

RESEARCH ARTICLE

Forecasting industry-specific employment under demographic change: A demographic approach to future industrial sustainability

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Abstract

South Korea's rapid population aging and persistent ultra-low fertility raise fundamental questions about the demographic sustainability of industrial labor systems. This study develops a demographic feasibility framework that assesses whether existing industry-specific employment structures can be maintained as birth cohorts contract. Using microdata from the Korean Regional Employment Survey (2008–2023) and national population projections to 2040, we estimate required labor volumes and required employment shares through a LASSO-assisted log-linear model and assess whether future labor requirements remain demographically compatible with the maximum feasible supply, rather than forecasting realized employment paths. The analysis reveals widening gaps between the labor that industries require and the maximum feasible supply that future populations can provide. Scientific and technical services show the steepest increases in required employment shares, driven by their reliance on shrinking high-skill cohorts. Manufacturing, while facing more stable overall demand, displays rising dependence on older workers and intensifying replacement pressures as these cohorts diminish. These patterns demonstrate that emerging labor shortages reflect structural demographic ceilings rather than cyclical or market-correctable imbalances. The findings situate demographic feasibility as a generalizable framework for evaluating industrial sustainability in aging societies and underscore the need for long-term workforce strategies that account for cohort dynamics rather than short-term economic conditions.

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1. Introduction

South Korea has undergone an unprecedented demographic transformation, experiencing both ultra-low fertility and rapid population aging within a remarkably short period. This transition is reshaping not only the absolute size of the working-age population but also the fundamental structure of labor supply, raising critical questions regarding the long-term sustainability of the country's industrial labor force. Previous research on industrial employment has largely focused on economic drivers, such as technological change, restructuring, and global competition, in assessing future industrial prospects

(Didier, 2024; Kim, 2018), while labor supply has often been treated as an elastic resource that adjusts through market mechanisms and institutional responses (Keane, 2011; Pissarides, 2000). However, once population decline and shifts in age composition pass certain thresholds, the functional sustainability of industrial systems can no longer be explained solely by supply–demand adjustments or wage responses. Instead, the demographic ceiling of the potential labor supply becomes a binding constraint shaping the long-term trajectory of industries (Golley & Tyers, 2006).

These demographic constraints do not manifest uniformly across industries. In manufacturing, the steady decline in young labor market entrants, combined with workforce aging and the retirement of older cohorts, has contributed to a structural contraction of the traditional workforce base (Cho, 2020; Hwang, 2012; Park, 2016). In contrast, the information and communications technology (ICT) sector and the professional, scientific, and technical services sector have experienced persistent increases in labor demand due to technological upgrading and the expansion of high-skilled tasks. However, the absolute number of highly educated young workers required to sustain these industries has already entered a phase of contraction (Korea Association for ICT Promotion, 2023). Consequently, manufacturing faces quantitative labor shortages, whereas knowledge-intensive sectors confront structural deficits in high-skilled labor—revealing asymmetric demographic constraints rooted in population change. These dynamics signal not merely sector-specific challenges but a broader unraveling of the growth-era equilibrium in which industrial structure and population structure were mutually reinforcing.

Industrial labor market studies have mainly explained future employment through economic and technological forces such as automation, offshoring, and skill mismatch (Acemoglu & Restrepo, 2019; Goos *et al.*, 2014; Sala, 2011). More recent research further shows that firm-level technological change and productivity transitions continue to increase demand for high-skill labor in knowledge-intensive sectors, even as automation restructures routine work (Criscuolo *et al.*, 2021; Lindner *et al.*, 2022). Demographic research, by contrast, has shown that fertility decline, aging, and cohort shrinkage set upper bounds on labor supply, but usually at an aggregate level rather than at the level of industry-specific labor structures (Alkema *et al.*, 2015; Bloom *et al.*, 2010; Bloom *et al.*, 2024; Lee & Mason, 2006). Recent cross-national work likewise suggests that long-term demographic change is becoming increasingly consequential for macroeconomic performance and labor-market adjustment in aging societies (Smith *et al.*, 2024).

What remains underdeveloped is a quantitative framework that links future cohort composition to industry-specific employment structures across multiple sectors. This study addresses that gap by integrating employment microdata with demographic projections to assess whether future age–gender–education cohorts can sustain current industrial labor requirements.

Moreover, industrial labor force structures cannot be explained by demographic shifts alone. Life-course research shows that occupational interests and industry preferences formed in early adulthood exhibit substantial stability into mid-life (Low *et al.*, 2005). These early choices interact with institutional selection systems, educational structures, and labor-market rigidities to produce cohort-specific patterns of path dependence (DiPrete & Eirich, 2006). In Korea, strong credentialism and rigid internal labor markets constrain inter-industry mobility, and major industries—such as manufacturing, ICT, and science and technological services—have been shaped by distinct cohorts that entered them under specific opportunity structures. Previous studies highlight how Korea’s legal, economic, and organizational governance systems reinforce such rigidity and suppress mobility across cohorts (Hlasny, 2016; Kim, 2023). Consequently, substitution across industries is structurally limited, and demographic change operates not as a one-time shock but as a cumulative and cohort-driven process. The growing tendency among young workers to avoid manufacturing, together with persistent mismatches between manufacturing vacancies and the preferences of young job seekers, further intensifies structural imbalances across industries (Cho, 2020; Kim & Park, 2017).

Accordingly, this study asks three connected questions: Can Korea’s future population sustain the labor requirements of major industries? How do these constraints differ by age, gender, and education composition? Which sectors are likely to experience the fastest widening gap between required labor and feasible demographic supply?

To answer these questions, this study proposes a demographic feasibility model that evaluates the compatibility between industry-specific labor requirements and population-based potential supply. The key contribution is to treat observed employment structures as a baseline counterfactual and then ask whether future population composition alone would be sufficient to reproduce them. Empirically, the study combines a least absolute shrinkage and selection operator (LASSO)-assisted log-linear model with national population projections to estimate required labor, maximum feasible supply, and the gap between them across industries. The framework is therefore designed not to predict the exact future path of employment, but to identify where demographic constraints will make current industrial structures hardest to sustain.

1.1. Background and theoretical considerations

Research on labor markets and research on demography have usually approached employment structure from different angles. Labor-market studies emphasize technological change, institutions, and shifting skill demand, whereas demographic studies emphasize age structure, cohort size, and labor-force composition (Acemoglu, 1998; Autor *et al.*, 2003; Bloom & Williamson, 1998; Lee & Mason, 2011). The unresolved question is how these two processes interact at the industry level. This section therefore develops demographic feasibility as a framework for linking industrial labor requirements to future cohort composition.

