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REVIEW ARTICLE

Exercise and frailty in later life: A systematic review and bibliometric analysis of research themes and scientific collaborations

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Abstract

Exercise is a promising intervention for frailty, but optimal protocols and implementation approaches remain unclear. In this review, a bibliometric analysis was conducted to synthesize research growth, collaborations, intellectual structure, and gaps in the literature on frailty and exercise over the past two decades. The Web of Science and Scopus databases were searched for relevant publications from 1987 – 2024. The bibliometric analysis examined publication trends over time, contributing countries, institutions, authors, journals, research themes and hotspots, collaboration patterns, and evidence gaps. Data visualization and mapping were conducted using VOSviewer, Biblioshiny, and ScientoPy. A total of 447 publications were included in the analysis. The results indicate that research output has grown rapidly since 2010, led by the United States of America (USA), China, Japan, Spain, and Italy. The University of Valencia (n = 12) and the School of Medicine, USA (n = 11) were the most prolific institutions. Five key research clusters were identified through keyword analysis: (i) Frailty assessment, (ii) clinical trials, (iii) cognition, (iv) exercise protocols, and (v) physical outcomes. Regional collaborations were prominent between European, North American, and East Asia-Pacific countries. The bibliometric analysis revealed a surge in publications, with research concentrated in a few productive hubs. There is potential for newer institutions to emerge through international collaborations. Addressing gaps in qualitative, psychosocial, economic, implementation, and translational research could accelerate the translation of evidence into policy and practice. Continued knowledge sharing and partnerships focused on priority gaps can optimize exercise interventions amidst global population aging. This review synthesized the growth, collaborative landscape, and intellectual structure of research on frailty and exercise over nearly four decades. The findings provide insights to inform future research directions and facilitate the translation of evidence into optimized exercise protocols that can be implemented at scale to benefit frail older adults.

Keywords: Bibliometric analysis; Exercise; Frailty; Content analysis

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1. Introduction

The unprecedented demographic shift toward an aging global population poses immense challenges for health-care systems worldwide. By 2050, the number of individuals aged 65 and above is projected to reach a staggering 2 billion, more than

quadrupling from 461 million in 2004 (Fent, 2008; Lutz *et al*., 2008). This stark reality amplifies the urgency to address frailty; a multidimensional geriatric syndrome characterized by decreased physiological reserves and heightened vulnerability to adverse health outcomes (Feng *et al*., 2017; Walsh *et al*., 2023). Estimates suggest that over 10% of older adults globally are afflicted by this debilitating condition (Clegg *et al*., 2013).

Frailty's deleterious consequences, including functional decline, hospitalization, and increased mortality, underscore the imperative for effective interventions (Fiatarone *et al*., 1994; Iskandar *et al*., 2021). Exercise has emerged as a promising therapeutic modality, with mounting evidence supporting its potential to prevent, delay, or even reverse frailty in later life (Binder *et al*., 2005). However, the heterogeneity of frailty manifestations and individual variations in functional capacity necessitate a nuanced approach to exercise prescription for this vulnerable population (Huang *et al*., 2020).

Over the past two decades, research exploring exercise interventions for frailty has expanded significantly, investigating diverse modalities such as resistance training (Wolf *et al*., 2006), aerobic exercise (De Labra *et al*., 2015), tai chi (Cesari *et al*., 2014), and multicomponent programs (Muscedere *et al*., 2019). Concurrently, efforts have intensified to optimize exercise parameters, progression criteria, and implementation strategies tailored to frail individuals (Wang *et al*., 2022). Nonetheless, the lack of consensus on diagnostic criteria and outcome measures continues to hinder the synthesis and translation of findings across studies (Li *et al*., 2022).

As the global burden of frailty escalates, optimizing exercise interventions has become a pressing priority. A bibliometric analysis was conducted in this review to map the evolution, intellectual structure, and collaborative networks within the research landscape on exercise and frailty over the past two decades. By identifying research hotspots, knowledge clusters, and gaps, this review endeavors to inform future research agendas and facilitate the translation of evidence into practice, ultimately fostering healthier aging trajectories worldwide.

The specific objectives of this bibliometric analysis are twofold: (i) To elucidate changes over time in research themes, trends, and patterns of scientific collaboration within the field of exercise and frailty, and (ii) to determine research hotspots and knowledge clusters through co-citation and keyword analysis, while simultaneously pinpointing research gaps and future directions to guide further inquiry in this domain. To achieve these objectives, this review will explore the following research questions:

- RQ1: What are the publication trends in research on exercise and frailty over the past two decades?
- RQ2: What are the main research themes and hotspots that have emerged from keyword analysis?
- RQ3: What are the current research gaps and future hotspots that should be prioritized for further research on exercise and frailty?

2. Methods

2.1. Bibliometric and procedural analysis

In this review, a bibliometric analysis was conducted using data retrieved from the Web of Science (WoS) and Scopus databases (Vieira & Gomes, 2009). Both Scopus and WoS provide comprehensive coverage of research output, with the core documents in both databases having a higher citation impact (Azizan & Zaki, 2023). WoS and Scopus cover a broad range of academic disciplines, making them suitable for capturing relevant studies from different fields related to the relationship between exercise and frailty (Azizan *et al*., 2024).

The literature search was performed on January 6, 2024, with no date restrictions, including all document types and languages. Searching within the "title" field in bibliometric analysis ensures precision by targeting articles where search terms, such as "exercise" and "frail" or "frailty" are central. This approach increases relevance and efficiency and focuses on capturing studies directly related to the main themes of interest. Figure 1 illustrates the employed systematic approach. The following search strings were used:

- WoS: "exercise" (Title) and "frail" OR "frailty" (Title)
- Scopus: (TITLE ("exercise") AND TITLE ("frail" OR "frailty"))

The initial search yielded 970 papers. After omitting 205 articles based on document type, 765 papers remained. Duplicated articles found in both databases were removed, leaving a final set of 447 papers (335 from WoS, 112 from Scopus). Publication trends over time (RQ1) were analyzed using the scientometric tool ScientoPy. To identify knowledge clusters and emerging topics for the second research question (RQ2), co-citation analysis was performed using VOSviewer, while keyword co-occurrence analysis, which also sheds light on evolving topics, utilized both VOSviewer and the Biblioshiny app. Research gaps and future directions, corresponding to the third research question (RQ3), were determined through an integrative analysis synthesizing the various bibliometric results obtained.

3. Results

3.1. Key bibliometric information

Table 1 presents key bibliometric information describing the dataset of 447 documents on exercise interventions

for exercise and frailty research. The timespan covered extends from 1987 to 2024, encompassing sources from 231 different peer-reviewed journals, books, and other publications. On average, the documents were published 7.91 years ago and have received 40.67 citations each. In terms of document contents, 1,276 author keywords (Keywords Plus ID) and 770 author keywords (DE) were identified. The 447 documents were produced by a total of 2,352 unique authors, with 2,364 documents attributed to single authorship by 13 different authors.

Regarding author collaboration, the average number of co-authors per document was 10.8. However, only 3.8% of the papers involved international co-authorship between researchers from different countries. The most common document type was journal articles (371), followed by reviews (64). Other document types included conference papers, proceedings papers, book chapters, and retracted publications. Only 14 (3.1%) of the 447 documents were single-authored.

In summary, Table 1 provides an overview of the dataset dimensions, authorship trends, content, collaboration patterns, and document types included in this bibliometric analysis of research on exercise and frailty over a 37 years span. The data indicate a collaborative field with growing international participation in recent years.

3.2. Publication trends in research on exercise and frailty

The publication output on exercise interventions for frailty, as sourced from the WoS and Scopus databases, is shown in Figure 2. A total of 335 papers were published in WoS sources, compared to 112 from Scopus sources. Overall, publication trends indicate a growing research interest in this field over the past four decades. Before 2000, fewer than 10 papers were published annually. After 2010, the output exceeded 20 papers per year, indicating an uptick in research activity. The period from 2016 – 2021 demonstrated the highest productivity, with publications per year peaking at 40 in WoS and 16 in Scopus in 2021.

The WoS corpus demonstrates greater maturity, with an average document age of 22.5 years, compared to 7.5 years for Scopus. The average yearly output across both databases is 13.4 papers. However, the average number of citations per document is higher for WoS (58) versus Scopus (19). This is reflected in the higher h-index of 58 for WoS compared to 19 for Scopus. In summation, while Scopus has indexed more recent papers in this field, the WoS dataset contains older, more highly cited articles published over a longer time span of 37 years, compared to the 16 years covered by Scopus. The growth in publications over the past decade highlights the rising research interest in exercise interventions for frailty.

3.3. Main research themes and hotspots

A keyword co-occurrence analysis was conducted on 765 keywords extracted from the dataset to identify major research themes and hotspots in exercise interventions for frailty. After setting a threshold of a minimum of five keyword occurrences, 47 keywords met the criteria for cluster analysis. Five distinct clusters emerged, representing broad categories of research focus over the past two decades. Each cluster contained keywords with strong co-occurrence, reflecting a thematic area of inquiry in the literature on frailty and exercise. Figures 3 and 4 illustrate the mapping.

3.3.1. Aging cluster (red)

The aging cluster identified in the bibliometric analysis of exercise interventions for frailty underscores the depth and scope of the research dedicated to understanding frailty in the aging population. It reveals a concerted effort toward studying the epidemiology of frailty, with a focus on the prevalence, patterns, and causes of frailty among older adults (Bandeen-Roche *et al*., 2015; Wolf *et al*., 2006). Research within this cluster is fundamental in grasping the impact of frailty on public health and planning appropriate health-care strategies. Another crucial aspect of the aging cluster is the focus on screening and assessment.

This research avenue involves the development and validation of tools designed to effectively detect frailty (Pialoux *et al*., 2012; Vellas *et al*., 2013). Accurate assessment methods are critical in identifying individuals at risk of frailty or those who are pre-frail – individuals who are not yet frail but show signs of vulnerability. Some researchers have argued that while tools such as slow gait speed, PRISMA 7, and timed get-up-and-go test show high sensitivity for identifying frailty in older adults, their limited specificity prevents them from being used as accurate single tests (Clegg *et al*., 2014).

Within this cluster, there is also an emphasis on characterizing the frailty spectrum. Acknowledging that frailty is not a binary state, research distinguishes between various levels of health in the elderly – from robust to pre-frail to frail. This spectrum approach promotes a nuanced understanding of how frailty can develop and progress, allowing for targeted interventions at each stage (Puts *et al*., 2017).

The examination of risk factors for frailty is another integral research theme within the cluster. Identifying factors such as age-related physiological changes, diseases, lifestyle choices, and environmental influences can help in

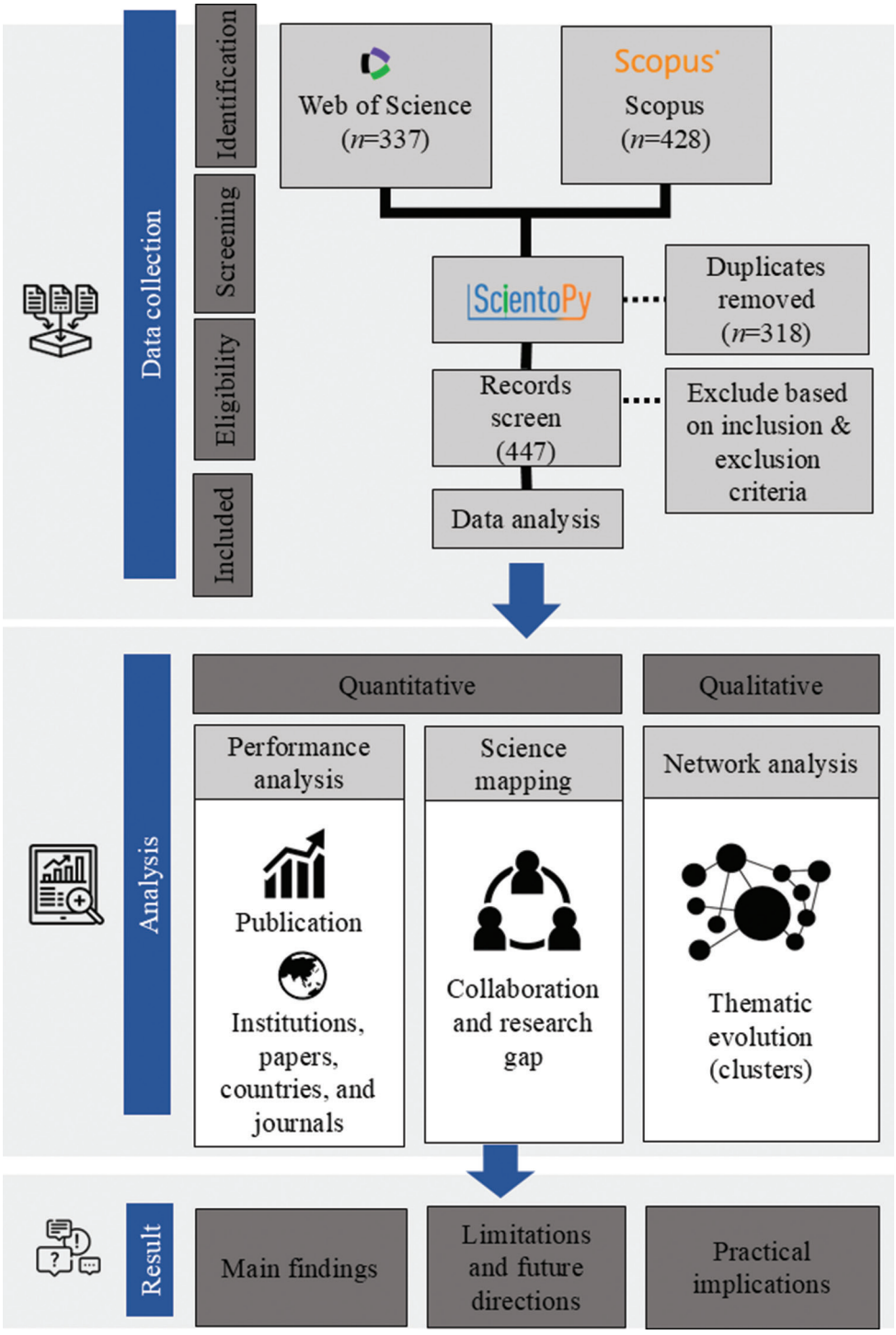

Figure 1. The flowchart of the review

creating prevention and management plans tailored to the needs of the elderly (Leng *et al.*, 2014). Finally, the focus on pre-frailty and early detection highlights an investment in preventative measures. Recognizing the phase before frailty sets in allows for early and potentially more effective interventions, such as exercise programs and nutritional guidance, aiming to arrest or reverse the progression to frailty and extend the health span of older adults (Apóstolo *et al.*, 2018; Dent *et al.*, 2019; Kolle *et al.*, 2023; Money *et al.*, 2023).

Table 1. Key bibliometric information

Description	Results
Main information about the retrieved data	
Timespan	1987 – 2024
Sources (journals, books, etc)	231
Documents	447
Annual growth rate (%)	0
Document average age	7.91
Average citations per doc	40.67
Document content	
Keywords plus (ID)	1,276
Author's keywords (DE)	770
Authors	
Authors	2,352
Authors of single-authored documents	13
Authors' collaboration	
Single-authored documents	14
Co-authors per documents	10.8
International co-authorships (%)	3.803
Document types	
Article	371
Article; book chapter	1
Article; early access	4
Article; retracted publication	1
Conference paper	1
Proceedings paper	4
Review	64
Review; early access	1

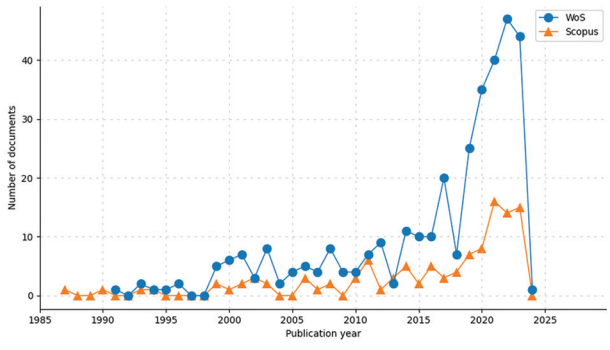

Figure 2. Publication trends in research on exercise and frailty

3.3.2. Clinical trials cluster (green)

Keywords such as "randomized controlled trials," "systematic reviews," and "meta-analyses" indicate the growth of intervention studies (Shears *et al.*, 2017; Negm *et al.*, 2019; Negm *et al.*, 2017). High-quality trials have tested various exercise modalities, dosages, delivery modes, and implementation strategies. Reviews have synthesized evidence on dose-response effects, comparative effectiveness, and impacts on outcomes. Randomized controlled trials are considered the gold standard in clinical research for determining the effectiveness of interventions (Akobeng, 2005). In the field of frailty, these trials are critical for evaluating a range of exercise programs and their outcomes on seniors' health (Angulo *et al.*, 2020; Mulasso *et al.*, 2022). They examine different exercise modalities, such as strength training or aerobic activity (Aguirre & Villareal, 2019), and assess the optimal dosage and best approaches for administering these programs to the elderly population.

Systematic reviews and meta-analyses, on the other hand, aggregate findings from multiple studies to provide a comprehensive overview of the research landscape (Ahn & Kang, 2018; Tawfik *et al.*, 2019). By pooling the data from various high-quality trials, systematic reviews can assess the dose-response effects of exercise, which refers to how changes in exercise regimen (e.g., intensity, duration) are related to the level of improvement in frailty symptoms. These reviews also evaluate comparative effectiveness, comparing different types of exercise or interventions to determine which are most effective for preventing or mitigating frailty. In addition, systematic reviews and meta-analyses examine the impacts of exercise interventions on outcomes such as mobility, independence, and overall quality of life for seniors (Brigola *et al.*, 2015; Han *et al.*, 2023). They synthesize evidence to inform clinical practice and policymaking, guiding health-care providers in recommending the most effective exercise strategies for the prevention and management of frailty.

3.3.3 Cognition cluster (blue)

The cognition cluster, indicated by keywords such as "cognitive frailty" and "cognitive impairment," showcases a rising interest in the mental aspects associated with frailty in elderly populations (Han *et al.*, 2023). Growing evidence underlines cognitive decline as both a component and a consequence of frailty, noting that the two often coexist. Research in this area is delving into the bidirectional relationship between physical and cognitive decline, suggesting that physical frailty can contribute to cognitive deterioration, while cognitive issues can exacerbate physical frailty (Azizan *et al.*, 2021; Hwang *et al.*, 2023; Peng *et al.*, 2023). This complex interplay, where impairments in one domain can negatively influence the other, often leads to a cycle that accelerates the overall decline in health and functioning in older adults (Xue *et al.*, 2022).

Awareness of this interconnectedness is driving investigations into how combined interventions could

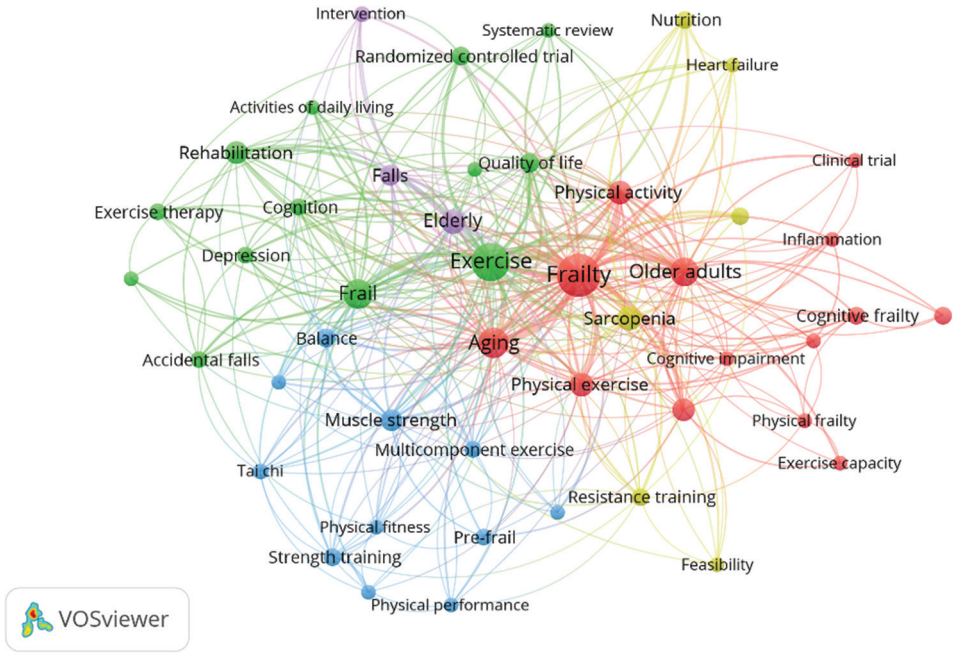

Figure 3. Network mapping of the main research themes and hotspots in the research on exercise and frailty

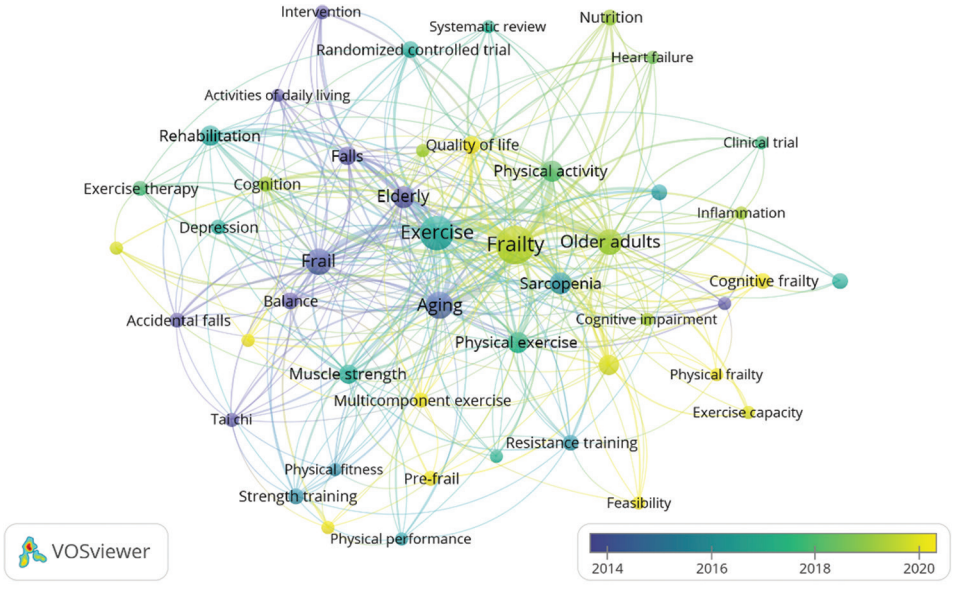

Figure 4. Overlay network mapping of the main research themes and hotspots in the research on exercise and frailty

be more beneficial than addressing either cognitive or physical aspects in isolation. By designing interventions that simultaneously target both cognition and physical health – for instance, combining physical exercise with cognitive training – researchers hope to more effectively combat the progression of frailty (Travers *et al.*, 2018; Yoon *et al.*, 2018; Yu *et al.*, 2021). In contrast, while high-speed resistance exercise training has been shown to effectively improve cognitive function and physical performance in older adults with cognitive frailty, it does not significantly alter frailty scores (Nagai *et al.*, 2018).

