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Forecasting the Future of Female Labor Force Participation in the Turkish Labor Market via Artificial Intelligence Modeling and the Strategic Role of Higher Education

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Abstract

Although the female labor force participation rate is one of the fundamental indicators of sustainable development, Türkiye lags significantly behind the OECD average in this regard. This study aimed to analyze the closing process of the gender gap in the Turkish labor market and to develop education-based policy scenarios in line with the 2050 vision. In the research, Bayesian Ridge regression, a predictive artificial intelligence model, was employed using TURKSTAT data from the 2005-2024 period, with predictive performance tested through a train-test split and time-series cross-validation against Ordinary Least Squares. According to the baseline scenario projection, where current socioeconomic dynamics continue without intervention, the model predicted that female and male labor force participation rates in Türkiye could only reach full parity in 2081, with findings presented together with 95% confidence intervals. To achieve full parity in 2050, an extra acceleration need of 0.74 percentage points annually in the female labor force participation rate was identified. As a result of the deterministic cohort shifting simulation applied to meet this acceleration need, it was verified that a regular annual increase of 2.45% in the transition rate of female high school graduate cohorts to higher education makes the parity target of 78.49% in 2050 mathematically achievable. The analyses revealed that strategic and intergenerational interventions in the educational composition may be among the most effective policy tools for Türkiye to reach its mid-century employment targets. By systematically integrating machine learning predictions with educational policies, this study presents a unique and practically applicable methodological contribution to the literature.

Keywords: Female labor force participation, Turkish labor market, Gender equality, Artificial intelligence, Bayesian ridge regression.

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Yapay Zekâ Modellemesi ile Türkiye İş Gücü Piyasasında Kadın Katılımının Geleceğinin Tahmini ve Yükseköğretimin Stratejik Rolü

Özet

Kadın iş gücü katılım oranı, sürdürülebilir kalkınmanın temel göstergelerinden biri olmasına rağmen Türkiye, bu alanda OECD ortalamasının oldukça gerisinde kalmaktadır. Bu çalışma; Türkiye iş gücü piyasasındaki cinsiyet açığının kapanma sürecini analiz etmeyi ve 2050 yılı vizyonu doğrultusunda eğitim temelli politika senaryoları geliştirmeyi amaçlamıştır. Araştırmada, 2005–2024 yıllarına ait TÜİK verileri temele alınarak tahmine dayalı bir yapay zekâ modeli olan Bayesyen Ridge regresyonu uygulanmıştır. Modelin öngörü performansı; eğitim-test ayrımı ve zaman serisi çapraz doğrulaması ile sınanmış, sonuçlar Sıradan En Küçük Kareler yöntemiyle karşılaştırılarak değerlendirilmiştir. Mevcut sosyoekonomik dinamiklerin müdahalesiz devam ettiği baz senaryo projeksiyonuna göre Türkiye'de kadın ve erkek iş gücü katılım oranlarının ancak 2081 yılında tam eşitliğe ulaşabileceği öngörülmüştür. Bulgular, tam eşitlik projeksiyonlarına ilişkin %95 güven aralıklarıyla birlikte sunulmuştur. 2050 yılında tam eşitliğin sağlanabilmesi için kadın iş gücü katılım hızında yıllık %0,74 puanlık bir ekstra ivme ihtiyacı saptanmıştır. Bu ivme ihtiyacını karşılamak amacıyla uygulanan deterministik kohort kaydırma simülasyonu sonucunda; liseden mezun olan kadın kuşaklarının yükseköğretime geçiş oranında her yıl düzenli olarak yapılacak %2,45'lik bir artışın, 2050 yılındaki %78,49'luk eşitlik hedefini matematiksel olarak ulaşılabilir kıldığı ortaya konmuştur. Yapılan analizler, eğitim kompozisyonundaki stratejik ve kuşaklararası müdahalelerin, Türkiye'nin yüzyıl ortası istihdam hedeflerine ulaşmasında en etkili politika araçlarından biri olabileceğine işaret etmektedir. Bu çalışma, makine öğrenmesi tahminleri ile eğitim politikalarını sistematik biçimde entegre ederek literatüre özgün ve uygulanabilir bir metodolojik katkı sunmaktadır.

Anahtar Kelimeler: Kadın iş gücü katılımı, Türkiye iş gücü piyasası, Cinsiyet eşitliği, Yapay zekâ, Bayesyen ridge regresyonu.

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Extended Abstract

Women's labor force participation is widely recognized as a key component of sustainable economic development and a measurable indicator of gender equality. Integrating women into the labor market is also a strategic macroeconomic priority that can mobilize underutilized productive capacity. However, women's participation rates remain persistently lower than men's worldwide, particularly in Türkiye. Türkiye has one of the lowest female labor force participation rates among OECD countries, posing a significant obstacle to its long-term macroeconomic goals and 2050 vision. Although the existing literature has extensively examined determinants such as demographic change, household constraints, and regional inequalities, predictive and simulation-based projections remain limited. In particular, there is a lack of forward-looking, data-driven models that estimate the extent of educational expansion required to achieve full gender parity and the likely timeline for doing so. This study addresses this gap by identifying the projected parity year at which women's and men's labor force participation rates intersect and by quantitatively modeling the educational interventions required to bring full parity forward to the target year of 2050.