1.2. Demographic restructuring and labor supply

Demographic research consistently shows that fertility decline, aging, and cohort shrinkage constrain labor supply (Elvery & Brizuela, 2022; Leitner & Stehrer, 2019; Smith *et al.*, 2024). Recent projection studies have improved estimates of future population trajectories (Akella & Farah, 2025; Alkema *et al.*, 2015), yet they remain focused on aggregate population change rather than on whether specific industry-level employment structures can be sustained. The demographic feasibility framework extends this literature by linking future cohort sizes to observed industry-specific age–gender–education employment structures. This matters because demographic change affects not only the number of workers available, but also their composition across age and skill groups (Bloom *et al.*, 2024; Lee & Mason, 2011). As large cohorts retire and smaller cohorts enter the labor market, the resulting replacement pressures are likely to differ sharply across industries (Kang & Kim, 2013; Korea Employment Information Service, 2025; Macunovich, 2002).

1.3. Industrial transformation and skill-biased technological change

Industrial restructuring—driven by technological advancement, global value chain reorganization, and service-sector expansion—has reshaped the demand for skills (Acemoglu, 2002; Autor *et al.*, 2003). In manufacturing, continued automation, offshoring, and process upgrading have reduced traditional middle-skill jobs while expanding technical and managerial roles (Goos *et al.*, 2014). These changes exert structural pressures that shift the labor base of manufacturing from “large-scale, middle-skill, male, middle-aged” to “smaller-scale, high-skill, and professional.” Conversely, knowledge-intensive sectors such as ICT and professional, scientific, and technical services have benefited directly and indirectly from skill-biased technological change, leading to sustained increases in demand for highly educated workers (Criscuolo *et al.*,

2021; Lindner *et al.*, 2022). Labor demand is more elastic in science, technology, engineering, mathematics, and ICT sectors than in most other sectors, while labor supply in these fields is constrained due to lengthy education, qualification, and career formation processes (You, 2016). South Korea was able to meet this demand for some time through the expansion of higher education. However, as the size of younger cohorts declines, the absolute supply of highly educated youth is shrinking—even as demand continues to rise—creating a structural imbalance. When industrial restructuring interacts with demographic change, industry-specific labor constraints intensify in distinct ways: manufacturing faces the dual pressures of “large-scale retirements + declining youth entry,” whereas knowledge-intensive sectors face “rising demand + shrinking pools of highly educated young workers.”

1.4 Cohort imprinting and path dependency in occupational choice

Labor market composition is not simply the outcome of current equilibria; rather, it reflects the long-term accumulation of institutional, economic, and educational conditions that shaped each cohort at the time of labor market entry. Recent life-course research finds that early occupational choices and career formation exhibit strong stability and path-dependent characteristics into mid- and late adulthood, demonstrating that structural conditions at specific historical moments produce distinct cohort-based patterns of occupational and industrial selection (Johnson & Mortimer, 2011; Moen, 2016). Path dependency is particularly evident in countries where inter-industry mobility barriers are high and internal labor markets are strong (Doeringer & Piore, 2020). In South Korea, exam- and certification-based selection, corporate-centered career systems, strong preferences for stable jobs, and norms of major–occupation matching have jointly reinforced such path dependency. These institutional and cultural features may function as mechanisms through which initial industrial choices become reproduced over the course of life. Studies using the Korea Labor and Income Panel Study (KLIPS) and the Economically Active Population Survey (EAPS) repeatedly show that inter-industry mobility is structurally constrained by education level, gender, and firm size (Oh *et al.*, 2022). Manufacturing, ICT, and scientific and technical service sectors exhibit cohort-specific entry patterns that remain stable over time, limiting the degree to which workers can substitute across industries. This body of research highlights that industrial labor bases cannot be easily altered through short-term policy adjustments and that cohort-based entry patterns move through the age structure over time, generating increasing “rigidity” in industrial labor configurations.

Such constraints suggest that demographic change reshapes industrial labor bases not as one-time shocks but as long-term, cumulative effects.

1.5. Demographic feasibility as an analytical framework

Conventional labor market projections typically estimate employment levels based on economic demand, assuming that labor supply adjusts through wages, participation, and migration (Acemoglu & Autor, 2011). However, in the context of population decline, these adjustment mechanisms face structural limits. Research from Japan and East Asia shows that aging and population decline exacerbate mismatches between industrial labor demand and supply, and that these mismatches vary by industry depending on age-education structures (Ha & Lee, 2018; Lee & Mason, 2011). Yet even these studies focus primarily on “how much employment will occur” rather than evaluating whether future population structures can demographically sustain the labor required by current industrial configurations. The concept of demographic feasibility fills this gap by evaluating:

- (i) required labor—the labor demand implied by past industrial structure and growth trends;
- (ii) maximum feasible supply—the labor that future populations could potentially provide;
- (iii) compatibility between required and feasible labor.

This approach does not aim to predict actual employment trajectories or wages. Rather, it assesses whether current industrial structures are demographically sustainable under projected population change—offering a distinct perspective from traditional economic or skills-based forecasting models. This framework extends core insights from demographic theory by formalizing how cohort dynamics shape the feasibility of industrial labor structures. Unlike traditional demographic forecasting models—which typically provide aggregate projections of population size, age structure, or dependency ratios (Alkema *et al.*, 2015)—the demographic feasibility framework evaluates whether specific industry-level employment structures can be sustained by future cohort sizes. This micro-structural orientation distinguishes the framework from macro-level projection approaches that do not assess sector-specific demographic constraints. While research on the demographic dividend and cohort replacement emphasizes macro-level consequences of age-structural change, these approaches provide limited guidance on whether specific industrial configurations remain sustainable as birth cohorts contract. Likewise, labor economics typically assumes that wage adjustments and labor-supply elasticity can mitigate shortages, but such mechanisms cannot operate when demographic ceilings

become binding. By integrating required labor, feasible population-based supply, and their structural compatibility, the demographic feasibility framework addresses this gap and reframes labor shortages as a population-structural constraint rather than a cyclical or market-based outcome. This conceptualization situates the analysis within the broader tradition of demographic constraint theory while offering a sector-specific formulation that previous studies have not articulated.

1.6. Hypotheses

These theoretical considerations imply several empirical expectations regarding how demographic structure shapes industry-specific labor requirements. Accordingly, this study proposes the following hypotheses:

H1. Assuming current industrial employment structures remain unchanged, required employment levels will not substantially decline—and may increase—even as the total population decreases.

H2. Manufacturing will exhibit the greatest imbalance between required employment and available population due to concentrated retirements among baby-boom cohorts and declining youth entry.

H3. ICT and scientific and technical service industries will show the highest required employment shares relative to the size of youth cohorts because their demand for highly educated young workers will rise more quickly than the size of the corresponding cohorts.

2. Data and methods

This study combines industrial employment microdata with population statistics to evaluate whether current industrial structures are demographically sustainable under future population change. The analytical strategy focuses on identifying how changes in population size and structure constrain industry-specific employment. Descriptive statistics, chi-square tests, and Kruskal–Wallis tests were conducted to examine differences in workforce composition across industries in 2008 and 2023. Descriptive analyses and nonparametric tests were performed in IBM SPSS Statistics (Version 29.0; IBM Corp., United States of America), whereas LASSO variable selection, generalized linear model estimation, validation, and projections were conducted in R Statistical Software (Version 4.4.0) and SAS (Version 9.4).

