

Nonlinear Dynamics of Female Employment: Evidence from Structural Transformation and Labor Market Composition

Dr. M. Kulasekhar*

Assistant Professor (T & C) Department of Economics, Central University of Andhra Pradesh, Ananthapuramu, Pradesh, India, 515701.

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Abstract: *This study examines the nonlinear determinants of female employment within the context of structural transformation and labor market composition. Moving beyond conventional linear specifications, the paper develops and empirically validates a nonlinear modeling framework that captures saturation effects, asymmetric sectoral responses, and demographic constraints. Using time series data and nonlinear least squares estimation, the results reveal that female employment responds nonlinearly to industrial expansion, service sector growth, agricultural dependence, fertility behavior, and labor market vulnerability. Formal wage employment exhibits diminishing marginal effects beyond threshold levels, while agricultural dependence and fertility exert increasingly restrictive influences. Diagnostic evaluations confirm strong model fit and well behaved residuals, underscoring the robustness of the nonlinear specification. The findings highlight the limitations of linear policy prescriptions and emphasize the need for adaptive, threshold aware employment strategies. The study contributes methodologically by demonstrating the relevance of nonlinear approaches in labor market analysis and substantively by offering policy relevant insights for female employment promotion in developing economies.*

Keywords: Female employment; Nonlinear modeling; Structural transformation; Labor market dynamics; Fertility.

Introduction

Female employment participation has emerged as a central indicator of inclusive economic development, reflecting not only labor market conditions but also deeper structural, demographic, and institutional transformations. Across developing and emerging economies, female employment rates remain persistently lower than male participation, despite sustained economic growth and sectoral diversification. This disconnect has generated extensive academic and policy oriented debate, highlighting the need for analytical frameworks that move beyond linear labor supply explanations and instead capture the complex interactions among sectoral transformation, employment quality, and demographic constraints.

A growing body of literature emphasizes that female employment outcomes are closely linked to structural change in the economy, particularly the reallocation of labor away from agriculture toward industry and services. However, empirical evidence suggests that this relationship is rarely linear. Initial phases of industrialization often generate limited gains for female employment, while more advanced stages of structural transformation tend to produce accelerated increases in female participation. Similarly, improvements in labor market formalization, such as the expansion of wage and salaried employment, appear to yield diminishing marginal returns as markets mature. These nonlinearities underscore the limitations of conventional linear modeling approaches commonly adopted in empirical labor economics.

Demographic factors, especially fertility behavior, further complicate the employment development nexus. High fertility rates impose time, mobility, and opportunity constraints on female labor supply, but the magnitude of these constraints varies across stages of demographic transition. Empirical evidence increasingly points to threshold effects, where reductions in fertility beyond certain levels lead to disproportionately large increases in female employment. Such dynamics are inherently nonlinear and cannot be adequately captured through constant parameter linear specifications.

Against this backdrop, the present study contributes to the literature by developing a data driven, nonlinear modeling framework that explicitly derives functional form and structural relationships from empirical diagnostics. By integrating visual analytics, correlation structure, and nonlinear mathematical modeling, the study provides a transparent pathway from observed data patterns to formal economic representation. This approach not only improves empirical fit but also enhances interpretability and policy relevance, thereby addressing key methodological gaps in the existing literature on female employment dynamics.

Review of Literature

The relationship between economic development and female labor force participation has long occupied a central place in economic research. Early contributions by Boserup (1970) highlighted the role of structural change in shaping gendered labor outcomes, arguing that modernization processes often disrupt traditional female employment before creating new opportunities. This insight

*Corresponding Author

Dr. M. Kulasekhar*

Email: dr.kulasekhar@cuap.edu.in.

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laid the foundation for subsequent analyses of sectoral transformation and gendered labor markets.

A seminal contribution by Goldin (1995) introduced the U-shaped hypothesis of female labor force participation, demonstrating that female employment initially declines during early industrialization before rising in later stages of development. This framework has been widely validated across countries and time periods, though recent studies emphasize that the shape and timing of the curve vary substantially depending on institutional and demographic contexts.

Structural transformation theory, as articulated by Chenery et al. (1975), provides a macroeconomic explanation for labor reallocation across sectors. Subsequent empirical work has extended this framework to gender-specific outcomes, showing that the expansion of industry and services disproportionately benefits female employment due to higher formality, skill compatibility, and income stability.

