



Structural divergence in Türkiye's paper consumption: Category-specific evidence from an ARDL and ECM framework

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ABSTRACT

Background and Aims This study examined the long-run evolution of paper consumption in Türkiye over 2000–2024 by distinguishing printing and writing papers from recovered paper.

Methods Annual data from FAOSTAT, the World Bank, and UN Comtrade were used to construct category-specific apparent-consumption series, and descriptive analysis, ADF,

KPSS, Zivot–Andrews tests, ARDL bounds testing, and ECM estimation were applied.

Results Printing and writing paper consumption rose to about 1.25 million tonnes in the mid-2010s and then declined to about 0.87 million tonnes in 2024; over the same period, domestic production coverage fell from 0.53 to 0.29, while import dependence increased from 0.48 to 0.79. Recovered paper consumption increased from about 0.94 to 4.21 million tonnes, but its domestic production coverage weakened to 0.64 and import dependence rose to 0.37 by 2024. Cointegration was supported only for printing and writing papers; in the preferred model, the bounds F-statistic was 6.323 and the error-correction coefficient was -0.978 ($p=0.001$).

Conclusion Paper consumption in Türkiye did not operate as a single integrated market; instead, it followed category-specific demand paths and supply structures. Strengthening domestic collection, sorting, and recycling capacity was concluded to be essential for a more resilient paper economy.

Key Words: ARDL, ECM, import dependence, paper consumption, printing and writing papers, recovered paper, Türkiye

Türkiye'nin kâğıt tüketiminde yapısal ayrışma: ARDL ve ECM çerçevesinden kategoriye özgü bulgular

ÖZ

Giriş ve Hedefler Bu çalışma, 2000–2024 döneminde Türkiye'deki kâğıt tüketiminin uzun dönemli gelişimini, yazı-baskı kâğıtları ile geri kazanılmış kâğıtları birbirinden ayırarak incelemektedir.

Yöntemler FAOSTAT, World Bank ve UN Comtrade yıllık verileri kullanılarak kategori bazlı görünür tüketim serileri oluşturulmuş; tanımlayıcı çözümleme, ADF, KPSS ve Zivot–Andrews birim kök testleri ile ARDL sınır testi ve hata düzeltme modeli uygulanmıştır.

Bulgular Yazı ve baskı kâğıdı tüketimi 2010'lu yılların ortasında yaklaşık 1,25 milyon tona ulaşmış, ancak 2024 yılına gelindiğinde 0,87 milyon tona gerilemiştir. Aynı dönemde yerli üretimin tüketimi karşılama oranı 0,53'ten 0,29'a düşerken, ithalat bağımlılığı 0,48'den 0,79'a yükselmiştir. Geri kazanılmış kâğıt tüketimi ise yaklaşık 0,94 milyon tondan 4,21 milyon tona çıkmış; buna karşın yerli üretim karşılama oranı 0,64'e zayıflamış ve ithalat bağımlılığı 2024 itibarıyla 0,37'ye ulaşmıştır. Eşbütünleşme ilişkisi yalnızca yazı ve baskı kâğıtları için doğrulanmıştır; tercih edilen modelde sınır F-istatistiği 6,323, hata düzeltme katsayısı ise -0,978 ($p=0,001$) olarak hesaplanmıştır.

Sonuçlar Türkiye'deki kâğıt tüketiminin tek ve bütünleşik bir pazar yapısında olmadığı, bunun yerine kategoriye özgü talep patikaları ve arz yapıları izlediği tespit edilmiştir. Daha dirençli bir kâğıt ekonomisi inşa edebilmek için yerli toplama, ayrıştırma ve geri dönüşüm kapasitesinin güçlendirilmesinin elzem olduğu sonucuna varılmıştır.

Anahtar Kelimeler: ARDL, ECM, ithalat bağımlılığı, kâğıt tüketimi, baskı ve yazı kâğıtları, geri kazanılmış kâğıt, Türkiye

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1. Introduction

The pulp and paper industry occupies a strategically important position within the forest-based bioeconomy because it links raw-material extraction, industrial processing, trade, waste management, and environmental performance within a single value chain. At the same time, the sector is far from homogeneous across countries. Dai et al. (2024) show that paper-related sectors accounted for about 3.2% of global anthropogenic greenhouse-gas emissions over 1961–2019 and argue that country-specific strategies are essential because emission structures and mitigation options differ markedly across national systems. In a complementary systems analysis for the United States, Charles et al. (2024) note that the pulp and paper industry is energy-intensive, representing about 9% of total U.S. industrial energy use and 2.5% of U.S. industrial greenhouse-gas emissions, while also exhibiting distinctive interactions with biomass, electrification, and upstream forest resources. Together, these studies indicate that paper-sector transitions must be interpreted within country-specific market, resource, and policy conditions rather than through a single universal template (Charles et al., 2024; Dai et al., 2024).

One of the clearest structural shifts in recent decades has been the divergence between declining graphic-paper markets and expanding packaging- and recovery-related segments. Hasegawa et al. (2022) report that global graphic-paper production rose until 2007, peaked at approximately 156 million tonnes, and then declined to about 110 million tonnes by 2019. They further argue that the traditional positive linkage between income growth and graphic-paper demand has weakened at higher income levels, largely because digital media have displaced printed communication. This decoupling between economic growth and resource-intensive production is not limited to final paper demand; recent evidence indicates that aggregate economic growth has also partially decoupled from upstream chemical wood pulp production in advanced European economies due to structural shifts toward service-oriented sectors (Aydoğan, 2026a). In parallel, packaging has become the dominant paper-and-paperboard segment, accounting for 59% of global production in 2018, with continued support from population growth, income growth, e-commerce, and takeaway consumption. This reconfiguration implies that paper demand can no longer be treated as a unified aggregate market; instead, category-level analysis has become necessary to distinguish mature or declining paper segments from expanding fibre-based uses (Hasegawa et al., 2022).

The mechanisms behind this divergence are not only consumption-side, but also technological and trade-related. Vivas et al. (2024) identify digitalization, changing social behaviour, and sustainability as three major megatrends reshaping the pulp and paper industry, and they emphasise that the shift “from paper to paperless” reduces the supply of recycled fibres traditionally derived from printing and writing papers. Shen and Lovrić (2022), examining global trade in graphic paper and pulp products over 1995–2017, likewise show that declining newsprint trade is mirrored in printing and writing paper and mechanical wood pulp, while several Asian countries have become increasingly prominent in the evolving trade network. Their results also suggest that structural network effects can be more explanatory than classical gravity-type

variables alone. Taken together, these studies imply that the contemporary paper economy is being reshaped simultaneously by digital substitution, raw-material reallocation, and changing trade structures, all of which can alter both domestic availability and international dependence (Shen and Lovrić, 2022; Vivas et al., 2024).

The growing role of recovered paper further complicates this picture. Recycling is often presented as a straightforward circular-economy solution, but the literature shows that its material and market performance depends critically on collection systems, sorting quality, contaminants, and domestic processing capacity. Jin et al. (2023) report that the U.S. paper recycling rate has recently been around 66–68%, with 46 million tonnes recycled in 2018 and more than 155 million tonnes of avoided CO₂ emissions, yet only a limited share of recyclable paper was reprocessed domestically because of quality constraints and insufficient demand for recycled products. Belle et al. (2024) reach a related conclusion for Germany: although the country achieved a recovered-paper utilization rate of 83% and a recycling rate of 85%, the quality of paper for recycling changes continually because of legislation, innovations, coatings, laminates, and other impurities, and raw-material quality remains a central concern for the industry. These studies suggest that the recovered-paper segment cannot be understood solely as a quantity problem; it is equally a problem of material quality, regulation, and recycling-system design (Jin et al., 2023; Belle et al., 2024).

International trade adds a further layer of instability to paper-market adjustment. Cheng et al. (2023) show that China’s pulp and paper import structure changed substantially under the combined effects of the COVID-19 pandemic, the U.S.–China trade dispute, and restrictions on waste-paper imports. In particular, they find that packaging-paper imports increased during the pandemic and that China’s import orientation shifted away from some traditional partners toward new suppliers. The broader implication is that paper trade patterns can be rapidly reorganized by policy shocks, supply-chain disruptions, and changes in waste-paper regulation. For countries whose domestic markets already depend on imported pulp, paper, or recovered fibre, such restructuring can materially affect both input security and category-specific supply dynamics.

These issues are especially relevant in the Turkish case. Gür and Eşidir (2024) describe Türkiye’s paper and paper-products sector as increasingly dependent on foreign inputs, particularly cellulose/pulp, while also noting that domestic waste-paper collection remains insufficient relative to sectoral needs. They report that paper imports rose from USD 939 million in 2000 to USD 3.96 billion in 2022 and note that Europe’s paper recovery rate is around 70–75%, compared with 40–45% in Türkiye. On the waste-management side, Koyuncu et al. (2026) show that awareness of packaging-waste recycling is widespread in Türkiye, but actual separation behaviour remains more limited: although more than 75% of survey respondents stated that they recognized recycling symbols, only 45% reported regularly separating packaging waste. This combination of rising import dependence and incomplete domestic recovery suggests that Türkiye provides a particularly relevant setting in which to study how paper categories evolve under simultaneous pressure from macroeconomic growth, trade exposure, and uneven recycling capacity (Gür and Eşidir, 2024; Koyuncu et al., 2026).