3.3.4. Exercise cluster (yellow)

Numerous exercise-related keywords, such as "physical activity," "endurance," and "resistance training," dominate this largest cluster (Casas-Herrero *et al.*, 2019; Flores-

Bello *et al*., 2024; Lin *et al*., 2022; Sadjapong *et al*., 2020; Talar *et al*., 2021). Keywords such as "endurance training," "resistance training," and "tai chi," indicate the diverse range of exercise modalities explored as interventions for older adults at risk of or experiencing frailty. The prominence of this cluster suggests that exercise is considered a potentially powerful intervention for improving outcomes in frailty. Research within this cluster encompasses a variety of exercise regimens, from low-impact activities like tai chi – known for its benefits on balance and mental well-being (Kasim *et al*., 2020; Lee & Chu, 2023) – to more traditional endurance and resistance training, which target cardiovascular health and muscle strength, respectively (Izquierdo *et al*., 2021; Mauricio *et al*., 2024; Seguin & Nelson, 2003).

Previous studies have focused on how these different modalities of exercise can affect the frailty process. These trials seek to determine not only the effectiveness of such interventions in improving the physical and functional capacities of older adults but also the optimal protocols for delivering these benefits (Boreskie *et al*., 2022). This area of research includes assessing factors such as frequency, intensity, and duration of exercise. Multicomponent exercise programs, which combine various types of physical activities to address a range of physical capabilities, are also critical areas of study within this cluster (Edna Mayela *et al*., 2023). These programs aim to optimize the benefits of exercise by targeting multiple aspects of health and physical function that contribute to frailty. The exercise cluster thus highlights an extensive body of evidence that supports the use of physical activity as a key component in the management and treatment of frailty. Ongoing research continues to refine the understanding of how best to use exercise to prevent and reverse frailty symptoms, with the goal of providing tailored, effective exercise protocols to promote the health and independence of the aging population.

3.3.5. Physical function cluster (purple)

Keywords such as "disability," "balance," and "sarcopenia" (Azizan, 2024) indicate a focus on functional outcomes such as strength, mobility, and falls (Evans *et al*., 2023; Rodrigues *et al*., 2022). Studies have assessed the impact of exercise on reducing functional decline, falls, hospitalization, and loss of independence (Sun *et al*., 2021). The presence of these keywords delineates a focus on tangible, measurable aspects of physical health that critically affect the quality of life in older adults. This cluster underscores the importance of strength, mobility, and fall prevention as key indicators of healthy aging. Studies within this cluster have explored how various forms of exercise can bolster these aspects of physical function (Lafrenière *et al*., 2016; Valenzuela, *et al*., 2020; Valenzuela *et al*., 2020). Engaging in targeted physical activities has been shown to help reduce the risk of falls, improve overall balance and mobility, and combat the effects of sarcopenia, thereby enhancing muscle function and prolonging physical independence (DeVito *et al*., 2003; Dipietro *et al*., 2019; Gschwind *et al*., 2013; Kovács *et al*., 2013; Rubenstein *et al*., 2000). Research on this cluster emphasizes the significance of exercise interventions not only in improving measurable physical capabilities but also in reducing the incidence of functional decline (Cancela *et al*., 2016; Gill *et al*., 2002). By focusing on how exercise can help maintain or increase strength and mobility, these studies seek to prevent the onset of disability that can lead to increased dependence on others.

Moreover, this cluster hints at the broader implications of maintaining physical function, such as the reduction of hospitalizations and the associated health-care costs. The ability to independently perform activities of daily living without assistance is a key factor in avoiding prolonged hospital stays and admissions to long-term care facilities (Weening-Dijksterhuis *et al*., 2011). In essence, the physical function cluster represents a crucial arena where the practical benefits of exercise are scrutinized in terms of functional capabilities. The ultimate goal of the research within this cluster is to inform interventions that can help older adults maintain their independence and continue to lead active, fulfilling lives.

3.4. Top countries in research on exercise and frailty

The bibliometric analysis reveals that research on exercise and frailty is dominated by countries from North America, Western Europe, and East Asia. The United States of America (USA), Japan, and Spain emerge as the top three most productive countries, contributing a significant number of publications in this field. Interestingly, China demonstrated the highest annual growth rate and papers per decade per year, indicating a rapidly growing interest in this area of research. This trend highlights the potential for collaborations between these productive regions, which could enhance the quality and impact of future publications.

3.4.1. Leading institutions in research on exercise and frailty

At the institutional level, the research landscape is dispersed, with only a handful of institutions publishing more than five papers. The University of Valencia in Spain stands out as the most prolific institution, followed by the School of Medicine in the USA and the Division of Human Nutrition and Epidemiology in the Netherlands. While European institutions dominate the top 20 list, there is a

notable presence of institutions from North America and East Asia, reflecting the global interest in this research area. The dispersion of publishing across 136 institutions suggests opportunities for newer groups to make significant contributions, provided adequate collaborations can be forged.

3.4.2. Prominent journals for publications on exercise and frailty

The analysis of collaborative patterns and networks reveals geographical clustering with some inter-regional links between leading groups. Regional clusters are evident, with strong collaborations among European, North American, and Asian countries. However, cross-cluster collaborations are also visible, with countries such as Spain, the USA, and Australia occupying central positions, bridging multiple regional clusters. At the institutional level, prominent nodes like the University of Valencia and the University of Coimbra anchor research hubs within their respective regional clusters, while institutions like the University of Sydney and Tufts University enjoy high global connectivity. The visualization highlights the potential for targeted partnerships bridging regional clusters, which could enhance the vibrancy of global research collaborations in the fields of frailty and exercise.

3.5. Current research gaps and future hotspots for further research on exercise and frailty

The bibliometric analysis in this review reveals several gaps in the literature on frailty and exercise. The vast majority of studies utilize quantitative methodologies, such as randomized controlled trials and cohort studies (Reeves *et al*., 2018). However, qualitative designs are rarely adopted to gain an in-depth understanding of patient experiences, feasibility, and implementation barriers (Niazi *et al*., 2022). Mixed-methods approaches could provide richer contextual insights, which are crucial for optimizing interventions. Another significant gap is the predominant focus on physical performance outcomes, such as strength, balance, and mobility (Ip *et al*., 2012). Patient-reported outcomes, including quality of life, well-being, and social connectedness, are measured less frequently (Ligezka *et al*., 2022). Expanding outcome measurements to include psychosocial impacts could provide a more holistic evaluation of interventions. There is also a dearth of health economic analyses and cost-effectiveness data, which are crucial for informing policy decisions regarding reimbursement and the scaled-up delivery of interventions (Meunier., 2022). In addition, implementation research and knowledge translation studies are lacking, reflected by the gaps between evidence and practice in adopting frailty exercise programs (Li *et al*., 2023; Yi *et al*., 2023). Future research should address these gaps while exploring emerging priority areas such as technology-enabled exercise interventions, cognitive training, nutritional approaches, pre-frailty prevention, and risk-stratified protocols tailored to specific frailty profiles (Jeong *et al*., 2022). Continued international cooperation, evidence sharing, and integrated knowledge translation can help advance research on frailty and exercise for greater impact. Figure 5 provides an illustration of the thematic map of the field.

4. Discussion

The bibliometric analysis conducted in this review provides a comprehensive overview of research activity, collaborations, and intellectual structure in the field of

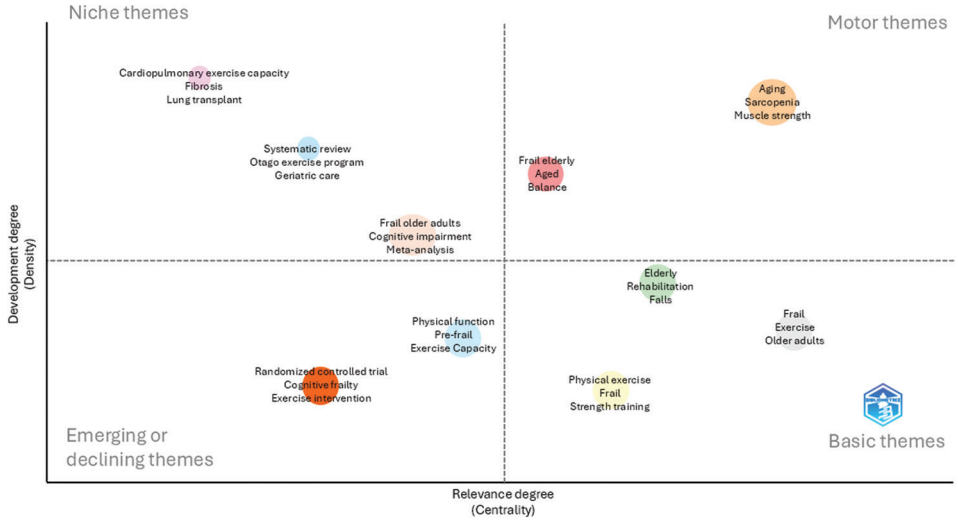

Figure 5. Thematic map of the research on exercise and frailty. Map created with Biblioshiny

exercise interventions for frailty over the past two decades (Shamliyan *et al*., 2013). The findings offer valuable insights to inform future research directions and translation of evidence into policy and practice. The rapid growth in publications in recent years highlights a rising interest in this area, corresponding to the global increase in frailty prevalence (Hui *et al*., 2022). However, research remains concentrated in a handful of productive countries and institutions, primarily in Europe, North America, and East Asia. Targeted efforts to expand capacity, particularly in South Asia, Africa, and South America, through research networks and collaborations could enhance the global evidence base (Li *et al*., 2016).

The analysis of leading journals revealed that research on frailty (Seldeen *et al*., 2022) and exercise is predominantly published in niche gerontology, rehabilitation, and geriatrics sources. As further supported by Welstead *et al*. (2020), the main global research topics in geriatrics and gerontology are older adults, education and training, and adults aged 80 years and older. Increasing visibility in high-impact general and sports medicine journals could elevate the profile and multidisciplinary reach of this research (Neto *et al*., 2023). In addition, higher interdisciplinarity in research fronts is significantly associated with a 20% increase in research impact (Okamura, 2019).

Bibliometric indicators also suggest that there is scope to improve the impact and dissemination of publications through open-access platforms, social media engagement, and integrated knowledge translation approaches (Fetscherin & Heinrich, 2015). The five knowledge clusters identified in this analysis offer a conceptual map, highlighting research emphases on assessment, clinical trials, cognition, exercise protocols, and physical outcomes. However, qualitative research, psychosocial factors, economic analysis, implementation strategies, and translational dimensions appear to be understudied (Rahayu *et al*., 2021; Sarkies *et al*., 2021). Addressing these evidence gaps could accelerate the translation of research into policy and practice.

The exploration of emerging hotspots, such as technology-enabled interventions and pre-frailty prevention, also warrants more attention (Gené Huguet *et al*., 2018; Mugueta-Aguinaga & Garcia-Zapirain, 2017; Tan *et al*., 2022). While country- and institution-level collaborations are evident, cross-cluster partnerships between leading, novice, and underrepresented research hubs could introduce new perspectives. South-South networking beyond regional clusters could further strengthen global frailty research capacity (Wu, 2023). In addition, integrated knowledge translation involving co-production with patients, practitioners, and policymakers remains limited but could enhance the relevance and application of research findings.

5. Conclusions

The bibliometric analysis conducted in this review provides a comprehensive overview of the global research landscape on exercise interventions for frailty over the past four decades. The findings reveal a rapidly growing publication output, especially since 2010, signaling heightened research interest amid accelerating population aging worldwide. However, research activity remains concentrated within a select group of productive countries, such as the USA, China, Japan, Spain, and Italy, with most leading institutions located in Europe, North America, and East Asia. Expanding collaborative networks to include underrepresented regions such as South Asia, Africa, and South America could strengthen the global evidence base.

Five major knowledge clusters emerged, focusing on frailty assessment, clinical trials, cognition, exercise protocols, and physical function outcomes. While quantitative studies evaluating exercise impacts on functional measures such as strength, mobility, and falls have been widely conducted, qualitative research exploring patient perspectives and implementation barriers is lacking. Incorporating mixed methods and patient-reported outcomes, such as quality of life, could provide a more comprehensive understanding to optimize interventions.

From a clinical perspective, synthesizing evidence on effective exercise modalities, intensities, and progressions tailored to frailty phenotypes can guide patient-centered prescriptions. However, translating research into practice remains challenging due to limited economic analyses, implementation studies, and integrated knowledge translation efforts involving key stakeholders. Cost-effectiveness data will also be crucial to drive reimbursement policies and the widespread adoption of frailty exercise programs by health-care providers.

Moving forward, priorities for future research should address identified gaps in qualitative contexts, psychosocial impacts, health economics, implementation strategies, and integrated knowledge translation. Exploring emerging areas such as technology-enabled exercise delivery, cognitive training, nutritional co-interventions, pre-frailty prevention, and risk-stratified protocols based on frailty profiles is also warranted. International research consortia can accelerate multi-center studies and open data-sharing to generate robust, globally representative evidence.

Ultimately, continued multidisciplinary collaboration, harnessing expertise across geriatrics, rehabilitation,

nursing, sports science, and public health, is vital to advance this field. By adopting a holistic, person-centered lens spanning therapeutic interventions to health system implementation, research on exercise and frailty can optimize strategies to support healthy, independent living for the growing global population of older adults.

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Conflict of interest

The author declares that she has no competing interests.

Author contributions

This is a single-authored article.

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Availability of data

The data that support the findings of this study are available from the corresponding author on reasonable request.

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REVIEW ARTICLE

Early-life determinants of frailty: A comprehensive review

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Abstract

Frailty is a complex, aging-related clinical syndrome characterized by decreased reserves to stressors. Factors in early life are posited to have a long-term impact on health through separate and combined effects of biological, behavioral, and psychosocial mechanisms. There is a consensus that physical, behavioral, psychosocial, and environmental risk factors in early life play essential roles in developing frailty in old age. Over the past two decades, we have witnessed a proliferation of literature on early-life risk factors for frailty in developed and developing countries and areas. We summarized empirical studies examining how early-life risk factors contributed to the development of frailty. We classified risk factors into four dimensions: biological factors, socioeconomic circumstances, healthy lifestyles, and environmental exposures. We identified a wide range of biological (body size and intelligence), social (education, parental education, and socioeconomic conditions), lifestyle (childhood health status and nutritional status), and environmental factors (home environment, neighborhood quality, and traumatic wartime experience) associated with frailty in old age. Future research should adopt novel methodologies to address the complexity and interconnectedness of risk factors in distinct early-life stages, use more rigorous study designs and analytic tools to unravel the underlying mechanisms, and pay more attention to the transition and progression of frailty. This review highlights the enduring impact of early-life experiences on frailty and suggests the necessity of designing frailty interventions from a life course perspective. Interventions improving early-life circumstances might delay or even prevent the emergence of frailty in old age.

Keywords: Frailty; Aging; Early-life risk factors

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1. Introduction

Frailty is a multifaceted syndrome related to aging that reduces an individual's resilience to stress factors. It impacts around 10% of older adults living in communities globally (Collard *et al.*, 2012). Frail individuals have a compromised ability to maintain system

homeostasis due to dysregulations across multiple physiological systems. The susceptibility to hospitalization, disability, and mortality, as well as difficulties in recovering from stressors in frail older adults, has been well documented (Ensrud *et al.*, 2008; Ma *et al.*, 2020; Vermeiren *et al.*, 2016; Wu *et al.*, 2019; Xu *et al.*, 2020). Frailty is conceptualized as a distinct clinical entity from disability; however, research in this area has been slow for multiple reasons, such as an incomplete understanding of the natural history and etiology of frailty. A significant advancement in the field came in 2001, introducing two commonly used assessment tools: the frailty phenotype and the frailty index (Fried *et al.*, 2001; Mitnitski *et al.*, 2001). Following that, there has been an increase in empirical research on frailty, concentrating on developing new instruments, quantifying the burden of frailty, establishing its relationship with negative health results, and pinpointing associated risk factors.

Factors during early life are theorized to have a long-term impact on subsequent health through individual and combined effects of biological, behavioral, and psychosocial mechanisms. There is a consensus that physical, behavioral, psychosocial, and environmental risk factors in early life are related to the development of frailty in old age. Over the past two decades, we have witnessed a proliferation of literature on early-life risk factors for frailty in developed and developing countries and areas. There have been limited efforts to thoroughly understand the impact of early-life risk factors on the development of frailty in later life (Barrera *et al.*, 2023). The present study is among the first to systematically review and summarize these factors and the mechanisms driving their association with frailty in old age. We summarized empirical studies examining how early-life risk factors contributed to the development of frailty. We classified these risk factors into four dimensions: biological factors, socioeconomic circumstances, healthy lifestyles, and environmental exposures (Figure 1). This study enhances our understanding of early-life risk factors for frailty and provides crucial insights for developing targeted frailty prevention strategies to mitigate these early-life risk factors.

Researchers have sought to capture the complexity of frailty by proposing various assessment instruments grounded in distinct theoretical frameworks (Buta *et al.*, 2016; Cigolle *et al.*, 2009; Guo *et al.*, 2022; Wu, 2023). These frameworks serve as the basis for understanding and quantifying the frailty construct and guide the development of measurement tools that can be applied across diverse settings and for different purposes. In general, frailty assessment tools can be classified into four categories based on their constituent components: physical, cognitive, social, and biopsychosocial frailty. The present study focused on physical frailty because it has received the most attention in research and has significant health implications. Physical frailty is often considered the entry point for frailty assessment in clinical settings due to its relative ease of measurement and strong predictive value for identifying individuals at risk of poor health outcomes.

2. Methods

2.1. Search strategy

This review was conducted in adherence with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Page *et al.*, 2021). We searched PubMed, one of the largest and most comprehensive databases for biomedical literature, for original research papers published from since its inception until June 1, 2023, focusing on studies investigating the link between early-life risk factors (measured before the age of 18 years) and physical frailty in later life. The search utilized keywords and their variations, including early life, newborn, baby, infancy, childhood, adolescence, and frailty. We also reviewed the bibliographies of relevant original research articles and reviews that satisfied our inclusion criteria.

2.2. Inclusion and exclusion criteria

Two researchers, H.L. and M.W., independently reviewed the titles and abstracts to assess the suitability of the studies. They, the full texts of articles that met the initial screening criteria were examined. Any disagreements in the article selection process were resolved through discussions between the two investigators. Consultation from a third investigator (C.W.) was acquired if necessary. We initially screened the titles and abstracts to identify potentially eligible papers and then thoroughly examined their full text. Subsequently, we reviewed the full text of all 355 records and selected 40 based on their relevance to our research topic – the link between early-life risk factors and physical frailty in later life.

3. Key findings

3.1. Biological factors

Multiple studies have identified the role of body size in early life, such as birth weight, body length, and body mass index (BMI), in the development of frailty. In addition, childhood intelligence has been linked to frailty. Most evidence was produced in studies focusing on populations in developed regions; more attention should be paid to developing countries and areas.