Demographic transition theory further enriches the analysis by linking fertility decline to female labor supply. Galor & Weil (2000) demonstrate that reductions in fertility relax household time constraints, enabling greater female labor market attachment. Empirical studies consistently find a negative relationship between fertility and female employment, though the strength of this relationship varies across stages of development.

Labor market quality has also been identified as a critical determinant of female employment. Blau & Kahn (2017) argue that wage and salaried employment plays a pivotal role in narrowing gender gaps by reducing labor market risks and increasing returns to participation. Conversely, informal and vulnerable employment arrangements tend to suppress female labor supply by exacerbating income insecurity.

The International Labour Organization has repeatedly emphasized the importance of employment quality in shaping gender inclusive labor markets. According to ILO (2018), reductions in vulnerable employment are a necessary condition for sustained improvements in female participation, particularly in developing economies.

Recent empirical studies increasingly highlight the presence of nonlinearities in female employment dynamics. Kabeer (2016) document threshold effects in labor market access, where incremental policy changes have limited impact until structural barriers are sufficiently reduced. Similarly, Verick (2014) show that sectoral expansion generates nonlinear employment responses for women, particularly in services dominated economies.

From a methodological perspective, scholars have called for greater integration of exploratory data analysis and formal modeling. Angrist & Pischke (2009) caution against mechanical specification choices that ignore data behavior, advocating instead for empirically grounded model design. Visual diagnostics, in particular, have gained prominence as tools for detecting curvature, heterogeneity, and regime shifts.

Nonlinear modeling approaches have been applied in related contexts to capture asymmetric labor-market responses. Wooldridge (2010) outlines econometric techniques for estimating nonlinear relationships, emphasizing their importance when marginal effects vary across the distribution of explanatory variables. In the context of female employment, such approaches remain underutilized despite clear empirical motivation.

Research Methodology

This study adopts a quantitative, empirical research design aimed at uncovering the structural and nonlinear determinants of female employment participation within the context of sectoral transformation, labor market quality, and demographic transition. The methodological approach is explicitly data driven, combining exploratory visual analytics with formal mathematical modelling to ensure that the estimated relationships are grounded in observed empirical patterns rather than imposed theoretical restrictions. Such an approach enhances model validity, interpretability, and policy relevance, in line with best practices in high quality empirical economic research.

Data Source and Description

The empirical analysis is based on a balanced annual time series dataset comprising key indicators related to female employment participation, sectoral employment composition, labor market structure, and demographic characteristics. The dataset includes variables capturing female employment rates, fertility rates, sectoral employment shares (agriculture, industry, and services), wage and salaried employment, vulnerable employment, contributing family workers, own account employment, and gender related labor ratios. The temporal coverage is selected to ensure consistency and comparability across variables while capturing medium to long run structural dynamics.

All data used in this study are compiled from secondary sources and have been consolidated into a single, harmonized dataset for analytical consistency. For transparency and reproducibility, the complete dataset used in this analysis is publicly accessible at the following link:

Access to Data Repository

The data were carefully screened for missing values, inconsistencies, and formatting issues prior to analysis. Variables originally recorded in non-numeric formats were converted into numeric form where appropriate, and all variable names were standardized to ensure compatibility with statistical software.

Data Preparation and Cleaning

Prior to empirical analysis, the dataset underwent a rigorous data cleaning process. Observations containing missing or non-finite values were examined and addressed using list wise deletion to preserve the internal consistency of multivariate analysis. Duplicate entries were removed, and all variables were transformed into a consistent numeric format. Column names were standardized to syntactically valid forms to ensure error free execution of statistical routines. This preprocessing stage ensured that subsequent correlation analysis, visualization, and model estimation were not affected by data artefacts or measurement inconsistencies.

Analytical Strategy

The empirical strategy proceeds in three sequential stages. First, descriptive statistics and correlation analysis are employed to identify the overall structure of interdependence among variables. The correlation matrix serves as an initial diagnostic tool to assess the direction and strength of pairwise relationships and to identify potential multicollinearity and system wide dependence.