2.1. Data

Employment data come from the Statistics Korea Regional Employment Survey (RES) microdata (2008–2023). This survey collects information on employment status, industry, occupation, demographic characteristics, and

region for approximately 250,000 individuals annually, enabling a detailed reconstruction of employment structures by age, gender, education, marital status, and industry. Validation against the Census of Establishments shows discrepancies of less than 1%, confirming reliability. Following common practice, we use annual data for 2008–2010, third-quarter data for 2011–2012, and second-half data for 2013–2023 to maintain temporal consistency (Kim *et al.*, 2015). Population data consist of (i) the mid-year resident population (2008–2023) and (ii) the national medium-variant population projections (2024–2040) from Statistics Korea. These data provide age- and gender-specific population counts, defining the potential labor base available to industries at each time point.

2.2. Key conceptual definitions

In this study, demographic ceiling refers to the maximum potential labor supply determined by the size of relevant age–gender–education cohorts in the population. Required labor denotes the level of labor demand implied by existing industry-specific employment structures, and maximum feasible supply represents the labor that future cohort sizes could provide under current demographic conditions. These definitions clarify the conceptual boundaries of the demographic feasibility framework.

2.3. Industry classification and analytical scope

To ensure reproducible classification in the RES microdata, each observation was assigned to one of four analytical industry categories based on its Korean Standard Industrial Classification (KSIC) industry code. High-tech manufacturing was operationalized as C20–C31, traditional manufacturing as C10–C19 and C32–C34, ICT as J, and scientific and technical services as M. The manufacturing subdivision was informed by the Ministry of Trade, Industry and Energy's classifications of materials–components–equipment and root industries. High-tech manufacturing includes technology-intensive sectors, whereas traditional manufacturing includes more traditional labor-intensive sectors such as food, textiles, apparel, and furniture. This operationalization allows the industry grouping used in the analysis to be directly reproduced from the source data. Differences in foreign labor dependence were also considered. Using RES data, long-term correlations (2008–2023) show strong negative associations between manufacturing (C) and ICT (J) and scientific and technical services (M): -0.68 and -0.75 , respectively. Because these sectors move in opposite directions relative to manufacturing, they are included alongside the two manufacturing subsectors. This design allows us to analyze how demographic change creates distinct labor constraints across contrasting industry

types. The analytical sample includes workers aged 20–69 with valid industry codes, excluding Sejong City due to data limitations. The translated classification used for this coding is summarized in Table 1.

2.4. Variable construction

The analytical unit is an industry–population cell defined by year, gender, education, employment status, marital status, five-year age group, and industry classification. The analysis covers the years 2008–2023. Gender consists of two categories: male and female. Education level is grouped into four categories: middle school or below, high school, university, and graduate school. Employment type is classified into wage workers and non-wage workers. Marital status includes three categories: married, unmarried, and divorced/widowed. Age groups are defined as ten five-year categories, from 20–24 to 65–69. Industry classification consists of four categories: high-tech manufacturing, traditional manufacturing, scientific and technical services, and ICT. The dependent variable is the log-transformed number of workers in each industry–population cell, defined as $\log(\text{employment} + 1)$. This transformation was used to reduce skewness in the cell-level employment counts and to retain cells with zero observed workers. Zero-inflation is minimal because most industry–age–gender cells in the RES microdata contain observed employment, and the $\log(\text{employment} + 1)$ transformation sufficiently stabilizes remaining sparsity without biasing coefficient interpretation. The independent variables capture demographic composition via age–gender population shares, defined as the share of each age–gender cell within the total domestic population in that year. The key hypothesis is that these demographic compositions influence industry-specific employment, tested through interactions between five-year age shares and industry categories. Control variables include year, gender, education, employment status, marital status, five-year age group, and industry category. To isolate the effect of population composition from population size, we include the log of each cell's population count—defined as the number of residents by year, five-year age group, and gender—as an offset term. This treats population size as the baseline exposure and allows estimated coefficients to be interpreted as effects on employment ratios rather than absolute employment counts.

2.5. Descriptive statistics

Before modeling, cross-tabulations were conducted to examine associations between industry employment and demographic characteristics in 2008 and 2023 across the four focal industries. Specifically, gender, five-year age groups (20–69), education level (four categories), and

Table 1. Translated industry classifications and corresponding KSIC codes

Industry category	10th Korean Standard Industrial Classification (KSIC) codes	Industry description
High-tech manufacturing	C20–C31	Manufacture of chemicals and chemical products; pharmaceuticals and medical substances; rubber and plastic products; non-metallic mineral products; basic metals; fabricated metal products (excluding furniture); electronic components; computers; electronic and optical equipment; electrical equipment; machinery and equipment; motor vehicles and trailers; other transport equipment.
Traditional manufacturing	C10–C19, C32–C34	Manufacture of food products; beverages; tobacco; textiles; wearing apparel and fur products; leather, bags, and footwear; wood and wood products; pulp, paper, and wood-based products; printing and media reproduction; coke, briquettes, and refined petroleum products; furniture; other miscellaneous manufactured goods; repair and installation of industrial machinery and equipment.
Scientific and technical services	M70–M73	Research and development services; professional services; architectural and engineering services; other scientific and technical services.
Information and communications technology sector	J58–J63	Publishing; motion picture, video, and audio production and distribution; broadcasting; postal and telecommunications services; computer programming; systems integration and management; information services.

Notes: KSIC codes correspond closely to ISIC Rev. 4 classifications, ensuring conceptual and cross-national comparability.

marital status (three categories) were cross-classified by industry categories—high-tech manufacturing, traditional manufacturing, ICT, and scientific and technical services. For categorical variables (gender, five-year age groups, education level, and marital status), chi-square tests of independence were applied to assess distributional differences across industries. For continuous variables such as monthly wage, normality assumptions were evaluated, and nonparametric Kruskal–Wallis tests were employed due to deviations from normality (Kruskal & Wallis, 1952). All descriptive and χ^2 /Kruskal–Wallis analyses were conducted using IBM SPSS Statistics. This step establishes the demographic determinants of required labor and ensures theoretical coherence for the later modeling.

2.6. Modeling strategy

The modeling strategy proceeds in two stages. In the first stage, a high-dimensional LASSO model is estimated using all main demographic and industry effects together with candidate two- and three-way interactions that capture how employment structures vary across cohort characteristics and sectors. The penalty parameter is selected by cross-validation, and only predictors with non-zero coefficients are retained for the second-stage model. This step reduces dimensionality while preserving the interactions most relevant for out-of-sample prediction.