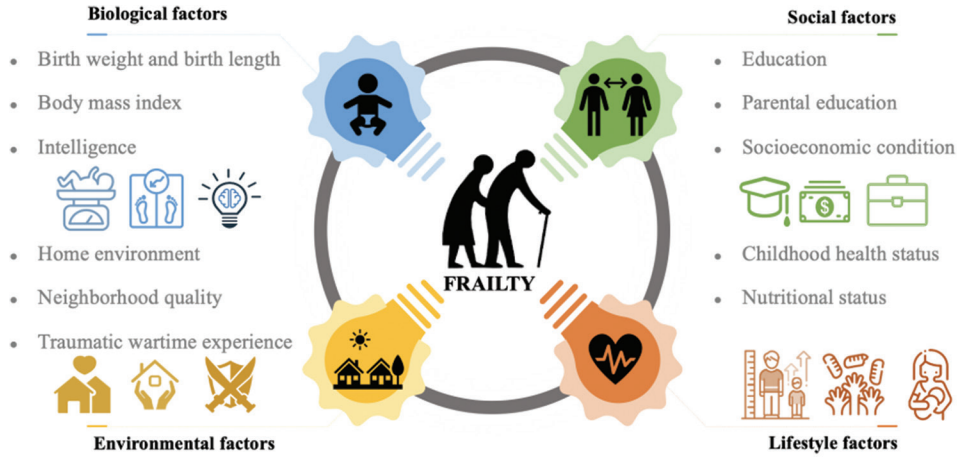

Figure 1. Early-life biological, social, lifestyle, and environmental factors for frailty in old age

3.1.1. Birth weight and birth length

Infants with birth weights deviating from the standard range present a heightened risk of experiencing an array of adverse health outcomes, both in the immediate and long-term future (Haapanen *et al.*, 2018; Maharani *et al.*, 2023). Haapanen *et al.* (2018) found that lower birth weight and shorter birth length were associated with a higher risk of frailty, as measured by the physical frailty phenotype approach, among 1078 older adults from the Helsinki Birth Cohort Study. Frail individuals had a mean birth weight of 3.25 kg, significantly lower than the non-frail ones (3.45 kg). The average birth length was significantly shorter among the frail than the non-frail individuals (49.5 vs. 50.5 cm). Pre-frail individuals also had a lower mean birth weight and length than non-frail individuals. A 1-kg increase in birth weight was associated with a 60% lower risk of frailty. More recently, Maharani *et al.* (2023) found that either low (<2.5 kg) or high birth weight (>4.0 kg) was associated with a higher level of frailty than normal birth weight among over half a million middle-aged and older adults from UK Biobank. These findings underscored the impact of birth weight on frailty development in old age.

3.1.2. BMI

Haapanen *et al.* (2018) revealed an inverse relationship between BMI at birth and frailty in old age using data from 1078 older adults in the Helsinki Birth Cohort Study. A one-unit increase in birth BMI was associated with a 98% lower risk of frailty at 71 years. In a comparison paper, Haapanen *et al.* (2019) investigated whether body size growth later in infancy and childhood was related to frailty in old age and found sex-specific results. Greater BMI gain between 2 and 11 years was associated with frailty among boys, while no similar associations were found among girls. Taken together, these findings suggest that persons with smaller body sizes at birth are at an increased risk of developing frailty. At the same time, only males are more likely to be frail due to accelerated BMI gain during childhood.

In addition to BMI at birth, Haapanen *et al.* (2022) found an association between higher maternal BMI and increased offspring frailty level, as assessed by the frailty index, in midlife and a slower increase in frailty level into old age. These findings shed new light on the critical life stages for preventing frailty and highlight the importance of improving health for women of reproductive age to reduce health disparities.

Different plausible mechanisms, such as environmental factors, genetics, epigenetics, and early-life programming, might influence the association between childhood growth and frailty in later life. The period of early infancy is crucial for muscle development. An adverse prenatal environment may compromise muscle tissue development at the expense of the development of vital organs (*e.g.*, the brain) (Hales & Barker, 2013). As a result, infants born with smaller body size might have reduced muscle tissue, which could manifest as decreased muscle strength, a key frailty criterion (Ylihärsilä *et al.*, 2007).

3.1.3. Intelligence

Using data from the Lothian Birth Cohort 1936 conducted in Scotland, Gale *et al.* (2016) examined whether and how intelligence in childhood was related to frailty in old age among 876 community-dwelling adults at an average of 70 years. All participants were tested for general intelligence at the age of 11 years as part of the Scottish Mental Survey. A standard deviation decrease in intelligence was associated with a 57% risk of frailty in sex-adjusted analyses; however, the association attenuated and was no longer significant after adjusting for potential

mediators, including educational attainment, attained social class, and health behaviors in adulthood. A further mediation analysis found that the association between intelligence and frailty was mediated through educational achievement, highlighting the benefits of lifelong learning and cognitive engagement for maintaining physical health in later life.

3.2. Social factors

Educational attainment and socioeconomic conditions in childhood have been well-documented as key contributors to frailty in old age. Research conducted in developed and developing countries and areas consistently suggests that individuals with lower educational attainment and those who grew up in disadvantaged socioeconomic conditions are more susceptible to frailty.

3.2.1. Education

Studies have consistently shown a negative association between education attainment and frailty, suggesting that lack of education could amplify the risk of developing frailty over life. Alvarado *et al.* (2008) examined the association between education and frailty using data from a cross-national survey of older adults living in five large Latin American cities (Bridgetown, Barbados; Sao Paulo, Brazil; Santiago, Chile; Havana, Cuba; and Mexico City, Mexico). Individuals with no schooling (*i.e.*, people who have never received any forms of formal education, participants who cannot read or write) had an increased odds of frailty later in life than those with more than 12 years of schooling, with odds ratios (ORs) ranging from 1.39 to 3.03. Studies focusing on European populations showed similar findings. Soler-Vila *et al.* (2016) analyzed data from a cohort of 1857 community-dwelling individuals aged 60 and above. They discovered that older women with primary or lower education had about 3 times the likelihood of being frail compared to those with a university education. Similarly, Herr *et al.* (2015) found that having ten or fewer years of schooling was associated with 45% higher odds of being frail in a cohort of 2350 French adults aged 70 years or above. Bai *et al.* (2023) observed comparable results regarding the association between lower education levels and an increased risk of frailty, after analyzing data from the UK and Sweden. More recently, Li *et al.* (2020) found a nearly dose-response correlation between education and frailty: older Chinese adults with a primary school, middle school, and high school or higher education had a 36%, 59%, and 77% reduced probability of becoming frail, respectively, than the illiterate ones.

In addition to directly affecting frailty, education is a mediator between factors in earlier life stages and frailty. Using data from over half a million middle-aged and older adults in the UK Biobank study, Maharani *et al.* found that being born in the UK, not breastfeeding, maternal smoking, and birth weight outside of a normal range was associated with lower educational attainment, which, in turn, led to a higher level of frailty (Maharani *et al.*, 2023).

Several studies explored the mechanisms underlying the connection between low educational attainment and high risk of frailty and have identified mediators from different dimensions. Maharani *et al.* (2023) examined the role of material, biomedical, behavioral, social, and mental factors in the relationship between education and frailty. Income, self-efficacy, obesity, cognitive function, and chronic conditions were the most important mediators. Using data from 14,082 community-dwelling persons from 11 European countries, Etman *et al.* (2015) found that alcohol consumption, social participation, depression, and chronic conditions collectively accounted for the different frailty levels caused by educational inequalities. These findings underscore the multifaceted impact of educational attainment on the development of frailty, revealing a complex interplay of lifestyle, psychosocial, and health-related factors.

3.2.2. Parental education

The importance of maternal and paternal education for childhood growth has been well established. Few studies have considered the role of maternal and paternal education in developing frailty in old age. Using data from 6806 individuals aged 60 years or older collected from the China Health and Retirement Longitudinal Study, Li *et al.* (2020) found that individuals whose paternal education was literate were 26% less likely to be frail than those whose fathers were illiterate. A subsequent study of the same data set, assessing frailty using the Frailty Index, reported similar findings (Yan *et al.*, 2022). Interestingly, maternal education was not related to frailty among older Chinese adults. Caution should be exercised when interpreting these findings as the study observed that over 95% of participants' mothers had no formal education; hence, maternal education might not adequately reflect this cohort's socioeconomic conditions during the early stages of life.

3.2.3. Socioeconomic conditions

Socioeconomic disadvantage in childhood has been consistently linked to an increased risk of frailty in adulthood. Researchers have used several parameters to assess socioeconomic conditions of the children, such as the father's social class, occupation class, and household income, and examined its role in shaping the development of frailty in old age. Gale *et al.* (2016) found that a lower father's social class was associated with a higher risk of

frailty among older adults in Scotland. The participants' educational attainment partially explained the effect of the father's social class on frailty. Similarly, Rogers *et al.* (2021) investigated the association between social class, classified into four categories, and frailty among 8711 adults aged at least 50 years from the 1958 British birth cohort. Individuals with fathers in the highest social class (class I/II professional/managerial) had a 10.3%, 27.8%, and 42.0% lower risk of frailty than those in the class III skilled non-manual, class III skilled manual, and classes IV/V partly/unskilled manual category, respectively.

By analyzing data from a survey focused on older adults residing in five major Latin American cities, Alvarado *et al.* (2008) found that individuals reporting good childhood socioeconomic circumstances were less likely to be frail later in life than those reporting poor socioeconomic circumstances during childhood; the adjusted ORs ranged from 1.05 to 1.52 across five cities. Herr *et al.* (2015) found that living standards in childhood (well-off, limited, or deprived) could influence the development of frailty. Individuals who experienced constrained or underprivileged living conditions had an elevated risk of frailty than those who lived in more prosperous circumstances. Similar findings were reported in developing countries. By examining the relationship between a family's financial situation and frailty among older Chinese adults, Li *et al.* (2020) found that individuals in a better financial situation had a substantially reduced likelihood of becoming frail compared to those in worse economic conditions. Van der Linden *et al.* (2020) explored the mechanisms linking early-life socioeconomic conditions and frailty in old age. Using data from 21,185 individuals aged at least 50 years from 14 European countries, they found that adulthood socioeconomic conditions (*i.e.*, education, occupational class, and satisfaction with household income) mediated the association between childhood socioeconomic conditions and risk of frailty. A recent study focused on the gender-specific impact of childhood socioeconomic deprivation on frailty among Chinese middle-aged and older adults, showing that this association was more pronounced in women than men (Wang, 2023a). Taken together, these findings underline the importance of addressing socioeconomic disparities throughout life to reduce the risk of frailty in late adulthood, particularly among women.

Poor early-life socioeconomic conditions are associated with a higher risk of frailty in later life through various interconnected mechanisms. Nutritional deficiencies during critical developmental periods can influence physical growth and immune function (Smith & Pollak, 2020). Chronic stress associated with economic hardship could result in long-term alterations in stress response systems (Ridley *et al.*, 2020). Socioeconomically disadvantaged individuals are more likely to adopt unhealthy behaviors, such as smoking and physical inactivity, which subsequently heightens their risk of developing frailty.

3.3. Lifestyle factors

Childhood health and nutritional status have consistently emerged as vital factors influencing the risk of frailty in old age. Research continually points toward individuals who had adverse health conditions and dietary shortcomings in childhood as being more prone to frailty in their later years.

3.3.1. Childhood health status

Alvarado *et al.* (2008) found that individuals reporting excellent childhood health were less likely to develop frailty in old age than those reporting poor health in childhood. Li *et al.* (2020) also detected the same pattern in China. Through the examination of the association between childhood health status and frailty in old age among over 6000 older Chinese adults, they found that individuals reporting better health before reaching age 15 had a 26% lower risk of frailty in old age than those reporting average health. Worse childhood health was linked to a 2.9% increase in frailty risk.

3.3.2. Nutritional status

Research has consistently highlighted a negative relationship between nutritional adequacy and frailty, suggesting that nutritional deficiencies increase the risk of frailty over one's lifespan. Alvarado *et al.* (2008) found that individuals living in Latin America who experienced hunger during childhood had a significantly higher risk of frailty, with OR ranging from 1.15 to 1.70. By analyzing data from over 6000 older Chinese adults, Li *et al.* (2020) found that severe starvation (*i.e.*, a family member starved to death) during childhood was associated with a 30% higher risk of being prefrail. Based on the data from the same study, Ye *et al.* (2021) found that experience of food deficiency during childhood (*i.e.*, not enough food to eat before age 12) was associated with 30% higher odds of frailty in old age. In addition, Gao *et al.* (2022) found that early-life nutritional deprivation could increase the risk of frailty in old age using data from 7342 older Chinese adults in the Chinese Longitudinal Healthy Longevity Survey. They revealed that individuals having experienced hunger in childhood (*i.e.*, often went to bed hungry as a child) had 13% higher odds of being frail than those without. These results collectively suggest that prevention of food deficiency during childhood might delay or even prevent frailty among middle-aged and older adults.

In addition to food deprivation during childhood, a history of breastfeeding was associated with a lower level of frailty (Maharani *et al.*, 2023). Through the analysis of data from over half a million middle-aged and older adults from UK Biobank, Maharani *et al.* (2023) found that individuals who were breastfed as babies had a lower frailty index than those without a history of breastfeeding. Breast milk, rich in nutrients, antibodies, and growth factors contribute to healthier early-life development, improving muscle strength and overall physical function (Lisboa *et al.*, 2021; von Bonsdorff *et al.*, 2011).

3.4. Environmental factors

Environmental factors during childhood, including domestic violence, neighborhood quality, and traumatic wartime experiences, profoundly impact frailty in old age. Residing in a safe and supportive home and neighborhood environment during childhood might reduce the risk of frailty, while exposure to traumatic wartime experiences in early life was associated with a higher risk of later-life frailty.

3.4.1. Home environment

Safe, supportive, and nurturing family relationships and home environments are central to children's and adolescents' development and health. Mian *et al.* (2022) conducted a cross-sectional study to examine the association between early home environment and frailty among over 27 thousand adults aged 45 – 85 years from the Canadian longitudinal study on aging. Individuals experiencing more adverse childhood events, including physical abuse, sexual abuse, emotional abuse, neglect, and exposure to domestic violence, before age 16 had elevated levels of frailty later in life. Threat-based early-life adversities (*e.g.*, violence) affect health outcomes in later life by accelerating the biological aging processes, including expedited pubertal development and accelerated cellular aging (Colich *et al.*, 2020).

3.4.2. Neighborhood quality

Li *et al.* (2020) examined how neighborhood quality during childhood contributed to frailty in old age among over 6000 older Chinese adults. Childhood neighborhood quality was assessed by four items quantifying whether the neighborhood they lived in before age 17 was safe, willing to help, close-knit, and clean and attractive. Each item was dichotomized, and the sum score measured the overall neighborhood quality. Individuals with the highest neighborhood quality had 11.4% and 4.8% lower risk of being prefrail and frail than those with the lowest quality, respectively.

3.4.3. Traumatic wartime experience

Zimmer *et al.* (2022) examined the association between traumatic wartime experiences in early-life and later-life frailty using data from 2447 Vietnamese adults aged at least 60 years from the Vietnam Health and Aging Study. Latent class analysis was employed to categorize individuals based on the number and kinds of traumatic events that they experienced during the American war. It identified nine wartime exposure classes, ranging from extreme to non-exposed. Individuals who experienced more severe exposures, such as heavy bombing, direct witnessing of death, sleep disturbances, and life-threatening fears during wartime, which exhibited higher levels of frailty compared to those who did not. These findings highlight the enduring impact of traumatic wartime experiences on frailty in old age. Dimitriadis *et al.* (2023) found that adverse childhood experiences, including exposure to war, were associated with a higher level of frailty index in later life based on a sample of older adults in the Netherlands. Experiencing traumatic war events in the early life can impair an individual's ability to regulate stress. This impairment can lead to the accumulation of severe stress, which, in turn, disrupts the development of immune and metabolic systems, ultimately accelerating the aging process (Ellis & Del Giudice, 2014; Greenblatt Kimron *et al.*, 2019; Schneiderman *et al.*, 2005).

4. Concluding remarks

Through collective efforts, researchers have identified various early-life risk factors for frailty in developed and developing countries and areas. These achievements have paved the way for a future research agenda on preventing frailty. Four topics merit further discussion in future research. First, there is a need for more comparative studies across different countries and regions to clarify how social and cultural environments influence the health impacts of adverse childhood experiences on frailty in later life. A recent study using data from China and Europe has shown varying relationships between adverse childhood experiences and frailty in old age (Wang, 2023b). These variations were observed not only between China and Europe but also among different European countries. Second, most previous studies needed to adequately consider the complexity and interconnectedness of different risk factors in distinct early-life stages. Future research needs to adopt new methodologies, such as the polysocial approach (Figueroa *et al.*, 2020; Herrin *et al.*, 2023; Javed *et al.*, 2021; Ping *et al.*, 2021; Tang *et al.*, 2023; Tang *et al.*, 2023; Zhao *et al.*, 2022), to comprehensively measure the aggregated effects of various early-life risk factors on frailty in old age. Third, future research should pay more attention to unraveling the mechanisms underlying the associations

between risk factors in early-life stages and frailty in old age using more rigorous study designs and more advanced analytic approaches. This endeavor is critically essential to corroborate their causal relationships and, in turn, leads to effective interventions. Fourth, frailty is a dynamic process instead of a static state; transitions between frailty states over time are frequent among older adults (Gill *et al.*, 2006; Mendonça *et al.*, 2020; Walsh *et al.*, 2023). Most, if not all, studies focused on the association between early-life risk factors and the onset of frailty. Whether and how early-life circumstances contribute to the transition and progression of frailty is largely unknown. More efforts should be devoted to understanding their roles in frailty transitions, especially progression to death among the frail individuals.

While this review offers significant insights into the early-life determinants of frailty, several limitations must be acknowledged. First, most studies rely on retrospective self-reports, which are prone to recall bias and inaccuracies. Second, there is a predominance of studies conducted in developed countries, potentially limiting the generalizability of findings to low- and middle-income regions. Third, the complexity and interconnectedness of various risk factors often needed to be fully addressed, necessitating more comprehensive and integrative methodologies. In addition, most of the research focuses on the onset of frailty, with a limited investigation into how early-life factors influence the transition and progression of frailty over time. Finally, while associations have been established, the causal mechanisms underlying these relationships remain largely unexplored, highlighting the need for rigorous longitudinal studies and advanced analytic techniques to unravel these complex interactions. Future research should address these gaps to provide a more holistic understanding of the early-life determinants of frailty.

In summary, over the past two decades, increasing attention has been paid to identifying early-life risk factors for frailty. Researchers have conducted empirical studies to examine whether and how early-life experience contributes to the development of frailty in old age in both developed and developing countries and regions. A wide range of biological, social, lifestyle, and environmental factors in early-life stages have been linked to the onset of frailty in later life. These findings highlight the enduring impact of early-life experiences on health and suggest the necessity of studying the mechanisms and interventions of frailty from a life course perspective. Interventions that improve early-life circumstances might delay or even prevent the emergence of frailty in middle and old age.

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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

Not applicable.

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Availability of data

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RESEARCH ARTICLE

American Indian census rolls: An underutilized source of historical demographic information on tribal populations

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Abstract

Historical information on tribal populations in the United States is incomplete. American Indians and Alaska Natives were not enumerated with the general population until the 1940 decennial census. However, Indian Census Rolls were produced for the period 1885 – 1940 under the auspices of the Bureau of Indian Affairs in the U.S. The information given in the Indian Census Rolls varies but usually includes the roll number, age, gender, tribal identity, and relationship to the head of the family. In this paper, we present background information on Indian Census Rolls and demonstrate how the digitized microfiche census roll schedules can be assembled into an Excel file. We also provide examples of the potential uses of Indian Census Rolls. We conclude that Indian Census Rolls can not only help bridge the gaps in the historical demography of American Indians but also provide the basis for a clearer picture of the current and future demographic characteristics of American Indians.

Keywords: Indian Census Rolls; Historical Indian demographics; 1937 Lummi tribe demographic profile; Excel reporting template

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1. Introduction

Historical information on tribal populations in the United States is scattered and discontinuous (NCAI Policy Research Center, 2021:2). American Indians and Alaska Natives (AIAN) were not always counted in the decennial census. It was not until 1850 that counts of AIAN populations on reservations were provided by the Commission of Indian Affairs to the Census Bureau (U.S. Census Bureau, 2021a). The 1890 census was the first to attempt to count all American Indians; however, these records were lost during a fire in 1921 (U.S. Census Bureau, 2021b). The loss of the 1890 records made the 1900 census seminal in terms of the information about American Indians it collected because that information is still available (Johansson & Preston, 1978).

Under the U.S. Constitution (Article 1, Section 2), which specifies that a census be taken every 10 years, "Indians not Taxed" were excluded from the decennial count,

meaning that the AIAN populations on reservations and in "unsettled" areas of land were not counted in the initial censuses that started in 1790. As indicated by the fact that counts of the AIAN populations on reservations were not done until 1850, it was the "conquest" of "unsettled areas of land" by the non-AIAN population and the forced relocation of AIAN populations onto reservations that led to a substantial increase in the number of reservations. This, in turn, led to the emergence of tribal census counts because they were needed to manage the reservations by the elements of the federal bureaucracy that oversaw them. It was not until 1924 when the Indian Citizenship Act of 1924 was passed and went through litigation that the AIAN population was routinely counted in the decennial census. This process, however, did not start until the 1940 decennial census; and for the 1950 census, the Bureau of Indian Affairs requested a separate schedule to enumerate reservation areas (U.S. Census Bureau, 2021a). Implementation of the mail-out/mail-in census questionnaire in 1970 meant race and tribal affiliation became self-reported, which led to more people identifying themselves as AIAN in census counts (U.S. Census Bureau, 2021a).