The theoretical framework draws on empirical research on the Turkish labor market. Previous studies consistently identify education as one of the most important determinants of women's labor force participation. Research has shown that higher educational attainment can alter demographic patterns by delaying the age at first marriage and reducing fertility rates while also providing a buffer against macroeconomic shocks and traditional household constraints. The transition from an agriculture-based economy to an urban economy often leaves women with lower levels of education in unpaid family work or outside the labor force because of household responsibilities. Higher education, however, can help overcome these structural barriers. The literature also emphasizes the cohort effect, suggesting that long-term transformations in labor markets are driven primarily by generational shifts rather than sudden behavioral changes within the existing adult population. Building on these insights, this study seeks to develop actionable, data-driven policy guidance.

To achieve this objective, the study employs a two-stage analytical framework that combines predictive machine learning with deterministic policy simulation. The primary dataset consists of official labor market statistics published by the Turkish Statistical Institute (TurkStat) and covers the twenty-year period from 2005 to 2024. These time-series data include overall labor force participation rates and breakdowns by educational attainment. In the first stage, predictive time-series modeling was used to construct a baseline scenario in which current socioeconomic dynamics continue without external policy shocks. Bayesian ridge regression was employed because its regularization framework helps manage statistical uncertainty and reduce the risk of overfitting. The model was trained on historical data to project the baseline trajectories of labor force participation

rates. The second stage consisted of a goal-oriented scenario analysis targeting 2050. A deterministic simulation model was developed based on the compositional effect and the cohort-shift principle. Using the net employment premium associated with moving from high school-level attainment to higher education, the model establishes an algebraic balance equation to estimate the annual increase required in the proportion of female high school graduate cohorts transitioning to higher education.

The empirical findings derived from the Bayesian ridge model reveal that the convergence of women's and men's labor force participation rates in Türkiye is likely to proceed slowly under the baseline scenario. Although women's labor force participation is projected to follow a steady upward trend, the gender gap would not close completely until 2081 if current socioeconomic trends continued without strategic intervention. The model further projects that a gender gap of 18.76 percentage points would remain in 2050. Achieving full parity by that year would require women's labor force participation rate to increase by an average of 1.60 percentage points annually. The baseline annual increase, however, is projected to be only 0.86 percentage points. The analysis therefore identifies a need for an additional annual increase of 0.74 percentage points, which would need to be generated through targeted public policies.

The final stage of the analysis presents the results of the educational composition simulation designed to generate this additional annual increase of 0.74 percentage points. Analysis of the 2024 baseline data indicates that moving from high school-level attainment to higher education is associated with a net employment premium of 30.20 percentage points among women. Based on this premium, the deterministic model estimates that an additional 2.45% of female high school graduate cohorts would need to transition to higher education each year for the labor force participation rate to reach the projected parity level of 78.49% in 2050. This scenario illustrates how relatively small but consistent intergenerational interventions targeting educational composition could contribute to substantial macroeconomic change over time.

The findings indicate that achieving full gender parity in the Turkish labor market by 2050 is mathematically feasible under the assumptions of the model, but would require sustained and strategically targeted educational intervention. The continuation of current socioeconomic trends without additional policy measures would postpone parity until the late twenty-first century. Based on these findings, the study recommends that policymakers develop targeted mechanisms—including scholarships, university admission quotas, and vocational guidance programs—to increase the transition of young female high school graduates to higher education. A key limitation of the deterministic model is that it treats labor demand and macroeconomic fluctuations as exogenous variables. Future research should integrate the education–employment projection model with sectoral employment needs and regional labor market dynamics to provide a more comprehensive framework. By combining machine-learning-based

projections with education-oriented policy scenarios, this study offers a novel methodological contribution and a concrete roadmap for narrowing the gender gap.

Keywords: Female labor force participation, Turkish labor market, Gender equality, Artificial intelligence, Bayesian ridge regression.

1. Introduction

Women's labor force participation, one of the most fundamental components of sustainable development and social welfare, is regarded both as a driver of economic growth and as one of the clearest indicators of gender equality. In the global economy, integrating women into the labor market is not only a matter of rights but also a strategic necessity for bringing underutilized capacity into the economy. However, worldwide and especially in Türkiye, women's labor force participation rates exhibit a structural lag relative to men's participation rates. Türkiye remains one of the OECD countries with the lowest female labor force participation rates; this poses a serious obstacle to the country's macroeconomic objectives for 2050. The historical roots of this structural gender gap in Türkiye lie in the alignment of post-1950 economic growth strategies with family models (İlkkaracan, 2012). A comprehensive study examining pooled employment data and household survey data for 1955–2009 found that there had never been a demand-side intervention in the labor market challenging the "male breadwinner" family model and that this had institutionalized the gender-based division of labor as a structural constraint on women's labor supply. Combined with the prevalence of informal employment and the absence of measures for reconciling paid work and family life, this institutional constraint further deepens supply-side barriers and structurally limits women's ability to translate their individual investments in education into labor force participation (İlkkaracan, 2012).

The factors affecting women's labor force participation have been examined extensively across various dimensions, including demographic change (Akgeyik, 2017), household constraints (Ayvaz Kızılgöl, 2012), and regional inequalities (Er, 2014). Although much of the existing research has empirically demonstrated the positive effect of education on participation (Tansel, 2002), this conclusion has also been reaffirmed in more recent work (Gençtürk, 2022). Nevertheless, there remains a lack of forward-looking, simulation-based, and data-driven projections indicating "how large an educational leap" would be required to achieve full parity and "in what year" it could be achieved. This gap in literature calls for moving beyond traditional statistical methods by using predictive artificial intelligence (AI) models and goal-oriented scenario analyses.

