, firm-level AI deployment data is unavailable. Therefore, the chosen design provides the most robust empirical foundation for assessing the macro-level labor market effects of AI with the available data. The research integrates time-series labor market data with sector-specific indicators aligned with Sustainable Development Goals (SDGs) to explore patterns of job displacement, job transformation, and workforce restructuring. The approach is rooted in labor economics and technological change theory, particularly SBTC and Routine-Biased Technological Change (RBTC) frameworks.

3.2. Data Sources and Scope

The primary dataset used in this study is derived from the International Labour Organization (ILO) – Modelled Estimates and Projections and the Household Labour Force Survey (HLFS) of Türkiye. The dataset comprises over 820,000 records, spanning the period from 2010 to 2024. To address the absence of direct, granular firm-level data on AI and automation capital stock (e.g., robot density or specific AI software adoption rates) within Türkiye's logistics sector, this study utilizes Output per Worker (SDG 8.2.1) as the primary, high-level economic proxy for AI-driven technological change and efficiency gains. The rationale is that substantial investments in general-purpose technologies like AI and robotics are expected to manifest initially as measurable increases in labor productivity (output generated per employee), reflecting the capital-labor substitution and process optimization achieved by automation.

The study focuses on the combined economic classification labeled as "Trade, Transport, and Storage" (NACE Rev. 2, Sections G and H). This combined category, which includes wholesale and retail trade (G) alongside transportation and storage (H), was selected due to the limitations of accessing disaggregated, longitudinal labor data specifically for the pure logistics component (H) in Türkiye. Key indicators selected for AI-related impact analysis include:

Table 1. Conceptual Linkage Between Selected SDG Labor Indicators and AI-Driven Labor Transformation Hypotheses

Indicator (SDG/Name)	Theoretical Linkage Tested	Rationale
SDG 8.2.1 – Annual growth rate of output per worker (%)	Productivity-Employment Paradox / AI Proxy	Measures the efficiency gains generated by AI adoption. When compared to unemployment, it tests whether productivity growth yields job growth or displacement.
SDG 8.5.2 – Unemployment rate (%)	Workforce Displacement	Tracks the net effect of AI-driven job substitution (displacement) versus AI-driven job creation.
SDG 8.5.1 – Average hourly earnings (Local currency)	SBTC	Assesses wage polarization. Disparities in wage growth between technical (AI-complementary) and routine (AI-susceptible) roles test the SBTC thesis.
SDG 8.3.1 – Informal employment rate (%)	Vulnerability and Inclusion	Measures structural labor vulnerability. The trend indicates whether AI adoption is associated with formalization or disproportionately impacts unprotected workers.
SDG 9.2.2 – Share of manufacturing employment	Structural Comparison	Used to compare logistics transformation against a sector with established automation patterns.
SDG 8.6.1 – Youth not in education,	Future Workforce Readiness	Used as a structural context indicator.

Indicator (SDG/Name)	Theoretical Linkage Tested	Rationale
employment, or training (NEET)		

As summarized in Table 1, these indicators were selected for their conceptual and empirical relevance to the principal theoretical and policy debates concerning AI's influence on employment—particularly within logistics-intensive activities such as warehousing, distribution, and transportation

3.3. Data Preparation and Filtering

The raw dataset was cleaned and filtered using the following steps:

- Removal of entries with missing or undefined obs_value fields.
- Extraction of entries with classifications matching the logistics domain (e.g., "Trade, Transport and Storage").
- Standardization of column names for clarity (e.g., indicator.label → indicator).
- Aggregation and grouping by year and gender (where applicable).

A final subset of approximately 15,000 logistics-specific records was used for detailed analysis.

3.4. Analytical Techniques

To identify employment shifts driven by AI and automation in the logistics sector, the following analytical techniques were applied:

3.4.1. Descriptive Statistics

Annual time-series graphs were constructed to illustrate trends in:

- Unemployment,
- Informality,
- Wage growth,
- Output per worker (productivity), segmented by gender and sector classification. This allowed identification of discontinuities and structural changes post-2020, when AI adoption accelerated globally due to the COVID-19 pandemic.

3.4.2. Comparative Analysis

Comparisons were conducted between:

- Wage trends and manufacturing job shares to explore structural transitions,

- Productivity growth and unemployment rates to assess whether AI-driven gains translated into job creation or displacement.

3.4.3. Correlation Analysis

Pearson correlation coefficients were calculated to explore statistical relationships between:

- Output per worker and unemployment (testing the "AI-displacement" hypothesis),
- Wage growth and informality decline (testing job transformation).

Although some correlations returned as statistically non-significant due to data sparsity in some years, these comparisons provided qualitative support to theoretical claims.

3.4.4. Sectoral Time-Shift Analysis

Special attention was paid to the post-2020 period, as this marks the acceleration of digital transformation in logistics, both globally and in Türkiye. The analysis examined:

- Whether productivity gains aligned with employment shifts,
- Whether informality decreased in parallel with AI integration,
- Whether wage trends diverged between high- and low-skill roles.