An information gap exists in U.S. census data from 1900 to 1940 in the demography of American Indians (U.S. Census Bureau, 2021a; National Archives, n.d.). However, another source of American Indian information, known as the "Indian Census Rolls," was produced for the period 1885 – 1940 (National Archives, 2014). The Indian Census Rolls are not as well known, as familiar, and as easily accessed as decennial census data and, in our opinion, have been underutilized as a source of historical American Indian demographic information. These rolls were generally submitted annually (National Archives, 1967). Many of the 692 rolls are available from the National Archives except the rolls for 1940. The information found in the available rolls usually includes the English and/or Indian name of the person, roll number, birth date and age, gender, tribal identity, and relationship to the household head. In 1930, they started reporting Indian blood quantum, marital and ward status, and whether the subject lived on the reservation in question. It is crucial to note that not all reservations or tribes were counted annually and that only enrolled tribal members are fully listed in the rolls (National Archives, 2014). Some tribes, particularly those in the Eastern U.S., have never been under Federal jurisdiction. Furthermore, because many persons with some degree of Indian blood did not maintain tribal connections, their names do not appear on the rolls. For the Five Civilized Tribes of Oklahoma (Cherokee, Chickasaw, Choctaw, Creek, and Seminole Indians), there is only an 1885 census of the Choctaw Indians (National Archives, 2014).

This paper presents background information on the Indian Census Rolls, which includes changes that occurred in how the information was gathered over time along with the accuracy of this information. It also demonstrates how the digitized microfiche census roll schedules can be assembled into an Excel file (that serves as a future template). The paper further provides examples of what these Indian Census Rolls can provide by: (1) Presenting an extracted summary of demographic information for the Lummi tribe from its 1937 Indian census roll; (2) discussing a long-term population forecast a tribe (Hopi) based on the tribe's 1937 roll; and (3) providing an age-gender "backcast" for the Hopi tribe from 1940 to 1900 using data from the same roll. We conclude that Indian census rolls not only help fill the 1900 to 1940 gap in the historical demography of American Indians but also provide the basis for a clearer picture of American Indians from 1940 to 1970 as well as their current and future demographic characteristics.

2. Indian Census Rolls

2.1. History and contents

The act of Congress 1884 did not specifically state that the annual report had to include the names and personal information of tribal members. A year later, a directive came out that specifically stated that the annual report had to include name, gender, age, and household relationship. One important change in the Indian Census Rolls occurred in 1930 concerning tribal members who did not live on the reservation, which led to those living off the reservation being counted. Residents of the reservation in question who were enrolled on another reservation were to be recorded on the other reservation's tribal roll.

The earliest Indian Census Rolls were handwritten, but eventually, the Commissioner of Indian Affairs issued instructions that the information had to be typed, not handwritten, and in accordance with a standard template and procedures for reporting those not listed in the preceding year. The rolls continued along these lines from 1921 to 1940, when, with a few exceptions, tribal census rolls stopped being assembled. This occurred because, under the Indian Reorganization Act of 1934, tribes were encouraged to specifically set up a constitution that gave recognized criteria for determining membership and enrollment.

2.2. Accuracy

Despite the guidance and instructions, there were continuing inaccuracies as to who was listed in an Indian census roll, and a given roll may not be a list of all those who were officially considered "enrolled." Some tribes started using a given census roll as a basis for determining membership eligibility in that a member has to show lineal

descent from a member listed on the "base" roll. In general, by the mid-1930s, the presence of a name on a roll was a clear indication that the person in question was a tribal member.

2.3. The 1937 – 1939 Indian Census Roll #593

As an example of an Indian census roll, we discuss information for the Lummi Tribe, the original inhabitants of the Puget Sound lowlands, in Washinton State from the 1937 – 1939 Indian Census Roll #593, pages 71 to 124 (National Archives, 1965). It contains individual census records for the Clallam, Lummi, Muckleshoot, Nooksack, Puyallup, Skagit-Suiattle, Snohomish, Suquamish, and Swinomish Tribal areas as of January 1, 1937. It also contains birth and death information for 1932 to 1936 and supplemental census rolls for January 1, 1938, and January 1, 1939. These supplemental rolls only list additions to the 1937 census rolls.

Appendix A1 presents an example of the Lummi census roll information. The information is organized by household with an empty line on the census schedule after each household. For example, the Johnson household has two members, a "husband" and a "wife" (Victor and Amelia). Number (Column 1) is a consecutive count of the enrolled Lummi's. "N.E" is used to indicate a non-enrollee, a person who is not included in the consecutive count of tribal members. After all of the information for this household was written into the census schedule, the next line was left empty.

Indian Census Rolls for 1937 also contain surnames and first names, and demographic information on gender, age at last birthday, birth date, marital status, and household relationship. The age of those under 1 year is given as a fraction of the year since the date of birth. Marital status is classified as single or unmarried, married, or widowed of either gender. The household head, whether husband or father, widow, or unmarried person of either gender, is designated by the agent. The agent also assigned the appropriate term to designate the relationship of the person to the household head. In the Lummi records, the relationship to the head is "brother," "dau" (daughter), "grandson," "sister," "son," "step-dau" (step-daughter), "step-son," and "wife."

A tribal name is identified in column 6, and an "N.E" (Not Enrolled) person will have a tribal name other than Lummi. If a person identifies as a member of multiple tribes, the tribes are listed with a hyphen (*e.g.*, Lummi-Clallam). Degree of blood or blood quantum if denoted as an (f) for full blood (100%). Other blood quantum values in the Lummi census rolls are 0.25. 0.50, 0.625, and 0.75.

Column 10 contains the jurisdiction where the member in question is enrolled. The term jurisdiction includes all reservations and public allotments under the Indian agency. If the person does not live in the jurisdiction where enrolled, then the city, post-office county, and state of this person's location are given (columns 11 – 14). The 1937 Lummi census rolls indicate an on-reservation household population of 598, an off-reservation household population of 132, and one person who resides in group quarters off-reservation (in this case, the person is shown as being in prison). "Ward" (column 15) is either a "yes" or "no." We use "yes" on the "ward" variable as an indicator of Lummi Tribal membership. As a side note, we found that "ward" is not a perfect indicator of Lummi Tribal membership. Just over 90% of the records show the expected consistency between the "tribal membership" entry and the "ward" entry. In these cases, the tribal membership entry is " Lummi" and the ward entry is "yes" (and where the tribal membership is listed as "not Lummi," ward is listed as "no"). However, there are inconsistencies. There are four records (0.5%) where a person is listed as "Lummi" living on another tribe's reservation and the entry for ward is "no"; while in 67 records (9.2%), the person's tribal membership is listed as "Lummi" living on another tribe's reservation and the entry for ward is "yes." There is one record (0.1%) where a tribe other than Lummi is listed, but the "ward" entry is "yes."

Originally prepared on microfiche, the Indian Census Rolls need to be presented through computerized means to cater to modern needs. To this end, we developed an Excel workbook that contains features that facilitate the inputting of individual census records from microfiche. All variables shown in Appendix A1 are accommodated in this Excel workbook, "LUMMI TRIBE cases 1 to 661 V8_WardAdj2.xlsx," which is available from the authors. It contains eight worksheets: (1) *Documentation*, which includes a directory to the eight worksheets; (2) *Summary*, which displays a summary of the data found in worksheet 7 along with the Excel code that extracts and assembles them from worksheet 7; (3) *Lummi 1937 Pyramids*, which contains graphic representations (population pyramids) of the 1937 Lummi tribal members and Lummi and non-Lummi by age and gender, along with the Excel code that generates the data from worksheet 4 that is organized in a format that facilitates the construction of the population pyramids; (4) *Data*, which contains the input data for worksheet 3 along with the Excel code that extracts these data from worksheet 2 and assembles them into an age by gender format that facilitates the creation of the population pyramids; (5) *Lummi 1937 Sex Ratios by Age*, which shows the sex ratios of Lummi and non-Lummi males and females and Lummi males and females by age and contains the Excel code that assembles these ratios from worksheet 7; (6) *Age GRP X Sex X Tribal Status*, a worksheet that displays median age

and other summary indicators, along with the Excel code that generates this information from the data in worksheet; (7) *Census Data*, a worksheet containing the transcribed data from the digitized microfiche file, M 595, which were entered independently by different people on different spreadsheets and reconciled (where there were differences) into a single worksheet; and (8) *Coding Inconsistencies*, which lists the records (by microfiche page roll) found to have inconsistent coding between Tribal identification and Ward status. The majority of these inconsistencies are due to the fact that children whose parents are clearly Lummi members have not yet been enrolled.

Although not shown in Appendix A1, the Indian census rolls indicate people who died after January 1, 1937, by placing a line through them and indicating the date of death. The last two columns (AC, and AD, respectively) in worksheet 7 display this information. One column (AC) indicates if a death has occurred, and the second column (AD) lists the date of death. Nineteen deaths are recorded in the Lummi census roll. On the first row of every new household, the template accumulates data at the household level enabling the calculation of total household population, the total household population by blood quantum, and persons per household for each household both on and off the reservation. The total household population by blood quantum is calculated by summing up the blood quantum fractions for each person in the household. For example, if the three persons in a household are 50% Lummi, the household population would be 1.5 for both the Lummi and non-Lummi populations.

3. Lummi housing and demographics, 1937

There were 731 people counted in the 1937 Lummi Indian census roll. All but one lived in households and that person was listed as a resident of San Quentin Prison in California (that is, this person resided in "group quarters," not a household). The household population of 730 lived in 194 households. The majority were enrolled in the Lummi tribe 661 (661 of 731 or 90%) while 70 persons (10%) were not enrolled (N.E). Table 1 shows the Lummi household population living on the reservation was 4.5 times larger than those living off the reservation (598 vs 132). Correspondingly, the on-reservation Lummi population lived in 157 households and the off-reservation population in 37 households. As a result, the average number of Lummi living in households was somewhat higher (3.8) on the reservation than off the reservation (3.6). Larger household sizes and overcrowding on Indian Reservations are long-standing issues (Pindus *et al.*, 2017). In 2018, for example, the average household size was 3.6 on Indian Reservations, which is higher than the average for the general U.S. population, which was 2.6 (Rodriguez-Lonebear *et al.*, 2020).

Both the Lummi and non-Lummi populations have more males than females (Table 2). There are 5% more males than females in the Lummi population, but the sex ratio is much more skewed for the non-Lummi population (1.59). The much higher sex ratio is influenced by the relatively small number of records for the non-Lummi population roll. This table illustrates that small numbers may be an issue when analyzing individual tribal data from Indian census roll records, especially when subdividing the data by demographic and tribal characteristics.

As noted, Indian Census Rolls also contain data on marital status. Table 3 shows the population broken down by marital status (married, single, and widowed) and tribal identification. The small number issue is also apparent in this table, especially for non-Lummis, which have only 5 and 6 persons single or widowed, respectively. For the total and the Lummi populations, most are single (59% total and 63% Lummi). Around 30% of the Lummi population is married compared to 83% of the non-Lummi population. In both populations, between 7% and 8% of the population are widowed. Due to relatively small counts, caution is needed when interpreting the non-Lummi data.

Table 4 and Figure 1 show the population in 5-year age groups by gender for the Lummi population. The age and gender breakdowns were not large enough to be meaningful for the non-Lummi population. Moreover, the age data were missing for 43 non-Lummi males and 20 non-Lummi females. The shape of the population pyramid (Figure 1) with its broad base and narrow tapering at the older ages is indicative of a population with high birth and death rates (Britannica, 2023). Also notable, there are more males (36) than females (22) above the age of 60 (Table 4). This pattern suggests that male survival rates were higher than female survival rates at older ages 90 or so years

Table 1. Lummi household characteristics, 1937

	Households	Household population	Persons per household
On Lummi Reservation	157	598	3.81
Off Lummi Reservation	37	132	3.57
Total	194	730	3.76

Source: National Archives (1965).

Table 2. Lummi population by gender, 1937

	Total	Male	Female	Sex ratio
Lummi	661	338	323	1.05
Non-Lummi	70	43	27	1.59
Total	731	381	350	1.09

Source: National Archives (1965).

Table 3. Lummi population by marital status, 1937

	Total (%)	Married (%)	Single (%)	Widowed (%)
Population count				
Lummi	661	197	419	45
Non-Lummi	66	55	6	5
Total	727	252	425	50
Population count				
Lummi	100.0	29.8	63.4	6.8
Non-Lummi	100.0	83.3	9.1	7.6
Total	100.0	34.7	58.5	6.9

Source: National Archives (1965).

Table 4. Lummi population by age and gender, 1937

Age	Total	Male	Female	Sex ratio
0 – 4	76	41	35	1.17
5 – 9	79	35	44	0.80
10 – 14	90	46	44	1.05
15 – 19	78	43	35	1.23
20 – 24	67	32	35	0.91
25 – 29	42	26	16	1.63
30 – 34	52	30	22	1.36
35 – 39	32	11	21	0.52
40 – 44	25	12	13	0.92
45 – 49	22	11	11	1.00
50 – 54	20	8	12	0.67
55 – 59	19	7	12	0.58
60 – 64	18	11	7	1.57
65+	40	25	15	1.67
Total	660	338	322	1.05
Median age	20.5	20.5	20.5	
% Under 5	11.5	12.1	10.9	
% 20 – 64	45.0	43.8	46.3	
% 65+	6.1	7.4	4.7	

Source: National Archives (1965).

ago, which is consistent with demographic knowledge. By comparison, the 5-year 2021 American Community Survey (U.S. Census Bureau, 2023) shows 83 males and 181 females over the age of 60 on the Lummi Reservation, indicating that survival rates for Lummi females are now higher than those for Lummi males at older ages. This is also consistent with the general demographic knowledge.

Table 4 also shows the sex ratio by age for the Lummi population. The ratios vary substantially by age group, further attesting to the relatively small numbers when the data are broken down by gender and detailed age groups. The largest sex ratios are seen in ages 25 – 29 and 60+, and the smallest ratios occur in ages 35 – 39 and 50 – 59. The median age is 20.5 years and does not vary by gender. The percentage of males under 5 (12%) is a bit higher than the percentage of females (11%). For the working ages (20 – 64), there is a larger percentage of females (46%) than males (44%). Males in the oldest age group (65+) comprise over 7% of the population compared to under 5% for females.

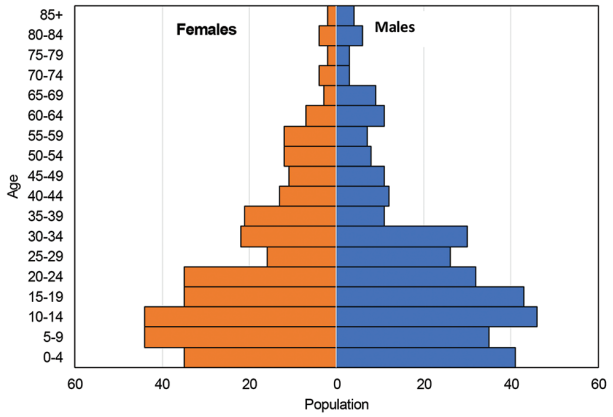

Figure 1. Lummi population pyramid, 1937

4. Examples using Indian Census Rolls

4.1. Benchmark for long-range population projections

The cohort-component method (CCM) is the most widely used method for projecting populations and demographic characteristics such as age and gender (Smith *et al.*, 2013; Wilson, *et al.*, 2022), and the CCM approach has been used to generate projections of tribal members and reservation populations (Howell, 2020, Rogers & Gillaspy, 2014; Greene, 2017; and Swanson, 2019). However, there is a host of challenges to overcome when using this approach with a tribal population, which is typically small in size (Cannon & Percheski, 2017; Raftery & Ševčiková, 2023). Swanson (2022) provides an approach for overcoming the problems of using the CCM approach to develop long-range projections by employing the 1937 Hopi Indian census roll. The data from this census roll were assembled into an Excel workbook using the same procedures described in section 2.3 for the Lummi tribe.

As with all of these rolls, the 1937 Hopi census roll provided the 5-year age and gender information needed to launch a CCM. Importantly, as with all age-gender structures (Caswell *et al.*, 2018; Preston & Vierboom, 2021; United Nations, 2017), this information represents the Hopi tribe's past and future demographic trends. As such, it is an appropriate foundation for the CCM. Given the lack of direct fertility information for the Hopis, Swanson (2022)

used the child-woman ratio (Baker *et al.*, 2017, pp. 46 – 48) to represent fertility. The CCM also requires information on survivorship by age and gender, so for the mortality component, Swanson (2022) employed "life tables" specific to birth cohorts by year from 1900 to 2100 (Bell & Miller, 2005) to survive them to extinction. No information on migration was needed because the population is essentially closed to migration—the data represent everybody who is a member of the tribe. If the projection involved only the Hopi Tribal Reservation area, migration on and off the reservation would have to be accounted for in the cohort-component model (Greene, 2021). Using these data, the CCM was run in 5-year cycles to the year 2017, with an 80-year projection horizon. To assess their accuracy, the projections for 1992, 1997, 2002, 200, 2012, and 2017 were compared to Hopi Tribal membership data (available annually from 1989 to 2018). These projections generally performed very well (Swanson, 2002: 1842 – 1844).

The specifics of the preceding overview are found in an Excel workbook available from the authors, "HOPI LEXUS DIAGRAM & FORECAST V5.xlsx." It contains worksheets that include the initial 1937 Hopi population by age and gender along with the life tables used to survive the 1937 population by age and gender to extinction as well as the subsequent birth cohorts (in 5-year cycles, *i.e.*, 1942, 1947, 1952,…, 2017) to extinction. The birth cohorts were generated in 5-year cycles by applying, as stated above, the Child-Woman Ratio, which in the case of the Hopi consisted of those aged 0 – 4 to females aged 20 – 20. This workbook contains all of the input data and Excel codes needed to accomplish: (1) The generation of births; (2) the survivorship of the initial age structure and the subsequent birth cohorts; and (3) the assembly of the birth and survivorship results into a series of projections from 1942 in 5-year cycles to the projection target year, 2102. In addition, a Lexus Diagram is included in this workbook that assembles the counts for each age 5-year group (0 – 4 to 115 – 119) over the projection horizon, which is in 5-year cycles, 1937, 1942, 1947,…, 2092, 2097, 2102.

The work by Swanson (2022) suggests that his approach is worth considering where long-term projections are required for a tribal population. The CCM process applied to the Indian Census Rolls done between 1934 and 1940 can also be used to generate "estimates" that would provide a perspective on changes in the size of the AIAN population in general as well as in regard to specifical tribes (Liebler *et al.*, 2016; Passel, 1996; Thornton, 1979).

4.2. Filling gaps in historical tribal data

Indian census rolls can help fill the gap in historical American Indian tribal demographic and household information. For illustration, we draw on the 1937 census roll for the Hopi tribe, located in Northeast Arizona, to create a historical series for the Hopi population from 1900 to 1940 by age and gender and work in the form of a backcast that provides decennial age-gender information for the Hopi from 1940 to 1900 (Swanson & Tayman, 2024).

Eight steps were used complete these estimates: (1) Assembled an age-gender distribution from the 1937 Hopi Indian census roll along with a projection of this population to 1942, found in Swanson (2022); (2) interpolated between the 1937 and 1942 data to obtain an estimated age-gender distribution for Hopi tribal members in 1940; (3) developed decennial rates of change by age between 1900 and 1940, assembled in an earlier study from the Hopi tribal data collected by Census Bureau in the 1900 census (Johansson & Preston, 1978); (4) generated the 1910, 1920, and 1930 tribal populations by age using the decennial linear change calculated in step (3); (5) computed the ratios of females/total population by age for 1900 and 1940; (6) applied the interpolated ratios to estimate the female populations by age for 1910, 1920, and 1930; (7) subtracted the females by age from the total population by age to estimate the male population by age for 1910, 1920, and 1930; and (8) assembled the decennial age-gender data and present them for 1900 to 1940 by decade. A paper by Swanson & Tayman (2024) contains details of the data and methods used in these estimates.

Table 5 shows population estimates by age and gender from 1900 to 1940 by decade for the Hopi tribe, which shows an increase of 1,635 between the total population estimated for 1940 (3,487) and the 1900 number (1,852). As evidence of the reliability of these estimates of the total Hopi tribal population, we look at the estimates provided by Kunitz (1974a, p. 9) that have dates matching up closely with the dates for which we have numbers. Corresponding to the 1900 number of 1,852 produced by Johansson & Preston (1978, p. 5) is a 1901 estimate of 1,841; and our 1930 estimate of 3,079, is an estimate of 2,752. Finally, corresponding to our 1940 estimate of 3,348 is an estimate of 3,444.