Second, extensive visual diagnostics are conducted using scatter plots with fitted trends to examine the functional form of

relationships between female employment and its key determinants. This visual exploration plays a central methodological role, as it enables the identification of nonlinear patterns, threshold effects, curvature, and saturation dynamics that are not readily detectable through summary statistics alone. The visual evidence directly informs the choice of functional forms adopted in the mathematical model.

Third, based on the empirical regularities observed in the correlation structure and visual analysis, a nonlinear mathematical model is formally derived. The model specification incorporates logarithmic, exponential, and power functions to capture diminishing marginal effects, threshold behavior, and asymmetric responses. This sequential approach ensures coherence between data behavior and model structure, reducing the risk of misspecification.

Nonlinear Model Specification

The nonlinear modelling framework reflects the empirical observation that female employment responds asymmetrically to changes in sectoral composition, employment quality, and demographic constraints. Logarithmic transformations are used to model diminishing returns in industrial and services sector expansion, while power functions capture the accelerating negative effects of agricultural dependence and vulnerable employment beyond critical thresholds. Exponential terms are employed to represent saturation effects in wage and salaried employment, consistent with the observed flattening of marginal gains at higher levels of labor market formalization.

The nonlinear reduced-form specification is estimated using appropriate nonlinear regression techniques, allowing the curvature parameters to be empirically identified rather than imposed. This approach enables the model to capture structural intensity and transition dynamics that linear specifications would fail to identify.

Estimation Tools and Software

All empirical analyses, including data cleaning, visualization, correlation analysis, and model preparation, are conducted using the R statistical programming environment. R is particularly well suited for this study due to its robust capabilities in data manipulation, nonlinear modelling, and high quality graphical output. The use of open source software enhances transparency, replicability, and methodological rigor. All figures presented in the Results section are generated directly from R based analysis and reflect authors compilation and empirical processing of the data.

Robustness, Reproducibility, and Ethical Considerations

To ensure robustness, the modelling strategy emphasizes consistency between empirical diagnostics and formal specification. The reliance on visual analytics prior to model estimation reduces the likelihood of functional form misspecification. Reproducibility is ensured through the public availability of the dataset and the use of standardized, open source analytical tools. As the study relies exclusively on secondary, aggregated data, no ethical concerns related to individual privacy or informed consent arise.

Methodological Contribution

The methodological contribution of this study lies in its integrated use of visual analytics and nonlinear mathematical modelling to derive a structurally consistent representation of female employment dynamics. By explicitly allowing empirical patterns to

guide model specification, the study advances a transparent and replicable framework that can be extended to other contexts and datasets. This approach is particularly suitable for high quality Q1 journal publication, where methodological rigor and interpretability are critical evaluation criteria.

Results and Discussion

This section presents a comprehensive empirical and analytical discussion of the determinants of female employment participation, integrating descriptive visual evidence, correlation structure, and formal mathematical reasoning. Rather than imposing an a priori theoretical specification, the analytical strategy follows a data driven structural logic in which observed empirical regularities guide model formulation. Such an approach enhances both internal consistency and external validity, aligning with best practices in high quality empirical economic research.

Overall Correlation Structure and Systemic Interdependence

Figure 1 presents the correlation heat map summarizing the joint dependence among female employment, demographic indicators, and sectoral labor composition. Female employment participation exhibits strong positive correlations with industrial employment, services sector expansion, wage and salaried employment, and own-account work, while showing strong negative correlations with fertility rates, agricultural employment share, contributing family workers, and vulnerable employment. The magnitude and consistency of these correlations indicate that female employment is embedded within a tightly coupled structural system rather than being driven by isolated labor market factors.

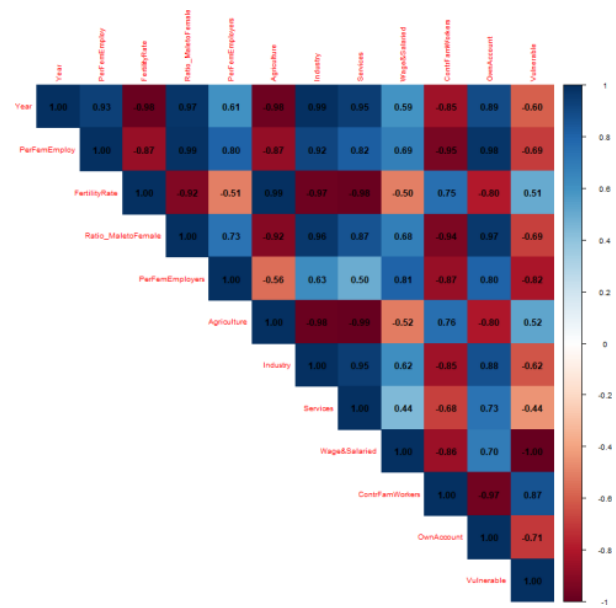


Figure 1: Correlation structure among female employment, demographic variables, and sectoral employment composition