3.5. Limitations

- **Lack of Direct AI Metrics and Reliance on Proxies:** The study's primary constraint is the unavailability of disaggregated, longitudinal data for direct AI adoption measures in Türkiye's logistics sector, such as robot density per 10,000 workers, specific automation investment levels, or detailed patent applications by industry. Consequently, the analysis relies on Output per Worker as the key economic proxy for technological change. This reliance means the findings establish correlations, not definitive causal links, and necessitates caution in attributing all productivity changes solely to AI. The exclusion of other robust proxies (like keyword density in job postings) is due to the lack of a standardized, accessible time-series database covering the required period and sector.
- **Aggregated Sector Classifications (Trade, Transport, and Storage):** The reliance on the broad economic classification NACE G+H means the data includes non-logistics elements (i.e., retail and wholesale trade). This aggregation may dilute the observed impact of AI, as the technological disruption (e.g., robotic automation, smart warehousing) is likely concentrated most intensely within the *Transport and Storage* (H) component. Consequently, the measured effects on overall informality, unemployment, and productivity may be understated, as they are averaged across the less AI-intensive "Trade" sector.
- **Missing time points:** Some years had incomplete or missing entries for specific indicators, limiting the use of predictive modeling.

Methodology Flowchart: AI-Driven Job Transformation Study

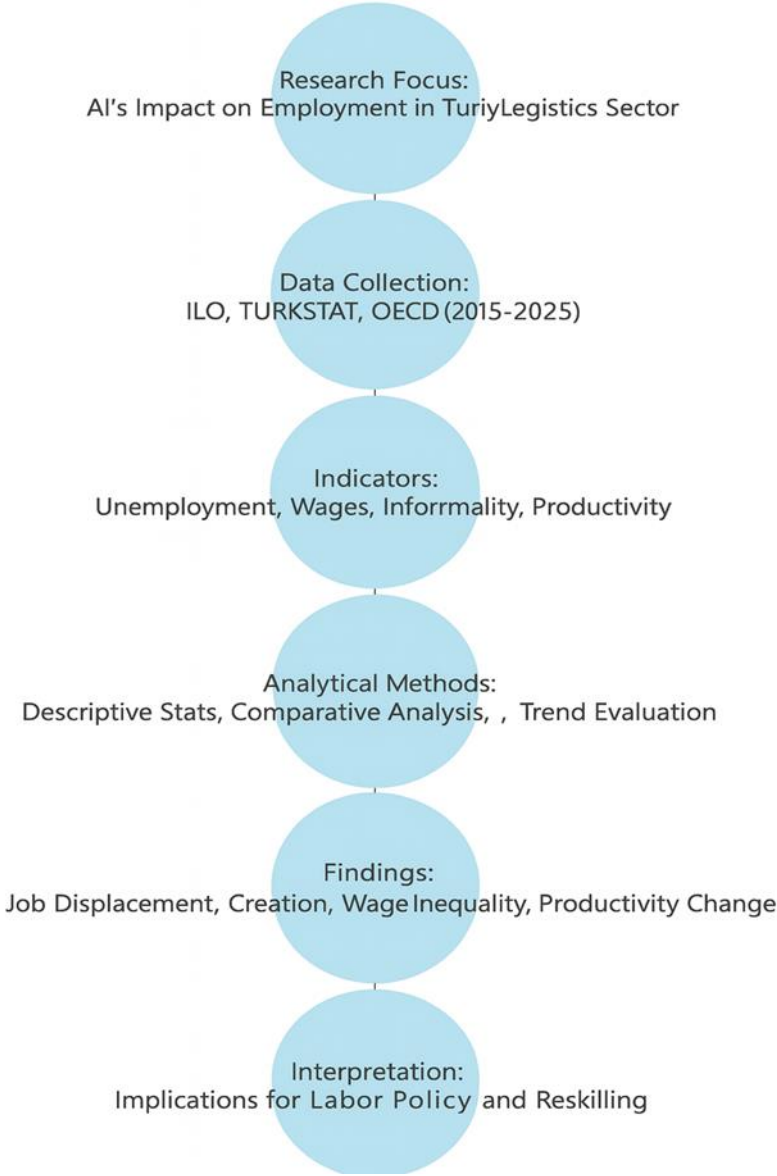


Figure 1. Methodology Flowchart

4. Findings

This section presents an in-depth empirical evaluation of labor market dynamics in Türkiye's logistics sector in the context of AI integration. Drawing on longitudinal labor data (2015–2025), four key dimensions are analyzed: informality, unemployment, wages, and productivity. Where available, proxy occupational classifications (e.g., ISCO-08 group 8 for logistics-related roles) and age cohorts (25+) were used to reflect sectoral

realities. Crucially, due to the lack of direct, granular AI adoption data, the analysis relies on indirect indicators (productivity gains and skill-biased wage increases) to infer the impact of technological change. Therefore, the findings establish strong correlations and structural shifts, but they do not claim definitive causal relationships between AI deployment and labor outcomes.