Between 1900 and 1940, the Hopi tribal population experienced an increase of 88%, which is consistent with the findings by Kunitz (1974a, p. 9). Looking at age-specific percent changes, all but two age groups showed population growth between 41% and 99%. The population size of the age group 40 – 49 had grown by 126% and that of those aged 70+ by 442% between 1900 and 1940. These changes likely reflect differential errors between the 1940 estimates by age and the 1900 estimates by age, as well as intervening events that impacted the 1900 population as it aged. Some intervening events include the presence of endemic and

Table 5. Hopi population by age and sex, 1900 – 1940

Age	1940			1930			1920			1910			1900		
	Males	Females	Total	Males	Females	Total	Males	Females	Total	Males	Females	Total	Males	Females	Total
0 – 9	443	442	886	394	389	783	344	337	680	293	284	577	242	233	475
10 – 19	345	356	701	308	307	615	268	260	528	230	210	440	185	168	353
20 – 29	292	311	603	261	268	530	229	227	456	199	183	382	161	148	308
30 – 39	218	209	427	205	191	396	191	174	365	179	155	334	162	140	303
40 – 49	169	123	292	145	106	251	121	89	210	97	73	170	74	55	129
50 – 59	112	91	203	104	84	188	97	77	173	89	69	159	81	63	144
60 – 69	124	91	216	108	81	189	92	71	163	75	62	137	61	50	111
70+	100	60	160	76	52	127	53	41	95	31	31	62	15	15	30
Total	1,805	1,683	3,487	1,600	1,479	3,079	1,395	1,275	2,670	1,195	1,067	2,261	980	872	1,852

Source: Swanson and Tayman (2024).

epidemic diseases (Kunitz, 1974a, p. 14), the move to a wage economy, a rapid decline in birth rates (Kunitz, 1974a, p. 14), and intra-tribal disagreements that led to relocations within the reservation. There was also a major split between those who cooperated with government agencies and those who did not, a split that lasted at least into the 1950s (Spicer, 1962, pp. 187 – 209).

As one example of the effects of these issues, the number of Hopi tribal members aged 50 – 59 in 1940 increased by only 57% over the number of members aged 40 – 49 in 1900. However, those aged 50 – 59 in 1940 were aged 30 – 39 in 1920, which put this cohort in an age group at high risk of dying during the influenza pandemic of 1918 (Fujimura, 2003), a situation that also occurred among the Navajos (Brady & Bahr, 2014). Kunitz (1974a, p. 9), however, observed that epidemics and endemic diseases were more devastating among the closely-settled Hopis than among the Navajos.

We examined the changes between 1900 and 1940 visually by looking at population pyramids for these 2 years shown in Figure 2. The pyramids are coarse because of the 10-year age widths, but despite this, a comparison suggests that between 1900 and 1940, survivorship increased, which is consistent with the observations by Kunitz (1974a, p. 14) that mortality started decreasing significantly by the 1930s, considering the temporary increase caused by the 1918 influenza pandemic (Snipp, 1989, p. 65).

The Hopi tribal population may have come to a nadir in 1900. Johansson & Preston (1978, p. 5) found that there were more of them before 1900: "Hopis were once more numerous than in our period," and as the 1937 Indian Census Roll shows, there are many more in 1937 than found in 1900. This finding is supported by other work (Kunitz, 1974a; 1974b) and consistent with the observation by Snipp (1989, p. 63) that the population of American Indians

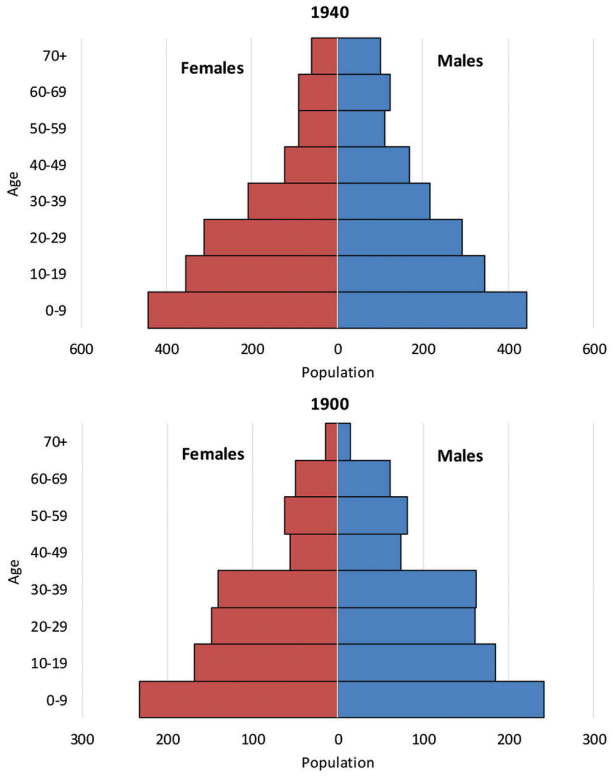

Figure 2. Hopi population pyramid, 1900 and 1940
Source: Based on data in Table 5.

declined to their lowest number in the 1890s. Some of these differences in the historical Hopi population may be due to census errors, but the numbers as they stand indicate that 1900 was a nadir for the Hopi tribal population.

Regarding demographic inertia, it is worthy to note that migration does not enter into the picture because the U.S. Hopi tribal population is "closed" to migration. Aside from the issue of census and estimation error, the main source

of uncertainty between 1900 and 1940 stems from changes in the number of births and deaths during this period. Importantly, the tribal data showed that the increase of the Hopi from 1900 to 1940 was not subject to the non-demographic (changes in reporting) factors identified as leading to substantial growth in the American Indian population after 1960 (Passel, 1996; Thornton, 1979; 1996).

The data employed to develop our demographic portrait of the Hopi tribal population are subject to inconsistencies and errors, and the changes shown between 1900 and 1940 are much "smoother" than the actual changes were. However, in the absence of evidence of any fluctuations, and given the "demographic inertia in play between 1900 and 1940, we believe the changes and the resulting age-gender numbers for 1910, 1920, and 1930 are reasonable.

5. Conclusions

Many of the 692 Indian Census Rolls that were produced for the period 1885 – 1940 are available from the National Archives (1967). As we noted at the outset, Indian Census Rolls do not come in computerized form and must be extracted from microfiche records. This is a tedious process requiring data input by hand and an iterative process to verify the resulting data. To this end, we developed an Excel template to aid in the transcription process. This template not only lists individual records from the Indian Census Rolls but also creates household-level variables, including household population and households on and off the reservations, and includes various tables and population pyramids depicting the data.

We used the Lummi Tribe from Northwest Washington State as a case study to show how demographic and housing characteristics in 1937 can be obtained from a tribal census roll. We also discussed two demographic applications that illustrate the efficacy of Indian Census Roll information. The first application was as a launching point for a projection of the Hopi tribal population that includes a benchmark (subsequent tribal membership data) that can be used for testing the accuracy of the CCM for producing long-term population projections. Such projections are coming into focus as these data are now being used for Native American Tribes involved in disputes over water rights (Swanson, 2019). The second application was the creation of historical information for the Hopi tribe from 1900 to 1940 by age, gender, and decade. We believe the Indian census rolls have been underutilized as a source of historical American Indian demographic information, which offers not only a reasonable alternative to fill in historical gaps in the demography of Native Americans but also serves as a source for determining their contemporaneous and future demographic characteristics.

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Conflict of interest

David A. Swanson is an Editorial Board Member of this journal but was not in any way involved in the editorial and peer-review process conducted for this paper, directly or indirectly. Separately, there are no potential conflicts or competing interests with any institutes, organizations, or agencies that might influence the integrity of results or objective interpretation of their submitted works.

Author contributions

Conceptualization: All authors
Formal analysis: All authors
Investigation: All authors
Methodology: All authors
Writing – original draft: All authors
Writing – review & editing: All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The Excel template, filled with 1937 data from the Lummi Tribe, is available from the corresponding author upon reasonable request.

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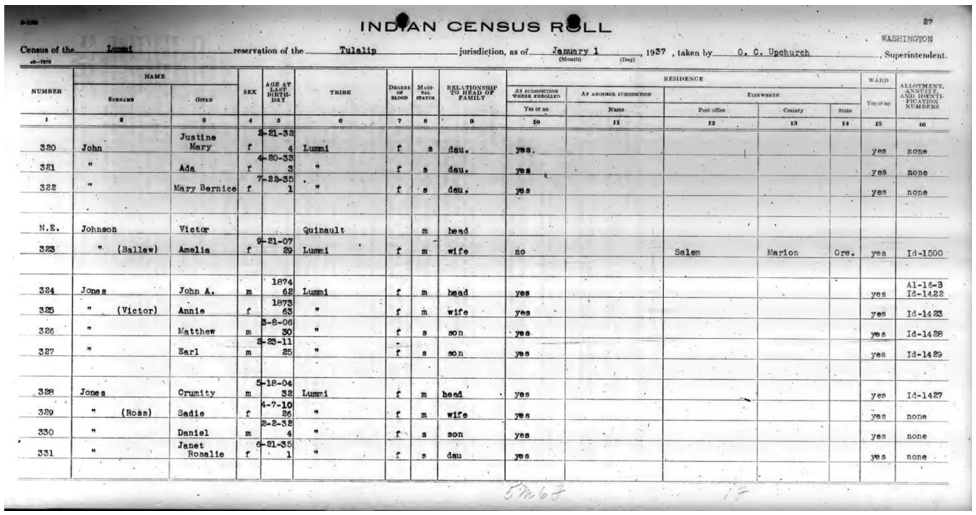
Appendix



INDIAN CENSUS ROLL

Census of the Lummi reservation of the Tulalip jurisdiction, as of January 1 (Month) (Day) 1937, taken by O. C. Upchurch, Superintendent. WASHINGTON

NUMBER	NAME: Surname	NAME: Given	SEX	AGE AT LAST BIRTHDAY	TRIBE	DEGREE OF BLOOD	MARITAL STATUS	RELATIONSHIP TO HEAD OF FAMILY	RESIDENCE: At jurisdiction where enrolled	RESIDENCE: At another jurisdiction	RESIDENCE: Elsewhere: Post office	RESIDENCE: Elsewhere: County	RESIDENCE: Elsewhere: State	WARD	ALLOTMENT, PATENT AND IDENTIFICATION NUMBERS
									Yes or no	Name				Yes or no	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
320	John	Justine Mary	f	8-21-32 4	Lummi	f	s	dau.	yes					yes	none
321	"	Ada	f	4-30-33 3	"	f	s	dau.	yes					yes	none
322	"	Mary Bernice	f	7-23-35 1	"	f	s	dau.	yes					yes	none
N.E.	Johnson	Victor			Quinault		m	head							
323	" (Sallee)	Amelia	f	9-21-07 29	Lummi	f	m	wife	no		Salem	Marion	Ore.	yes	Id-1500
324	Jones	John A.	m	1874 62	Lummi	f	m	head	yes					yes	A1-16-3 Id-1422
325	" (Victor)	Annie	f	1873 63	"	f	m	wife	yes					yes	Id-1423
326	"	Matthew	m	3-8-06 30	"	f	s	son	yes					yes	Id-1428
327	"	Earl	m	8-23-11 25	"	f	s	son	yes					yes	Id-1429
328	Jones	Crumity	m	5-18-04 32	Lummi	f	m	head	yes					yes	Id-1427
329	" (Ross)	Sadie	f	4-7-10 26	"	f	m	wife	yes					yes	none
330	"	Daniel	m	2-2-33 4	"	f	s	son	yes					yes	none
331	"	Janet Rosalie	f	6-21-35 1	"	f	s	dau	yes					yes	none

Appendix A1. Example of an Indian Census Roll, Lummi Tribe, 1937
Source: Microcopy 595 roll 593. National Archives and Records Service, Washington, DC. 1965

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RESEARCH ARTICLE

Internet use and cognitin among American middle-aged and older adults: The gendered moderating effect of age

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Abstract

The popularity of Internet use brings more potential for healthy cognitive aging among older adults. Emerging studies have examined the age and gender differences in the link between older adults' Internet use and cognition. However, few studies have investigated the gendered age difference regarding this association. The purpose of this study was to examine whether age would moderate the effect of Internet use on cognition among middle-aged and older adults and whether this relationship would be different between men and women. A total of 6,338 adults aged 50 or older were drawn on from the 2016 Wave of the Health and Retirement Study. Sequential linear regressions were conducted to examine the interactions between Internet use, age, and gender on cognition. The three-way interaction of Internet use, age, and gender was a significant predictor of cognition ($\beta = 0.01$, $p < 0.05$). Specifically, the positive effect of Internet use on cognition was higher among older women of older age than those of younger age, while the positive effect remained the same for older men of different ages. The Internet offers a valuable resource for engaging middle-aged and older adults in activities that not only provide social interaction but also stimulate cognitive processes. The study suggests that the aging process does not necessarily inhibit the cognitive benefits that middle-aged and older adults can gain from using the Internet. Findings from this study indicated that future Internet/technology training to increase cognition among middle-aged and older adults should be age- and gender-tailored.

Keywords: Internet use; Cognition; Gender; Age; Older adults; Middle-aged adults; United States

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1. Introduction

1.1. Internet use and cognition

The role of technological advances in improving cognitive health outcomes has become increasingly opaque over the past few decades. Brain plasticity refers to the brain's ability to adapt and change as a result of experiences (Sharma *et al.*, 2013), and researchers are

increasingly finding that Internet use provides an avenue for engagement in cognitive activities such as multitasking, information processing and communication (Klimova, 2016). Some studies have identified that cognitive ability in itself is a determinant of Internet use, with evidence showing that older adults with higher baseline cognition are more likely to gain benefit from Internet use (Freese *et al.*, 2006). Another study found that Internet use was a protective factor against health literacy decline among older adults (Kobayashi *et al.*, 2015).

Other studies have also found that Internet use improves health and financial decision-making, suggesting that Internet use can improve the functions of the prefrontal lobe (James *et al.*, 2013). In a longitudinal study assessing the impact of Internet use on cognition among middle and older adults in China, Yu & Fiebig (2020) found that Internet users were more likely to score higher on cognitive tests than non-users. Intervention research has also been used to verify that when older adults who engage in a computer training and Internet browsing course have improved cognitive functioning compared to a control group (Shapira *et al.*, 2007). These studies along with the neurobiological knowledge of brain plasticity suggest that Internet use could be both a protective factor for cognitive decline and an avenue to improve cognitive functioning.

1.2. The role of age in the link between internet use and cognition

The role of age on the impact of Internet use and cognition, especially among older adults, still remains a relatively understudied area. Most of the literature focuses rather on the differences in Internet use between older and younger adults, and the way Internet use affects the cognition of "digital natives" compared to "digital immigrants" (Loh & Kanai, 2016). Digital natives refer to the younger generation, who grew up with the Internet and are therefore more proficient in Internet use as well as more prone to Internet addiction (Loh & Kanai, 2016). Research has shown that "digital natives" experience rapid attention shifting, reduced deliberations, and increased multitasking that leads to higher distractibility and poor executive controls (Brand *et al.*, 2014; Carrier *et al.*, 2009; Ophir *et al.*, 2009). While Internet use significantly determines the likelihood and benefits of cognitive functioning among middle-aged and older adults, demographic factors such as age, gender, and socioeconomic status also play critical roles. Studies have indicated that affluent Internet users and those under the age of 65 engage more frequently with the Internet, which underscores the intersection of socioeconomic status and age in digital engagement (Keenan, 2009).

While researchers are concluding that Internet use has a negative impact on cognition among the younger generation, there is great consensus in the positive effects of Internet use on cognition for older adults (Firth *et al.*, 2019). Given the evolving understanding of digital technology's impact, it is crucial to differentiate between age groups in discussing Internet use and cognitive functioning. According to the United Nations (2023), people aged 50 to 65 are classified as middle-aged, while those over 65 are considered older adults. Although the research evaluating the moderating effect of age on Internet use and cognition is limited among middle-aged and older adults, there is substantial evidence suggesting that as middle-aged and older adults age, the general cognitive capacity for Internet use may decline, thereby reducing the effect of Internet use on improving cognitive functioning (Firth *et al.*, 2019; Freese *et al.*, 2006). However, a meta-analysis of studies assessing the relationship between video game training and cognitive functioning found that the magnitude of this effect was moderated by participants' age. Specifically, old-old adults aged 71 – 80 would benefit more from video game training than young-old aged 60 – 70 (Toril *et al.*, 2014). Another meta-analysis conducted by Zhang & Kaufman (2016) suggested a similar direction that the younger group of older adults might have smaller gains in cognitive functioning compared to the older group, although age as a moderator was not statistically significant.

1.3. Gender perspective

There have been mixed findings regarding the gender differences in Internet use among middle-aged and older adults, which also affect the relationship between Internet use and cognition by gender. Some studies have found that there were no differences in Internet use between men and women (Friemel, 2016), while others have found that men use the Internet more often (König *et al.*, 2018; Van Deursen and Helsper, 2015) and a study using the Health and Retirement Study found the opposite, with women using the Internet more than men did (Yu *et al.*, 2016).

The results for the role of gender on the impact of Internet use on cognition are also mixed and these stark differences are likely a result of variation in measures of cognition and Internet use. Ihle *et al.* (2020), for example, specifically assessed changes in the Trail Making Test over a 6-year period based on the frequency of Internet use and found that men had improvements in the test accomplishment time and therefore smaller cognitive decline compared to women. On the other hand, Yuan *et al.* (2019) evaluated the impact of smartphone use on cognitive health. They found that men had better visuospatial ability while women had better memory (Yuan *et al.*, 2019). These mixed findings

create ambiguous understandings of the role of Internet use on cognition and how gender and age moderate the effect.

1.4. The current study

The positive impact of Internet use on cognition among middle-aged and older adults has been well-documented and it is evident that those benefits diminish as age increases, due to a decrease in cognitive capacity to use the Internet. Considering the role of age as a moderator, and the mixed findings on the moderating effect of gender, the purpose of this study is to explore the interaction between Internet use, age, and gender on cognitive functioning. Specifically, the following research questions will be explored: (1) Does age moderate the association between Internet use and cognition? (2) Does the relationship differ between older men and older women?

2. Data and methods

2.1. Study samples

A study sample was drawn on from the 2016 Wave, the most recent available data, in the Health and Retirement Study (HRS). HRS is a nationally representative longitudinal panel study of the United States (U.S.) individuals aged over 50 years older and their spouses. Questions about participants' health, family structure, retirement plan, financial situation, subjective well-being, and lifestyles were asked. HRS is funded by the National Institute on Aging (grant number NIA U01AG009740) and conducted by the University of Michigan. HRS has been approved by the Institutional Review Board at the University of Michigan and the National Institution on Aging.

Two separate files – leave-behind questionnaire (LB Questionnaire) and RAND HRS Longitudinal File 2016 – were merged based on the identification variable. Regarding focal variables, Internet use was drawn from the LB Questionnaire; cognition, age, and gender were from the RAND file. All covariates were drawn from the RAND file. In the 2016 Wave, 20,912 adults participated in the interview. Among the 10,238 participants who were eligible for the Left-Behind Questionnaires, 6,338 participants aged over 50 completed and returned their questionnaires. Thus, the final analysis sample was 6,338. Bivariate analysis showed there were more men, ethnic minorities, and middle-aged and older adults living in poverty and not married/partnered in the non-responders. Furthermore, compared with responders, non-responders were younger, had less education, higher depression levels, lower cognitive functioning score, more difficulties in activities of daily living (ADL) and instrumental activities of daily living (IADL).

2.2. Measure

- *Cognition.* The dependent variable, cognition, was measured by a reduced version of the Telephone Interview for Cognitive Status (TIC) (Brandt *et al.*, 1988). Cognition in this study was a composite score of immediate (0 – 10) and delayed word recall (0 – 10), Serial 7s (0 – 5), backward counting (0 – 2), date naming (month, day, year, day of week; 0 – 4), object naming (scissors and cactus; 0 – 2), naming the President (0 – 1) and Vice President of the United States (0 – 1). It ranged from 0 to 35, with higher score indicating higher cognition.
- *Internet use.* The independent variable, Internet use, was measured by a single question. Participants were asked to report "How often do you use a computer for e-mail, Internet, or other tasks?" Response options were reversely coded as 1 = Never/not relevant, 2 = Not in the last month, 3 = At least once a month, 4 = Several times a month, 5 = Once a week, 6 = Several times a week, and 7 = Daily.
- *Age.* Age was the first moderator in this study. It was a continuous variable, ranging from 50 years old.
- *Gender.* Gender was the second moderator. It was measured dichotomously (0 = Men, 1 = Women).
- *Covariates.* Based on previous studies, socioeconomic factors, health behaviors, and health-related variables were included in this study. Socioeconomic factors included race, marital status, and years of education. Race (0 = White, 1 = Non-white) and marital status (0 = Others, 1 = Married or partnered) were measured dichotomously, and years of education were measured continuously. Health behaviors included frequency of doing light physical activities, moderate physical activities, and vigorous physical activities per week; current smoking status; and the amount of drinks per week. Participants were asked to report "How often do you take part in sports or activities that are mildly energetic, such as vacuuming, laundry, and home repairs?" Response options were 1 = Never, 2 = One to three times per month, 3 = Once per month, 4 = More than once per month, 5 = Every day. Questions about moderate physical activities and vigorous physical activities were asked, "How often do you take part in sports or activities that are moderately energetic, such as gardening, cleaning the car, walking at a moderate pace, dancing, floor or stretching exercises?" and "How often do you take part in sports or activities that are vigorous, such as running or jogging, swimming, cycling, aerobics or gym workout, tennis, or digging with a spade or shovel?" Responses to these two questions were measured the same way as the light physical activities. Participants were asked "Do you

smoke cigarettes now?", and the responses were dichotomous (0 = No, 1 = Yes). The amount of drinks per week was determined using two questions, "In the last three months, on average, how many days per week have you had any alcohol to drink? (for example, beer, wine, or any drink containing liquor.)" and "In the last three months, on the days you drink, about how many drinks did you have?"