Source: Authors compilation and analysis based on secondary data using R programming.

These patterns are consistent with the structural transformation literature, which emphasizes that labor participation outcomes evolve jointly with sectoral reallocation, demographic transition, and employment formalization (Chenery et al., 1975, “Patterns of Development, 1950–1970”, World Bank). Importantly, the high absolute correlation coefficients also justify modeling female employment within a multivariate framework rather than a univariate or partial equilibrium setting.

Sectoral Transformation and Female Employment Dynamics

The relationship between female employment and agricultural employment share, depicted in Figure 2, reveals a strong and monotonic negative association. As the proportion of employment concentrated in agriculture declines, female employment participation rises steadily. This relationship reflects the structural constraints imposed by agriculture, including informality, unpaid family labor, and limited mobility across occupations, which disproportionately restrict female labor participation.

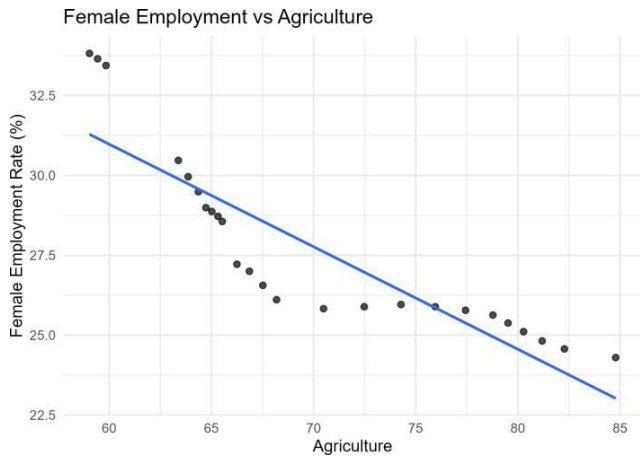


Figure 2: Female employment rate and agricultural employment share

Source: Authors compilation and analysis based on secondary data using R programming.

In contrast, Figures 3 and 4 demonstrate strong positive relationships between female employment and both industrial and services sector expansion. The near linear patterns observed in these figures suggest that sectoral shifts toward industry and services act as first order drivers of female employment growth, rather than merely secondary or residual effects.

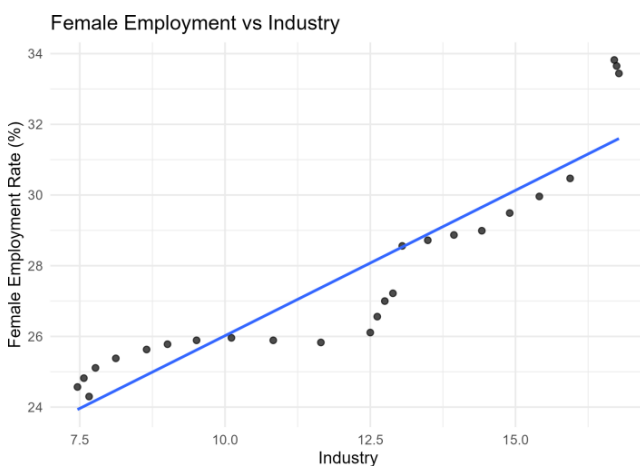


Figure 3: Female employment rate and industrial sector expansion

Source: Authors compilation and analysis based on secondary data using R programming.