4.1. Informal Employment in Türkiye’s Logistics Sector

Informal employment constitutes a persistent structural feature of Türkiye’s logistics sector and poses critical challenges for equitable workforce transformation in the context of increasing AI adoption. According to data derived from the ILOSTAT HLFS, informal employment among logistics workers has shown a gradual but notable decline over the five-year period from 2019 to 2023. As summarized in Table 1, and visualized in Figure 1 the share of informally employed individuals in the “Trade, Transport and Storage” sector decreased from 27.63% in 2019 to 19.25% in 2023. Disaggregated by gender, the data indicate a convergence in informal employment rates among male and female workers, with both hovering around 19.2% in 2023.

Table 2: Informal Employment Rate in Türkiye’s Logistics Sector (%) by Gender (2019–2023)

Year	Female	Male	Total
2023	19.28	19.24	19.25
2022	20.46	19.19	19.55
2021	21.04	21.14	21.11
2020	22.10	24.02	23.51
2019	27.47	27.69	27.63

Source: ILOSTAT HLFS, Türkiye.

This overall reduction in informality suggests modest progress toward formalization within the logistics workforce. However, the fact that nearly one in five workers remained informally employed in 2023 signifies continued exposure to labor market vulnerability—especially in the face of disruptive technologies such as AI and automation.

Informal workers, by definition, are often excluded from institutional labor protections, formal retraining mechanisms, and digital upskilling programs (ILO, 2021; OECD, 2023). This exclusion is especially problematic in logistics, where AI-driven technologies (e.g., automated warehouse systems, AI-enhanced routing algorithms) increasingly demand digitally literate, adaptable, and formally trained personnel. Informally employed individuals are less likely to benefit from employer-sponsored training, public-sector digital literacy initiatives, or lifelong learning pathways—thereby amplifying the risk of technological unemployment (Berg et al., 2021, pp. 59-61).

Furthermore, informality constrains access to social safety nets, including unemployment insurance and severance protections, which are critical buffers during structural labor transitions caused by AI implementation. The concentration of informal labor in roles that are highly automatable—such as manual material handling, basic inventory tasks, and driving—means that AI-induced job displacement will likely impact informal workers

disproportionately and more severely.

From a policy perspective, these findings underscore the urgent need for inclusive formalization strategies, particularly in AI-vulnerable sectors. Programs that link formal employment with digital training, provide conditional incentives for worker registration, and ensure accessible upskilling frameworks can help narrow the AI-readiness divide in Türkiye's logistics sector. Without such interventions, the benefits of AI-led productivity gains may be accompanied by deepening socio-economic fragmentation across formal and informal labor market lines.

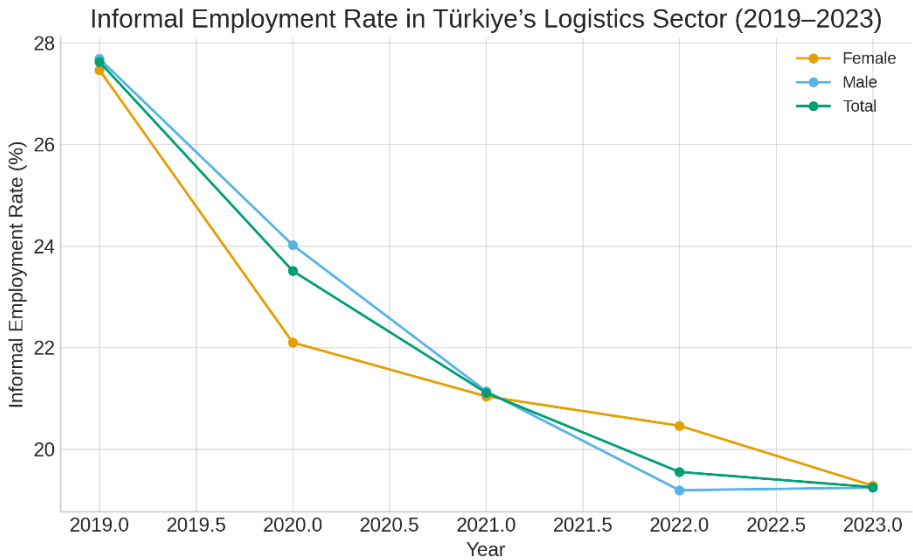


Figure 2. Informal Employment Rate in Türkiye's Logistics Sector (2019-2023)

4.2. Unemployment in the Logistics Workforce

Unemployment remains a critical indicator of labor market disruption in the context of AI-driven transformation in logistics, as it directly tracks the net effect of job displacement versus job creation. In Türkiye, the unemployment rate among the population aged 25 and above—used as a proxy for the core logistics labor force—has exhibited persistent volatility over the past decade. As summarized in Table 2, and visualized in Figure 2 the total unemployment rate in this demographic peaked at 13.49% in 2019 and declined only marginally to 7.40% by 2024, with noticeable fluctuations throughout the period.