Existing empirical studies, however, remain fragmented. Mohseni et al. (2025) estimate a recycled-paper demand function for Iran using a cointegration framework and show that long-run demand is shaped by GDP, prices, and internet use, while short-run adjustment is governed by a statistically significant ECM term; they also argue that recycled paper may behave as an inferior good in the long run as producers and consumers shift toward higher-quality virgin inputs. Aydin et al. (2023), by contrast, examine recovered-paper consumption from an environmental perspective and emphasize the resource-saving potential of recycling, noting that paper recycling can reduce wood use, water use, energy use, and landfill pressure, while also reporting that developed countries commonly achieve recycled-paper rates in the 70–75% range. These studies are valuable, but they do not resolve the central question addressed here: how different paper categories within a single country co-evolve under changing domestic demand, production, imports, and broader trade exposure. In particular, the literature still lacks a category-comparative time-series analysis for Türkiye that jointly examines printing and writing papers and recovered paper within a common empirical framework (Aydin et al., 2023; Mohseni et al., 2025).

Against this background, the present study investigates the long-run evolution of paper consumption and supply structure in Türkiye over 2000–2024 by focusing on two categories: printing and writing papers and recovered paper. Rather than treating paper demand as a single aggregate series, the study constructs category-specific apparent-consumption measures and examines how they relate to domestic production, imports, exports, and macroeconomic conditions. The empirical design therefore combines descriptive market decomposition with time-series diagnostics and category-specific ARDL modelling. This framework makes it possible to address three linked questions: whether the two categories exhibit common or divergent long-run trajectories, whether domestic availability is primarily production-led or import-supported, and whether stable long-run macro-demand relationships can be identified equally across categories.

The study makes three contributions. First, it provides a category-level account of Turkish paper consumption that distinguishes clearly between a traditional paper segment and a recovery-oriented fibre segment. Second, it brings trade structure directly into the interpretation by examining domestic production coverage and import dependence rather than relying on consumption levels alone. Third, it tests whether the long-run adjustment properties of these two categories are empirically symmetric, rather than assuming that all paper-related series respond similarly to macroeconomic demand conditions. In doing so, the article aims to connect market restructuring, circular-material use, and trade dependence within a single country case that is both industrially relevant and analytically underexplored.

2. Material and Methods

2.1 Study scope, data sources, and analytical frame

This study examines the long-run evolution of paper consumption and supply structure in Türkiye using annual data for 2000–2024. The empirical design combines official product-

level paper statistics with macroeconomic indicators and aggregate external-trade data. The analytical focus is deliberately category-specific rather than fully aggregated, because the descriptive evidence suggests that printing and writing papers and recovered paper evolved under different supply-demand configurations.

Three official data systems were used. First, annual macroeconomic and demographic indicators were obtained from the World Bank World Development Indicators, including GDP per capita (current US\$), household final consumption expenditure (current US\$), population, and individuals using the Internet (% of population). Second, product-level paper statistics were taken from FAOSTAT, which reports annual production and trade series for forest-product categories, including printing and writing papers and recovered paper. Third, broader external-trade information was obtained from UN Comtrade, using the HS 48 chapter covering paper and paperboard and related articles.

The empirical strategy was organized in five stages. First, the study constructed category-level consumption and supply indicators from the underlying production and trade data. Second, the main variables were examined descriptively through summary statistics, correlation analysis, and long-run visual inspection. Third, the stochastic properties of the log-transformed series were assessed using ADF, KPSS, and Zivot–Andrews tests. Fourth, alternative ARDL specifications were estimated for each paper category. Fifth, only models supported by the bounds-testing framework were carried forward to long-run and error-correction interpretation. This staged approach was chosen to align model specification with the actual data properties rather than imposing a single econometric structure *ex ante*. The logic of ARDL is especially useful when regressors may be a mixture of $I(0)$ and $I(1)$, provided none is $I(2)$ (Dickey and Fuller, 1979). Owing to this inherent flexibility in accommodating variables with varying orders of integration, the ARDL framework has been increasingly adopted in contemporary research to ensure robust long-run estimations (Bölük and Mert, 2015; Murthy and Okunade, 2016; Kripfganz and Schneider, 2023; Xuan, 2025; Aich et al., 2026).

2.2 Variable construction and notation

In this study, the following notation was used from the stochastic-testing stage onward:

- i. C_t^{PWP} : apparent consumption of printing and writing papers
- ii. C_t^{REC} : apparent consumption of recovered paper
- iii. Y_t : GDP per capita
- iv. H_t : household final consumption
- v. M_t : paper and paperboard imports
- vi. X_t : paper and paperboard exports

Their logarithmic forms are denoted by $\ln C_t^{PWP}$, $\ln C_t^{REC}$, $\ln Y_t$, $\ln H_t$, $\ln M_t$, and $\ln X_t$, respectively. The category-level dependent variables were constructed as apparent consumption series. For each paper category $j \in \{PWP, REC\}$, apparent consumption was defined as:

$$C_t^j = P_t^j + IM_t^j - EX_t^j \quad (1)$$

where P_t^j is domestic production, IM_t^j is import quantity, and EX_t^j is export quantity. This formulation is standard in material-balance analysis and provides a direct measure of domestic availability rather than final demand in the narrow national accounts sense. Two structural supply indicators were then derived for descriptive interpretation. The domestic production coverage ratio was defined as:

$$DPC_t^j = \frac{P_t^j}{C_t^j} \quad (2)$$

and the import dependence ratio as:

$$ID_t^j = \frac{IM_t^j}{C_t^j} \quad (3)$$

These ratios were used to distinguish between categories sustained primarily by domestic production and those more heavily dependent on imported supply. In the results section, these measures were especially useful for interpreting the contrast between printing and writing papers and recovered paper.

Per-capita consumption series were also constructed as:

$$PC_t^j = \frac{100 \times C_t^j}{POP_t} \quad (4)$$

where POP_t denotes total population and the factor 1000 converts tonnes to kilograms. In addition, the broader paper and paperboard trade balance was computed from the HS 48 trade series as exports minus imports, while total trade was defined as the sum of imports and exports. The ratio of total paper and paperboard trade to household final consumption was used only as a descriptive auxiliary indicator and was not retained in the preferred ARDL specifications.

Because the core econometric analysis focuses on long-run relationships and proportional adjustment, the principal modelled variables were transformed into natural logarithms. Log transformation improves interpretability in elasticity-type settings and reduces the scale imbalance between macroeconomic and product-quantity variables. It also aligns naturally with the ARDL–ECM representation adopted below (Pesaran et al., 2001). This methodological framework is consistent with an extensive body of empirical literature that employs the ARDL–ECM approach to examine long-run dynamics across various economic and industrial contexts (Jiang et al., 2012; Adeleye et al., 2018; Pata and Isik, 2021; Abid, 2025; Nguyen et al., 2026).

2.3 Descriptive analysis and preliminary association structure

The analysis began with standard descriptive statistics for all principal variables, including the number of observations, mean, standard deviation, minimum, and maximum. These statistics were reported both to characterize the scale differences between the two paper categories and to identify whether the trade and macroeconomic variables were of comparable order for subsequent modelling.

Bivariate association was then examined using the Pearson correlation coefficient. The correlation stage served a dual purpose. First, it provided a compact empirical summary of how the paper-consumption variables co-moved with macroeconomic and trade indicators. Second, it informed the later ARDL specification search by identifying potentially problematic collinearity. In particular, because GDP per capita and household final consumption are conceptually related macro-demand indicators, they were treated as alternative regressors rather than being jointly imposed in the preferred specifications.

The descriptive stage was also used to motivate the figure design. Long-run trajectories were first examined in levels and per-capita terms, then decomposed into production, imports, and exports, and finally converted into structural ratios of domestic supply coverage and import dependence. This progression was intentional: it moves the interpretation from simple trend description toward a more mechanism-oriented understanding of category-specific supply structure.

2.4 Unit root testing and structural-break diagnostics

Because spurious inference may arise when non-stationary variables are modelled in levels without appropriate cointegration structure, the order of integration of the main log-transformed series was examined before ARDL estimation. Two complementary conventional tests were first applied: the Augmented Dickey–Fuller (ADF) test and the KPSS test. The ADF regression can be written as:

$$\Delta z_t = \alpha + \beta_t + \gamma z_{t-1} + \sum_{i=1}^k \phi_i \Delta z_{t-i} + \varepsilon_t \quad (5)$$

where z_t denotes the series under test, t is a deterministic time trend where applicable, and k is the selected lag order. The null hypothesis $H_0: \gamma = 0$, corresponding to the presence of a unit root. Dickey and Fuller (1979) developed this framework for testing non-stationarity in autoregressive time series.