In the second stage, a log-linear generalized linear model is estimated using only the terms retained by LASSO. The dependent variable is the number of workers in each industry–population cell, modeled on the log scale as $\log(\text{employment} + 1)$. The final specification includes

year, gender, education level, employment status, marital status, five-year age group, industry category, age–gender population shares, and the selected interaction terms. The offset term is the log of the corresponding cell population, so the coefficients are interpreted as effects on employment intensity or employment ratios after normalizing for the size of the population at risk. These selected interaction terms include the age–gender population share interactions needed to estimate how demographic change affects industries differently. This specification assumes relative stability in cohort-specific career pathways over the projection horizon, in the sense that recently observed age–education–industry profiles provide a reasonable baseline for identifying how demographic constraints are distributed across industries (Johnson & Mortimer, 2011; Low *et al.*, 2005; Moen, 2016).

The general form of the model is as follows:

$$\begin{aligned} \log(\mu) = & \lambda + \lambda_a^{\text{year}} + \lambda_b^{\text{sex}} + \lambda_c^{\text{education}} + \lambda_d^{\text{employment}} + \\ & \lambda_e^{\text{marital status}} + \lambda_f^{5\text{-year age group}} + \\ & \lambda_g^{\text{industry}} + \lambda_h^{\text{age-gender population shares}} + \dots + \\ & \lambda_{fgh}^{5\text{-year age group, industry, age-gender population shares}} + \log(\text{pop}) \end{aligned} \quad (1)$$

where $\log(\mu) = \log(E(\text{employment} + 1))$

To evaluate predictive performance, root mean square error (RMSE), mean absolute error (MAE), and R^2 statistics were calculated using training data from 2008–2021 and validation data from 2022–2023. The final model trained on the full 2008–2023 period was then used

to generate projections for 2024–2040. These projections should be interpreted as a baseline counterfactual rather than as forecasts of realized employment under future technological, policy, or macroeconomic change. More specifically, the model assumes that the observed industry-specific employment structure remains sufficiently stable over the projection horizon to serve as an analytical baseline, thereby isolating the population-structural component of labor constraint. The resulting estimates were combined with Statistics Korea's population projections to derive the required employment ratios by industry, age group, and sex. These required employment ratios indicate the proportion of each age group that would need to be absorbed by specific industries to maintain their existing employment structures and are therefore useful for evaluating demographic constraints on future labor supply. Modeling and projections were conducted using R Statistical Software (Version 4.4.0) and SAS (Version 9.4).

2.7. Modeling rationale

The modeling strategy is designed to isolate the demographic mechanisms that structure industry-specific labor demand rather than to forecast employment trajectories under economic or technological change. LASSO is used as a variable-selection procedure to address the high-dimensional interactions among age, gender, education, and industry, yielding a parsimonious set of predictors while mitigating overfitting. The subsequent log-linear model is designed to model industry-specific employment patterns and allows coefficients to be interpreted in relation to proportional differences in employment rather than absolute levels, thereby directly linking demographic composition to industrial employment structures. By fixing the industrial employment structure to its observed pattern, the model separates demographic constraints from demand-side fluctuations and ensures that projected labor requirements reflect only the changing population base. This explicit delineation of purpose strengthens the interpretability of the demographic feasibility measures and clarifies that the framework evaluates structural demographic sustainability—not economic forecasting—within and across industries.

3. Results

This section first examines demographic and labor force changes between 2008 and 2023, then compares projected labor requirements and the required employment share by age group and industry for 2024–2040. The primary analytic focus lies not in precise numerical forecasts but in assessing the structural compatibility between Korea's demographic transition and industrial labor needs.

3.1. Demographic and labor force shifts across four industrial categories

Table 2 and 3 summarize changes in the employment structure of four sectors—traditional manufacturing, high-tech manufacturing, the ICT sector, and scientific and technical services—between 2008 and 2023 from both an absolute (size) and compositional perspective. Results from χ^2 tests indicate statistically significant differences across industries for all demographic variables, including gender, age, education, and marital status ($p < 0.001$).

3.1.1. Long-term changes in employment size

Traditional manufacturing and high-tech manufacturing either declined or grew only modestly, whereas the ICT sector and scientific and technical services expanded rapidly.

- Traditional manufacturing: 1,268,002 → 1,069,939 (16% decrease)
- High-tech manufacturing: 2,720,962 → 3,254,281 (20% increase)
- ICT sector: 594,406 → 1,055,890 (78% increase)
- Scientific and technical services: 734,404 → 1,346,602 (83% increase)

3.1.2. Shifts in age structure

Both manufacturing sectors exhibited clear aging trends:

- Traditional manufacturing (60s): 74,959 (5.9%) → 188,202 (17.6%)
- High-tech manufacturing (50s): 345,926 (12.7%) → 785,930 (24.2%)

In the ICT sector and scientific and technical services, though older groups also increased due to population aging, the expansion was much stronger among those in their 20s–40s. These knowledge-intensive sectors display a career-accumulating structure centered on the 30s and 40s.

3.1.3. Educational structure

While higher education levels increased across all industries, the pace differed sharply: Manufacturing sectors still have high proportions of workers with high school education or below.

- Knowledge-intensive industries exhibit rapid upskilling:
- ICT sector (Master's or above): 49,020 → 93,950 (92% increase)
- Scientific and technical services (Master's or above): 100,981 → 262,441 (160% increase)

This demonstrates a pronounced shift toward high-skilled labor in these industries.

Table 2. Baseline sociodemographic characteristics of workers by industry sector in 2008 ($n = 5,317,774$)

Characteristic	Traditional manufacturing		High-tech manufacturing		ICT sector		Scientific and technical services		χ^2	p -value
	n	(%)	n	(%)	n	(%)	n	(%)		
Gender										
Male	720,162	(56.8%)	2,144,585	(78.8%)	431,548	(72.6%)	506,781	(69.0%)	3,803,076	(71.5%)
Female	547,840	(43.2%)	576,376	(21.2%)	162,857	(27.4%)	227,623	(31.0%)	1,514,696	(28.5%)
Age group										
20s	147,735	(11.7%)	566,348	(20.8%)	174,086	(29.3%)	202,982	(27.6%)	1,091,151	(20.5%)
30s	314,372	(24.8%)	912,421	(33.5%)	256,097	(43.1%)	278,410	(37.9%)	1,761,300	(33.1%)
40s	465,286	(36.7%)	834,284	(30.7%)	122,565	(20.6%)	166,600	(22.7%)	1,588,735	(29.9%)
50s	265,649	(21.0%)	345,926	(12.7%)	35,139	(5.9%)	65,058	(8.9%)	711,772	(13.4%)
60s	74,959	(5.9%)	61,982	(2.3%)	6,519	(1.1%)	21,354	(2.9%)	164,814	(3.1%)
Education level										
Middle school or below	323,065	(25.5%)	270,948	(10.0%)	8,027	(1.4%)	9,282	(1.3%)	611,322	(11.5%)
High school	618,780	(48.8%)	1,281,895	(47.1%)	108,525	(18.3%)	103,544	(14.1%)	2,112,744	(39.7%)
Junior college/associate degree	312,756	(24.7%)	1,085,704	(39.9%)	428,833	(72.1%)	520,598	(70.9%)	2,347,891	(44.2%)
Graduate degree or higher	13,400	(1.1%)	82,413	(3.0%)	49,020	(8.2%)	100,981	(13.8%)	245,814	(4.6%)
Marital status										
Never married	211,154	(16.7%)	656,448	(24.1%)	234,018	(39.4%)	255,415	(34.8%)	1,357,035	(25.5%)
Married	955,623	(75.4%)	1,952,031	(71.7%)	350,918	(59.0%)	463,308	(63.1%)	3,721,880	(70.0%)
Divorced or widowed	101,224	(8.0%)	112,482	(4.1%)	9,469	(1.6%)	15,681	(2.1%)	238,856	(4.5%)
Monthly wage (10,000 KRW) ^a	116.3	[32,230]	205.8	[160,330]	226.9	[180,390]	217.6	[150,400]	188.4	[150,320]
Total	1,268,002	(100.0%)	2,720,962	(100.0%)	594,406	(100.0%)	734,404	(100.0%)	5,317,774	(100.0%)