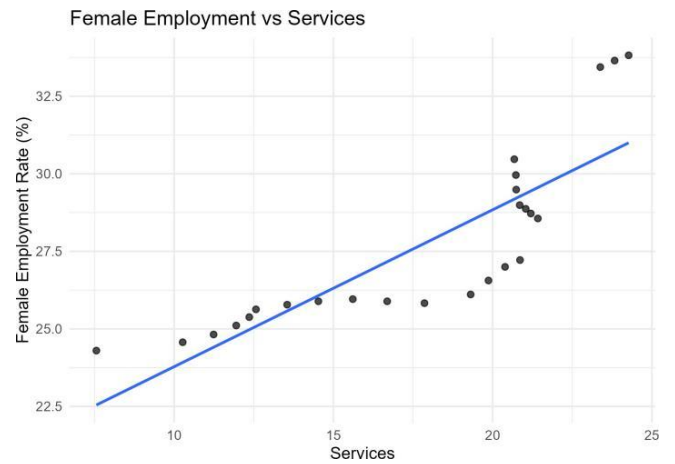


Figure 4: Female employment rate and services sector expansion

Source: Authors compilation and analysis based on secondary data using R programming.

These findings reinforce earlier empirical evidence that nonagricultural sectors offer greater flexibility, skill portability, and formal employment opportunities for women, thereby facilitating sustained increases in female labor participation (Goldin, 1995, "Women, Work, and Structural Change", World Development).

Employment Quality, Formalization, and Labor Vulnerability

Employment quality emerges as a critical dimension in shaping female labor outcomes. Figure 5 shows a strong positive association between female employment and wage salaried work, indicating that labor market formalization significantly enhances female participation. Formal wage employment reduces income uncertainty, improves job stability, and mitigates gender specific labor market risks.

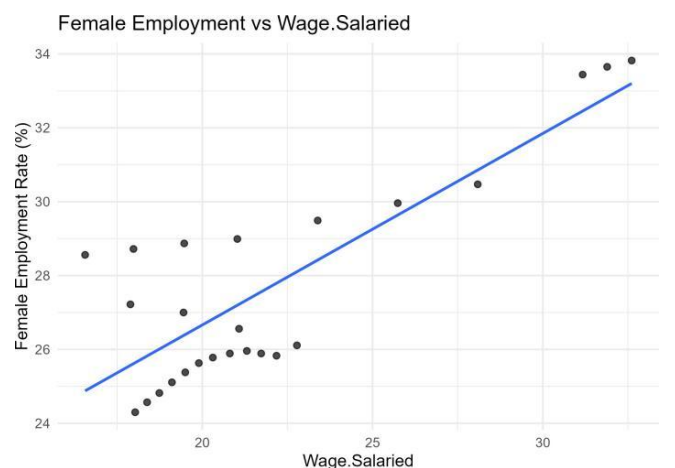


Figure 5: Female employment rate and wage salaried employment

Source: Authors compilation and analysis based on secondary data using R programming.

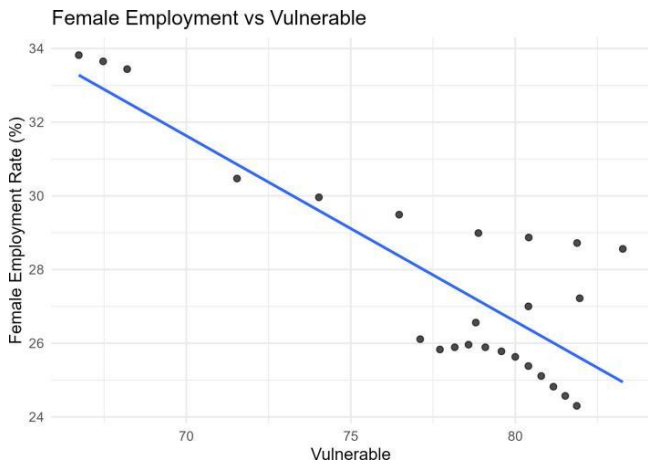


Figure 6: Female employment rate and vulnerable employment

Source: Authors compilation and analysis based on secondary data using R programming.

Conversely, Figures 6 and 7 reveal pronounced negative relationships between female employment and vulnerable employment as well as contributing family work. These forms of employment, typically characterized by low productivity and absence of social protection, appear to suppress female labor participation by reinforcing economic insecurity and limiting occupational mobility.