The KPSS test was used as a complement because its null hypothesis is stationarity rather than a unit root. In the present study, the joint use of ADF and KPSS was intended to reduce the risk of over-interpreting a single test outcome, especially in a relatively short annual sample. The KPSS procedure proposed by Kwiatkowski, Phillips, Schmidt, and Shin is specifically designed to test stationarity against the alternative of a unit root (Kwiatkowski et al., 1992).

To assess whether the stochastic characterization of the series changed once an endogenous break was allowed for, a Zivot–Andrews unit root test with one structural break was also employed. In generic form, the test augments the ADF framework with break dummies in the intercept and/or deterministic trend:

$$\Delta z_t = \alpha + \beta_t + \theta DU_t(\tau) + \psi DT_t(\tau) + \gamma z_{t-1} + \sum_{i=1}^k \phi_i \Delta z_{t-i} + \varepsilon_t \quad (6)$$

where $DU_t(\tau)$ and $DT_t(\tau)$ represent break dummies associated with a candidate endogenous break date τ . The break date is selected internally as the one that provides the strongest

evidence against the unit-root null. This procedure follows Zivot and Andrews (2002), who showed that allowing the break date to be determined endogenously generally reduces spurious rejections relative to approaches that impose the break exogenously.

The unit root stage was interpreted conservatively. A variable was treated as clearly $I(1)$ only when the level-series evidence was consistent with non-stationarity and the first-difference evidence was broadly consistent with stationarity. Borderline cases were explicitly retained as such rather than forced into a sharper classification than the sample justified. This conservative stance is especially important in annual samples of modest length.

2.5 ARDL specification strategy

The long-run modelling framework was based on the autoregressive distributed lag (ARDL) approach. The ARDL class is attractive in the present setting because it accommodates regressors that may be a mixture of $I(0)$ and $I(1)$, avoids requiring that all variables share the same integration order, and permits direct recovery of both long-run and error-correction representations when a level relationship is supported by the data. The framework follows the ARDL cointegration logic developed by Pesaran and Shin (2013) and formalized in the bounds-testing approach of Pesaran, Shin, and Smith (2001). The general ARDL specification was written as:

$$z_t = \alpha + \sum_{i=1}^p \varphi_i z_{t-i} + \sum_{m=1}^K \sum_{j=0}^{qm} \beta_{mj} \omega_{m,t-j} + u_t \quad (7)$$

where z_t is the dependent variable, $\omega_{m,t}$ are the regressors, p is the autoregressive lag order, and qm is the distributed lag order for regressor m .

Given the strong macro-correlation observed in the data, the study did not estimate a single saturated model. Instead, four theoretically motivated ARDL families were considered:

$$M1: \ln C_t^{PWP} = f(\ln Y_t, \ln M_t) \quad (8)$$

$$M2: \ln C_t^{PWP} = f(\ln H_t, \ln M_t) \quad (9)$$

$$M3: \ln C_t^{REC} = f(\ln Y_t, \ln X_t) \quad (10)$$

$$M4: \ln C_t^{REC} = f(\ln H_t, \ln X_t) \quad (11)$$

This architecture mirrors the empirical logic of the Results section. For printing and writing papers, domestic demand conditions and import dependence were treated as the most plausible long-run correlates. For recovered paper, the descriptive and correlation evidence suggested a stronger empirical connection with export-side dynamics, so exports were paired with the macro-demand indicators as alternative regressors.

Because the sample is annual and relatively short, lag searching was deliberately conservative. Only cointegration-eligible models were retained in the search, meaning that the dependent variable lag order and the lag orders of all included regressors were constrained to be at least one. Candidate orders were searched over a compact grid with $p, q_1, q_2 \in \{1, 2\}$, and the preferred order within each model family was selected using the Akaike information criterion (AIC). This choice reflects the

need to balance dynamic flexibility against the finite-sample penalty of over-parameterization.

2.6 Bounds testing, long-run representation, and ECM form

After lag selection, each candidate specification was recast into its unrestricted error-correction model (UECM) form in order to test for a level relationship. For the bivariate regressor case used here, the generic UECM representation can be written as:

$$\Delta z_t = \alpha + \lambda z_{t-1} + \delta_1 \omega_{1,t-1} + \delta_2 \omega_{2,t-1} + \sum_{i=1}^{p-1} \phi_i \Delta z_{t-i} + \sum_{j=0}^{q_1-1} \theta_j \Delta \omega_{1,t-j} + \sum_{k=0}^{q_2-1} n_k \Delta \omega_{2,t-k} + \varepsilon_t \quad (12)$$

The null hypothesis of no cointegration is:

$$H_0: \lambda = \delta_1 = \delta_2 = 0 \quad (13)$$

which was tested using the bounds-testing procedure of Pesaran, Shin, and Smith (2001). Cointegration was treated as supported only when the bounds statistic provided evidence against the null under the unrestricted intercept, no-trend case used in the estimated models.

For specifications supported by the bounds test, the normalized long-run relationship was then extracted from the estimated cointegrating vector. These long-run coefficients were interpreted cautiously, because in normalized ARDL output the coefficients reflect the cointegrating relation rather than a static ordinary least squares regression. Consequently, the primary evidence for retaining a long-run specification came from the combination of bounds-test support, sign-consistent error correction, and overall fit, rather than from overemphasizing any single long-run coefficient in isolation.

Finally, the preferred model was interpreted through its error-correction representation as follows:

$$\Delta z_t = \alpha + \rho ECT_{t-1} + \sum_j \theta_j \Delta \omega_{1,t-j} + \sum_k n_k \Delta \omega_{2,t-k} + v_t \quad (14)$$

where ECT_{t-1} denotes the lagged equilibrium error implied by the long-run relation. The coefficient ρ measures the speed at which short-run disequilibria are corrected. A negative and statistically significant ρ was treated as the necessary condition for stable convergence back to the long-run equilibrium.

In addition to the bounds-testing and ECM interpretation, post-estimation diagnostic tests were applied to the preferred cointegrated ARDL-ECM specification. Serial correlation was examined using the Breusch-Godfrey LM test, ARCH-type heteroskedasticity was assessed using the ARCH LM test, and residual normality was evaluated using the Jarque-Bera test. Parameter stability was further investigated using recursive CUSUM and CUSUMSQ tests at the 5% significance level. These diagnostics were used to assess whether the preferred model satisfies the residual and stability conditions required for reliable short-run and long-run interpretation.

2.7 Presentation logic and inferential scope

The empirical results were organized to match the modelling sequence. Descriptive statistics and long-run figures were used first to identify the category-level divergence and changing supply structure. Correlation and unit-root diagnostics then provided the statistical basis for model selection. ARDL estimation was subsequently used not as a blanket framework for all variables, but as a category-specific device whose admissibility depended on actual evidence of cointegration.

This point defines the inferential scope of the study. The ARDL-based long-run interpretation is not generalized across both paper categories. Rather, it is retained only for the category and specification for which the data support a stable level relationship under the bounds-testing framework. In the present study, that means the preferred long-run ARDL interpretation is restricted to printing and writing papers, while the recovered

paper models are discussed descriptively and comparatively, but not advanced as preferred long-run cointegrated specifications.

3. Results and empirical interpretation

3.1 Descriptive structure of the series and long-run divergence across paper categories

Before proceeding to formal stochastic diagnostics and ARDL estimation, the empirical structure of the series must first be established at the descriptive level. Two features are immediately relevant for the remainder of the analysis. First, the two paper categories do not share a common long-run trajectory. Second, the scale, dispersion, and external-trade profile of the variables already suggest that paper use in Türkiye evolved under markedly different supply-demand configurations across product groups.

Table 1. Descriptive statistics of paper consumption, macroeconomic conditions, and trade variables in Türkiye (2000–2024)

Variable	N	Mean	Std. Dev.	Min.	Max.
Printing and writing papers consumption (million tonnes)	25	0.928	0.280	0.364	1.254
Recovered paper consumption (million tonnes)	25	2.000	0.917	0.911	4.206
Printing and writing papers consumption per capita (kg)	25	12.148	3.259	5.495	16.466
Recovered paper consumption per capita (kg)	25	25.780	9.691	13.752	49.177
GDP per capita (current USD)	25	9,443.03	3,174.07	3,052.23	15,892.72
Household final consumption (billion USD)	25	418.58	148.39	127.36	737.66
Paper and paperboard imports (billion USD)	25	2.40	0.83	0.65	4.06
Paper and paperboard exports (billion USD)	25	1.25	0.75	0.17	2.84
Paper and paperboard trade balance (billion USD)	25	-1.16	0.51	-2.01	-0.21

Notes. The table reports the number of observations, mean, standard deviation, minimum, and maximum for the principal variables used in the empirical analysis over the period 2000–2024. Physical series are expressed in million tonnes or kilograms per capita, while trade and expenditure variables are reported in billion current USD to improve readability.