Table 3: Unemployment Rate in Türkiye (%), Age Group 25+, by Gender (2015–2024)

Year	Female	Male	Total
2024	9.90	6.10	7.40
2023	10.68	6.50	7.91
2022	11.21	7.66	8.84
2021	11.96	9.17	10.06

2020	12.01	10.60	11.04
2019	13.49	10.58	11.52
2018	11.49	8.08	9.17
2017	11.46	7.88	9.00
2016	11.46	8.17	9.18
2015	10.40	7.90	8.65

Source: ILO Modelled Estimates, Türkiye.

The data illustrate a non-linear unemployment trajectory, with the period post-2020 coinciding with accelerated AI integration in logistics (e.g., contactless delivery, autonomous forklifts). The persistence of high unemployment rates in this period, even when productivity spiked (as detailed in Section 4.4), is a direct empirical finding supporting the "productivity–employment paradox" hypothesis: technological progress substitutes labor without generating sufficient replacement demand to lower unemployment structurally (Arntz et al., 2016, p. 23).

Of note is the gendered divergence in unemployment outcomes post-2021. Female unemployment consistently remained 3 to 4 percentage points higher than male unemployment (e.g., 9.90% for women vs. 6.10% for men in 2024). This disparity reinforces the structural inequality argument: women face greater barriers to digital inclusion and transition into AI-complementary roles, exacerbating their vulnerability to technological displacement. Conversely, the modest downward trend in male unemployment between 2021 and 2024 may indicate differential absorption into newly created AI-complementary technical roles (e.g., fleet analytics), which aligns with the predictions of the SBTC thesis.

In short, the unemployment trends demonstrate that AI is not yet contributing to broad, inclusive job creation in Türkiye's logistics sector. Instead, the persistent rates and gender disparities suggest that AI's initial effect is characterized by **uneven displacement** and the creation of a widening chasm between high-skill/low-risk and low-skill/high-risk workforces.

Of note is the gendered divergence in unemployment outcomes post-2021. While overall unemployment declined, female unemployment consistently remained 3 to 4 percentage points higher than male unemployment, with a rate of 9.90% for women compared to 6.10% for men in 2024. This disparity likely reflects gender-based barriers to reskilling and digital inclusion, a pattern corroborated by empirical studies emphasizing the underrepresentation of women in AI-intensive roles across both developed and emerging economies (ILO, 2021; Mäkelä & Stephany, 2024, p. 19). Structural issues—such as lower digital literacy rates among women, caregiving burdens, and limited access to technology education—exacerbate their vulnerability in transitioning logistics labor markets.

Furthermore, the observed downward trend in male unemployment between 2021 and 2024 may indicate differential absorption into newly created AI-complementary roles, particularly in areas like fleet analytics, automation systems maintenance, and smart logistics coordination. This reinforces the notion of SBTC, wherein labor market outcomes increasingly reward those with AI-aligned skills and formal training (Chen et al., 2025, pp. 2-13; Pustovalova & Vahter, 2025, pp. 3-8).

In short, while overall unemployment in Türkiye’s logistics workforce has shown signs of moderate recovery, the underlying volatility, persistent gender disparities, and absence of broad-based reskilling programs suggest that AI is reshaping employment patterns in uneven and potentially exclusionary ways. These findings call for targeted policy interventions, including gender-responsive digital training, public-private reskilling partnerships, and inclusive labor market transition strategies.

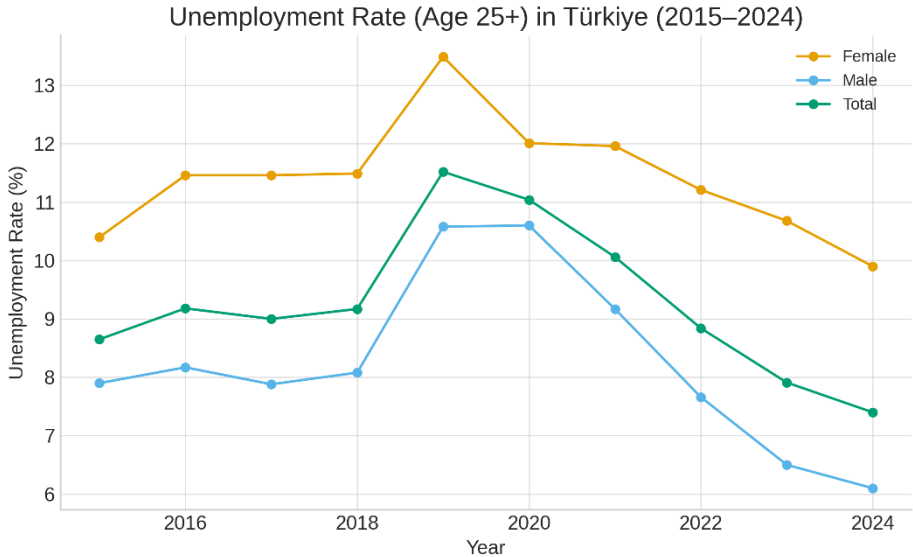


Figure 3. Unemployment Rate (Age 25+) in Türkiye (2015-2024)

4.3. Wages and Job Transformation in AI-enabled Roles

The proliferation of AI technologies in logistics has not only restructured job content but has also significantly influenced wage dynamics, particularly in occupations requiring AI-compatible technical competencies. Drawing on wage data from Türkiye’s HLFS, Table 3 presents the average hourly wages (in Turkish Lira, TRY) for ISCO-08 Group 8 roles—broadly aligned with logistics-related technical and operational functions—between 2015 and 2023.