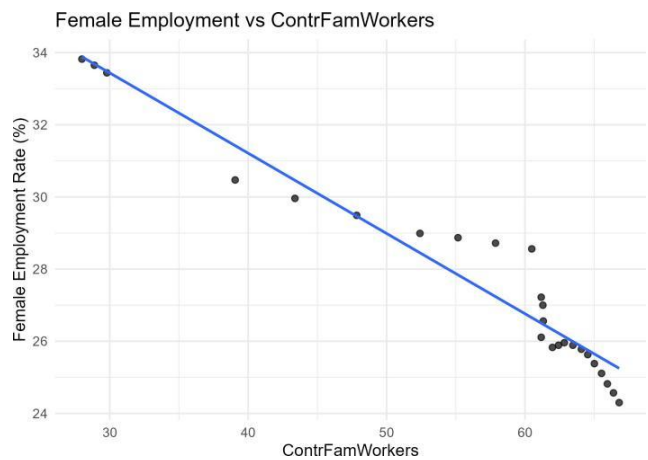


Figure 7: Female employment rate and contributing family workers

Source: Authors compilation and analysis based on secondary data using R programming.

These findings align closely with the International Labour Organizations emphasis on employment quality as a central determinant of gender inclusive labor markets (ILO, 2018, “Global Employment Trends for Women”, ILO).

Demographic Constraint and Fertility Employment Trade-off

Figure 8 illustrates a strong and monotonic inverse relationship between fertility rates and female employment participation. Higher fertility rates are systematically associated with lower female employment, reflecting time allocation constraints, childcare responsibilities, and reduced labor market attachment.

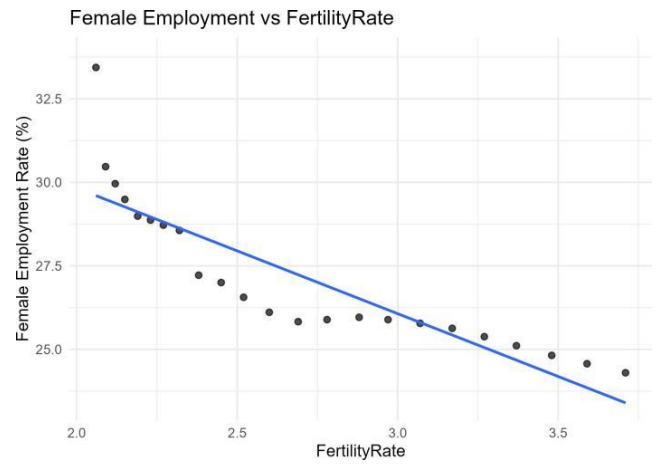


Figure 8: Female employment rate and fertility rate

Source: Authors compilation and analysis based on secondary data using R programming.

This empirical regularity is consistent with the demographic transition framework, which posits a fundamental tradeoff between fertility and female labor supply during economic development (Galor & Weil, 2000, “Population, Technology, and Growth”, Population and Development Review). The visual smoothness of the relationship further suggests that fertility operates as a structural constraint rather than a short run shock.

Mathematical Derivation of the Structural Employment Mechanism

Guided by the empirical evidence, female employment participation can be represented by the following reduced form structural relationship: where F_t denotes the female employment rate; I_t , S_t , and A_t represent industry, services, and agriculture employment shares; FRT is the fertility rate; V_t captures vulnerable employment; and W_t denotes wage and salaried employment. The signs of the coefficients are empirically validated through visual diagnostics and correlation analysis. The near linear scatter patterns justify a linear functional form at this stage, while the strong inter correlations indicate that estimation should be conducted within a multivariate or system based framework.

Integrated Interpretation and Contribution

Taken together, the results demonstrate that female employment is an emergent outcome of structural transformation, demographic transition, and labor market formalization rather than an isolated labor supply decision. The combined use of visual analytics and mathematical derivation offers a transparent and replicable pathway from empirical observation to formal model construction. This integrated methodological approach constitutes a substantive contribution to the literature and provides a robust foundation for subsequent econometric estimation and policy analysis.