Notes: Values are presented as weighted counts and percentages unless otherwise indicated. Weighted counts were rounded to whole numbers for presentation; therefore, category totals may not exactly equal the overall total. ^aMonthly wage is presented as median [Q1, Q3] in units of 10,000 Korean won (KRW).
Abbreviation: ICT: Information and communications technology.

Table 3. Baseline sociodemographic characteristics of workers by industry sector in 2023 ($n = 6,726,172$)

Characteristic	Traditional manufacturing		High-tech manufacturing		ICT sector		Scientific and technical services		χ^2	p -value
	n	(%)	n	(%)	n	(%)	n	(%)		
Gender										
Male	601,454	(56.2%)	2,467,510	(75.8%)	686,907	(65.1%)	839,172	(62.3%)	184,512.3	<0.001
Female	468,485	(43.8%)	786,771	(24.2%)	368,983	(34.9%)	506,890	(37.7%)		
Age group										
20s	105,103	(9.8%)	422,390	(13.0%)	250,352	(23.7%)	266,442	(19.8%)	1,044,287	(15.5%)
30s	214,259	(20.0%)	836,492	(25.7%)	356,092	(33.7%)	400,762	(29.8%)	1,807,605	(26.9%)
40s	243,608	(22.8%)	897,859	(27.6%)	272,853	(25.8%)	358,962	(26.7%)	1,773,282	(26.4%)
50s	318,767	(29.8%)	785,930	(24.2%)	145,867	(13.8%)	212,286	(15.8%)	1,462,850	(21.7%)
60s	188,202	(17.6%)	311,611	(9.6%)	30,726	(2.9%)	107,609	(8.0%)	638,148	(9.5%)
Education level										
Middle school or below	141,681	(13.2%)	147,651	(4.5%)	3,090	(0.3%)	4,550	(0.3%)	296,972	(4.4%)
High school	466,782	(43.6%)	1,234,816	(37.9%)	107,942	(10.2%)	126,922	(9.4%)	1,936,462	(28.8%)
Junior college/associate degree	439,150	(41.0%)	1,710,702	(52.6%)	850,908	(80.6%)	952,148	(70.7%)	3,952,908	(58.8%)
Graduate degree or higher	22,326	(2.1%)	161,112	(5.0%)	93,950	(8.9%)	262,441	(19.5%)	539,829	(8.0%)
Marital status										
Never married	258,564	(24.2%)	942,357	(29.0%)	538,366	(51.0%)	526,535	(39.1%)	2,265,822	(33.7%)
Married	697,347	(65.2%)	2,105,624	(64.7%)	493,498	(46.7%)	775,472	(57.6%)	4,071,941	(60.5%)
Divorced or widowed	114,027	(10.7%)	206,300	(6.3%)	24,026	(2.3%)	44,054	(3.3%)	388,407	(5.8%)
Monthly wage (10,000 KRW) ^a	250.0	[150,300]	320.0	[250,450]	330.0	[250,500]	320.0	[230,500]	300.0	[230,450]
Total	1,069,939	(100.0%)	3,254,281	(100.0%)	1,055,890	(100.0%)	1,346,062	(100.0%)	6,726,172	(100.0%)

Notes: Values are presented as weighted counts and percentages unless otherwise indicated. Weighted counts were rounded to whole numbers for presentation; therefore, category totals may not exactly equal the overall total. ^aMonthly wage is presented as median [Q1, Q3] in units of 10,000 Korean won (KRW).
Abbreviation: ICT: Information and communications technology.

3.2. Model Performance evaluation

The predictive accuracy of the model was evaluated using R^2 , MAE, and RMSE (Table 4). To validate the model's generalizability, the full dataset covering 2008–2023 was split into a training period (2008–2021) and a validation period (2022–2023). The high level of explained variability and relatively low prediction errors indicate that the model accurately reproduces observed employment patterns across demographic–industry cells. The strong performance during the out-of-sample validation period confirms that the model was not overfit and generalizes effectively to unseen data.

Table 4. Performance evaluation of the industry-specific employment prediction model

Metric	Value
R^2	0.92
MAE	1,021
RMSE	3,397

Abbreviations: MAE: Mean absolute error; RMSE: Root mean square error.

3.3. Required labor volume and required employment share

Figure 1 presents the age-specific employment shares of the four focal industries from 2008 to 2023. The figure shows a clear contrast between the younger age profiles of the ICT sector and scientific and technical services and the older age profiles of the manufacturing sectors, especially traditional manufacturing, where employment is more heavily concentrated in middle-aged and older cohorts. This age-structural contrast provides the baseline for the demographic mismatch discussed in Figure 2.

Figure 2 presents: (i) historical employment (2008–2023) and projected labor requirements (2024–2040); and (ii) those requirements expressed as a share of the 20s–60s population. This pattern matters because it signals intensifying inter-industry competition for shrinking working-age cohorts, a structural condition that cannot be mitigated through short-term labor-market adjustments.

Korea's population aged 20–69 will decline from 37.6 million in 2024 to 32.0 million in 2040 (–15%). The total required labor force across the four industries also peaks around 2028 and then decreases, but much more slowly than the population. As a result, the required employment share increases, reflecting mounting demographic pressure on industrial labor supply.

Even if an industry's absolute employment requirement remains constant, population decline means that a larger share of each age group participates in industry-specific employment. This indicates intensifying inter-industry competition for labor and possible reduced sustainability in certain sectors.

Industry-specific trends differ:

- Traditional manufacturing and high-tech manufacturing: labor requirements stabilize or decline gently.
- ICT sector: required labor increases rapidly; by 2040, labor demand is projected to reach 1.5× the current level.
- Scientific and technical services: required labor grows steadily, and the required employment share rises as the population declines.