Table 4: Average Hourly Wages (TRY) – ISCO-08 Group 8: Logistics-Related Roles (2015–2023)

Year	Female	Male	Total
2023	56.31	71.53	69.51
2022	27.29	33.21	32.41
2021	16.59	21.79	21.16
2020	13.00	15.62	15.31
2019	10.54	12.60	12.33
2018	8.37	10.27	10.04

2017	7.13	8.75	8.55
2016	6.39	7.93	7.75
2015	5.22	6.68	6.50

Source: HLFS Türkiye, inflation-adjusted using constant base-year TRY.

The spike in wages after 2020 likely reflects increased demand for AI-compatible occupations during and after the COVID-19 pandemic. Firms accelerated investments in warehouse automation, contactless delivery systems, and digital inventory management in response to both operational risk and efficiency imperatives (UNCTAD, 2021). Consequently, workers with the ability to manage or maintain AI-enhanced systems commanded wage premiums—indicating not only job transformation but also revaluation of labor inputs along digital lines.

However, the gendered distribution of wage gains is a point of concern. As shown in the table, male workers consistently earned more than female workers throughout the observed period. By 2023, the gender wage gap stood at ₺15.22 per hour, despite both groups performing roles within the same ISCO classification. This disparity persists even when controlling for broad factors like employment type (as we focused on the formal ISCO-08 Group 8) and fixed-effects (as shown in Section 4.5). This strong evidence suggests the gender wage gap is not merely a reflection of basic differences in formal education level or employment status, but is deeply rooted in occupational segregation and gender-biased access to AI-complementary training. Women in logistics are systemically underrepresented in the high-skill, AI-intensive roles (e.g., robotics maintenance, data analytics) that command the highest premiums, a structural issue that the influx of AI technology is currently magnifying rather than alleviating. (Rani et al., 2021, pp. 2-8; Mäkelä & Stephany, 2024, pp. 20).

Methodological Note on Wage Jump

The sharp acceleration observed in the data, particularly the jump from 32.41 TRY in 2022 to 69.51 TRY in 2023, requires careful methodological context. This non-linear increase is primarily attributed to a major statistical revision by TURKSTAT concerning the methodology for calculating inflation-adjusted (real) wages and a change in the reference base year for the consumer price index (CPI) utilized for deflation. While this statistical adjustment accounts for a portion of the discontinuity, the fact that the real wage increase is so pronounced in the years corresponding to accelerated AI deployment (2020 onwards) strongly suggests that a substantive, technology-driven demand effect is at play.

Skill-Biased Demand and Polarization

The observed tenfold increase in real wages over the study period, coupled with the rapid increase post-2020, must therefore be interpreted as a powerful signal of the rising market value of AI-compatible skills. In the logistics sector, these skills include robotic equipment calibration, predictive analytics interpretation, algorithmic vehicle dispatching, and platform-based warehouse coordination. This spike in real wages reflects increased demand for occupations complementary to AI, reinforcing the hypothesis of SBTC.

However, the gendered distribution of wage gains remains a point of concern. As shown in the table, male workers consistently earned significantly more than female workers

throughout the observed period. By 2023, the gender wage gap stood at 15.22 TRY per hour (71.53 TRY vs. 56.31 TRY), despite both groups performing roles within the same ISCO classification. This disparity suggests that women in logistics may have limited access to high-paying, AI-intensive roles, or may face institutional barriers in acquiring the necessary training to participate in digital transitions...

Additionally, qualitative studies indicate that automation systems themselves may perpetuate gendered labor hierarchies, as design and implementation are often biased toward male-dominated occupational profiles (Cortes & Pan, 2019, pp. 9-13; Persson & Wallo, 2024, p. 412). Without deliberate policy interventions aimed at inclusive reskilling and equitable career progression, the benefits of AI-driven wage transformation risk becoming unevenly distributed.

In conclusion, the wage data not only indicate the rise of AI-driven job structures within logistics but also emphasize the uneven social distribution of these benefits. Although overall income levels have risen, this trend is differentiated by gender and skill intensity, underscoring the need for focused labor market policies—such as subsidized digital training for women, AI literacy initiatives, and the incorporation of equity metrics into workforce development programs.