Table 1 summarises the descriptive properties of the principal variables used in the empirical analysis. Apparent consumption of recovered paper occupied a much larger quantitative space than apparent consumption of printing and writing papers throughout the sample. Mean apparent consumption was 0.928 million tonnes for printing and writing papers, compared with 2.000 million tonnes for recovered paper. The same difference is visible in per-capita terms: the corresponding sample means were 12.148 kg and 25.780 kg, respectively. Recovered paper also displayed substantially wider upper-range expansion, reaching a maximum of 4.206 million tonnes, whereas printing and writing papers peaked at 1.254 million tonnes. These descriptive differences are not merely scalar; they indicate that the two categories belong to materially different empirical regimes within the broader paper economy.

The broader macroeconomic and external-sector environment also changed materially over the period 2000–2024. GDP per capita averaged USD 9,443.03, while household final consumption averaged USD 418.58 billion. At the same time, paper and paperboard imports averaged USD 2.40 billion, compared with mean exports of USD 1.25 billion, implying an average trade balance of USD -1.16 billion. Even at the descriptive stage, the empirical picture is therefore one of category-specific consumption dynamics embedded in a persistently import-exposed paper market. The long-run trajectories shown in Figure 1 make these descriptive asymmetries more transparent.

Figure 1 confirms that paper consumption in Türkiye evolved in a highly category-specific manner. Apparent consumption of printing and writing papers increased from approximately 0.49 million tonnes in 2000 to around 1.25 million tonnes in the mid-2010s, before weakening and ending the sample near 0.87 million tonnes in 2024 (Figure 1A). Recovered paper, by contrast, expanded much more strongly, rising from roughly 0.94 million tonnes at the beginning of the sample to around 4.21 million tonnes by the end. The same asymmetry is visible in per-capita terms (Figure 1B): printing and writing papers remained comparatively modest and softened in the later years, whereas recovered paper consumption per capita increased to nearly 49.2 kg per person.

The category-level trajectories unfolded alongside a changing macroeconomic and trade environment. GDP per capita and household final consumption both display broad long-run expansion despite visible interruptions, particularly around the late-2000s and the subsequent adjustment phase (Figure 1C). Over the same period, paper and paperboard imports remained consistently above exports (Figure 1D), indicating persistent net import dependence in the broader market. Taken together, Table 1 and Figure 1 establish the central descriptive result of the study: growth in paper use in Türkiye was not generalized across categories but became increasingly concentrated in recovered paper rather than in printing and writing papers.

3.2 Quantity decomposition and supply-side restructuring

Aggregate consumption paths alone do not reveal how domestic availability was assembled. For that reason, the next step is to decompose apparent consumption into production,

imports, and exports. This is substantively important because similar apparent-consumption levels can be sustained by very different combinations of domestic production and external supply.

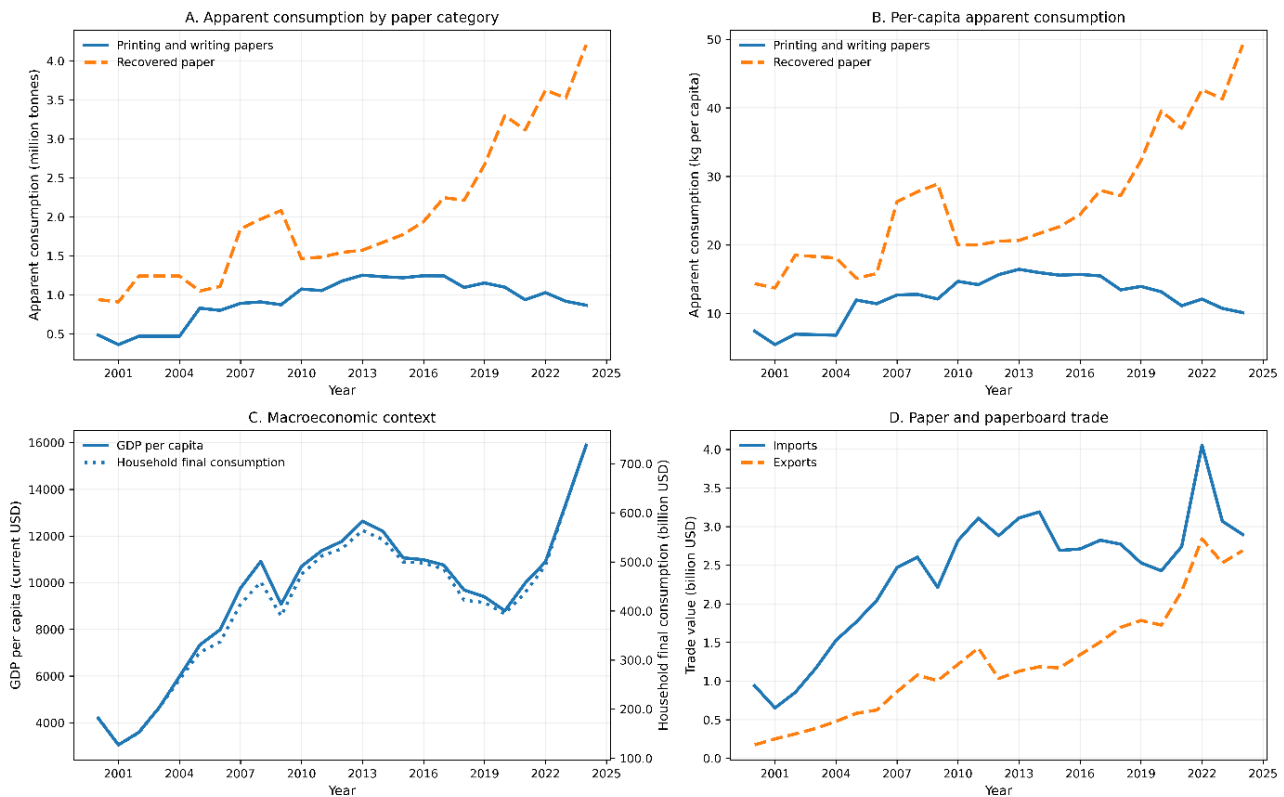


Figure 1. Long-run evolution of paper consumption and market context in Türkiye, 2000–2024. Panel A presents apparent consumption for printing and writing papers and recovered paper. Panel B reports the corresponding per-capita apparent consumption series. Panel C summarizes the macroeconomic context using GDP per capita and household final consumption. Panel D shows total imports and exports in paper and paperboard trade.

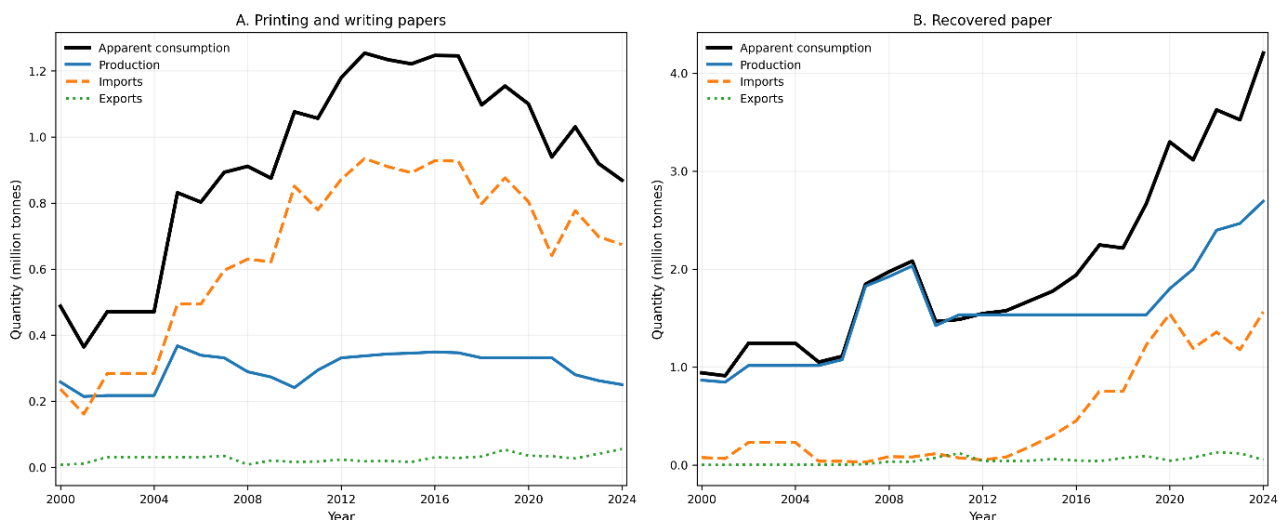


Figure 2. Production, imports, exports, and apparent consumption by paper category in Türkiye, 2000–2024. Panel A shows the long-run evolution of production, imports, exports, and apparent consumption for printing and writing papers. Panel B presents the corresponding series for recovered paper. In both categories, exports remain small relative to domestic production and imports, while the gap between domestic production and apparent consumption highlights the changing role of imports in domestic availability.