3.4. Age-industry decomposition: Required labor volume and required employment share

The age-specific decomposition results (Figure 3) show that labor supply constraints manifest more strongly within cohorts. This matters for policy because it illustrates a collapse in cohort replacement logic: even stable demand cannot be met if the underlying population base contracts faster than industries can adapt. In both traditional manufacturing and high-tech manufacturing, the demand for labor remains heavily concentrated among workers in their 40s–60s, with the share of older workers continuing to rise. However, this cohort is projected to shrink rapidly over the next 10–15 years, meaning that even if demand in manufacturing remains relatively stable, the sector will inevitably face structural constraints in securing replacement labor. In other words, the long-term sustainability of manufacturing employment—the largest employment base in Korea—is shaped not only by new labor demand but also by retirements and replacement needs.

By contrast, the ICT sector relies predominantly on highly educated younger workers, whose population is declining at a comparatively rapid pace. As a result, ICT represents an industry where rising labor demand and shrinking labor supply occur simultaneously. Scientific and technical services also exhibit a strong dependence on highly skilled professional workers, with demand concentrated in the 30s–40s age range. Yet this cohort has a particularly narrow supply base and is expected to experience a significant decline, leading scientific and technical services to show the fastest increase in the required labor-to-potential-population share among the four sectors.

Despite substantial structural differences across

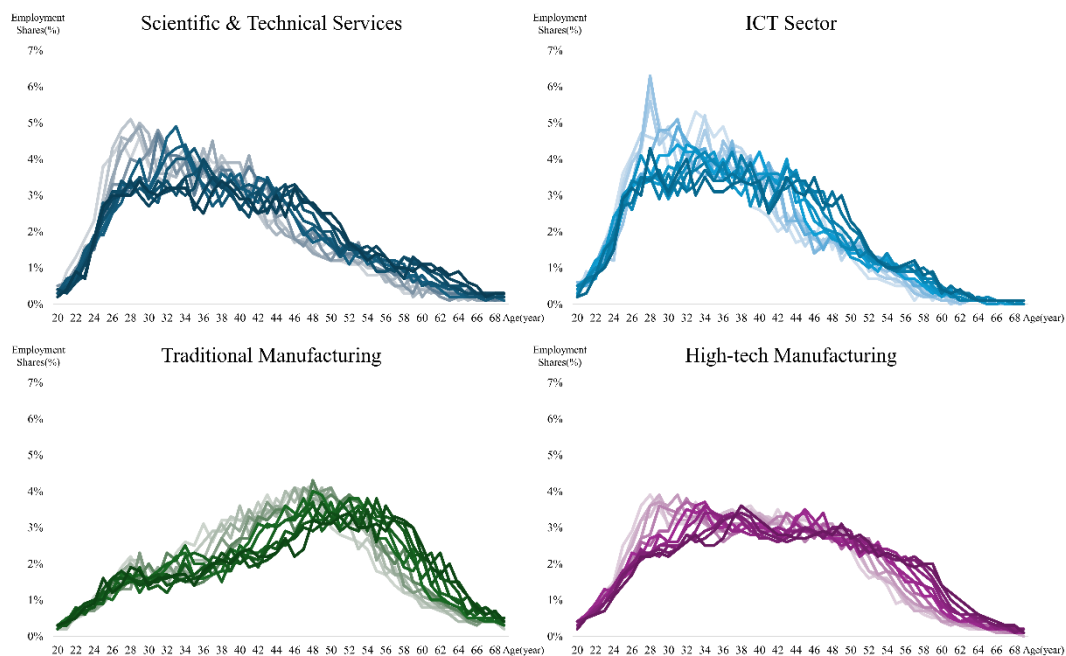


Figure 1. Age-specific worker shares by industry (2008–2023), illustrating younger age profiles in the ICT sector and scientific and technical services and older age profiles in manufacturing, especially traditional manufacturing. Abbreviation: ICT: Information and communications technology.

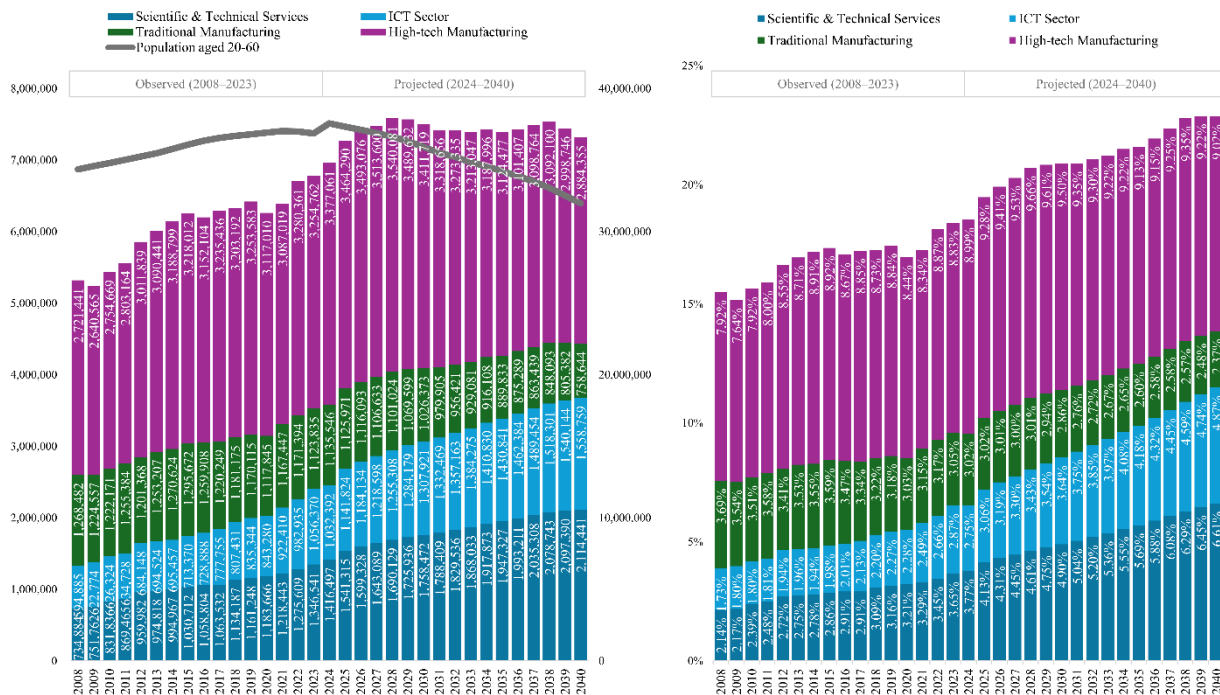


Figure 2. Observed (2008–2023) and projected (2024–2040) employment counts and required employment shares across four industry sectors, showing that required workforce shares rise as the working-age population shrinks faster than the labor needed to maintain current industrial structures. Abbreviation: ICT: Information and communications technology.

industries, these patterns demonstrate that the share of the working-age population needed to sustain each industry will rise across all sectors. The key issue is not merely how labor demand evolves, but whether the demographic base capable of meeting that demand remains sufficient. The strong cohort effects observed in the age-industry structure reinforce this point. The fact that ICT and scientific and technical services currently have large shares of workers in their 20s–30s does not imply that these cohorts will reproduce the age structure now seen in manufacturing when they later reach their 50s–60s. Industrial employment structures are path-dependent, reflecting the size, education levels, and career preferences of each cohort, and there is no guarantee that younger cohorts will substitute for the employment patterns of today's older workers.