Health-related factors included doctor-diagnosed diseases, such as high blood pressure, diabetes, cancer, depression, ADL, IADL, and self-rated health. Doctor-diagnosed diseases were measured dichotomously (0 = No, 1 = Yes). Depression was measured using the Center for Epidemiological Studies Depression (CESD) scale (Radloff, 1977). Eight questions about feelings that participants had experience in the past week, such as whether they "felt depressed," "felt activities were efforts," "slept restless," "was happy," "felt loneliness," "enjoyed life," "felt sad," and "could not get going" in much of the time were asked (0 = No, 1 = Yes). Questions on "was happy" and "enjoyed life" were reversely recoded in this study (0 = Yes, 1 = no). Depression was the unweighted sum of the eight items. ADL was measured by the total number of limitations on bathing, dressing, eating, getting in/out of bed, and walking across a room. ADL ranged from 0 to 5, with higher score indicating more limitations. IADL was measured by the total number of limited instrumental activities, such as using a phone, using money, taking medications, shopping for groceries, and preparing for hot meals. IADL ranged from 0 to 5, with higher score indicating more limitations. Self-rated health status was assessed by a 5-point Likert scale and reversely recoded (1 = Poor, 2 = Fair, 3 = Good, 4 = Very good, and 5 = Excellent).

2.3. Statistical analysis

First, descriptive analysis was conducted to better understand the characteristics of the sample. Second, bivariate analysis – *t*-test and chi-squared test – were performed to analyze the associations between cognition and covariates, and the associations between gender and covariates. Third, multilinear regressions were conducted to examine the interaction between Internet use and age, as well as the three-way interaction of Internet use, age, and gender on cognition among older adults. Model 1 included Internet use, age, and covariates; Model 2 added the interaction of Internet use and age to the analysis; Model 3 added gender; Model 4 added the interaction of Internet use and gender, and the interaction of age and gender; and Model 5, the final model, added the three-way interaction of Internet use, age, and gender. Due to multicollinearity, continuous variables defining the interactions – Internet use and age – were centered at their mean values. After centering, the variance inflation factors were all lower than 4, lower than the commonly adopted cutoff value of 5.0 (Sheather, 2009). All analyses were performed using Stata 14.2. (StataCorp LP. College Station, Texas).

3. Results

3.1. Sample characteristics

As shown in Table 1, the average use of the Internet among the sample was nearly 5, almost once a week (M = 4.98, SD = 2.59). The deviation from mean Internet use was 1.81e^-16 (SD = 2.59). The mean age was 67.36 years old (SD = 10.73) and the deviation from mean age was 2.39e^-15 (SD = 10.73). On average, sample's years of education was 13.09, a little above high school graduate. More than half of the sample were white (72.38%), women (59.64%), and married or partnered (62.67%). Most of the sample did not smoke now (87.18%). About 60% had been diagnosed with high blood pressure, 26% with diabetes and 16% with cancer. The average frequencies of doing light and moderate activities were 3.39 (SD = 1.05) and 3.03 (SD = 1.29), in the range of once a week and more than once a week; and the average frequency of vigorous activities was 2.06 (SD = 1.32), about one to three times per month. The mean drink per week was about 2.72 (SD = 6.51), depression was 1.36 (SD = 1.91), limitations on activities of daily living was 0.30 (SD = 0.83), limitations on activities of instrumental daily living was 0.23 (SD = 0.70), and self-rated health was 3.13 (SD = 1.02).

In terms of cognition, differences were found on gender, race, marital status, current smoking status, and being diagnosed with high blood pressure and diabetes. To be more specific, being women, white, married, or partnered had higher cognition, while being a current smoker, and being diagnosed with high blood pressure and diabetes had lower cognition.

Gender differences were identified on marital status, engagement with light, moderate, and vigorous activities, having drinks, being diagnosed with high blood pressure and diabetes, depression, ADL, IADL, and self-rated health status. Specifically, compared with older men, older women reported more light activities, less moderate and vigorous activities, less drinks per week, higher levels of depression, more ADL and IADL, and lower self-rated health status, and also, they were less likely to be married or partnered, being diagnosed with high blood pressure and diabetes.

3.2. Multilinear regressions on sample's cognition

Multilinear regression results are summarized in Table 2. In Model 1, more Internet use ($\beta = 0.370$, $p < 0.001$) was associated with a higher level of cognition, while older age ($\beta = -0.091$, $p < 0.001$) was associated with

Table 1. Sample characteristics

	M (N)	SD (%)	Cognition	t	Men	Women	t (χ^2)
Internet use	4.98	2.59			4.93	5.01	−1.16
(dev) Internet	$1.81e^{-16}$	2.59			-0.05	0.03	−1.16
Age	67.36	10.73			67.48	67.28	0.75
(dev) Age	$2.39e^{-15}$	10.73			0.13	−0.09	0.75
Gender				−2.70**			
Men	2,429	40.38	21.83				
Women	3,586	59.62	22.24				
Race				11.25***			1.96
White	4,339	72.38	22.53		73.36	71.71	
Non-white	1,656	27.62	20.64		26.64	28.29	
Married/partnered				−8.98***			371.37***
No	2,244	37.33	21.29		22.73	47.22	
Yes	3,768	62.67	22.61		77.27	52.78	
Years of education	13.09	3.01			13.17	13.04	1.66
Light activity	3.39	1.05			3.20	3.52	−11.63***
Moderate activity	3.03	1.29			3.17	2.95	6.22***
Vigorous activity	2.06	1.32			2.29	1.90	11.37***
Smoke now				2.76***			0.79
No	5,503	87.18	22.15		86.9	87.68	
Yes	809	12.82	21.49		13.1	12.32	
Drink per week	2.72	6.51			4.12	1.75	14.47***
High blood pressure				9.76***			8.34**
No	2,459	39.36	23.06		36.58	40.31	
Yes	3,789	60.64	21.57		63.42	59.69	
Diabetes				8.56***			16.06***
No	4,655	74.08	22.47		71.29	75.93	
Yes	1,629	25.92	21.06		28.71	24.07	
Cancer				1.15			0.00
No	5,325	84.24	22.11		83.9	83.9	
Yes	996	15.76	21.90		16.1	16.1	
Depression	1.36	1.91			1.13	1.53	−8.02***
ADL	0.30	0.83			0.26	0.32	−2.50*
IADL	0.23	0.70			0.20	0.25	−2.32*
Self-rated health	3.13	1.02			3.16	3.11	2.03*

Notes: "dev" stands for mean deviation; "e" stands for exponent; *p<0.05, **p<0.01, ***p<0.001.
Abbreviations: ADL: Activities of daily living; IADL: Instrumental activities of daily living.

lower cognition. Covariates, such as race (β = −1.922, p < 0.001), years of education (β = 0.388, p < 0.001), light activities (β = 0.201, p < 0.01), vigorous activities (β = −0.131, p < 0.05), smoke status (β = −0.541, p < 0.01), IADL (β = −0.763, p < 0.001), and self-rated health status (β = 0.220, p < 0.001) were significantly associated with cognition among participants. In Model 2, the two-way interaction between Internet use and age was marginal significant (β = 0.004, p < 0.10). In Model 3, older women had.685-unit cognition higher than older men (p < 0.001). In Model 4, the two two-way interactions: Internet use × gender was marginally significant (β = 0.091, p < 0.10) and age × gender was significant (β = 0.033, p < 0.01). In Model 5, the three-way interaction among Internet use, age, and gender was significant (β = 0.010, p < 0.05). The significant three-way interaction is illustrated in Figure 1. As we can

Table 2. Multilinear regression coefficients on predicting sample's cognition

	Model 1		Model 2		Model 3		Model 4		Model 5	
	β	SE	β	SE	β	SE	β	SE	β	SE
Race	−1.922***	0.150	−1.939***	0.150	−1.936***	0.150	−1.936***	0.150	−1.931***	0.150
Married or partnered	0.089	0.127	0.078	0.127	0.260*	0.132	0.283*	0.132	0.279*	0.132
Years of education	0.388***	0.023	0.390***	0.023	0.393***	0.023	0.396***	0.023	0.397***	0.023
Light activities	0.201**	0.063	0.198**	0.063	0.127*	0.064	0.125	0.064	0.118	0.064
Moderate activities	0.062	0.054	0.060	0.054	0.080	0.054	0.080	0.054	0.081	0.054
Vigorous activities	−0.131*	0.052	−0.131*	0.052	−0.094	0.052	−0.095	0.052	−0.093	0.052
Smoke status	−0.541**	0.205	−0.556**	0.205	−0.522*	0.204	−0.532**	0.204	−0.508*	0.204
Drink per week	0.008	0.010	0.007	0.010	0.016	0.010	0.013	0.010	0.014	0.010
High blood pressure	−0.016	0.134	−0.025	0.134	−0.013	0.134	−0.012	0.134	−0.019	0.134
Diabetes	−0.152	0.143	−0.161	0.143	−0.105	0.143	−0.085	0.143	−0.092	0.143
Cancer	0.241	0.157	0.233	0.157	0.252	0.157	0.260	0.157	0.258	0.157
Depression	−0.071	0.037	−0.073*	0.037	−0.086*	0.037	−0.083*	0.037	−0.081*	0.037
ADL	−0.038	0.093	−0.036	0.093	−0.047	0.093	−0.052	0.093	−0.051	0.093
IADL	−0.763***	0.112	−0.753***	0.112	−0.754***	0.112	−0.760***	0.112	−0.760***	0.112
Self-rated health	0.220**	0.072	0.226**	0.072	0.222**	0.072	0.212**	0.072	0.213**	0.072
(dev) Internet use	0.370***	0.027	0.346***	0.030	0.336***	0.030	0.286***	0.041	0.316***	0.043
(dev) Age	−0.091***	0.007	−0.091***	0.007	−0.092***	0.007	−0.111***	0.009	−0.110***	0.009
(dev) Internet use×(dev) age			0.004+	0.002	0.004	0.002	0.004	0.002	−0.002	0.003
Gender (ref: men)					0.685***	0.134	0.597***	0.139	0.689**	0.145
(dev) Internet use×gender							0.091+	0.048	0.034	0.055
(dev) Age×gender							0.033**	0.012	0.033**	0.012
(dev) Internet use×(dev) age×gender									0.010*	0.005
R^2	0.356		0.357		0.361		0.362		0.363	
F	125.90		119.12		114.95		104.62		100.16	

Notes: "dev" stands for mean deviation; "e" stands for exponent; *p<0.05, **p<0.01, ***p<0.001.
Abbreviations: ADL: Activities of daily living; IADL: Instrumental activities of daily living.

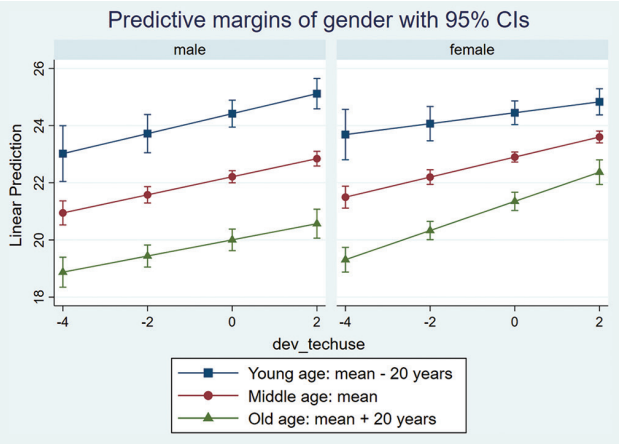

Figure 1. Positive effects of Internet use on cognition by age and gender
Note: "dev" stands for mean deviation.

see, among females, more Internet use was associated with high cognition, and this effect also increased with age. Specifically, compared with older women aged 67.36 years old, which was the mean age of the sample, older women who were 20 years older would have higher cognition increase with the same amount increase of Internet use, while older women who were 20 years younger would have less increase on cognition with the same amount increase of Internet use. However, the interaction effect of Internet use and age on cognition was not significant among males.

4. Discussion

The purpose of this study was to explore the moderating effect of age and gender on the impact of Internet use on cognition. Findings of this study indicated that gender moderated the interacting effect of Internet use and age on cognition. More specifically, the positive effect of Internet use on cognition was higher for women of older age than those of younger age, while the positive effect of Internet use on cognition was the same for men of different ages.

This result is likely reflective of gender and age differences in the way of technology use. Men are more agentic and task-oriented, while women are more communal and relationship-oriented (Bakan, 1966). Therefore, previous studies found that older men were more likely to use the Internet for personal activities, such as online shopping and banking and health-related usage, while older women were more likely to engage in social usage of the Internet (Wang *et al.*, 2024a; Wang *et al.*, 2024b). Despite the direct cognitive stimulation in learning new techniques while using the Internet for some personal activities, these activities become less cognition-stimulating once older men acquire the techniques. Meanwhile, the cognitive stimulation effect of social usage of the Internet, favored more by women, is consistent. In addition, digital games, especially casual games, such as card/dice, classic board games, quiz/trivia, and puzzles, are also popular among middle-aged and older adults (De Schutter, 2011; Weiser, 2000). Previous studies revealed that females tended to spend more time playing casual games than men, and social interaction was the most important motive in predicting playing time (De Schutter, 2011). As a result, middle-aged and older women may gain more cognitive benefits from Internet use than their counterparts of men (Wang *et al.*, 2024a), echoing with findings from this study. Regarding the age difference, compared to older women, younger women are more likely to engage in Internet use for communication, such as chatting, sending emails, and meeting new people, suggesting that older women may be the largest consumers of digital games and other cognitively stimulating Internet activities, thereby resulting in a higher cognitive gain (van Boekel *et al.*, 2017). This finding is consistent with a recent study indicating that the cognitive benefit of Internet use was partially through reduced depressive symptoms for young-old adults but enhanced self-control for old-old adults (Wang *et al.*, 2024). In two studies on computer games, both Pearce (2008) and De Schutter (2011) found that their participants, of whom the majority were older females, expressed their fondness for the intellectual challenge of traditional games. As such, the gender and age differences in how the Internet is used likely results in a higher cognitive gain for women of older ages (Choi & Dinitto, 2015).

The use of Internet to play games, search for information, and use social media requires cognitive processes that include sensory and motor processing of the hand and thumb, learning new information, and complex processes (Gindrat *et al.*, 2015). Internet use also requires attention, memory, and executive processing, which can all diminish through the process of atrophy – the natural process of aging that is associated with cognitive decline (Firth *et al.*, 2019). As a result, studies have found that older adults who have limited cognitive functioning tend to have lower Internet use and that those with higher cognition at baseline gain a greater increase in cognition as a result of Internet use (Freese *et al.*, 2006). This would suggest that as middle-aged and older adults increasingly get older, their natural cognitive decline would slow or inhibit the amount of cognitive benefit gained from Internet use. This has even been found to differ with gender, with a study finding that men experienced lower cognitive decline as a result of Internet use compared to women (Ihle *et al.*, 2020). The results of this study question previous findings, indicating that the natural aging process does not inhibit middle-aged and older adults from gaining cognitive benefits from Internet use.

The Internet is a vast world that includes a number of interactive activities and engages cognitive functioning in a way that may not be readily accessible to older adults (Hunsaker & Hargittai, 2018). In general, social participation decreases in older age and there is evidence showing that decreased social participation leads to faster cognitive decline (James *et al.*, 2011). This is likely due to a concept called "cognitive reserves," which is the brain's ability to withstand the natural cognitive decline that comes with aging (Hwang *et al.*, 2018). Middle-aged and older adults who are not engaged may have less cognitive reserves as they participate only in activities of daily living that do not stimulate the brain (Kelly *et al.*, 2017). The Internet provides an avenue not only for social engagement but also for the active use of cognitive processes that may otherwise be unavailable (Hunsaker & Hargittai, 2018).

This engagement may protect middle-aged and older adults from atrophy and even improve cognitive processes through activities such as brain games (Bonnechère *et al.*, 2020). Brain games are activities that stimulate the mind, which include crossword puzzles, Scrabble, Chess, Sudoku, Trivia, and Bridge (American Association for Retired Persons, n.d; Harvard Health, 2020). Other activities that could stimulate the brain include learning a new language; engaging in physical activity, learning a new subject, and learning to play an instrument – which are all available through the Internet and can improve cognition (Zheng *et al.*, 2015). Due to physical limitations, middle-aged and older adults are also often unable to attend these stimulating activities in person but with the digital age, the acquisition of knowledge is readily available from the comfort of their homes (Hunsaker & Hargittai, 2018).

The advantages of Internet use are opaque, and this study adds to existing literature by showing that the benefits gained from Internet use on cognition can be attained at any age, and regardless of gender. Practitioners serving geriatric populations should consider additional

ways to integrate technological tools into their services, to provide more opportunities for social engagement (Zhang & Kaufman, 2015). Support groups for example could be offered online and incorporate mind-stimulating activities such as Charades or Pictionary. These games would encourage middle-aged and older adults to recall images, think, and then depict them accurately to another person.

The educational system could also reach a wider audience by creating programs specific for middle-aged and older adults with cognitively challenging content that be taken from the comfort of their homes (O'Connor, 2017). On a macro level, policies geared toward the provision of Internet access, technological devices, and opportunities to learn how to use them would ensure equitable access to the benefits of Internet use on cognition for all middle-aged and older adults (Sun *et al.*, 2020). All these attempts to create engagement opportunities for middle-aged and older adults could be instrumental in improving cognitive outcomes in older adulthood and improving overall quality of life.

This study has several limitations that must be noted. First, the cross-sectional research design does not allow for causal inference: no conclusion about whether technology use increases cognitive functioning or cognitive functioning increases technology use could be achieved. Future longitudinal analysis is needed for further examination of causal associations. Second, Internet use is measured by a single-item question. Future study may need to include questions on specific types of Internet use, duration of usage, and Internet use efficiency. Third, among the total eligible participants, the 38% non-response rate may bias the findings in this study. Bivariate analysis indicates significant differences between older responder and non-responders on age, gender, race, education, marital status, poverty status, depression level, cognition, ADL, and IADL.

5. Conclusions

The role of Internet use on cognition has been well-documented in the literature but little attention has been paid to the moderating effects of age, gender, and Internet use on cognitive functioning. This study aimed to fill this gap in the literature by examining the effect of the three-way interaction between age, gender, and Internet use on cognition among older adults, using a nationally representative sample. Results indicated that Internet use improved cognitive functioning regardless of age or gender and that this effect was even more pronounced for women, who gained increased cognitive benefit from Internet use as they grew older. This provides validation for the importance of Internet use among middle-aged and older adults and calls for increased virtual engagement that can be accessible to all older adults. Future research should focus on testing specific interventions to improve cognitive gain from Internet use among older adults.

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Conflict of interest

Kun Wang is the Editorial Board Member of the journal but did not in any way involve in the editorial and peer-review process conducted for this paper, directly or indirectly. Other authors declare no conflicts of interest.

Author contributions

Conceptualization: Kun Wang
Formal analysis: Kun Wang
Investigation: Kun Wang
Methodology: Kun Wang
Writing – original draft: Kun Wang, Zainab Suntai
Writing – review & editing: All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The data utilized in this study are derived from the Health and Retirement Study (HRS), a longitudinal panel study that surveys a representative sample of approximately 20,000 people in America, covering topics such as health, retirement, and socioeconomic status among adults over the age of 50. The HRS is sponsored by the National Institute on Aging (NIA) and conducted by the University of Michigan. Researchers interested in accessing HRS data for academic and research purposes can do so through the HRS website (http://hrsonline.isr.umich.edu/).

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ACCSCIENCE PUBLISHING

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RESEARCH ARTICLE

Demographic changes, technology growth, and retirement policy reform: Implications for U.S. housing dynamics

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Abstract

As the population aging process continues, concerns about how this situation impacts the housing market and social security rise. To address this question, this paper presents a developed and calibrated general equilibrium life-cycle model incorporating two production sectors to analyze the impacts of demographic structure changes and retirement policy reforms on housing price fluctuations and household choices. The model calibrated to the U.S. macroeconomic data between 1968 and 2018 suggests that in an economy with unlimited land supply, the housing supply curve exhibits perfect elasticity, rendering demographic changes insignificant in housing price fluctuations, while technological advancements lead to decreased prices. A 1% growth in productivity in both sectors results in a 2.6% decrease in house prices. Furthermore, a 1% decrease in population and a 5-year early retirement led to significant reductions of 25% and 30% in individual social security payments and 9% and 18% in interest rates, respectively. This suggests that during a recession caused by demographic structural changes, households become more conservative and prioritize precautionary saving strategies, increasing savings and investing more in housing assets. Consistent with empirical findings, during an economic boom, a decline in the capital-output ratio and the real housing price suggests a decrease in savings and housing asset investment. The rise in consumption drives the capital demand of the non-housing sector to increase, stimulating business expansion and labor inflow.