Figure 2 shows that printing and writing papers consumption remained structurally above domestic production throughout the sample. Domestic production fluctuated within a relatively narrow band, while imports consistently exceeded exports and served as the principal balancing component in domestic availability. Exports remained quantitatively small and did not materially reshape the supply picture. The substantive implication is clear: the domestic market for printing and writing papers was persistently supported by imported supply.

Recovered paper followed a different structure. In the earlier part of the sample, domestic production accounted for most of the quantity underlying apparent consumption, and the

consumption path initially remained close to domestic production. Over time, however, apparent consumption rose beyond production by an increasingly visible margin, particularly in the later years, and this widening gap coincided with a marked increase in imports. Exports remained comparatively small. Recovered paper thus began as a predominantly production-led category but gradually evolved toward a more mixed supply structure in which imports became increasingly visible.

The structural interpretation becomes even clearer once the level series are transformed into ratios that directly measure domestic supply coverage and import dependence.

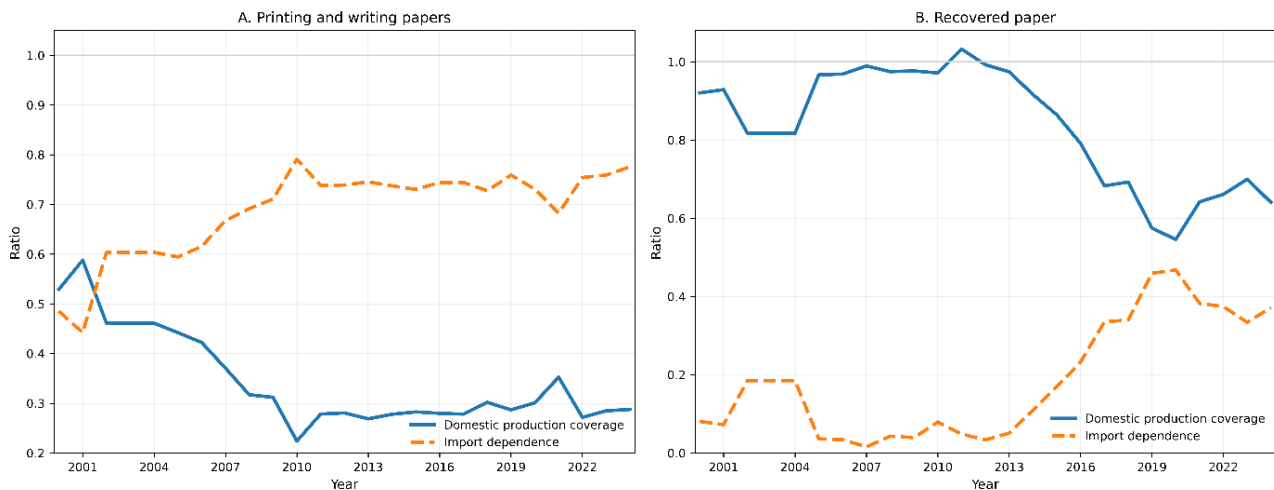


Figure 3. Domestic production coverage and import dependence by paper category in Türkiye, 2000–2024. The domestic production coverage ratio is defined as production divided by apparent consumption, while the import dependence ratio is defined as imports divided by apparent consumption. Panel A shows that printing and writing papers remained strongly import-dependent throughout the sample. Panel B indicates that recovered paper was initially characterized by high domestic supply coverage, although this weakened over time as import dependence increased.

Figure 3 summarises the same evolution in ratio form. For printing and writing papers, the domestic production coverage ratio declined from roughly 0.53 at the beginning of the sample to approximately 0.23 by 2010 and remained low thereafter, ending near 0.29 in 2024. In parallel, the import dependence ratio rose from around 0.48 to roughly 0.79 by 2010 and stayed elevated through the end of the period. This is strong evidence that printing and writing papers consumption in Türkiye remained structurally import-dependent across the full sample.

Recovered paper followed a different supply trajectory. Its domestic production coverage ratio was initially very high, generally around 0.9–1.0, and even slightly exceeded unity in the early 2010s, but later weakened, falling to approximately 0.64 by 2024. Over the same period, import dependence rose from a very low initial base to around 0.37 at the end of the sample. The key result is therefore not that recovered paper became more import-dependent than printing and writing papers; it did not. Rather, the more important conclusion is that even a category initially characterized by strong domestic supply coverage experienced a clear increase in import reliance over time.

Taken together, Figures 2 and 3 show that the two categories differ not only in their consumption trajectories, but also in their

supply architecture. Printing and writing papers were characterized by persistent import-supported domestic availability, whereas recovered paper moved from near-domestic coverage toward a more hybrid structure in later years.

3.3 Correlation structure and stochastic properties of the main series

Because the notation and variable construction have already been defined in Section 2, the results below are presented directly in their coded empirical form. The correlation matrix in Table 2 shows that the main variables are positively associated, but the strength of association differs across categories. Printing and writing papers consumption is strongly correlated with GDP per capita ($r = 0.782$), household final consumption ($r = 0.771$), and especially paper and paperboard imports ($r = 0.843$). Recovered paper consumption is also positively associated with the macroeconomic indicators, but its strongest bivariate relationship is with paper and paperboard exports ($r = 0.935$). This result is consistent with the descriptive evidence that the two categories evolved under different supply-demand configurations.

Table 2. Pearson correlation matrix of the main study variables

	C_t^{PWP}	C_t^{REC}	Y_t	H_t	M_t	X_t
C_t^{PWP}	1.000	0.368*	0.782***	0.771***	0.843***	0.543***
C_t^{REC}	0.368*	1.000	0.625***	0.642***	0.610***	0.935***
Y_t	0.782***	0.625***	1.000	0.997***	0.893***	0.752***
H_t	0.771***	0.642***	0.997***	1.000	0.885***	0.768***
M_t	0.843***	0.610***	0.893***	0.885***	1.000	0.797***
X_t	0.543***	0.935***	0.752***	0.768***	0.797***	1.000

Notes. Entries are Pearson correlation coefficients. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 3. Unit root properties of the main study variables based on ADF and KPSS tests

Variable	ADF (Level)	KPSS (Level)	ADF (1st Diff.)	KPSS (1st Diff.)	Inference
$\ln C_t^{PWP}$	-0.580	0.481**	-1.517	0.275	Likely I(1)
$\ln C_t^{REC}$	1.934	0.685**	-4.862***	0.111	I(1)
$\ln Y_t$	-1.377	0.515**	-4.310***	0.144	I(1)
$\ln H_t$	-1.609	0.533**	-1.761	0.129	Likely I(1)
$\ln M_t$	-1.880	0.533**	-3.537***	0.254	I(1)
$\ln X_t$	-2.949**	0.692**	-3.666***	0.420*	Mixed / borderline

Notes. ADF denotes the Augmented Dickey–Fuller test, for which the null hypothesis is the presence of a unit root. KPSS denotes the Kwiatkowski–Phillips–Schmidt–Shin test, for which the null hypothesis is stationarity. The reported values are test statistics for logarithmically transformed series. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

One result from Table 2 is particularly important for the model-selection stage. GDP per capita and household final consumption are almost perfectly correlated ($r = 0.997$), which implies that both variables should not be treated as independent macro controls within the same preferred specification. For that reason, the ARDL analysis below is organized around alternative model families rather than full specifications containing both macro indicators simultaneously. The time-series properties of the data also support a cautious modelling strategy.

The combined evidence from the ADF and KPSS tests in Table 3 indicates that most variables are non-stationary in levels. Recovered paper consumption, GDP per capita, and paper and paperboard imports exhibit a pattern broadly consistent with $I(1)$ behaviour. Printing and writing papers consumption and household final consumption are more cautiously described as likely $I(1)$, since the first-difference evidence is somewhat weaker under the ADF test even though the KPSS test no longer rejects stationarity after differencing. Paper and paperboard exports remain the least clear-cut case and are best treated as mixed/borderline. Crucially, none of the tested series displays a pattern suggestive of $I(2)$ behaviour, which preserves the admissibility of the ARDL framework.

To examine whether this characterization changes once a structural break is allowed for, the analysis also considered the Zivot–Andrews test.

As reported in Table 4, allowing for a single endogenous structural break does not materially overturn the level non-stationarity result. For all main variables, the Zivot–Andrews test fails to reject the unit-root null. At the same time, the

estimated break years are not random. They cluster around economically plausible periods, including the mid-2000s, the post-2008 adjustment phase, and the early-to-mid 2010s. These dates are best interpreted as candidate transition points rather than definitive regime breaks. Substantively, however, the key result is that the non-stationary characterization of the series in levels remains broadly intact even after allowing for one endogenous break in the deterministic component.