The primary objective of this study is to identify the "natural parity year" in which women's and men's participation rates in the Turkish labor market would fully intersect at the macroeconomic level and to quantitatively model the strategic educational initiative required to bring this process forward to 2050. The study employs Bayesian ridge regression, which can capture complex trends in time-series data with high accuracy, together with a deterministic simulation model built on the cohort-shift principle. This hybrid methodology not only describes the current situation but also measures how small-scale interventions in the transition rate from high school to higher education could generate an accelerating effect at the macro level.

The findings indicate that, under current trends, Türkiye would not achieve full parity until 2081; however, the 2050 target would be mathematically attainable if an additional 2.45% of each cohort of female high school graduates were directed to higher education every year. Through its concrete policy recommendation and AI-based projection method, this study aims to make an original methodological contribution to the literature on women's employment in Türkiye. The following sections present the theoretical framework of the analysis, the technical characteristics of the dataset, and the detailed implementation steps of the model.

Within this framework, the study addresses three main questions: (i) If current socioeconomic dynamics remain unchanged, in what year will women's and men's labor force participation rates in Türkiye reach parity? (ii) What additional annual increase in women's participation is required to achieve full parity by the target year of 2050? (iii) What annual increase in the transition rate from high school to higher education is required to generate this additional increase? The study is based on two main assumptions. First, under the baseline scenario, current trends will continue without any external policy intervention. Second, the nationwide female labor force participation rate can be treated as a weighted average calculated from the participation rates of groups at different levels of educational attainment (the compositional effect).

2. Literature Review

2.1. Empirical Studies on Women's Labor Force Participation in Türkiye

Women's decisions to participate in the labor market and the socioeconomic constraints that shape these decisions constitute a broad area of research in both national and international literature. Studies focusing on Türkiye show that women's employment is determined by multilayered variables such as educational attainment, household dynamics, regional inequalities, and macroeconomic transformations.

2.2. The Driving Role of Education and Human Capital

The most fundamental finding on which the literature agrees is the unequivocally positive effect of education on women's employment. A study examining women's labor force dynamics in Türkiye through demographic variables found, on the basis of TurkStat statistics for 2007–2016, that the principal factor driving the increase in employment participation rates was "the rise in educational attainment" (Akgeyik, 2017). The study also emphasized that demographic transformations accompanying higher educational attainment—such as the postponement of women's age at first marriage, changes in divorce rates, and declining fertility rates—accelerated labor market participation. The global validity of this strong relationship between educational attainment and women's labor supply was also confirmed in the context of developing countries (Yakubu, 2010). Using data from South Africa's 2008 Quarterly Labour Force Survey, Yakubu's empirical analysis with logistic regression models demonstrated, within the framework of Human Capital Theory (HCT), that education markedly increased women's likelihood of entering the labor force. More recent research retested these historical and international findings for Türkiye (Gençtürk, 2022). Analyzing the structural causes of the gender participation gap, Gençtürk attributed the continued large disparity between women's and men's participation in Türkiye, despite the overall upward trend, to sociodemographic constraints and argued that the transition to higher education is a strategic necessity for maximizing the potential of women at lower educational levels.

2.3. Household Dynamics, Marital Status, and Withdrawal from the Labor Force

The transformative power of education becomes more complex when women's household roles and microeconomic constraints are taken into account. One study addressed women's labor market entry decisions through a hierarchical framework and examined employment preferences using a nested logit model based on the assumption that decisions are made sequentially (Akın, 2002). The study found that marriage and a large number of children sharply suppressed women's employment, whereas education was the dominant factor directing women toward full-time and skilled employment. Similarly, a logit analysis using data for 2002–2008 to examine urban–rural differences highlighted the constraining effects of women's age and the number of dependents in the household on participation and empirically confirmed that education served as a fundamental lever for overcoming factors such as property ownership and household income when entering the labor market (Ayvaz Kızılgöl, 2012).

A study that deepened the analysis of household dynamics in the context of "discrimination and income inequality" applied a Mincer-type human capital model and the Oaxaca (1973) decomposition method to data from the 2002 Household Budget Survey (Gürler & Üçdoğruk, 2007). The probit model findings showed that being married and having children reduced women's participation disproportionately more than men's and that gender-based wage discrimination in the market could be overcome only by strengthening human capital endowments through education and experience. Approaching the issue from the reverse perspective of nonparticipation, another study focused on the "income effect" in logistic models developed for married and unmarried women in urban areas (Yıldırım & Doğrul, 2008). Its most striking finding was that higher spousal education and improved household economic well-being reinforced traditional roles and significantly reduced married women's willingness to work, or their labor supply. This finding demonstrates that women's employment should not be regarded solely as a means of combating poverty and that women's own independent educational attainment is essential.

2.4. Regional Differences, Urbanization, and Spatial Spillover Effects

Beyond individual factors, women's employment is also deeply affected by the spatial and urban dynamics of their location. A probit analysis conducted in Van Province examined the micro-level reflections of macro-level trends and confirmed the transformative role of education in overcoming local barriers (Levent et al., 2018). Extending the analysis of regional dynamics in Türkiye using data from the 2014 Household Labor Force Survey, a logit analysis disentangled the regional effects of educational levels and demonstrated that technical high school education consistently increased employment across all regions, from Western Marmara and the Aegean to eastern Türkiye (Korkmaz, 2016).