Keywords: Demographic structure; Lifecycle model; Retirement policy; Housing market

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1. Introduction

For many households, real estate assets and social security significantly influence their consumption and saving decisions throughout their life cycles. At present, as housing costs continue to soar, securing a comfortable dwelling has become an immense financial burden for younger generations. According to the report on housing asset distribution issued by the Organization for Economic Cooperation and Development (OECD), housing wealth accounts for around 50% of total household wealth on average across the 29 OECD countries in 2019, with over 40% of total wealth in the United Kingdom

(Aoki *et al*., 2004) and over 30% of household assets in the U.S. (Causa *et al*., 2019). Furthermore, social security has garnered substantial attention from researchers and policymakers due to factors such as population aging, declining fertility rates, and increasing life expectancy. In addition, as the fertility rate continues to decline, the concerns about the social security shortage encourage policymakers to implement retirement policy reform. These situations motivate us to investigate the effects of these macroeconomic factors on the housing market and households' lifecycle choices.

This paper mainly addresses two questions: (i) how the demographic changes, technological growth, and retirement policy reform impact the housing price and individual optimal choices and (ii) how these factors influence the macroeconomic variables such as gross domestic product (GDP) and the labor market.

This paper aims to tackle these economic inquiries through the construction of a comprehensive model, which features a two-sector general equilibrium life-cycle setup with distinctive attributes: an endogenous frictional housing market and a flexible labor market. The structural model applied in this paper is similar to that of Favilukis *et al.* (2017), which provides a two-sector theoretical model with multiple financial assets, and that of Chen (2010), which solves a life-cycle optimization problem with social security reform. Their work mainly focused on factors that drive the house price to fluctuate and individual consumption and savings behaviors. Favilukis *et al.* (2017) mainly examined the effects of the financial market on the housing market. They found that the relaxation of financing constraints and decline in the housing risk premium primarily account for the house price boom. This conclusion is consistent with the findings of Xu (2013) and Liu (2023) that mortgage debt innovation and low interest rates significantly account for over 50% of the increase in house prices. With a focus on the effects of social security reform, Chen (2010) found that both housing quantities and homeownership rates respond strongly to eliminating social security. Without a social security system, household's financial assets and housing assets increase rapidly.

Specifically, to examine the impacts on macroeconomic variables such as GDP and the housing market, we incorporate two production sectors: the non-durable goods sector and the durable (housing) goods sector. Both sectors use Cobb–Douglas production functions, with durable goods production requiring land, labor, and capital as inputs. A flexible labor market allows workers to move freely between the two sectors. In the housing market, prices are determined endogenously by aggregate supply and demand within a framework that includes transaction costs and credit constraints. This frictional housing market setup is designed to minimize real estate speculation. The economy operates under a Pay-As-You-Go (PAYG) system, with households retiring exogenously upon reaching the designated retirement age.

To accurately reflect the U.S. economy, the model is calibrated to the U.S. Bureau of Economic Analysis (BEA), Bureau of Labor Statistics (BLS), Federal Housing Finance Agency (FHFA), and National Income and Product Accounts (NIPA) data between 1968 and 2018. The calibration method follows established practices in previous literature and is consistent with findings in previous empirical analyses. After calibration, we solve the model numerically using the backward induction method and analyze the simulation results. The analysis includes conducting various counterfactual experiments to assess the impacts of demographic changes and technological growth and comparing simulation outcomes across different scenarios.

The influence of the housing market on the macroeconomy has long been a subject of intense scrutiny among researchers. For instance, Xu (2013) investigated the roles of mortgage innovation and interest rates in driving this increase. There is a consensus that the financial market plays a pivotal role in shaping house prices. Ng (2015) explored the contributions of housing preference shocks and monetary policy to house prices. Campbell and Hercowitz (2006) focused on the interaction between debt and the macroeconomy. Developing an incomplete market model, Zhao (2018) examined the impact of housing assets on retirement choices and consumption among the elderly, finding that the wealth effect of housing prices decreases labor participation and boosts consumption. Other factors such as environmental information (Wang and Yao, 2024), health shocks (D'Lima *et al*., 2021), and market rate (Mast, 2023) are also examined.

The determinants of social security have attracted the attention of numerous researchers. French (2005) developed the first theoretical model with endogenous retirement choice and found that the tax structure of pensions plays an important role in retirement behavior. By building a stochastic overlapping generation general equilibrium model featuring both wage and asset price shocks faced by households, Glover *et al.* (2020) found that a simulated recession can lead to a huge welfare loss of up to 10% lifetime consumption. The implications of PAYG on the birth rate and GDP per capita were examined using an overlapping generation model built by Chen and Miyazaki (2022). Cipriani and Pascucci (2020) and Cipriani and Fioroni (2022) investigated the interactions between

fertility choice and the social security scheme and found that the social security tax imposes a negative effect on the fertility rate and intensifies population aging.

This paper contributes to the existing literature in two aspects: first, our paper mainly focuses on the responses of housing price and social security to the macroeconomic variables through incorporating an endogenous frictional housing market into a two-sector lifecycle general equilibrium model. This model allows us to analyze the fluctuations of the housing market and social security benefits in a unified framework. Second, unlike previous studies (e.g., Floetotto *et al.*, 2016), which mainly focus on macroeconomic factors such as credit constraint, government intervention, and capital flow, our study delves into the fluctuations in housing prices under demographic changes, technology growth, and retirement policy reforms. In line with the work of Kaplan *et al.* (2020), this study investigates the fluctuations in equilibrium housing prices across various economic stages.

The rest of this paper is organized as follows. In section 2, we build up our benchmark model and calibrate the model. Section 3 presents our findings and simulation results. Section 4 is the discussion and section 5 is the conclusion. The Appendix contains the details of equilibrium equations and the algorithm of our numerical solution methods.

2. Life-cycle model

We constructed a life-cycle model to study the effects of demographic changes and technology growth on house prices and social security. In this discrete-time general equilibrium model, households enter and leave the economy with zero net financial and housing assets. Each period, households are endowed with 1 unit of labor time and employed in non-durable or durable goods sectors. Following the assumption of Favilukis *et al.* (2017), households can move freely between two sectors, and this free labor flow makes the equilibrium wage paid equally across two sectors. Households allocate their financial and labor income among consumption and housing services to maximize their lifetime value function. Households can use their houses as collateral to borrow against when purchasing new houses. The frictional housing market creates extra costs when a household sells its old house and moves to a new one.

2.1. Demographics

The demographic structure is assumed to be stationary (Chen, 2010), and the population grows at a constant rate *n*. Each individual has a maximum lifespan of *J* periods and retires at age *Jr*. Therefore, the household lives a two-stage life: the working stage and retirement stage. During the retirement stage, retirees receive periodic pension payments, which are equally distributed by the government.

We denote π_j as the probability of surviving onto age j+1 conditional on any age j where $j \in [0, J]$ and $\pi_j \in (0, 1)$ and $\pi_0 = 1$ and $\pi_J = 0$. We denote cohort born at time t with age 1 as P_t^1 and among these newborns, the number of survivals through age s is $\prod_{i=1}^{i=s}\pi_i P_{t+s}^{s+1}$. The total population at any time t is denoted as N_t, and it can be calculated as the sum of all living individuals of all ages, $N_t = \sum_{j=1}^{j=J}(\prod_{i=1}^{i=j}\pi_i P_t^j)$. Since the survival possibilities are fixed over time and the population grows at n, we can get the newborns at time t, which is $P_t^1 = (1+n)P_t^2$, where P_t^2 is the cohort of age 2 at time t who were born at t−1. Now let us denote μ_t^j as the fraction of individuals of age j in the whole population. Then, the fraction of newborns at time t is $\mu_t^1 = \frac{P_t^1}{N_t} = \frac{P_t^1}{P_t^1 + \sum_{j=2}^{j=J}(\prod_{i=1}^{i=j}\pi_i P_t^j)}$ Due to $P_t^1 = (1+n)P_t^2$ the proportion of the age 2 group is $\mu_t^2 = (1+n)^{-1}\pi_1\mu_t^1$, and the fraction of individuals for age j = 2, 3,…, J can be computed recursively by $\mu_t^{j+1} = (1+n)^{-1}\pi_j\mu_t^j$.

2.2. Household's preference

Households enter into the economy with no financial assets and no real estate assets. Each household is endowed with one unit of time in each period. Since leisure is not valued, the labor supply is inelastic. Households have no bequests in our model and thus have no incentives to leave any assets. Both financial and real estate assets of accidentally dead individuals are collected by the government and equally distributed to all living individuals in the next period in the form of government transfers.

Households allocate their income between both non-durable goods and housing service flows to maximize their lifetime utility:

$$\sum_{j=1}^{J}\beta^j\prod_{i=1}^{j}\pi_i u(c_j, h_j) \quad \text{(I)}$$

where β is the utility discount factor. Non-durable and housing consumption are denoted by c and h, respectively. The utility function is assumed to be a monotonic increase in both variables and concave. In particular, the period utility function follows Favilukis *et al.* (2017) and can be expressed as:

$$u(c_t, h_t) = \frac{\left(c_t^{\chi} h_t^{1-\chi}\right)^{1-\sigma} - 1}{1-\sigma} \quad \text{(II)}$$

where χ stands for the weight of non-durable consumption. The relative risk aversion coefficient is denoted as σ.

2.3. Production sector

There are two production sectors in our model: the non-durable goods sector and the housing sector. The former produces non-housing goods and is referred to as the consumption sector. The latter one builds houses like construction companies and is referred to as the construction sector. Both sectors maximize their profits by choosing input factors. Both the capital market and labor market are frictionless, and there are no restrictions on labor flow and capital flow. Thus, in equilibrium, the returns on both input factors are paid the same among sectors. Land, only provided by the government, is taken as a production factor in housing construction.

2.3.1. Consumption sector

The output of non-durable goods denoted as, Y_t^c, is produced using physical capital and labor input according to the Cobb-Douglas production function:

$$Y_t^c = Z_t^c \left(K_t^c\right)^{\alpha} \left(N_t^c\right)^{1-\alpha} \tag{III}$$

where Z_t^c refers to the productivity in the consumption sector. Capital and labor input are denoted by K_t^c and, respectively. α is the capital share.

Then the firm's problem can be written as follows:

$$\max_{\left\{K_t^c, N_t^c\right\}} D_{c,t+k} = Y_t^c - w_t N_t^c - \left(r_t + \delta\right) K_t^c \tag{IV}$$

where $D_{(c,t+k)}$ stands for the profit of the company. Physical capital depreciates at a constant rate δ, and r_t refers to the interest rate. I_t^c is the investment in the consumption sector.

The evolution path of aggregate capital in the consumption sector is:

$$K_{t+1}^c = I_t^c + \left(1-\delta\right) K_t^c \tag{VI}$$

The price of non-durable goods is normalized to 1.

2.3.2. Construction sector

The construction firm's problem is similar to the consumption firm's problem, except the construction firm uses an additional input: land. Land is only owned and provided by the government at a predetermined fixed price. The land stock is unlimited, and then the land demand of construction firms is determined by the land price. When a house is built and sold to the household, the land ownership is transferred to the house owner permanently and the government will not collect any property tax from it.

The housing production function is defined as:

$$Y_t^h = Z_t^h \left(L_t\right)^{1-\phi} \left[\left(K_t^h\right)^{\nu} \left(N_t^h\right)^{1-\nu}\right]^{\phi} \tag{VII}$$

where Z_t^h refers to the technology in the construction sector. The new residential investment at time t is Y_t^h. The land share in housing production is denoted as $1-\varphi$, and the capital share is referred to ν. The land, capital, and labor input are denoted by L_t, K_t^h and N_t^h, respectively.

The construction firms' problem can be written as:

$$\max_{\left\{K_t^h, N_t^h, L_t\right\}} D_{h,t+k} = Y_t^h p_t^h - w_t N_t^h - \left(r_t + \delta\right) K_t^h - p^l L_t \tag{VI}$$

Every construction company tries to maximize the profit $D_{h,t+k}$ in each period, where p_t^h is the relative house price in units of the non-durable consumption good. p^l is the relative land price, which is fixed and set by the government. The government spending G_t at time t is fully financed by the sale of the land $p^l L_t$.

The evolution path in the construction sector is:

$$K_{t+1}^h = I_t^h + \left(1-\delta\right) K_t^h \tag{VII}$$

where I_t^h stands for the investment in the housing sector.

The law of motion for the aggregate residential housing stock Ht is:

$$H_{t+1} = \left(1-\delta_h\right) H_t + Y_t^h \tag{VIII}$$

The houses depreciate at a constant rate $\delta_{h.}$ Based on the demographic information, we can easily calculate the aggregate house stock at time t:

$$H_t = \sum_{j=1}^{j=J} \left(\prod_{i=1}^{i=j} \pi_i P_t^j h_t^j\right) \tag{IX}$$

where the h_t^j is the individual's optimal housing service consumption at age j and time t.

2.4. Government and social security

Government in our model has three functions: the first one is to collect payroll tax and run the PAYG social security system; the second one is to distribute government transfers; and the third one is to lease the lands to finance government spending to maintain function. To simplify, we assume that each spending is financed separately. The aggregate social security pension is equal to the aggregate tax collected, the accumulated government transfers are equal to the market value of all the wealth including housing and financial assets left by the households who are

accidentally dead, and the government spending is equal to the revenue from leasing land.

The aggregate level government budget constraint can be expressed as:

$$G_t + B_t + Tr_t = p^l L_t + W_t \tau \quad \text{(X)}$$

where B_t is the aggregate social benefit, Tr_t refers to the accumulated government transfers at time t, and $W_t\tau$ refers to the total payroll tax collected from all working-age populations.

According to our assumption, each retiree gets an equal share of B_t, and denoted by b_t which is:

$$b_t = \frac{\sum_{j=1}^{j=Jr}(\prod_{i=1}^{i=j}\pi_i P_t^j) w_t \tau}{\sum_{j=Jr+1}^{j=J}(\prod_{i=Jr+1}^{i=J}\pi_i P_t^j)} \quad \text{(XI)}$$

In this equation, the numerator is the expression of B_t. The denominator captures the number of all retirees. Government transfer is uniformly distributed among all living households in the next period. Therefore, the expression is:

$$tr \quad \sum^{j\ J}[\frac{\prod^{i\ \ j}(1-\pi_i)\left[(1+r_{t+1})s_{t+1}^j + (1-\delta_h)p_{t+1}^h h_{t+1}^j\right]}{}) \ \# \quad \text{(XII)}$$

where the s_{t+1}^j refers to the financial asset of the age j group and $(1-\delta_h)p_{t+1}^h h_{t+1}^j$ stands for the rest of the market value of housing assets.

For the government spending, we have:

$$G_t = p^l L_t \quad \text{(XIII)}$$

The revenue from land sales is used to support government spending.

2.5. The household's problem

In each period, the event proceeds as follows. At the beginning of each period, households receive or make interest and principal payments from the previous period's savings or borrowings. They then supply labor to firms to earn wage income, and government transfers are deposited into their accounts simultaneously. For retirees, this is also when social benefits are paid. Then with all this income, agents decide whether to move to a new house. If they choose to move, they sell their old house and purchase a new one at current house prices. The expenditure on non-durable consumption is made. Then agents determine how much to save or borrow in financial assets. Finally, uncertainty about early death is revealed. Both forms of wealth of people who cannot survive are collected by the government and will be distributed in the next period as government transfer.

Every household makes decisions to maximize their lifetime utility:

$$V(s_t, h_t, j) = \max_{\{c_t, h_{t+1}, s_{t+1}\}} \left\{u(c_t, h_t) + \pi_j \beta V^{'}(h_{t+1}, s_{t+1}, j+1)\right\} \quad \text{(XVI)}$$

Which subjects to

$$\begin{aligned} & c_t + s_{t+1} + p_t^h(h_t - h_{t-1}) \\ & \le s_t(1+r_t) + I(j) w_t (1-\tau) - \delta_h p_t^h h_{t-1} \\ & + I(j) b_t + tr_t - tc(h_t, h_{t-1}) \end{aligned} \quad \text{(XV)}$$

$$s_{t+1} \ge -(1-\lambda) p_t^h h_t \quad \text{(XVI)}$$

$$tc(h_{t-1}, h_t) = \begin{cases} \tau_h p_t^h h_{t-1}, h_{t-1} \ne h_t \\ 0, h_{t-1} = h_t \end{cases} \quad \text{(XVII)}$$

$$c, h \ge 0 \quad \text{(XVIII)}$$

Equation XV is the budget constraint for a household and equations XVI and XVI are borrowing constraints. When a household attempts to buy a house, they are eligible to borrow money using the house as collateral, up to a maximum of $(1-\lambda)$ of the house's value. In this case, λ is the downpayment ratio, where $0 \le \lambda \le 1$ Borrowing behavior is denoted as a negative s_t. For simplicity, we assume that the interest rate for borrowing and saving is the same. The $I(j)$ here is an index function, which equals to 1 when $j > Jr$, and to 0, otherwise. The housing market is not perfectly liquid; if the household wants to move to a new house, the transaction cost tc (h_{t-1}, h_1) occurs which is proportional τ_h to the market value of the house. Since the government does not collect the property tax, the transaction cost mainly consists of the agents' commission fee.

2.6. Equilibrium conditions

A stationary equilibrium consists of value functions and cohort-specific decision rules $\{c, hs\}$ for each household, production plans $\{Y^h, Y^c, K, N, L\}$ for representative firms, and a set of endogenous prices $\{r, p^h, w, tr\}$, such that each of the following holds.

- Households optimize. Given the price set, the household's problem value function is solved, subject to constraints.
- The firm's profit is maximized.

$$w_t = (Z_t^c)^{\frac{1}{1-\alpha}}(1-\alpha)\left(\frac{\alpha}{r_t + \delta}\right)^{\frac{\alpha}{1-\alpha}} \quad \text{(XIX)}$$

- Wage equivalence

$$Z_t^c(1-\alpha)\left(\frac{K_t^c}{N_t^c}\right)^{\alpha} = Z_t^h\phi(1-\nu)(L_t)^{1-\phi}\left(K_t^h\right)^{\nu\phi}\left(N_t^h\right)^{\phi-\phi\nu-1}p_t^h \quad \text{(XX)}$$

- Interest rate equivalence

$$Z_t^c\alpha\left(\frac{K_t^c}{N_t^c}\right)^{\alpha-1} = \phi\nu Z_t^h(L_t)^{1-\phi}\left(K_t^h\right)^{\nu\phi-1}\left(N_t^h\right)^{\phi-\phi\nu}p_t^h \quad \text{(XXI)}$$

- Labor market clearance conditions

$$N_t^l = N_t^c + N_t^h \quad \text{(XXII)}$$

where N_t^l stands for the total labor force. In our model, the labor supply is inelastic, suggesting that N_t^l is the total number of the working-age population and can be expressed as $N_t^l = \sum_{j=1}^{j=Jr}(\prod_{i=1}^{i=j}\pi_i P_t^j)$.

- Housing market clearance conditions

$$H_{t+1} = H_t(1-\delta_h) + Y_t^h \quad \text{(XXIII)}$$

where the aggregate housing stock $H_t = \sum_{j=1}^{j=J}(\prod_{i=1}^{i=j}\pi_i P_t^j h_t^j)$.

- Good market clearance conditions

$$Y_t^c = C_t + G_t + I_t \quad \text{(XXIV)}$$

where the aggregate consumption, $C_t = \sum_{j=1}^{j=J}(\prod_{i=1}^{i=j}\pi_i P_t^j c_t^j)$, government spending, $G_t = p^l L_t$, and aggregate investment $I_t = I_t^c + I_t^h$.

- Capital evolutional path

$$K_{t+1} = I_t + (1-\delta)K_t \quad \text{(XXV)}$$

where K_t is the sum of two types of capital and is calculated as $K_t = K_t^c + K_t^h$.

- Savings

$$K_{t+1} = S_{t+1} \quad \text{(XXVI)}$$

The aggregate net savings equals the aggregate capital stock.

A numerical method is applied to solve the stationary equilibrium. In our model, we have three state variables, and household problems can be solved by a specific dimension matrix. The detailed solution procedure is presented in the Appendix.

2.7. Model calibration

In this section, we present our calibration procedure. The model is calibrated based on the U.S. BEA, BLS, FHFA, and NIPA data between 1968 and 2018. The parameters are summarized in Table 1. One period in our model corresponds to 1 year of calendar time. The maximum age an agent can live is 85 and the agent enters the economy when he is 21, which implies the J = 65. The normal retirement age for recent retirees is around 65 and thus, we set Jr = 45. The survival probability π_j is calibrated to the 2021 Actuarial Life Table, and represents the average death probability for both males and females.

The discount factor β is set to 0.97, which implies the long-term interest rate equal to 2.89%. The relative risk aversion parameter σ is set to be 2, which is standard in the macroeconomics literature. The weight of non-durable good consumption χ is calibrated by the steady-state equation: $\frac{\chi}{1-\chi} = \frac{c}{h}\frac{1+r}{p_h(1+r)-p_h'(1-\delta_h)}$. The annual data we use is from the BEA table between 1968 and 2018. The long-run relative price is close to 1.2, implying that the x = 0.85.

The housing market transaction cost τ_h is only paid by the house seller, which commonly includes the agent commission, transfer taxes, and property taxes. The commission fee is around 6% paid to both the seller's and buyer's agent. The taxes including transfers, property taxes, attorney fees, and real estate fees are around 2–4%. In total, the transaction cost falls between 8% and 10% in the U.S. Since the government does not collect property tax which implies the transaction cost τ_h = 6%, the typical commission fee charged by the agency. The down payment ratio λ equals to 20%, implying the loan-to-value ratio to be 80%. If a household's down payment is lower than 20%, the mortgage interest rate will be higher, and private mortgage insurance is required.