Table 4. Zivot–Andrews unit root test with one endogenous structural break

Variable	ZA statistic	p-value	Break year	Used lag
$\ln C_t^{PWP}$	-3.628	0.5953	2004	1
$\ln C_t^{REC}$	-4.187	0.2455	2009	1
$\ln Y_t$	-4.041	0.3273	2014	1
$\ln H_t$	-4.127	0.2770	2014	1
$\ln M_t$	-3.246	0.8198	2014	1
$\ln X_t$	-4.159	0.2603	2011	1

Notes. The Zivot–Andrews test allows for one endogenous break in the deterministic component of each series. Reported results are based on log-transformed variables. The null hypothesis is the presence of a unit root with no structural-break adjustment sufficient to induce stationarity. Break years should be interpreted as candidate endogenous break dates rather than as definitive regime boundaries.

The estimated break years also have plausible economic interpretations in the Turkish paper-market context. The 2004 break can be associated with Türkiye's post-2001 stabilization and recovery period, during which macroeconomic demand conditions and import capacity improved after the earlier financial crisis. The 2009 break is consistent with the Global

Financial Crisis and the associated contraction and rebalancing in industrial demand, trade flows, and consumption. The 2011 break may reflect the post-crisis normalization phase, during which paper and paperboard trade expanded under changing regional and global demand conditions. The 2014 break, observed for several macroeconomic and trade-related series, coincides with a period of weaker external financing conditions, exchange-rate volatility, and adjustment in import-dependent sectors. These interpretations should not be read as formal causal identification; rather, they indicate that the endogenous break years selected by the Zivot-Andrews procedure correspond to economically meaningful transition points in Türkiye's macroeconomic and paper-market environment.

3.4 ARDL model selection and evidence on cointegration

Given the descriptive structure, strong macro correlation, and mixed but broadly $I(1)$ -type stochastic properties of the series, the next step is to evaluate alternative ARDL specifications. The goal here is not merely to fit one model per category, but to determine whether the data support a stable long-run relationship under theoretically plausible combinations of macro-demand and trade variables.

The model-selection results reported in Table 5 show a clear asymmetry between the two paper categories. For printing and writing papers, both candidate ARDL families produce bounds-test evidence consistent with cointegration. The specification using GDP and imports ($M1$) yields a bounds statistic of 5.256, whereas the specification using household final consumption

and imports ($M2$) yields a stronger statistic of 6.323. Since $M2$ also performs better in terms of information criteria, it is retained as the preferred specification for long-run interpretation.

By contrast, the recovered paper models do not generate comparable evidence. The specification using GDP and exports ($M3$) yields a bounds statistic of only 2.042, and the household-consumption-plus-exports specification ($M4$) yields 2.190. In both cases, the null of no cointegration cannot be rejected. Accordingly, recovered paper is not carried forward as a preferred long-run ARDL model, and the remainder of the ARDL interpretation is confined to printing and writing papers.

This difference matters substantively. It suggests that the long-run adjustment mechanism captured by the ARDL framework is clearer for printing and writing papers than for recovered paper. Thus, while both categories display major structural change in the descriptive evidence, only the former yields sufficiently coherent cointegration evidence under the present annual specification.

3.5 Long-run and short-run dynamics in the preferred printing and writing papers model

Once the preferred ARDL specification has been identified, the remaining task is to interpret the long-run relationship and its associated short-run adjustment mechanism. Because the selected model $M2$ is the household-consumption and imports specification for printing and writing papers, the results below should be read as category-specific rather than representative of all paper-related series in the dataset.

Table 5. ARDL model selection and bounds test results

Model	Dependent variable	Regressors	Selected ARDL order	AIC	Bounds F-statistic	p-value
M1	lnC_t^{PWP}	lnY_t, lnM_t	(1, 2, 2)	-28.704	5.256	0.0147
M2	lnC_t^{PWP}	lnH_t, lnM_t	(1, 2, 2)	-31.300	6.323	0.0033
M3	lnC_t^{REC}	lnY_t, lnX_t	(1, 1, 1)	-13.469	2.042	0.5210
M4	lnC_t^{REC}	lnH_t, lnX_t	(1, 1, 1)	-13.898	2.190	0.4660

Notes. ARDL orders are reported in the form (p, q1, q2). Bounds-test decisions are based on the unrestricted intercept, no-trend specification.

Table 6. Long-run estimates from the preferred ARDL model for printing and writing papers consumption

Variable	Coef.	Std. Err.	t	P-value	95% CI Lower	95% CI Upper
Constant	8.999	4.653	1.934	0.053	-0.865	18.863
Household final consumption	-1.132	0.597	-1.895	0.058	-2.398	0.134
Paper and paperboard imports	0.345	0.546	0.633	0.527	-0.812	1.503

Notes. The table reports the normalised cointegrating vector from the preferred ARDL specification, with printing and writing papers consumption as the dependent variable. Coefficients are presented in logarithmic form. The preferred specification was selected on the basis of the AIC among cointegration-eligible models.

Table 7. Error-correction and short-run dynamics from the preferred ARDL model

Variable	Coef.	Std. Err.	t	P-value	95% CI Lower	95% CI Upper
Constant	-8.797	4.848	-1.815	0.088	-19.074	1.479
Error-correction term	-0.978	0.236	-4.149	0.001	-1.477	-0.478
Household final consumption (level)	1.107	0.594	1.864	0.081	-0.152	2.365
Paper and paperboard imports (level)	-0.338	0.522	-0.647	0.527	-1.443	0.768
Δ Household final consumption	-0.181	0.341	-0.531	0.603	-0.905	0.542
Δ Household final consumption (-1)	-0.948	0.387	-2.452	0.026	-1.767	-0.128
Δ Paper and paperboard imports	0.331	0.233	1.418	0.175	-0.164	0.825
Δ Paper and paperboard imports (-1)	0.568	0.354	1.606	0.128	-0.182	1.317

Notes. The table reports the unrestricted error-correction representation associated with the preferred ARDL model for printing and writing papers consumption. The error-correction term captures the speed at which short-run deviations are corrected toward the long-run equilibrium.

The long-run results for the preferred specification are reported in Table 6 as a normalised cointegrating vector. These estimates should therefore be interpreted carefully and not read as if they were simple static regression coefficients. Within that normalisation, household final consumption enters with borderline statistical significance ($p = 0.058$), whereas paper and paperboard imports remain positive but imprecisely estimated ($p = 0.527$). The constant is also borderline ($p = 0.053$). The strongest conclusion from Table 6 is therefore not the precision of each individual coefficient taken in isolation, but rather the existence of an overall long-run relationship for printing and writing papers consumption under the preferred model. The short-run side of the preferred specification is more informative.

As shown in Table 7, the error-correction term is negative and highly significant (-0.978 , $p = 0.001$), which is exactly the sign structure required for stable adjustment back toward the long-run equilibrium. The magnitude implies relatively rapid correction of disequilibrium at the annual frequency. Among the short-run regressors, the clearest result is the lagged first difference of household final consumption, which is negative and statistically significant (-0.948 , $p = 0.026$). By contrast, the short-run import terms are not statistically significant. Taken together, these results suggest that the preferred ECM specification is shaped more by the adjustment of domestic demand conditions than by immediate short-run import responses. The graphical fit of the preferred ARDL model is shown next.

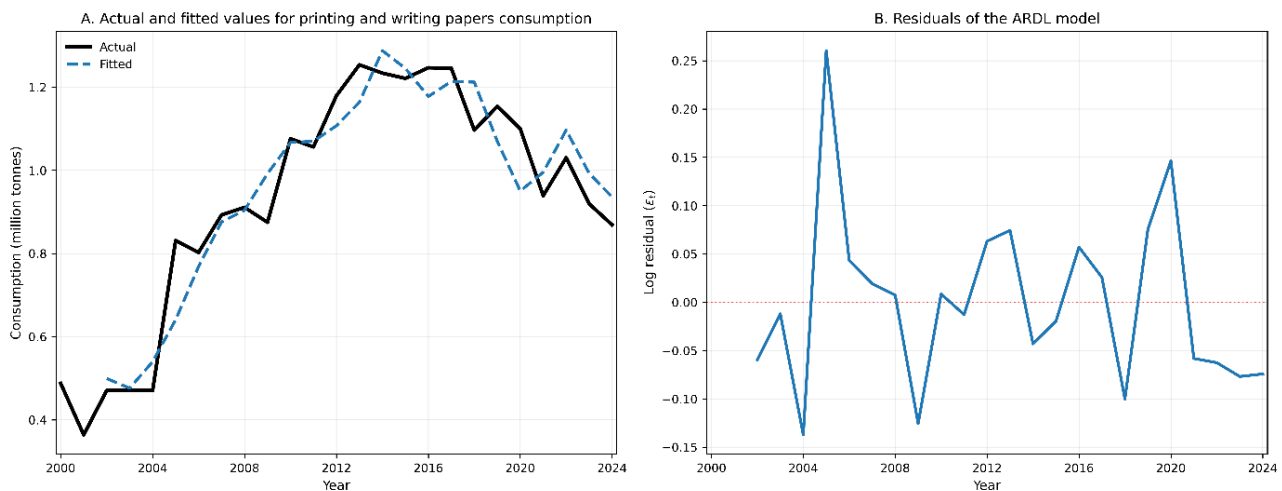


Figure 4. Actual and fitted values from the preferred ARDL model for printing and writing papers consumption in Türkiye, 2000–2024. Panel A compares the observed series with fitted values from the preferred ARDL specification. Panel B reports the corresponding residuals. The fitted series captures the broad medium-run dynamics of the observed series, while the residuals fluctuate around zero without a persistent directional pattern.