An analysis of urbanization and socioeconomic constraints using ordinary least squares (OLS) found that, despite the structural downward trend observed in women's employment in Türkiye, urban residence and increased education were the most resilient factors positively affecting entry into employment in the face of pressures created by spousal income and household size (Göksel, 2013). Taking this geographical perspective into a more advanced econometric dimension, a spatial analysis using data from 26 NUTS-2 regions was conducted (Er, 2014). The study found statistically significant positive spatial spillover effects: school enrollment and labor force participation rates in one region affected women's employment not only in that region but also in neighboring regions. It also emphasized that secondary-school enrollment was the principal factor mitigating fertility-related constraints (Er, 2014).

2.5. Structural Transformation, Macroeconomic Shocks, and the Cohort Effect

In addition to microeconomic constraints and regional differences, the course of women's employment is directly related to Türkiye's historical and macroeconomic transformations. One of the foundational studies in the literature conducted time-series analyses using cross-provincial data for 1980–1990 and demonstrated that economic crises and unemployment created a "discouraged worker" effect among women (Tansel, 2002). According to Tansel, high school and university education provide the strongest protection against this macroeconomic discouragement and help keep women connected to the labor market.

A vector autoregression (VAR) analysis of Türkiye's rural-to-urban migration and agricultural dissolution using data for 1988–2012 identified a structural break (Bozkaya, 2013). The study showed that women who migrated to cities as agricultural production declined and who lacked vocational education moved from the status of "unpaid family worker" in rural areas to that of "homemaker" in urban areas; the only factor offsetting this structural employment loss was an increase in general and vocational education. Similarly, panel data analyses covering 1988–2001 confirmed that unpaid family work and homemaker status were structural barriers to women's integration into the professional labor market and further noted that access to social security benefits, including retirement benefits, accelerated decisions to withdraw from the market (Özer & Biçerli, 2004).

Finally, one study placed employment dynamics on a generational rather than a static basis by examining survey data for 2000–2010 using cohort analysis (Talaş & Çakmak, 2013). The study empirically demonstrated that, beyond macroeconomic fluctuations, age and cohort membership were highly influential in women's labor force participation.

One of the most comprehensive microdata analyses to quantify this strategic necessity was conducted by Dayıoğlu and Kırdar (2010). Using household survey data for 1988–2006, this study, carried out in cooperation with the State Planning Organization and the World Bank, systematically analyzed the determinants and long-term trends of women's labor force participation in Türkiye. The research showed that the positive effect of education on women's labor supply was driven not only by higher income but also by fundamental changes in fertility behavior and marriage patterns; this finding provides a structural context for the 30.20-percentage-point net employment gain measured in the cohort-shift simulation used in the present study (Dayıoğlu & Kırdar, 2010).

These findings regarding Türkiye are also closely connected to the international literature. Goldin (1994) identified a U-shaped pattern in which married women's participation initially declines and then rises with economic development; she attributed the initial decline to the income effect and the subsequent rise to the substitution effect, which enables women—particularly those with secondary or higher education—to enter service-sector employment. However, the U-shaped relationship has

also been described as neither universal nor robust, because it does not hold for every country when tested using different datasets and methods (Lechman, 2014; Verick, 2018). Indeed, Verick (2018) documented the nonlinear course of women's participation in Türkiye, noting that the rate declined from 36.1% in 1989 to 23.3% in 2005 before rising to 33.5% in 2017.

A critical point emphasized by this literature is that translating higher educational attainment into women's employment depends not only on supply-side factors but also on demand-side conditions, including the creation of skilled jobs accessible to women (Verick, 2018). Using India as a case study, Klasen and Pieters (2015) showed that women's participation rates could stagnate despite rising educational attainment, demonstrating that optimism based on education alone may be insufficient.

From a methodological perspective, forward-looking, scenario-based projections have also been used in this literature. Richardson, Pacelli, and Richiardi (2018) projected women's participation rates for low-participation European countries using dynamic microsimulation and emphasized that such projections should be interpreted not as definitive forecasts but as benchmark scenarios indicating what would occur if existing dynamics continued.

Taken together, this rich and multidimensional literature indicates that overcoming women's historical disadvantages in market participation, regional constraints, and traditional domestic roles requires creating an "educational shock" at the macro level. Policymakers' ability to achieve long-term objectives such as those set for 2050 will depend on strategically directing new generations, or cohorts, toward higher education and skilled employment.

2.6. Effects of AI Tools on Gender Inequality

The AI-based forecasting approach that constitutes the methodological originality of this study should be considered not only as an analytical tool but also as an object of critical evaluation from a gender perspective. A systematic review of 36 peer-reviewed articles published between 2014 and 2020 found that although algorithmic decision-making systems in recruitment and human resource development may provide cost sa-

vings and efficiency gains, they may also expose certain groups to unfair treatment, implicit discrimination, and perceived injustice (Köchling & Wehner, 2020). The researchers emphasized in particular that algorithms trained on historical employment data risk reproducing and even deepening historical biases. This finding indicates that, when the Bayesian ridge model developed in the present study using historical TurkStat data is translated into policy recommendations, it should be interpreted in a manner that accounts for historical disadvantages rather than one that simply reinforces nominal equality of opportunity (Köchling & Wehner, 2020).