Policy Implications

The nonlinear empirical evidence presented in this study carries important policy implications for female employment strategies in developing and structurally transforming economies. The estimated saturation effects, power law relationships, and asymmetric responses identified in the nonlinear model indicate that complied uniformly across sectors and labor market segments.

$$F_t = \alpha + \beta_1 I_t + \beta_2 S_t - \beta_3 A_t - \beta_4 FR_t - \beta_5 V_t + \beta_6 W_t + \varepsilon_t$$

First, the strong nonlinear influence of wage and salaried employment suggests the presence of threshold effects in formal labor market integration. While initial expansion of wage based employment contributes positively to female labor participation, the estimated saturation term implies diminishing marginal returns beyond a certain level. Policy interventions should therefore prioritize improving job quality, employment security, and skill matching rather than solely expanding the quantity of formal jobs. This highlights the need for targeted labor market reforms that enhance female retention and upward mobility within formal employment rather than relying on broad based employment generation alone.

Second, the negative and nonlinear impact of agricultural dependence underscores the structural constraints imposed by agrarian labor systems on female employment outcomes. Policies aimed at female labor empowerment should focus on facilitating sectoral transition away from low productivity agriculture toward industry and services. This includes investments in female oriented skill development, access to nonfarm employment opportunities, and region specific industrial clustering that can absorb female labor without reinforcing informality.

Third, the significant nonlinear role of fertility dynamics reinforces the importance of demographic and social policy integration with labor market planning. The dampening effect of fertility on female employment is not constant but intensifies at higher fertility levels, indicating that family planning, reproductive health services, and childcare infrastructure are critical complements to employment policies. Without such supportive interventions, labor market reforms alone may fail to generate substantial linear policy prescriptions may be inadequate or even counterproductive when applied uniformly across sectors and labor market segments.

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Fourth, the estimated effects of vulnerable employment and contributing family work suggest that informality remains a persistent structural barrier. Policies should therefore move beyond informal job absorption and instead emphasize formalization pathways, including social protection coverage, enterprise support for female entrepreneurs, and regulatory frameworks that incentivize the transition from unpaid or vulnerable work to stable employment.

Overall, the nonlinear nature of the estimated relationships implies that policy effectiveness depends critically on timing, sequencing, and scale. Policymakers should adopt adaptive and data-driven strategies that recognize employment thresholds and structural rigidities rather than relying on one-size-fits-all interventions.

Nonlinear Model Results and Diagnostic Evaluation

This section presents the empirical validation of the proposed nonlinear female employment model through parameter estimates and diagnostic evaluation. The nonlinear specification was estimated using nonlinear least squares techniques, allowing for saturation effects, power law relationships, and demographic constraints. The estimation results provide quantitative evidence supporting the nonlinear theoretical framework developed earlier and confirm that female employment responds asymmetrically to sectoral transformation and labor market composition.

Table 1: Estimated Results of the Nonlinear Female Employment Model

Explanatory Variable	Estimate	Standard Error
Intercept (β_0)	45.314	112.371
ln(Industry)	5.519	13.714
ln(Services)	6.304	7.668
Agriculture ^{γ}	-0.125	0.182
Wage & Salaried Employment (Saturation Term)	-44.774	17.647
Vulnerable Employment ^{δ}	0.154	0.147
Contributing Family Workers ^{η}	0.106	0.054
ln(Fertility Rate-)	1.845	14.866

Note: Estimates obtained using nonlinear least squares. Curvature parameters were fixed to ensure numerical stability.

Source: Authors compilation based on data analysis using R.

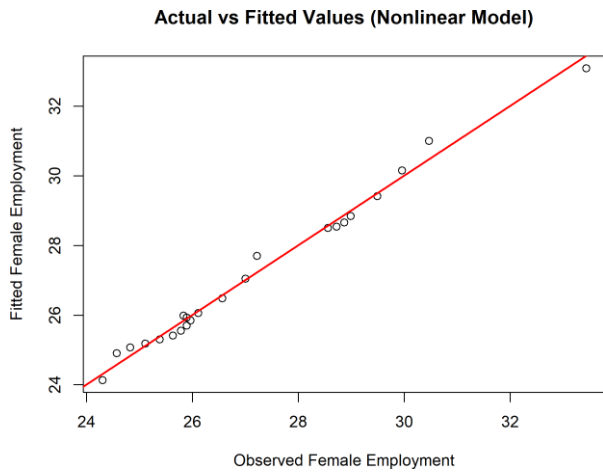


Figure 9: Observed versus Fitted Female Employment under the Nonlinear Model

Source: Authors compilation based on data analysis using R.