Figure 4 indicates that the preferred model captures the broad medium-run trajectory of printing and writing papers consumption reasonably well. The fitted series tracks the post-2005 rise, the elevated plateau in the 2010s, and the subsequent weakening phase with acceptable accuracy. It does not reproduce every short-lived fluctuation exactly, but it does recover the main turning points of the observed series. The largest deviations are concentrated in the mid-2000s, particularly around 2004–2006, when the observed series exhibits an abrupt upward shift. This pattern suggests that the preferred ARDL specification is effective in tracking the medium-run evolution of the series but is less successful in reproducing short-lived level adjustments during sharper transition episodes.

Overall, the ARDL results support a restrained but coherent conclusion. For printing and writing papers, there is evidence of a long-run relationship with macro-demand conditions and import-linked market structure, and this relationship is supported by a strong and correctly signed error-correction mechanism. For recovered paper, however, the present annual specifications do not yield equivalent evidence of cointegration. The empirical implication is therefore category-specific: long-

run ARDL interpretation is supported for printing and writing papers but not generalized across all paper-related series in the sample.

3.6 Model diagnostics and parameter stability

Because the preferred ARDL-ECM specification is used for long-run and short-run interpretation, additional residual diagnostic and parameter stability tests were conducted. The results are reported in Table 8.

The diagnostic results do not provide evidence of residual serial correlation or ARCH-type heteroskedasticity in the preferred ARDL-ECM specification. The Jarque-Bera test does not reject residual normality at the 5% significance level, although the result is borderline at the 10% level. In addition, the CUSUM and CUSUMSQ tests indicate that the recursive statistics remain within the 5% critical boundaries, supporting the stability of the estimated parameters over the sample period. These findings strengthen the interpretation that the cointegrated relationship identified for printing and writing papers is not driven by residual misspecification or unstable model parameters.

Table 8. Residual diagnostic and stability tests for the preferred ARDL–ECM model

Test	Statistic	p-value	Inference
Breusch–Godfrey LM test, lag 2	1.058	0.589	No evidence of serial correlation
ARCH LM test, lag 2	0.937	0.626	No evidence of ARCH-type heteroskedasticity
Jarque–Bera test	4.844	0.089	Normality not rejected at 5%
CUSUM test	0.517	0.952	Stable
CUSUMSQ test	0.281	0.276	Stable

Notes. The diagnostic tests were applied to the preferred ARDL–ECM model for printing and writing papers consumption. The Breusch–Godfrey, ARCH LM, and Jarque–Bera tests examine serial correlation, ARCH-type heteroskedasticity, and residual normality, respectively. The model uses 23 effective observations after lag adjustment. CUSUM and CUSUMSQ results indicate that the recursive statistics remain within the 5% critical boundaries.

4. Discussion

4.1 Structural divergence across paper categories

The principal contribution of this study is to show that paper consumption in Türkiye did not evolve as a single integrated market, but rather as two distinct category-specific trajectories. The descriptive results indicate that recovered paper occupied a much larger quantitative space than printing and writing papers over 2000–2024, with mean apparent consumption of 2.000 million tonnes versus 0.928 million tonnes, and a much higher upper bound (4.206 versus 1.254 million tonnes). The same divergence is visible on a per-capita basis. This pattern is not an incidental statistical contrast; it points to a deeper restructuring in the composition of paper use in Türkiye.

This category-specific divergence is consistent with broader market evidence showing that traditional graphic-paper segments have weakened, whereas packaging- and circularity-related paper segments have expanded. Hassegawa et al. (2022) report that global demand for graphic paper has declined over the last fifteen years, while packaging demand has increased, and Lemenkova (2025) similarly shows that in Italy the decline of newsprint has been accompanied by strong growth in packaging-related paper output under digitalization and e-commerce pressures. In the same direction, Mohseni et al. (2025) argue that the spread of the internet can reduce demand for printed materials while simultaneously stimulating demand for packaging paper, cardboard, and recycled-paper use through online shopping and logistics expansion. Read together with the present results, these studies suggest that the weakening of printing and writing papers in Türkiye should not be interpreted as an isolated national anomaly, but rather as part of a wider structural shift in paper markets.

The supply-side evidence strengthens this interpretation. In the present study, printing and writing papers remained structurally above domestic production throughout the sample, while the domestic production coverage ratio fell from roughly 0.53 at the start of the period to around 0.23 by 2010 and ended near 0.29 in 2024. Over the same period, the import dependence ratio rose from approximately 0.48 to 0.79 and remained elevated. Recovered paper followed a different path: it began with domestic production coverage close to 0.9–1.0, but later weakened to around 0.64, while import dependence rose to roughly 0.37 by the end of the sample. In other words, both categories became more externally exposed over time, but the extent and form of this exposure differed sharply between them.

This result is especially important because it shows that the rise of recovered paper in Türkiye should not be read as a simple story of domestic circularity replacing external sourcing. Rather,

recovered paper expanded under a more mixed supply structure in which imports also became increasingly important. That interpretation is consistent with Gür and Eşidir (2024), who note that the Turkish paper and paper-products sector remains constrained by imported inputs, pulp dependence, and insufficient domestic waste-paper collection, even though the sector has grown and advanced in some segments. Their trade figures also show the magnitude of the import issue, with paper imports rising from USD 939 million in 2000 to USD 3.96 billion in 2022. The present findings therefore place Türkiye within a broader class of paper markets where growth in secondary-fibre use can coexist with persistent, and in some cases rising, dependence on external raw-material and product flows.

4.2 Import dependence, recycling capacity, and the asymmetry of long-run evidence

A second major implication of the results concerns the relationship between domestic demand, trade structure, and recycling-system capacity. In the present data, the broader paper and paperboard market remained persistently net import dependent, with mean imports of USD 2.40 billion compared with mean exports of USD 1.25 billion. This external imbalance is not merely a macro backdrop; it materially shapes the interpretation of both the descriptive figures and the ARDL estimates. For printing and writing papers, imports were not a peripheral supplement but a central component of domestic availability. For recovered paper, domestic production remained more important, but the later widening gap between production and apparent consumption indicates that imports increasingly acted as an adjustment channel there as well.

This interpretation aligns with broader international evidence showing that pulp and paper trade structures are highly sensitive to shifts in costs, policy, recycling regulations, and supply-chain disruption. The sensitivity of these markets to structural changes underlines the operational necessity of regime-aware monitoring frameworks capable of tracking wood-related trade and production dynamics reliably under disruption (Aydoğan, 2026b). For example, Cheng et al. (2023) show that in China the structure of pulp and paper imports shifted significantly under trade disputes, waste-paper import restrictions, and the COVID-19 shock, with packaging-paper imports increasing and the centre of gravity of imports moving away from the United States toward Southeast Asia and South America. Jin et al. (2023) likewise demonstrate that dramatic changes in global recovered-paper markets, especially following Chinese import restrictions, forced a major reorganization of domestic recycling, sorting, and reprocessing strategies in the

United States. Together, these studies suggest that the Turkish pattern observed here, persistent import dependence alongside a growing recovered-paper segment, should be interpreted within a wider international reallocation of fibre supply and paper-market geography, rather than as a purely domestic demand phenomenon.

This international context also helps explain the asymmetry in the econometric results. Only the printing and writing papers models produced bounds-test evidence consistent with cointegration, and the preferred specification was the household-consumption-plus-imports model with a bounds F-statistic of 6.323. By contrast, neither recovered-paper model yielded support for cointegration. The most plausible interpretation is not that recovered paper is economically unstructured, but that its evolution is governed by a more fragmented system in which macro-demand indicators alone are insufficient to recover a stable long-run equilibrium relation under annual data. Recovered paper markets are likely conditioned by a combination of waste collection, sorting quality, recycling capacity, product standards, logistics, and trade rules. This reading is reinforced by Jin et al. (2023), who emphasize the importance of collection efficiency, sorting systems, and processing capacity in shaping paper-recycling outcomes, and by Dai et al. (2024), who argue that the role of recycling differs markedly across countries depending on forest endowment, waste management, and upstream–downstream conditions.

The contrast with Mohseni et al. (2025) is instructive here. In their study of recycled-paper demand in Iran, long-run demand is linked to GDP, prices, and internet use, and the error-correction coefficient indicates meaningful short-run re-equilibration. In the Turkish case, however, recovered paper does not display an equivalent cointegrated relation with the selected macro and trade regressors. This difference should not be treated as a contradiction so much as evidence of country-specificity. Mohseni et al. (2025) themselves stress that recycled-paper demand is shaped jointly by macroeconomic conditions, digitalization, and sector-specific substitution patterns. The Turkish results suggest that once recovered paper is embedded in a larger trade-dependent and capacity-constrained system, macro-demand proxies alone may no longer be sufficient to anchor a stable long-run relationship.