Indeed, unlike algorithmic systems based on past employment decisions, the approach followed in this study models only the trend in participation rates over time; in this respect, it does not directly carry the risk of learning discriminatory patterns identified by Köchling and Wehner (2020). Nevertheless, when the resulting projections are translated into policy recommendations, it is important that they be interpreted in a manner that does not reinforce existing structural disadvantages and that takes historical inequalities into account.

3. Method

This section explains the two-stage hybrid methodology designed to model the process of closing the gender gap in the Turkish labor market and to develop scenarios for the 2050 objectives. The following subsections first introduce the datasets underlying the research and then present the steps of the analytical model, which combines machine-learning forecasts with the cohort-shift principle.

3.1. Dataset

The primary material for the study consists of official labor force statistics published by the Turkish Statistical Institute (TurkStat). These data were compiled through the Household Labor Force Survey, which is conducted in accordance with the standards of Eurostat, the statistical office of the European Union, and the International Labour Organization (ILO). TurkStat's data-collection methodology is based on a household sampling system that covers all settlements across Türkiye. The population analyzed in the study represents the "noninstitutional working-age population" living in households within the borders of the Republic of Türkiye—that is,

persons aged 15 and older excluding residents of university dormitories, nursing homes, prisons, military barracks, and similar institutions.

In the first stage of data collection, the overall labor force structure was defined using the "Key Labor Force Indicators" for 2005–2024 (Türkiye İstatistik Kurumu [TÜİK], 2024a). The labor force was defined as the sum of employed and unemployed persons who supplied labor for the production of economic goods and services during the reference period. The labor force participation rate the share of this total in the noninstitutional working-age population was incorporated into the analysis by gender. In the second stage, the "Key Labor Force Indicators by Educational Attainment" (Türkiye İstatistik Kurumu [TÜİK], 2024b) were incorporated to model the effect of education on labor force participation. This dataset details the labor market positions of women who were illiterate or had completed less than high school, high school, vocational or technical high school, or higher education. Its statistics for 2020–2024, which reflect differences in participation between the high school and higher education levels in particular, formed a strategic component of the study.

The distinctive feature of the data-preparation stage was the processing and consolidation of TurkStat's 20-year general gender series and educational-attainment breakdowns into a purpose-built data matrix with a common time index. This final dataset enabled both the analysis of long-term trends using machine-learning algorithms and the calculation of the marginal weight of transitions between educational levels on labor force participation. Descriptive statistics for the variables used are presented in Table 1.

Table 1. *Descriptive Statistics for the Variables (2005–2024).*

Variable	n	Mean	SD	Min	Max	Period
Women's Labor Force Participation Rate (%)	20	29.11	5.31	21.20	36.80	2005–2024
Men's Labor Force Participation Rate (%)	20	69.72	1.98	67.10	72.50	2005–2024
Women: High School (%)	5	34.88	3.58	29.90	38.50	2020–2024
Women: Higher Education (%)	5	67.88	1.48	65.40	68.90	2020–2024

The overall participation series (Women_Overall and Men_Overall) contain 20 annual observations (n = 20), whereas the series disaggregated by educational attainment contain five annual observations (n = 5) because TurkStat began publishing this breakdown only in 2020. This limited sample size is also addressed as a limitation in interpreting the educational composition findings in the Limitations section.

3.2. Research Design

This study developed a two-stage hybrid analytical model to examine the process of closing the gender gap in the Turkish labor market and to generate quantitative policy scenarios. In the first stage, predictive time-series modeling was conducted using a predictive AI model. In the second stage, a goal-oriented scenario analysis was performed on the basis of these forecasts.

All analytical procedures, including data preprocessing, model training, and scenario simulations, were coded in the Jupyter Notebook development environment using the Python programming language (Foundation, 2024).

In the first analytical stage, a "baseline scenario" was constructed under the assumption that current socioeconomic dynamics would continue along their natural course without an external policy shock. Bayesian ridge regression was selected as the algorithmic foundation because of its ability to manage statistical uncertainty in future projections while minimizing fluctuations in time-series data and the risk of overfitting (MacKay, 1992). The scikit-learn library, which is widely used in the machine-learning literature, was employed to construct and train the model (Developers, 2024). Trained on historical data for 2005–2024, the model projected the growth trends in women's and men's labor force participation rates and identified the "natural parity year" in which these rates would intersect at the macroeconomic level.

3.3. Model Specification and Variables

The dependent variable in the model is the annual labor force participation rate (%) by gender, and the explanatory variable is the time index (year). Separate models were trained for the women's and men's series. The analysis involved compiling and preprocessing the series, training

the Bayesian ridge model, projecting the 2025–2081 period, identifying the natural parity year at which the women's and men's trend lines intersect, and calculating both the acceleration gap and the required increase in the transition to higher education for the 2050 target.