Consequently, the most severe long-term constraints are likely to emerge in the manufacturing sector. Although the required labor share in manufacturing declines modestly, the core cohorts responsible for filling these positions are shrinking so rapidly that replacement

becomes increasingly difficult. In contrast, the ICT sector and scientific and technical services face a different but equally structural challenge: the required labor share is rising much faster than the available population base, widening the gap between labor demand and potential supply—conditions that are expected to intensify future shortages of high-skilled labor.

4. Discussion

This study reinterprets the impact of Korea's rapid demographic transition on industrial labor force structures and employment sustainability from a demographic perspective, moving beyond traditional labor economics and industrial policy frameworks. The results demonstrate that population decline and aging do not exert uniform pressure across industries; instead, their effects vary depending on age–education composition, cohort structure, and technological characteristics. This finding aligns with prior research emphasizing that the size and distribution of birth cohorts constitute a central determinant of labor force feasibility within industries,

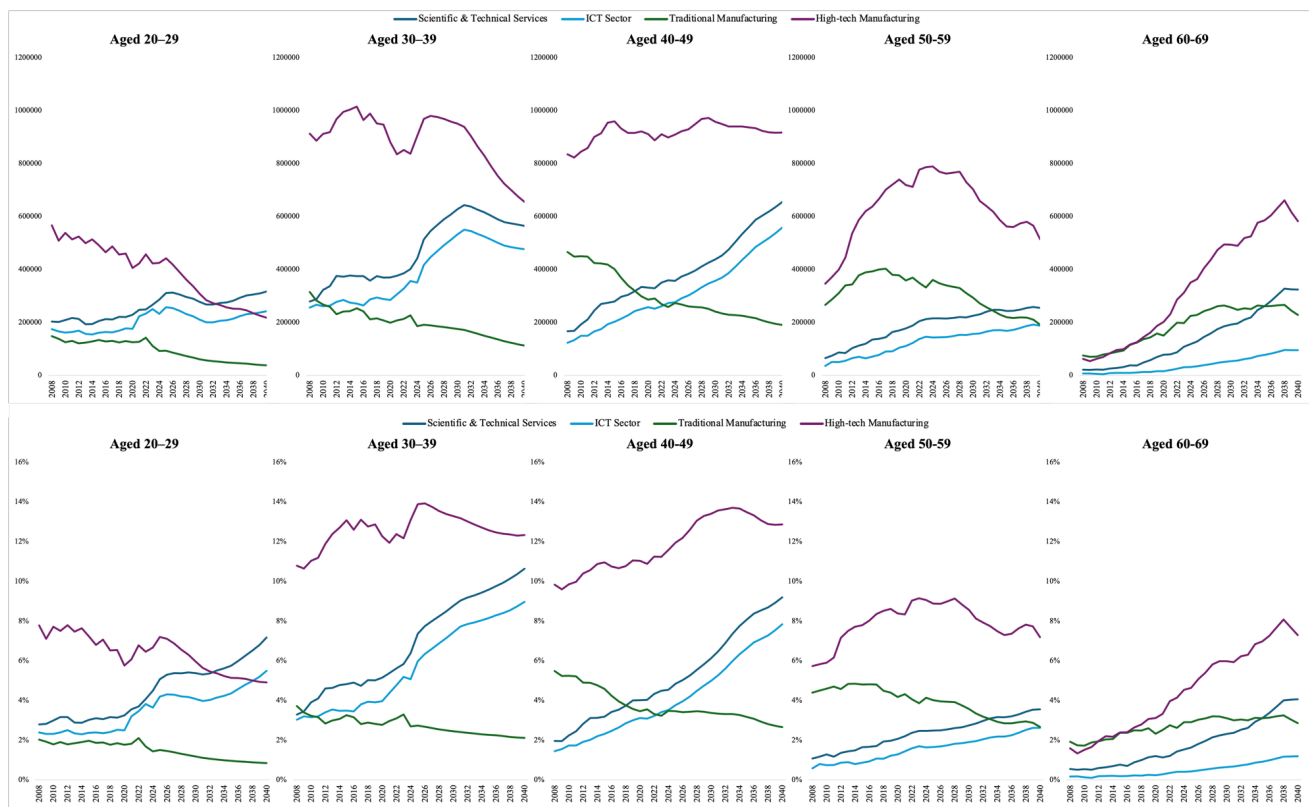


Figure 3. Observed (2008–2023) and projected (2024–2040) age-specific employment counts and employment shares by age group across four industry sectors, highlighting replacement pressure in manufacturing and widening demographic mismatch in knowledge-intensive sectors.

challenging the conventional view that industrial change is driven primarily by economic or technological factors (Lee & Mason, 2011).

4.1. Traditional manufacturing and the replacement burden

In the traditional manufacturing sector, labor is increasingly sustained by older middle-aged and senior cohorts. This demographic pattern is especially salient in traditional manufacturing, where overall labor demand is not projected to increase substantially, yet the current workforce is heavily concentrated among cohorts approaching retirement. This creates intense replacement pressure. Similar challenges have been documented in Korean manufacturing and in Japanese manufacturing industries facing workforce aging and skill-transfer difficulties (Ministry of Economy, Trade and Industry [METI], 2013; Park, 2016). However, this study shows that these pressures do not stem from dissatisfaction with wages or job content but from a demographic constraint: the shrinking birth cohorts entering the labor market make replacement structurally impossible—a cohort-driven retirement shock. Although the required workforce share (relative to the population aged 20–69) in traditional manufacturing declines over time, this does not signal an easing of constraints; rather, it reflects that even as the industry contracts, the size of the youth cohorts capable of replacing retirees has already fallen below a critical threshold.

4.2. Knowledge-intensive sectors and shrinking high-skill cohorts

By contrast, high-tech manufacturing, the ICT sector, and scientific and technical services face a fundamentally different set of constraints. All three sectors have experienced consistent employment growth from 2008 to 2023, and projected labor demand from 2024 to 2040 continues to rise meaningfully. Yet the number of highly educated young adults (ages 20–34) able to supply this labor is declining at a far faster rate. Prior research has often attributed such shortages to weaknesses in education systems, failures in career information, or skill mismatches (Autor, 2019; Hwang, 2019). However, this study demonstrates that the gaps observed in these sectors are not the result of skill mismatch but are structural shortages driven by demographic contraction. Similar patterns have been noted in European labor market research, where rapid declines in younger, highly educated cohorts have reduced the supply of skilled workers and generated structural shortages in knowledge-intensive sectors (Huteau *et al.*, 2022).