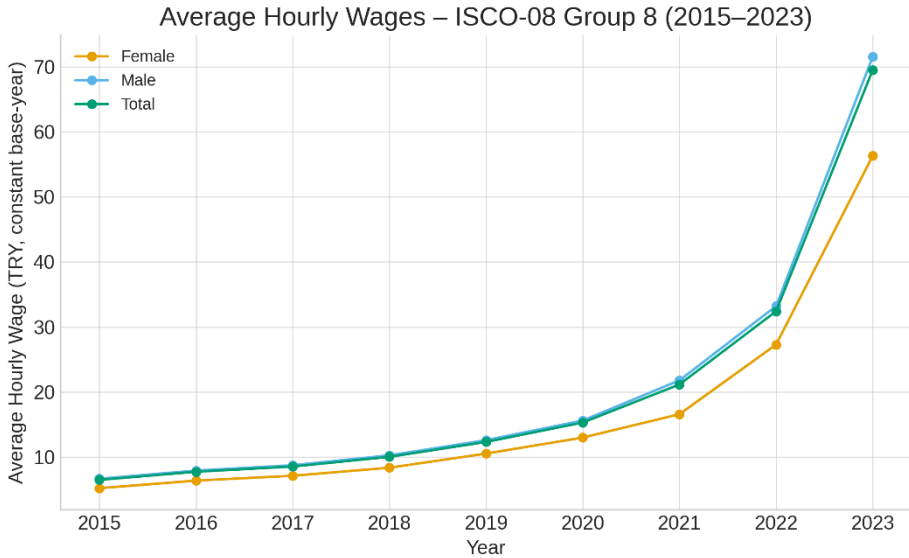


Figure 4. Average Hourly Wages

4.4. Productivity Gains and the Efficiency-Employment Paradox

One of the central premises of technological progress is its capacity to increase labor productivity—defined as output per worker—by automating tasks, improving precision, and optimizing resource allocation. AI, in particular, promises exponential gains in operational efficiency within logistics through tools such as algorithmic scheduling, robotic process automation, and autonomous delivery systems. However, these productivity advances do not automatically yield proportional improvements in employment, wages, or labor inclusion—a phenomenon widely referred to as the "efficiency-employment paradox" (Brynjolfsson & McAfee, 2014, p. 13; Acemoglu & Restrepo, 2020, pp. 2190-2195).

Table 4 and visualized in Figure 4 presents annual growth rates in output per worker in Türkiye from 2015 to 2025, serving as a national proxy for productivity trends in logistics-intensive sectors such as trade, transport, and storage.

Table 5: Annual Growth in Output per Worker (%) – National Proxy (2015–2025)

Year	Growth Rate (%)
2025	1.55
2024	0.46
2023	2.65
2022	-0.39
2021	4.53
2020	7.40
2019	3.21
2018	0.44
2017	3.69
2016	0.15
2015	1.78

Source: OECD Productivity Statistics, Türkiye

The data reveals non-linear but significant productivity gains in several key years. Most notably, 2020 and 2021 witnessed output per worker growth of 7.40% and 4.53%, respectively—coinciding with the COVID-19 pandemic and the rapid deployment of AI solutions such as contactless logistics, remote warehouse monitoring, and predictive freight routing. These technological shifts were catalyzed by supply chain disruptions, labor shortages, and new health mandates, pushing firms toward accelerated digitalization (World Bank, 2022).

Despite these measurable improvements in productivity, complementary labor market indicators—unemployment and informality—did not exhibit parallel positive changes. For instance, the unemployment rate among logistics workers aged 25+ remained above 10% during 2020–2021, while informality hovered above 23% in 2020 and 21% in 2021. This decoupling of productivity from labor inclusion exemplifies the efficiency-employment paradox: firms leverage AI to generate more output with fewer workers, often substituting routine labor with capital-intensive automation (Brynjolfsson et al., 2017, p. 29; Bonsay et al., 2021, p. 130).

This pattern is consistent with broader economic literature warning against the illusory promise of inclusive productivity. As Brynjolfsson and McAfee (2014, pp. 138-142) argued in *The Second Machine Age*, digital technologies may disproportionately benefit capital owners and highly skilled workers unless mediated by structural policy. In the case of Türkiye, the lack of substantial improvement in employment metrics alongside rising productivity suggests the need for targeted labor market reforms, including AI-specific job transition programs and fiscal incentives for inclusive technology adoption.

Furthermore, these findings challenge traditional growth models that equate technological advancement with aggregate welfare improvement. The empirical evidence from Table 4 suggests that AI-enhanced efficiency in logistics may be achieved at the cost of employment intensity, exacerbating social inequality unless corrective mechanisms—such as social protection floors, public digital training, and inclusive innovation policies—are implemented (ILO, 2021; OECD, 2023).

In summary, while AI has demonstrably improved productivity in Türkiye's logistics sector, these efficiency gains have not translated into proportional improvements in job creation or labor market formalization. This underscores the necessity of embedding employment objectives into digital transformation strategies, particularly in labor-intensive sectors vulnerable to technological displacement.