3.4. Technical Details of the Model

The model is a time-trend regression in which the participation rate is estimated using a centered year index ($y = \beta_0 + \beta_1 \cdot t$). In the Bayesian ridge approach, a zero-mean Gaussian prior is assigned to the coefficients, and Gamma hyperpriors are assigned to the noise and weight precision; these hyperparameters are estimated from the data through evidence maximization (MacKay, 1992). The model thereby limits overfitting through regularization and expresses uncertainty in the forecasts through the posterior distribution. To obtain numerical stability and interpretable uncertainty estimates, the year variable was centered on the sample mean (t = Year − 2014.5). The estimated coefficients of the final models trained on the full dataset (2005–2024) were as follows: for the women's model, $\beta_0 = 29.11$ and $\beta_1 = 0.8624$ percentage points/year ($\alpha = 0.508$, $\lambda = 1.339$); for the men's model, $\beta_0 = 69.72$ and $\beta_1 = 0.2471$ percentage points/year ($\alpha = 0.618$, $\lambda = 15.777$). Here, α represents noise precision, whereas λ represents the precision of the regularization (shrinkage) prior to the coefficient; both parameters were estimated automatically from the data through evidence maximization (MacKay, 1992). The temporary decline observed in 2020 because of COVID-19 was not modeled as a separate structural-break term but was retained as a natural part of the time series.

To evaluate the model's predictive performance, the data were divided into 2005–2020 (n = 16, training set) and 2021–2024 (n = 4, test set). The model was refitted using only the training set and compared with the observed values in the test set. Bayesian ridge regression was also compared with a simple linear-trend model estimated using ordinary least squares (OLS; Gujarati & Porter, 2009); the results are presented in Table 2.

Table 2. *Model Performance Metrics (Test Set: 2021–2024).*

Model	RMSE	MAE	MAPE (%)	R^2
Bayesian Ridge – Women	2.16	2.10	6.03	–1.15
OLS – Women	2.21	2.15	6.20	–1.26
Bayesian Ridge – Men	1.18	1.12	1.58	–2.71
OLS – Men	1.34	1.29	1.82	–3.79

The low performance observed on the test set resulted from the temporary COVID-19-related labor market shock in 2020, which occurred in the final year of the 2005–2020 training period and distorted the estimated trend; this issue is also noted in the Limitations section.

Five-fold time-series cross-validation was performed using an expanding-window approach. The mean RMSE was 1.93 (± 1.18) for Bayesian ridge regression and 1.87 (± 1.19) for OLS.

The time-series cross-validation yielded similar mean RMSE values for Bayesian ridge regression and OLS—1.93 and 1.87, respectively—indicating that the two methods performed similarly in terms of point-prediction accuracy. Bayesian ridge regression is characterized as an "AI model" in this study not because it provides greater point-prediction accuracy but because it (i) limits overfitting through regularization, (ii) automatically learns the coefficient and noise-precision hyperparameters (α and λ) from the data through evidence maximization, and (iii) provides a principled estimate of uncertainty (a confidence interval) through the posterior distribution in addition to a point estimate. These three features distinguish the method from classical OLS and are among the typical characteristics of probabilistic learning approaches in the machine-learning literature.

The use of machine-learning models in research on gender inequality represents an important methodological transformation. Previous research has emphasized that, as algorithmic systems become more widespread in labor markets, they may function both as analytical forecasting tools and as potential mechanisms of inequality; it has also systematically demonstrated that algorithms trained on historical data can reproduce existing structural biases (Köchling & Wehner, 2020). Although the Bayesian ridge regression approach adopted in this study forecasts historical trends, it positions the resulting projections as a starting point for direct policy in-

tervention and thereby offers a normative framework intended to prevent algorithmic bias from being transferred directly into policy outcomes.

In the second stage of the research, the policy-development phase, 2050 was set as the strategic policy target year with reference to international development goals. The deterministic scenario model treated the projected level of men's labor force participation in 2050 as the "target threshold" and algebraically calculated the "additional annual acceleration" that would need to be added to the existing baseline growth rate for women's labor force participation to reach this threshold.

In the study's final and most original analytical stage, a simulation was conducted to determine which educational policy, feasible at the micro level, could generate the identified annual acceleration required at the macro level. Methodologically, the study adopted the principle of the "compositional effect," according to which the country's overall female labor force participation rate is the weighted average of the participation rates of groups at different educational levels. Because the existing educational stock of the adult population cannot be changed uniformly in the short term, the model was structured around new generations, or cohorts. The statistical difference in participation between a woman with a high school education and a woman with a higher education degree was formulated as the "net employment gain." The policy projection established a deterministic balance equation by dividing the acceleration gap calculated for the 2050 target by this gain coefficient associated with higher education. This equation was used to empirically determine the additional annual share of the female high school graduate cohort that would need to be directed to higher education beyond the baseline trend.

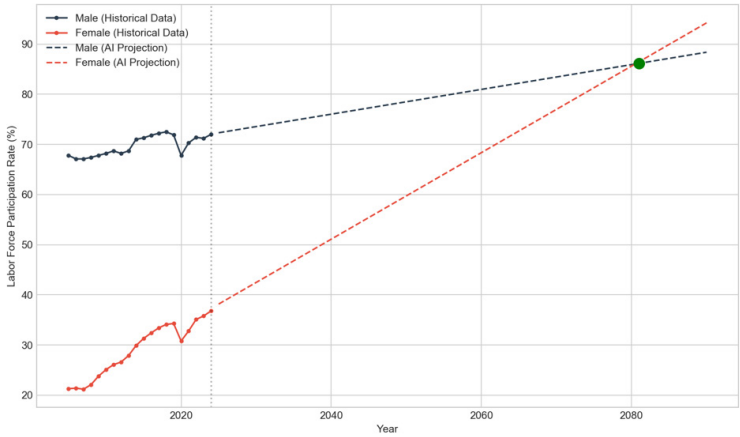
4. Findings

The empirical findings obtained from the predictive AI models and deterministic scenario analyses are examined under three subsections: the baseline projection, the target acceleration-gap analysis, and the educational-composition policy simulation. This section presents visualizations of the historical trends and forward-looking statistical targets generated by the model.