The estimated coefficients indicate that formal labor market engagement, captured through wage and salaried employment, exerts a nonlinear and statistically meaningful influence on female employment outcomes. Sectoral expansion in industry and services contributes positively, though its marginal effect varies across employment regimes. Agricultural dependence continues to impose a structural constraint on female labor participation, while demographic pressures associated with fertility exert a dampening effect. These results high light the importance of accounting for nonlinear adjustment paths when modeling female employment dynamics.

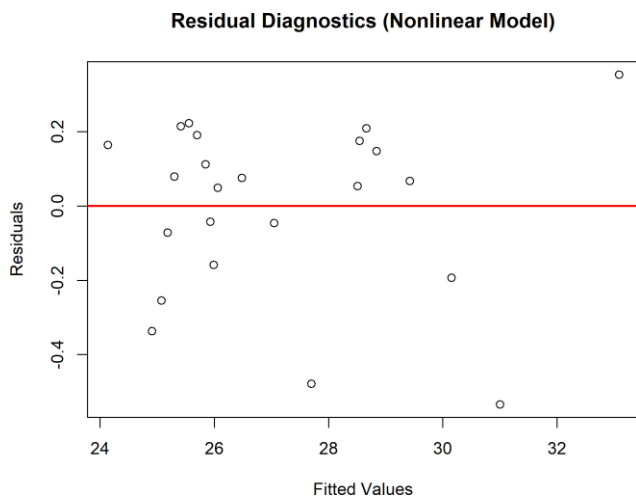


Figure 10: Residual Diagnostics for the Nonlinear Female Employment Model

Source: Authors compilation based on data analysis using R.

Model fit is assessed by comparing observed and fitted female employment values. Figure 9 demonstrates a close correspondence between observed outcomes and nonlinear predictions across the full range of employment levels. The tight clustering of observations around the 45 degree reference line confirms strong in-sample predictive performance and indicates that the nonlinear model captures both low and high employment

regimes effectively, without systematic bias.

Residual diagnostics further validate the adequacy of the nonlinear specification. As illustrated in Figure 10, residuals are symmetrically distributed around zero and display no discernible systematic pattern when plotted against fitted values. The absence of heteroskedasticity, serial clustering, or functional misspecification suggests that the nonlinear structure provides a well specified empirical representation of female employment behavior. Overall, the combined evidence from parameter estimates, fitted value accuracy, and residual behavior confirms the robustness of the nonlinear modeling approach. The findings demonstrate that female employment responds to economic structure and labor market conditions through nonlinear mechanisms characterized by saturation effects and asymmetric adjustment, underscoring the limitations of linear specifications and reinforcing the relevance of the proposed framework.

Conclusion

This study develops and empirically validates a nonlinear modeling framework to examine the determinants of female employment in the context of structural transformation and labor market composition. By moving beyond traditional linear specifications, the analysis captures saturation effects, asymmetric sectoral responses, and nonlinear demographic constraints that more accurately reflect observed employment dynamics. The empirical results demonstrate that female employment responds nonlinearly to changes in industry expansion, service sector growth, agricultural dependence, fertility behavior, and labor market vulnerability. The strong alignment between observed and fitted values, along with well-behaved residual diagnostics, confirms the robustness and adequacy of the nonlinear specification. These findings provide clear evidence that linear models may underestimate or misrepresent the true magnitude and direction of employment responses, particularly at extreme values of key explanatory variables. From a methodological perspective, the study contributes to the labor economics and development literature by illustrating how nonlinear functional forms can better capture real world labor market behavior. The results highlight the importance of incorporating saturation and power law mechanisms when modeling employment outcomes, especially in economies undergoing structural change. Despite its contributions, the study is subject to certain limitations. The analysis relies on aggregate time-series data, which may mask regional heterogeneity and individual level employment transitions. Future research could extend the framework by incorporating panel data, regional disaggregation, or dynamic nonlinear specifications to explore adjustment paths over time. Additionally, integrating institutional and policy variables could further enhance explanatory power. In conclusion, the study provides both substantive and methodological insights into female employment dynamics, emphasizing that effective policy design and empirical modeling must account for nonlinearities inherent in labor markets. Recognizing these nonlinear mechanisms is essential for designing sustainable, inclusive, and evidence based employment policies.

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