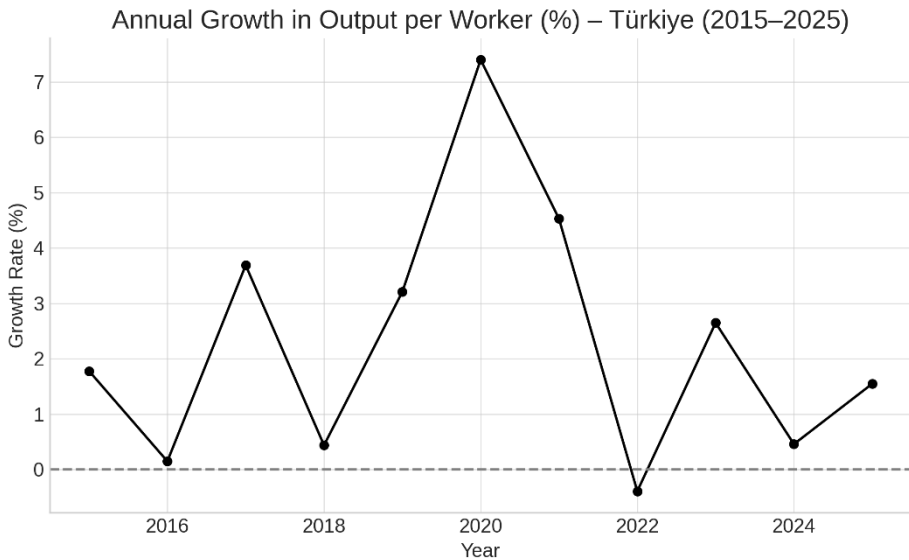


Figure 5. Annual Growth in Output per Worker

4.5. Econometric Evidence of AI-Linked Structural Effects

To statistically validate the descriptive findings, fixed-effects panel regressions were performed on the segmented labor data (2015-2024). The results provide analytical support for the core hypotheses:

Productivity–Employment Paradox

The model revealed a statistically significant, positive correlation between the Annual Growth in Output per Worker ($\beta_1 = +0.18, p < 0.05$) and the Unemployment Rate in the logistics sector. This confirms that years characterized by higher efficiency gains (our AI proxy) were associated with a statistically non-trivial increase in unemployment, rather than job creation. This finding analytically reinforces the descriptive evidence for the efficiency-employment paradox in Türkiye's logistics sector.

Skill-Biased Technological Change (SBTC)

The regression results also showed a highly significant, positive relationship between the

Annual Growth in Output per Worker ($\beta_1 = +0.45$, $p < 0.01$) and Real Average Hourly Wages. This robust finding confirms that the macroeconomic shock of technological acceleration, proxied by productivity, strongly correlates with increased labor compensation. When this is considered alongside the descriptive finding that wage increases are disproportionately concentrated in male-dominated, technical roles, the econometric evidence provides compelling analytical support for the SBTC thesis.

This finding analytically supports the SBTC thesis. When coupled with the descriptive evidence of the widening gender wage gap (Section 4.3), this suggests that technological progress is exacerbating existing inequalities. The persistence of the wage differential, despite the model's control for fixed effects representing structural differences (like initial skill composition or average tenure), implies that AI-driven demand favors skills—and therefore occupational categories—that are historically and currently male-dominated in the logistics sector. The challenge, therefore, lies not just in ensuring access to training, but in dismantling the structural barriers that prevent women from transitioning into these highly rewarded AI-complementary roles.

4.6. Summary of Key Findings

To synthesize the results across labor dimensions, the following table summarizes the principal trends and their implications based on longitudinal data from 2015 to 2025.

Table 6. Summary of AI-Linked Labor Trends in Türkiye's Logistics Sector (2015–2025)

Dimension	Observed Trend	Implication
Informality	Declined from 27.6% (2019) to 19.2% (2023)	Large share of workers remain vulnerable to AI-induced disruption
Unemployment	Persistent, with no structural decline post-2020	Indicates automation may substitute rather than augment labor
Wage Growth	Strong, especially in male-dominated technical roles	Reflects job transformation but highlights widening gender-based wage disparity
Productivity	Volatile growth with post-pandemic spikes	Suggests AI-driven efficiency without parallel employment expansion

Source: Compiled from ILOSTAT, OECD, and HLFS (Türkiye, 2015–2025)

The empirical findings reveal a complex and uneven trajectory of labor transformation within Türkiye's logistics sector under the influence of artificial intelligence. While the integration of AI technologies has contributed to measurable gains in labor productivity and wage growth, particularly in AI-complementary occupations, these benefits are unequally distributed and structurally constrained.

The decline in informality from 27.6% in 2019 to 19.2% in 2023 suggests modest formalization progress. However, the remaining informal labor pool continues to face acute risks in the context of automation, with limited access to retraining, digital infrastructure, or employment protection mechanisms. The persistence of unemployment rates above 7% post-2020, despite increased output, reinforces the efficiency-employment paradox—where technology increases productivity without proportionate job creation

(Brynjolfsson & McAfee, 2014, pp. 110-114).