4.1. Baseline Scenario: Projection of the Natural Parity Year

In the first stage of the study, the assumption that the current dynamics of the Turkish labor market would continue along their natural course without any external policy shock was tested. Forecasts based on the Bayesian ridge AI model and historical data for 2005–2024 indicate that, although women's labor force participation rate follows a steady upward trend, its rate of convergence toward the structural saturation level of men's participation is quite slow. The model predicts that, if the current growth trend continues without intervention, the gender gap between women's and men's participation rates will not close completely until 2081. This long-term baseline growth projection and the macroeconomic point at which the two groups' trend lines intersect are visualized in Figure 1.

Figure 1. *Time-Series Projection of Gender Parity in the Turkish Labor Market.*



The participation rates projected by the model for selected short-, medium-, and long-term reference years across the forecast horizon (2025–2081), together with the narrowing gender gap in percentage points, are summarized in Table 3.

Table 3. *AI-Based Baseline Projection of Labor Force Participation.*

Year	Women (%)	Men (%)	Gender Gap (pp)
2025	38.17%	72.31%	34.15
2030	42.48%	73.55%	31.07
2040	51.10%	76.02%	24.92
2050	59.73%	78.49%	18.76
2060	68.35%	80.96%	12.61
2070	76.98%	83.43%	6.46
2081	86.46%	86.15%	−0.31

The findings in Table 3 and Figure 1 confirm that women's labor force participation in Türkiye has a positive growth trajectory. However, this baseline growth is clearly insufficient to achieve the mid-century (2050) targets referenced in international development visions. Under the model's baseline scenario, a substantial gender gap of 18.76 percentage points is projected to remain between the two groups even in 2050. This finding demonstrates that allowing the process to continue along its "natural course" is not a sustainable policy.

Table 4. *Projections with 95% Confidence Intervals for Selected Years (Centered Model).*

Year	Women's Projection (95% CI)	Men's Projection (95% CI)
2025	38.17 [35.20–41.13]	72.31 [69.63–75.00]
2030	42.48 [39.27–45.69]	73.55 [70.65–76.44]
2040	51.10 [47.24–54.97]	76.02 [72.55–79.49]
2050	59.73 [55.05–64.40]	78.49 [74.30–82.68]
2060	68.35 [62.78–73.92]	80.96 [75.98–85.95]
2070	76.98 [70.46–83.49]	83.43 [77.61–89.26]
2081	86.46 [78.87–94.06]	86.15 [79.36–92.93]

The confidence intervals were derived from the posterior predictive variance of the Bayesian ridge model (at the 95% level, ±1.96 standard errors). The uncertainty interval widens as the forecast horizon increases. Although the point estimate for the natural parity year is 2081, parity could occur as early as 2063 under the optimistic scenario calculated from the upper and lower confidence bounds of the women's and men's trends; under the pessimistic scenario, it may not occur by the end of the century.

4.2. Goal-Oriented Scenario: Analysis of the 2050 Acceleration Gap

In the second stage of the study, 2050 was selected as the target year for the policy projection, and the magnitude of the macroeconomic intervention required to close the gap was analyzed. According to the AI model's projection, the structural saturation point that men's labor force participation rate will reach in 2050 is 78.49%. For women's labor force participation to reach this threshold and achieve full parity in 2050, it must increase by an average of 1.60 percentage points per year from its 2024 starting point.

Under the model's baseline scenario, however, the current annual increase in women's participation is only 0.86 percentage points. This statistical difference between the required and baseline rates creates an "additional acceleration gap" at the macro level. The results indicate that reaching the 2050 target requires an additional increase of 0.74 percentage points in women's participation each year through external public policies, incentives, and structural reforms. This acceleration gap is calculated as the difference between the required annual increase and the baseline trend: 1.60 − 0.86 = 0.74 percentage points/year.

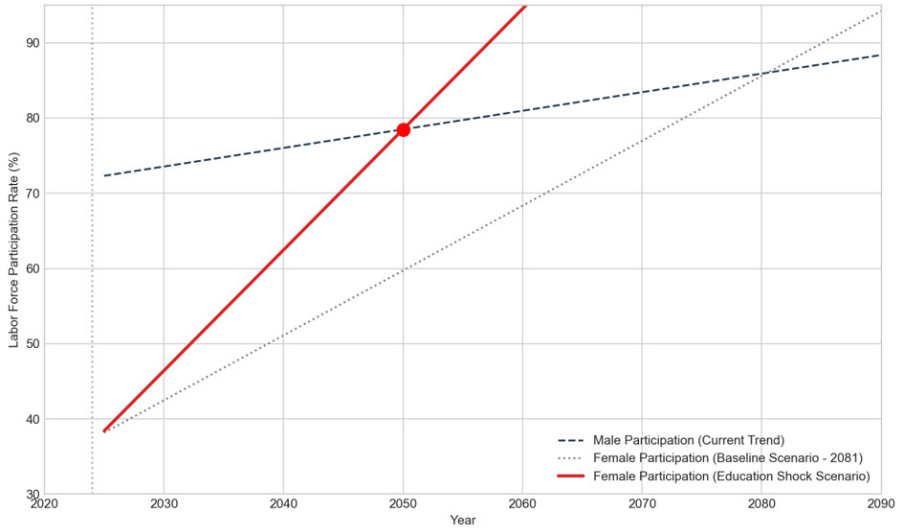
4.3. Educational Composition and Cohort-Effect Simulation Results

In the final and most critical stage of the findings, the study simulated which specific policy could close the identified additional annual acceleration gap of 0.74 percentage points. A deterministic model based on educational composition was constructed for this purpose. An in-depth analysis of the 2024 baseline dataset empirically confirmed that moving a woman's educational attainment from high school to higher education generated a substantial "employment gain" of 30.20 percentage points in her likelihood of participating in the labor force.