For printing and writing papers, the econometric evidence points in a different direction. The preferred ARDL model supports cointegration, and the associated ECM yields a negative and highly significant error-correction term of -0.978 , implying rapid adjustment back toward long-run equilibrium after short-run shocks. At the same time, the normalized long-run coefficients themselves are not sharply estimated, which cautions against over-reading them as direct elasticities. The stronger conclusion is therefore structural rather than coefficient-specific: printing and writing papers consumption in Türkiye still behaved like a macro-demand-linked and import-mediated segment, even while its long-run growth potential weakened. This is fully compatible with the descriptive evidence of a mature or pressured paper segment operating under rising import exposure and digital substitution.

The magnitude of the error-correction coefficient deserves particular attention. An adjustment coefficient of -0.978 at the annual frequency implies that almost the entire disequilibrium

from the previous period is corrected within the following year. In the context of Türkiye's printing and writing papers market, this rapid adjustment is economically plausible for three related reasons. First, the category is highly import-mediated, as shown by the persistently low domestic production coverage ratio and high import-dependence ratio; therefore, deviations between domestic demand and available supply can be corrected relatively quickly through import volumes rather than through slower domestic capacity expansion. Second, printing and writing papers represent a mature and increasingly pressured segment under digital substitution, which limits the persistence of excess demand and encourages faster stock and procurement adjustment. Third, because apparent consumption is constructed from production, imports, and exports, annual rebalancing in trade flows can mechanically translate into rapid correction in the measured consumption equation. Thus, the high ECT magnitude should be interpreted as evidence of fast annual market re-equilibration in an import-dependent and demand-constrained segment, rather than as evidence of instantaneous physical adjustment within the year.

4.3 Implications for fibre security and circular policy

From a policy perspective, the results support a dual conclusion. First, the expansion of recovered paper in Türkiye is meaningful and should be regarded as an economically and materially important part of the sector's transformation. Second, that expansion has not eliminated structural dependence on external supply. Dai et al. (2024) argue that countries with limited forest resources often need both sustainable imports and stronger waste-paper recycling to address raw-material scarcity. Their analysis also emphasizes that recycling effects are highly country-specific and cannot be treated as universally identical across all national systems. In that sense, the Turkish evidence fits a pragmatic circular-economy reading: recycling and recovered-paper use can relieve fibre scarcity, but they do not automatically create self-sufficiency.

The domestic recycling bottleneck is also visible from the broader Turkish waste-management literature. Koyuncu et al. (2026) show that although packaging-waste awareness is widespread in Türkiye, only 45% of respondents report regularly separating packaging waste, and the study identifies source separation as a critical condition for improving recycling performance. This is directly relevant to the present results. If recovered-paper use is rising while import dependence also rises, then one plausible inference is that domestic recovery and quality-sorting systems are not yet strong enough to fully absorb growing fibre demand. The policy implication is therefore not simply “recycle more”, but rather “collect better, sort better, and process better”. Source separation, infrastructure, and quality control matter as much as aggregate recycling rhetoric.

The environmental interpretation should also remain disciplined. Aydın et al. (2023) frame recovered-paper consumption within a broader sustainability logic, emphasizing that recycling can reduce waste, conserve natural resources, and relieve environmental pressure, although the net effects vary across contexts. Dai et al. (2024) go further by showing that the climate and resource effects of recycling are not uniform across countries and depend heavily on waste-management quality and upstream forest conditions. The present study is not a life-cycle

or emissions analysis, so it cannot claim that Türkiye's recovered-paper expansion is automatically equivalent to proportional environmental improvement. What it can say, more cautiously, is that the sectoral shift toward recovered paper is economically substantial and materially consistent with a transition toward a more circular fibre base, even though that transition remains incomplete and still embedded in import dependence.

More broadly, the findings reinforce the importance of national heterogeneity in pulp and paper transitions. Lipiäinen et al. (2022) show that even within Europe, decarbonization possibilities differ strongly according to sector structure and resource endowment, and Charles et al. (2023) similarly stress that pulp and paper transition pathways vary across regions depending on biomass availability, electrification options, and industrial structure. Although the present article does not estimate emissions pathways, its demand-side and trade-side results point to the same general principle: Türkiye's paper transition cannot be read through a single universal model. Printing and writing papers and recovered paper follow different economic logics, and any viable policy strategy must treat them accordingly.

Finally, the present results also indicate where future research should move. The recovered-paper side of the Turkish market is unlikely to be fully explained without direct measures of collection efficiency, waste-paper recovery, sorting quality, prices, exchange-rate pass-through, and packaging-specific end use. Cheng et al. (2023) highlight the importance of trade costs, exchange rates, and policy shocks in pulp and paper imports, while Mohseni et al. (2025) show that prices and internet use can materially affect recycled-paper demand. A next-stage study for Türkiye would therefore benefit from integrating explicit price variables, exchange-rate measures, domestic recycling indicators, and, where possible, higher-frequency data. That would allow the descriptive and comparative asymmetry identified here to be tested in a more structurally complete econometric setting.

5. Conclusions

This study examined the long-run evolution of paper consumption and supply structure in Türkiye over the period 2000–2024 by distinguishing between printing and writing papers and recovered paper rather than treating paper demand as a single aggregate market. Using annual data compiled from FAOSTAT, the World Bank, and UN Comtrade, the analysis combined descriptive decomposition, structural ratio analysis, unit-root diagnostics, and category-specific ARDL–ECM modelling.

Three conclusions emerge. First, paper consumption in Türkiye evolved along two clearly differentiated category-specific trajectories. Printing and writing papers followed a weaker and ultimately softening path, while recovered paper expanded much more strongly in both aggregate and per-capita terms. This confirms that the Turkish paper market cannot be interpreted as a homogeneous demand system and that category-level disaggregation is essential for meaningful empirical inference.

Second, the two categories also differed sharply in their supply architecture. Printing and writing papers remained

structurally import-dependent throughout the sample, with domestic production covering only a limited share of apparent consumption and import dependence remaining persistently high. Recovered paper initially displayed strong domestic production coverage, but this advantage weakened over time as import dependence increased. The rise of recovered paper in Türkiye should therefore not be interpreted as a simple transition to domestically closed-loop circularity. Rather, it reflects a more mixed structure in which growing use of recovered fibre has coexisted with continued external dependence.

Third, the econometric results were category-specific rather than universal. Evidence of cointegration was found only for printing and writing papers. The preferred ARDL specification linked this category to household final consumption and paper-and-paperboard imports, and the associated ECM yielded a negative and highly significant error-correction term, indicating stable adjustment toward long-run equilibrium. By contrast, the recovered-paper models did not produce equivalent bounds-test evidence. This suggests that recovered paper in Türkiye is shaped by a more fragmented adjustment process in which macro-demand indicators alone are insufficient to recover a stable long-run relationship under annual data.

These findings carry both analytical and policy implications. Analytically, they show that paper-market transition in Türkiye is best understood through a category-specific and supply-aware framework, not through aggregate paper-demand indicators alone. From a policy perspective, the results imply that increasing recovered-paper use, while important, is not by itself sufficient to reduce structural dependence on external supply. If Türkiye aims to strengthen fibre security and move toward a more genuinely circular paper economy, greater attention must be given to domestic collection systems, source separation, sorting quality, and recycling capacity expansion. In other words, the critical challenge is not only to use more recovered paper, but also to create the domestic institutional and industrial conditions that allow a larger share of that demand to be met internally.

A further econometric limitation concerns sample size. The study uses annual observations for 2000–2024, yielding only 25 observations. Although the ARDL bounds-testing approach is relatively well suited to small samples compared with traditional cointegration techniques, an $N=25$ annual sample still imposes strict degrees-of-freedom constraints, especially when distributed lags and diagnostic checks are included. For this reason, the model-selection procedure was kept deliberately parsimonious, the lag search was restricted to a compact grid, and the econometric findings were interpreted as category-specific long-run evidence rather than as unrestricted structural causal estimates.

The study should also be read in light of several limitations. The analysis uses annual data and a parsimonious macro-trade specification, which necessarily abstracts from explicit price effects, exchange-rate movements, collection efficiency, and product-quality differences in recovered fibre. These omitted mechanisms are likely to be especially important for explaining the absence of cointegration in the recovered-paper models. Future research could therefore extend the present framework by incorporating price variables, exchange rates, domestic recycling indicators, and higher-frequency data, thereby

providing a more complete account of how paper consumption, trade, and circular-material use interact in the Turkish market.

Consequently, the evidence supports a restrained but clear conclusion: Türkiye's paper transition has been real, but uneven. Recovered paper has become increasingly important, yet the system remains materially and structurally exposed to imports. The Turkish paper economy is therefore best characterized not as fully transformed, but as partially reconfigured under conditions of differentiated category dynamics and incomplete circular adjustment.

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