4.3. A shared shrinking labor pool

Importantly, the labor constraints facing the four industries do not operate independently. Because all sectors—including manufacturing, services, and the public sector—draw from the same shrinking pool of young workers, labor shortages manifest as inter-sectoral competition rather than industry-specific challenges. As such, workforce shortages cannot be resolved through internal adjustments or short-term policy shifts within individual sectors; instead, they require coordinated strategies that recognize the demographic ceiling limiting the overall labor supply.

4.4. The analytical value of the required workforce share

A key contribution of this study is the observation that, although the absolute level of required labor differs across industries, the required workforce share relative to the future population increases markedly in high-tech manufacturing, the ICT sector, and scientific and technical services. This means that, under population decline, these industries must absorb an increasingly larger portion of the national population to maintain their current functions. By contrast, traditional manufacturing follows a downward trajectory in its required workforce share, yet it remains constrained by the concentration of workers in aging cohorts and the extremely small size of replacement cohorts. In other words, three industries experience demographic constraints through rising workforce shares, whereas traditional manufacturing experiences constraints through concentrated replacement burdens. This highlights the analytical importance of the required workforce share—a metric rarely considered in prior labor force research.

4.5. Policy implications under demographic constraint

These findings underscore that industrial, education, and immigration policies cannot operate independently. Strategies to increase youth inflows into manufacturing face fundamental limits when the youth population itself is shrinking. Although strengthening domestic education and training remains important for high-tech manufacturing, the ICT sector, and scientific and technical services, the declining absolute number of highly educated young adults means that domestic sources alone cannot meet rising demand. In practice, attracting international talent will require more than general calls for migration: it implies sustained coordination across visa policy, credential recognition, language and settlement support, higher-education planning, and industry targeting (Hugo, 2008; Pan & Theseira, 2023). Such coordination is difficult in practice because industrial policy, higher-education

planning, and immigration governance are often administered through separate institutions with different policy timelines and objectives. The broader implication is that industrial strategy must be designed around demographic constraint rather than around demand growth alone.

4.6. Theoretical and methodological contributions

Overall, this study contributes to the existing literature in three ways. First, it demonstrates quantitatively how the interaction between demographic structure and industrial structure generates labor shortages, thereby reframing industrial sustainability beyond purely economic or technological considerations. Second, by integrating microdata on employment with population projections, it provides a methodological framework suitable for analyzing the structural challenges faced by countries undergoing rapid population decline. Third, it introduces the concept of demographic feasibility—that industrial labor structures must be reorganized within the limits of future population capacity—offering a theoretical basis for redesigning industrial, educational, and immigration strategies.

4.7. Broader relevance beyond South Korea

Although the analysis focuses on South Korea, the mechanisms documented here reflect broader demographic–industrial dynamics observed across low-fertility, rapidly aging societies. Japan faces similar cohort-driven labor constraints as population aging reshapes intergenerational transfers and the effective labor supply across key sectors of the economy (Ogawa *et al.*, 2010). Taiwan likewise confronts a tightening labor supply and slower growth as low fertility and workforce aging reduce the size of core working-age cohorts (Huang *et al.*, 2019). Singapore and other city-states have increasingly turned to immigration as a strategy to relieve labor force constraints, particularly in medium- and high-skilled occupations (Hugo, 2008; Pan & Theseira, 2023). In Southern Europe, persistent very low fertility has sharply limited the replenishment of youth cohorts, raising concerns about the long-term sustainability of industrial renewal (Billari, 2008; Goldstein *et al.*, 2009). These parallels suggest that demographic feasibility is not a Korea-specific phenomenon but a framework that is most transferable to societies experiencing sustained low fertility, rapid aging, and shrinking younger cohorts. At the same time, cross-national differences in labor-market flexibility, educational systems, migration regimes, and inter-industry mobility mean that the specific form and intensity of demographic constraints must be interpreted in context.

4.8. Limitations and future research

Several limitations should be acknowledged. First, the projections are intentionally constructed as a baseline counterfactual in which industrial structures and occupational compositions are held constant. They should therefore be interpreted as compatibility constraints under projected demographic change rather than as predictions of realized employment under future technological change, automation, institutional reform, or shifts in labor-market norms. Technological change may alter the internal task composition and labor demand of industries over time, especially in manufacturing and knowledge-intensive sectors (Acemoglu & Restrepo, 2019; Goos *et al.*, 2014; Lindner *et al.*, 2022). The analysis is also based on headcount rather than hours worked and therefore does not capture adjustments through overtime, changes in working time, or part-time staffing, which may soften the immediate manifestation of labor pressure in some industries. Moreover, although the framework treats observed industry-specific employment structures as its baseline, some skills are partially transferable across sectors, meaning that realized reallocation may be somewhat more flexible than the model assumes, even if such mobility remains institutionally constrained in Korea. Second, because the study focuses on four broad industrial categories, it cannot fully capture heterogeneity across sub-industries, firm sizes, or regional labor markets, and finer-grained industry or regional modeling may reveal variation masked by the present categorization. Accordingly, national-level averages may conceal sharper shortages or temporary surpluses in specific local labor markets. Third, the analysis does not explicitly model immigration, cross-border labor mobility, delayed retirement, or changing labor-force participation among women and older adults. Future changes in educational attainment and credential requirements may also reshape education-to-industry matching in ways not captured by historically observed patterns. Future research should test the sensitivity of the results to alternative fertility, migration, participation, retirement, and technological-substitution scenarios, examine finer sub-industry and regional labor-market variation, and extend the framework through cross-country comparison. Even with these limitations, the framework remains useful as a diagnostic baseline for identifying where population-structural pressure is likely to be strongest.

5. Conclusions

This study examined whether South Korea's future population can sustain the labor requirements of four major industries under a baseline scenario that holds current employment structures constant. By linking

industry-specific employment structures to projected cohort sizes, the analysis shows that demographic change is not a background condition but a binding constraint on industrial labor sustainability. Across all four sectors, the gap between required labor and feasible population-based supply widens over time, although the mechanism differs by industry.

Traditional manufacturing is constrained mainly by replacement pressure as older cohorts retire and smaller youth cohorts fail to replenish them. High-tech manufacturing, ICT, and scientific and technical services face a different constraint: rising demand must be met by a shrinking pool of highly educated young adults. Read as a baseline counterfactual, these results indicate the magnitude of demographic pressure that future policy, migration, or technological adjustment would need to offset. Korea's industrial future will therefore depend not only on technology or competitiveness but also on demographic feasibility, and the same logic is likely to matter in other low-fertility, aging societies.

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Conflict of interest

The authors declare that they have no competing interests.

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Ethics approval and consent to participate

This study uses secondary anonymized microdata from the Statistics Korea Regional Employment Survey and

national population projections. Access to RES microdata requires approval from Statistics Korea. Because the study used anonymized secondary data, ethics approval was not applicable.

Consent for publication

Not applicable. This study does not involve human subjects or personal data requiring consent for publication.

Availability of data

The data that support the findings of this study are available from Statistics Korea. Access to the Regional Employment Survey (RES) microdata is restricted and requires approval from Statistics Korea. Aggregated population data and national population projections are publicly available at <https://kostat.go.kr>.

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