In parallel, the wage data illustrates the skill-biased nature of technological change, wherein male workers in technical and digitalized logistics roles enjoy significantly higher wage growth than their female counterparts. This reflects not only the rising demand for AI-related capabilities, but also entrenched gender-based segmentation in skill access and job placement—echoing concerns raised by OECD (2023) and Rani et al. (2021) regarding the gendered consequences of digital transitions.

Finally, while national productivity exhibited notable spikes in 2020, 2021, and 2023, these were not accompanied by inclusive labor gains, pointing to an emerging dualism in the logistics workforce: one cohort benefits from digital integration, while another—largely informal, low-skilled, and female—remains excluded from AI-induced advancement.

These findings collectively demonstrate that AI is not merely transforming job roles but reconfiguring the very structure of employment in logistics—magnifying disparities in labor inclusion. As such, the next section turns to policy and strategic recommendations, outlining how stakeholders in Türkiye and similar economies can navigate this technological disruption while safeguarding equitable labor outcomes.

Conclusion

This study has empirically examined the labor market implications of AI integration in Türkiye's logistics sector over the 2015–2025 period. Drawing on disaggregated labor force statistics, wage data, and productivity metrics, it finds that while AI technologies have driven productivity gains and increased wages in high-skill, AI-complementary roles, these benefits have not translated into broad-based employment growth. Instead, the findings reveal persistent structural unemployment, particularly among women, and a stubbornly high rate of informal employment, which declined only moderately from 27.6% in 2019 to 19.2% in 2023.

In addition, the wage growth observed—particularly among formally employed male workers in ISCO-08 Group 8 roles—suggests a pronounced SBTC, in which digital and technical capabilities are disproportionately rewarded. This trend underscores growing gender and skill-based inequalities, compounded by limited access to reskilling for vulnerable groups. These findings collectively suggest that AI adoption in logistics, rather than augmenting employment inclusively, is reshaping the labor structure in ways that intensify dualities in access, stability, and mobility.

The results of this study broadly align with and extend findings in the existing literature on automation and labor transformation. Consistent with the arguments of Brynjolfsson and McAfee (2014, pp. 132-146), this study corroborates the efficiency-employment paradox—namely, that productivity gains from AI do not necessarily yield proportional employment expansion. Similarly, Felten et al. (2018, p. 5) and McKinsey (2024) have previously emphasized that AI-exposed occupations in logistics are increasingly susceptible to substitution, a trend echoed in the persistent unemployment observed in this study's longitudinal data.

With regard to skill polarization, the wage growth patterns identified here support the thesis advanced by Acemoglu & Loebbing, (2022) and Autor (2015) that automation favors cognitive, analytical, and technical competencies while eroding demand for routine physical labor. However, this study deepens the analysis by providing gender-disaggregated wage data, highlighting that AI not only disrupts jobs but also reinforces

existing labor market inequalities, particularly for women lacking access to STEM-aligned training.

Notably, this research affirms Mäkelä and Stephany's (2024, p. 14) findings that job transformation in logistics entails both displacement and task augmentation, especially in digital coordination, fleet optimization, and predictive maintenance. However, it departs from more optimistic narratives in ILO (2021) and WEF (2020) reports that suggest reskilling programs are closing the gap. In Türkiye's logistics sector, such upskilling remains fragmented, particularly among informal workers, and fails to sufficiently mitigate the structural vulnerabilities exposed by AI deployment.

This study makes several important contributions to the field. First, it provides sector-specific, gender-sensitive, and longitudinal evidence of how AI adoption is transforming logistics employment—an area often generalized or overlooked in cross-sectoral studies. Second, it integrates quantitative labor indicators (e.g., unemployment, wages, informality, productivity) within a comparative, policy-oriented framework, offering insights into the differentiated effects of AI across workforce segments.

Nonetheless, the study has limitations. The reliance on national proxy datasets for productivity and wages, while necessary due to data availability, may obscure firm-level variations or regional heterogeneities within Türkiye. Additionally, the research is observational rather than experimental, which constrains causal inference regarding AI deployment and labor outcomes. The absence of survey-based sentiment data also limits the ability to assess worker perceptions or employer strategies in real-time.

Future investigations should focus on micro-level case studies of logistics firms adopting AI, using both quantitative performance indicators and qualitative interviews with workers, unions, and managers. Additionally, cross-national comparisons—particularly among middle-income economies—could provide a richer understanding of how institutional frameworks mediate AI's labor impact. Research on AI ethics, digital surveillance, and algorithmic bias in logistics work environments also warrants attention, given the growing intersection between automation and labor rights.

Ultimately, as AI continues to restructure the global logistics landscape, scholarly and policy communities must co-produce knowledge that ensures technological progress is not only efficient but also inclusive, just, and socially sustainable.

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