Because the educational stock of the adult population cannot be changed in the short term, a "cohort-shift" simulation was conducted using cohorts of recent high school graduates. A clear policy requirement was identified by dividing the target gap of 0.74 percentage points by the 30.20-percentage-point employment gain associated with higher education. Accordingly, achieving the 78.49% parity target in 2050 requires macroeconomic incentives that would enable an additional 2.45% of the

cohort of young female high school graduates to transition to higher education each year beyond the baseline trend, thereby increasing the enrollment rate. The net employment gain of 30.20 percentage points is the difference, in the 2024 data, between the labor force participation rates of women with higher education and women with a high school education. The required additional transition rate is obtained by dividing the annual acceleration gap by this gain coefficient: 0.74 ÷ 30.20 ≈ 2.45% per year, cumulatively. Figure 2 presents the acceleration that this planned higher education intervention would create in women's labor force participation, how it would narrow the gap, and the targeted parity point in 2050.

Figure 2. *2050 Gender Parity Scenario with an Educational-Composition Intervention.*



5. Discussion and Conclusion

The baseline results of this study are consistent with earlier findings showing that women's labor force participation follows a steady upward trend (Akgeyik, 2017). This pattern is also reported in more recent research (Gençtürk, 2022). However, the model's projection of parity in 2081 demonstrates that this increase is progressing quite slowly relative to international development objectives. The role of education as a "protective

shield," identified in earlier research (Tansel, 2002), is operationalized in this study as a quantitative acceleration requirement. The analysis identifies an "additional acceleration gap" of 0.74 percentage points per year in women's participation in order to reach the parity threshold of 78.49% in 2050.

The cohort-shift simulation based on educational composition confirmed the 30.20-percentage-point "net employment gain" associated with the transition from high school to higher education. This result is consistent with research arguing that education is the most resilient mechanism for keeping women in the labor market (Tansel, 2002). Related work likewise identifies education as a resilient mechanism for sustaining women's labor force participation (Gürler & Üçdoğruk, 2007). In particular, observations concerning women confined to homemaker status in urban areas after agricultural dissolution (Bozkaya, 2013) acquire a basis for a structural solution through the present study's recommendation of an additional annual higher education transition rate of 2.45%. Using the "cohort effect" identified in previous research (Talaş & Çakmak, 2013) as a policy instrument, this study empirically demonstrates how small but regular increases in the educational attainment of younger generations of women can produce substantial transformation at the macro level.

The findings should be compared not only with supporting studies but also with studies reporting different results. Klasen and Pieters (2015), who showed that women's participation can stagnate despite increases in educational attainment, and Verick (2018), who emphasized that participation depends on demand conditions as much as on supply, demonstrate the conditional nature of the study's education-only scenario.

6. Conclusions and Recommendations

This study analyzed the process of closing the gender gap in the Turkish labor market through AI-based projections and education-oriented scenarios. The findings show that, if current socioeconomic dynamics are left to follow their natural course, full parity will not be achieved until 2081 and that a strategic "educational shock" is therefore critically important for attaining the 2050 objectives. The scenario findings indicate that full gender parity in the Turkish labor market by 2050 appears attainable through a strategic annual increase of 2.45% in the higher education tran-

sition rate of female high school graduate cohorts, as identified by the AI model's projections.

Based on the study's findings, policymakers and decision-makers are advised to develop specific incentive mechanisms—including scholarships, admission quotas, and guidance programs—to accelerate the transition of young female high school graduates to higher education. This study, however, was constructed using TurkStat's official time-series data and the marginal differences between educational levels. The deterministic model treats as exogenous the manner in which labor supply generated by rising educational attainment would be absorbed under labor demand conditions and macroeconomic fluctuations. Future studies should integrate the education–employment model with sectoral employment needs and regional labor market dynamics (Er, 2014).

7. Limitations

The deterministic model treats labor demand conditions, sectoral and regional differences, wage levels and the gender pay gap, the burden of unpaid household care, and macroeconomic fluctuations as exogenous. The model also does not establish a causal relationship among participation rates; instead, it provides a trend projection under the assumption that current trends will continue. Because of the short time series (n = 20) and the structural break caused by COVID-19 in 2020, the natural parity year of 2081 and the 2050 scenario results should be interpreted not as definitive forecasts but as conditional projections within a broad uncertainty band (Table 4).

Another critical consideration in translating data-driven forecasting models into policy is the potential for algorithms to reproduce gender inequality. A systematic review demonstrates that training an algorithm on historical employment decisions may systematically disadvantage historically marginalized groups because, even without direct access to gender, the algorithm can identify patterns in the data associated with protected groups (Köchling & Wehner, 2020). Therefore, the data infrastructures and algorithmic systems used to implement the policy projection developed in this study should be supported by transparency and oversight mechanisms that reinforce gender equality; this should be a priority for future research.

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