The depreciation rate of capital is calibrated to match the depreciation-capital ratio. The fixed assets data and depreciation can be found on the BEA Real Depreciation table. Private non-residential fixed assets contain two types of capital: equipment and structures. They depreciate at two different rates; the average depreciation rate of equipment and structures is 0.13 and 0.03, respectively. This paper takes the average and sets δ to 0.081. The house depreciation rate is calibrated through the depreciation-residential investment ratio. The δ_h is set equal to 0.023, which is the average annual rate between 1999 and 2018.

The current payroll tax rate in the U.S. is set to 15.3% based on the Internal Revenue Service, which includes 6.2% from the employer, 6.2% from the employee, and 2.9% from Medicare. We mainly focus on social security which is τ= 12.4%.

The paper calibrates the capital share α in the non-durable goods production function, which takes the form

Table 1. Parameter values of the benchmark model

Parameter	Description	Value (%)
Demographics		
J	Maximum age	65
Jr	Retirement age	45
πj	Conditional survival possibilities	Actuarial Life Table (2021)
n	Population growth rate	0
Preferences		
Σ	Coefficient of risk aversion	2
χ	Share of non-durable goods	0.85
B	Discount factor	0.97
Production		
α	Capital share in consumption sector	0.35
ϕ	Non-land share in housing sector	0.9
ν	Capital share in housing sector	0.3
δ	Capital depreciation rate	0.081
δh	Housing depreciation rate	0.023
g	Technology growth rate	0
Government		
pl	Land price	1
τ	Payroll tax rate	12.4
Market		
λ	Down payment ratio	20
τh	Transaction cost	6

of the Cobb–Douglas function. $Y_t^c = Z_t^c \left(K_t^c\right)^{\alpha} \left(N_t^c\right)^{1-\alpha}$ to match the U.S. NIPA data. The average capital-income share, α, is set equal to 0.35 between 1954 and 2018. The land share $(1-\phi)$ in the construction industry is set to 10% to match the average land-residential ratio. The capital share $\nu = 0.3$ follows Favilukis *et al.* (2017), where the capital share is set to match the evidence used in Davis and Heathcote (2005).

3. Simulation results

This section presents the results of our analysis, focusing on the impact of demographic and technological changes on the housing market and social security. We compare steady-state outcomes across different models, with each period's general equilibrium solved numerically. Both household lifetime consumption and saving behaviors, as well as macroeconomic outcomes, are examined. Table 2 compares equilibrium values across three scenarios. The benchmark model assumes no demographic or technological change. The second scenario introduces a 1% population decline ($n = -1\%$), whereas the third considers a 1% technology growth rate ($g = 1\%$)). In addition, we simulate the effects of an aging population through early retirement, with Table 3 highlighting its impacts.

Table 2. The equilibrium value set of the benchmark model

Variables	Description	Benchmark	Population decline	Technology -enhanced
r^*	Interest rate	0.0649	0.0590	0.1144
ph^*	House price	1.4145	1.4145	1.3769
tr^*	Government transfer	0.4189	0.4857	0.5424
w^*	Wage income	5.6430	5.7705	8.0006
b^*	Social security payment	2.5869	1.9385	3.6677
Bene	Social security account	2973.17	2802.77	4215.35

3.1. Comparison among alternative economies

The equilibrium values of our price set $\{r^*, p_h^*, tr^*, w^*\}$, are presented in Table 2. Demographic change causes the aggregate social security stock to decrease at the same rate as the total population. With this balanced growth path, we detrend the data and take the average over a long time interval.

The second column shows that population decline has no effect on house prices in this deterministic model. A possible explanation is that construction firms reduce the pace of new housing projects to align with falling demand. Since demographic changes are predictable, the aggregate demand is known to construction companies. Moreover, the model assumes an unlimited land supply, so land prices remain unaffected by population changes. The interest rate drops by around 9% due to decreased aggregate demand, leading to reduced production and lower demand for capital. Government transfers, funded by the assets of deceased individuals, increase by 16% per household. Wages rise by 2% due to a labor shortage. However, under the PAYG system, social security benefits per retiree drop by 25% due to a smaller tax base, and the aggregate social security account decreases by 5.7%.

The third column summarizes the results for an economy with 1% technology growth. Unlike the benchmark, where values are constant, the price set fluctuates over time in this scenario. We calculate the average equilibrium allocations over 65 years. Rising productivity leads to higher wages, interest rates, and social security benefits, except for house prices. A 1% increase in housing technology reduces house prices by 2.6%, likely due to lower costs from increased productivity and faster-growing housing supply relative to demand. Higher social security payments discourage savings and real estate investment, whereas

Table 3. Alternative economy with retirement policy reform

Variables	Description	Benchmark	Earlier retirement
r^*	Interest rate	0.0649	0.0532
ph^*	House price	1.4145	1.4145
tr^*	Government transfer	0.4189	0.3831
w^*	Wage income	5.6430	5.9043
b^*	Social security payment	2.5869	1.7796
Bene	Social security account	2,973.17	2,828.97

the higher interest rate suggests a lack of capital due to reduced household savings. As wages increase by nearly 42%, consumption of both durable and non-durable goods surges, driving investment in production. In this deterministic economy, the housing market is primarily influenced by productivity.

Table 3 presents the results of the retirement policy reform, where the retirement age is lowered from 65 to 60. We examined the effects of an aging population on the housing market by reducing the retirement age while keeping other conditions constant. The house price remains unaffected by this early retirement policy, as changes in demand do not impact the housing market in a deterministic model. Salaries increase by 5.9%, likely due to a labor shortage, giving workers more negotiation power. The decrease in interest rates suggests that households are incentivized to save more to offset the reduced social security benefits. Government transfers declined by 8%, indicating a reduction in real property investment. Early retirement increases the number of retirees and reduces the workforce without changing the total population. Despite higher wages, the aggregate payroll tax revenue decreases, leading to a 4.8% reduction in aggregate social security. Individual social benefits are significantly reduced, dropping by nearly 30%.

In summary, our findings indicate that in a non-stochastic economy, demographic changes do not affect house prices due to a perfectly elastic supply curve. Since future population trends are predictable, firms can adjust production to match demand, maintaining stable house prices. Technological growth in the production sector is the key factor influencing house prices. Unlike house prices, social security payments are sensitive to both total factor productivity (TFP) and population changes. A 1% change in the population growth rate can cause approximately a 5.7% change in aggregate social security accounts, which in turn inversely affects household housing consumption.

3.2. Macroeconomic implications

In this section, we explore the responses of macroeconomic variables. Table 4 summarizes the statistical properties

Table 4. Aggregate effect on macroeconomic variables

Variables	Benchmark	Population decline	TFP enhanced	Early retirement
GDP	36924	34793	52337	32658
Y_c/GDP	0.9682	0.9794	0.9480	0.9626
$Y_h p^h/GDP$	0.0318	0.0205	0.0519	0.0374
K_c/Y_c	2.39	2.49	2.17	2.72
K_h/Y_h	2.61	2.73	2.37	2.92
N_c/N	0.9691	0.9800	0.9488	0.9638

Abbreviation: TFP: total factor productivity.

of business cycle variables. The GDP is calculated as the sum of non-durable good output and the market value of new residential investments: $GDP = Yc + Y_h^* p^h$. The average tangible capital-output ratio between 1929 and 2015 is around 2.7. In the total private sector, the percentage of labor employed in the consumption sector is 94% over the period of 1968 to 2018.

The population decline column in Table 4 presents the simulation results for the model with a declining population. As expected, the decrease in population and labor force leads to a proportional decline in GDP. Although per capita housing consumption increases, the aggregate demand for housing services falls, reducing the percentage of new residential investment. The capital-output ratios in both sectors increase by approximately 4%, indicating that the demand for capital decreases more than household savings due to falling demand and output. The lower interest rate further confirms that the supply of capital exceeds demand. In addition, labor shifts from the construction industry to the consumption sector.

The TFP-enhanced column in Table 4 shows the model results under technology growth. In an expanding economy, demand for both non-durable and durable goods rises. The increasing supply, in turn, drives demand higher. The lower house prices suggest that output growth outpaces demand. The non-durable production-to-GDP ratio is lower than in the benchmark model, indicating that non-durable goods consumption grows more slowly than GDP. Positive economic expectations discourage saving, leading to a decrease in the capital-output ratio. The smaller labor ratio suggests a shift of labor from the consumption sector to the construction industry.

The early retirement column in Table 4 illustrates the results of the model with early retirement. Compared to the benchmark model, the percentage of non-durable production relative to GDP decreases as people exit the labor market 5 years earlier. Consequently, GDP falls by 11%. The lower non-durable-to-GDP ratio also indicates that the demand for non-durable goods declines more sharply than GDP. In

the benchmark model, the share of newly constructed houses relative to GDP is lower than in the early retirement scenario, where individuals increase their investment in real property to offset the loss in retirement benefits. Both capital-output ratios rise by 11%, and households' financial assets are higher than in the benchmark economy. The shift in labor from the non-durable to the durable goods industry is driven by the increased demand for housing.

3.3. Life-cycle profiles

In this section, we examine the impact of technology and demographic changes on life-cycle consumption patterns and financial assets. Figure 1 displays individual lifetime consumption from ages 21 to 85, with the coordinate 0 corresponding to age 20. Notably, all Figures (Figures 1-4) are smoothed using a polynomial trendline function.

Figure 1 illustrates the results of the benchmark model, showing that with housing market friction, the consumption of durable goods is more dispersed than that of non-durable goods. The savings curve, representing a household's financial assets, indicates that the household repays their mortgage before age 40. After that, the financial assets keep decreasing and are used to finance expenditures on consumption and housing services.

Figure 2 shows the life-cycle profiles of individual variables under a decreasing population scenario. Compared to the benchmark model, the entire savings curve shifts downward. The declining demand leads to reduced production, which further decreases the demand for input factors, resulting in a lower interest rate than in the benchmark.

With a decreasing population, per capita housing service consumption is slightly higher. Housing services not only provide utility to households but also serve as a financial investment. In the benchmark model, housing assets constitute 37.2% of total wealth, whereas in the decreasing population model, this share increases to 39.2%. This rise in housing service consumption significantly dampens the consumption, leading to more compressed non-durable consumption with smaller variance. Although per capita housing consumption rises, the need for new housing construction diminishes due to the shrinking population. The labor and capital shift toward the consumption sector, as evidenced by the increase in the ratio of labor in the consumption sector to total labor.

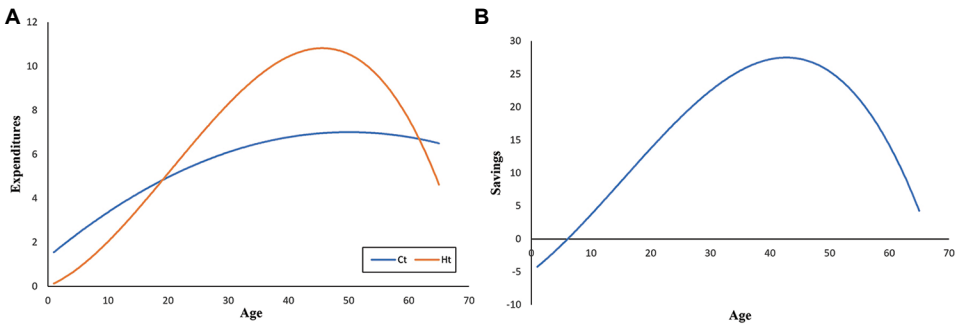

Figure 1. Benchmark results. (A) Lifecycle consumption and housing service expenditures. (B) Lifecycle savings. Abbreviations: Ct: Consumption; Ht: Housing service.

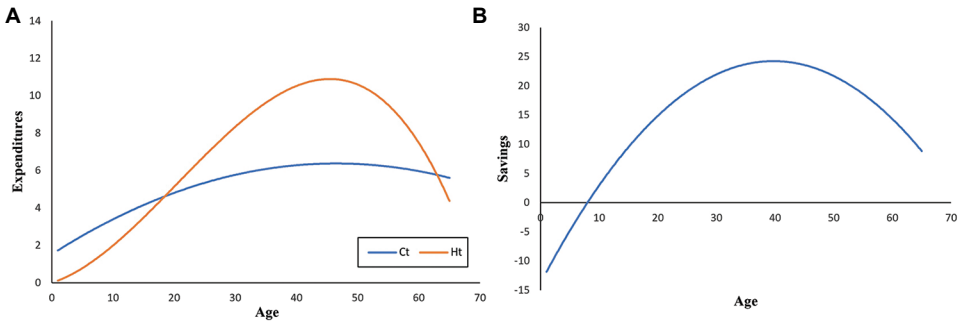

Figure 2. Alternative economy with decreasing population. (A) Lifecycle consumption and housing service expenditures. (B) Lifecycle savings. Abbreviations: Ct: Consumption; Ht: Housing service.

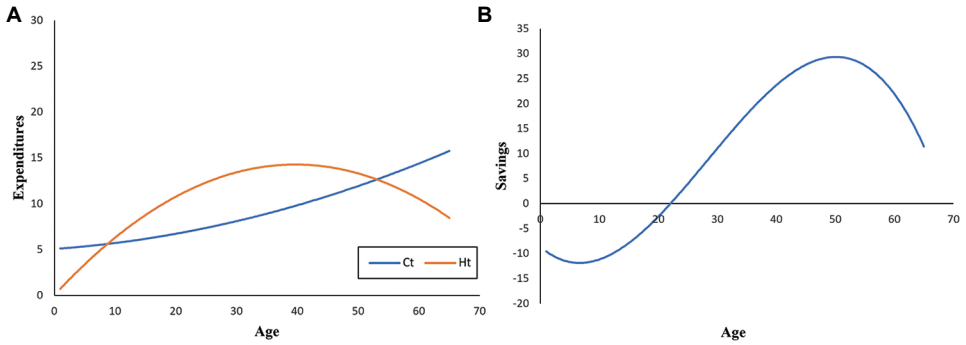

Figure 3. Alternative economy with growing technology. (A) Lifecycle consumption and housing service expenditures. (B) Lifecycle savings. Abbreviations: Ct: Consumption; Ht: Housing service.

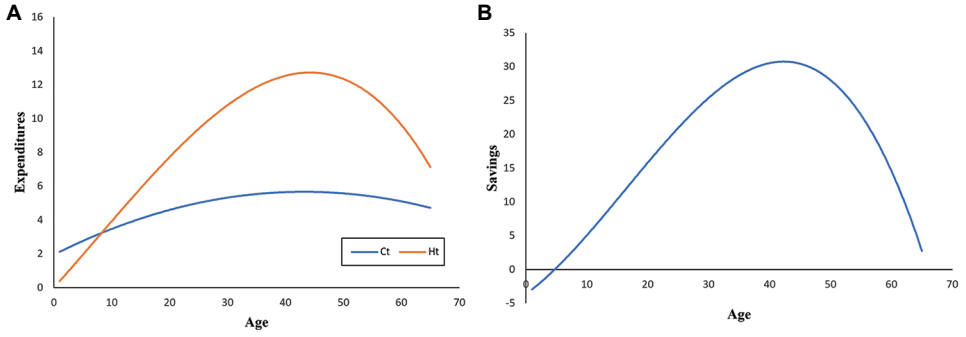

Figure 4. Alternative economy with early retirement. (A) Lifecycle consumption and housing service expenditures. (B) Lifecycle savings. Abbreviations: Ct: Consumption; Ht: Housing service.

Figure 3 illustrates the impact of technology growth on lifetime choices. The effect of productivity growth is significant, with consumption of both types of goods exceeding their levels in the benchmark economy. As technology advances, the relative house price declines at a steady rate of 0.1%. This improvement in living standards is driven by higher income and social security benefits. Increased confidence in the future economy leads households to raise their financial leverage. Given the larger weight on non-durable goods consumption, households tend to allocate a greater proportion of their income to these goods, resulting in more dispersed consumption patterns. Unlike in the benchmark model, non-durable goods consumption follows an upward trend, with demand increasing over the lifetime compared to housing services. This shift influences the labor flow between sectors, causing the ratio of labor in the non-durable goods sector to total labor to slightly increase.

Figure 4 illustrates the impact of early retirement policy. This shift negatively affects social benefits, prompting individuals to save more in both financial and housing assets to compensate for the loss, leading to an overall increase in savings. Despite higher wage income, households do not increase or even maintain their non-durable goods consumption. Housing consumption surges for two reasons: lower interest rates make acquiring a better home more affordable and households view housing as a risk-free investment due to stable house prices. In this scenario, real property assets account for nearly 41% of the total wealth. At retirement, consumption generally peaks and then gradually declines. Households reduce their housing assets to help finance their consumption needs. Compared to the benchmark model, when households anticipate lower future income, they tend to reduce non-durable goods consumption and increase investment in risk-free assets.

In summary, demographic changes primarily affect social security, wages, and government transfers, with little to no impact on the housing market. House prices are influenced by supply-side productivity, given the unlimited land supply and fixed land prices. During economic expansion, households are more likely to increase debt holdings, whereas, in a recession, they tend to increase the share of real estate assets in their total wealth.

4. Discussion

Our analysis reveals that in this economy, demographic changes have an insignificant impact on equilibrium housing prices due to the perfectly elastic supply. However,

technological growth reduces housing prices, indicating that long-term house prices are more influenced by supply than demand, assuming wages remain unchanged. This stability is likely because construction firms can anticipate and adjust to demand changes driven by demographic shifts, stabilizing prices. Conversely, technological advancements lower construction costs, leading to price changes. Demographic changes also affect interest rates and social security benefits. A 1% population decrease, or a 5-year early retirement reduces interest rates by 9% and 18%, respectively, causing households to save more, which creates an imbalance between savings and capital demand, leading to a GDP decline. Social security payments increase by 25% and 30%, prompting households to invest a larger share of their wealth in housing assets (increases by 2% and 4%, respectively), indicating a more conservative saving approach during downturns.

During economic booms, rising productivity in both sectors leads to lower house prices and higher wages, boosting consumption of both durable and non-durable goods, with non-durable goods consumption growing faster. Increased wages also raise social security payments, reducing the incentive to save. The capital-output ratio drops by nearly 10%, and interest rates rise, reflecting increased capital demand as businesses expand. Over time, the share of real estate in total wealth decreases, and labor shifts from construction to non-durable goods production, reflecting employment trends during economic expansions.

The findings reveal that demographic changes, such as population decline and early retirement, significantly affect social security benefits and interest rates but have little impact on equilibrium house prices due to a perfectly elastic housing supply. This suggests that while aggregate demand may decrease, house prices remain stable because supply adjusts accordingly. To stabilize the housing market, governments could implement policies such as affordability programs or encourage flexibility in housing supply. To counter the decline in social security benefits and lower interest rates, reforms could include automatic benefit adjustments based on demographic trends, exploring alternative funding mechanisms such as investing in profitable portfolios, postponing the retirement age, or providing subsidies for technological improvements.

In addition, labor shortages from demographic shifts may require targeted policies to sustain economic growth and stabilize wages. Promoting workforce participation among older individuals can be achieved through flexible retirement policies, incentives for delayed retirement, and part-time or flexible work options. Enhancing skills development through lifelong learning, vocational training, and re-skilling initiatives is also crucial. As productivity improvements reduce construction costs and influence house prices, investing in technological advancements and promoting a flexible housing supply can benefit overall social welfare. During economic expansions, rising wages can reduce household savings and increase interest rates, so policies that encourage balanced consumption, such as tax incentives for savings and support for retirement plans, are essential for maintaining economic stability.

5. Conclusions

In this study, we constructed a general equilibrium model with an endogenous housing market to study the effects of demographic changes, technological development, and retirement policy reform on the housing market and social security benefits. In this framework, variables such as house price, interest rate, wage, and labor flow are endogenous and determined by market conditions. In addition, we explored the impact of demographic shifts and TFP growth on macroeconomic outcomes and household lifetime profiles. The key findings include that housing prices are mainly driven by supply-side factors rather than demand. Demographic changes significantly impact social security payments, with lower future income prompting households to increase their savings and housing assets, leading to a decrease in interest rates.

However, this paper has several limitations that could inspire future research. First, the model does not consider the renter's problem and lacks the examination of aggregate shocks, which may limit the realism and applicability of the results. Future research could examine how demographic shocks, such as a baby boom or unexpected immigration increases, impact house prices and social security. The assumption of unlimited land supply limits its applicability, and future models could incorporate the relationship between land prices and population changes. Moreover, this life-cycle framework could be adapted to address various policy issues, such as monetary policy, fiscal policy, or retirement policies. For example, introducing an Individual Retirement Account plan instead of the PAYG system could influence household savings and consumption behavior.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: All authors
Formal analysis: All authors
Investigation: All authors
Methodology: All authors
Writing–original draft: All authors
Writing–review & editing: All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

All data are secondary data from publicly available data sources: Land price (FHFA): https://www.fhfa.gov/data/hpi/datasets; Government spending (BEA): https://www.bea.gov/data/government/receipts-and-expenditures; GDP and Residential investment (NIPA): https://apps.bea.gov/iTable/?reqid=19&step=2&isuri=1&categories=survey#; Employment data: (BLS) https://www.bls.gov/data

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Appendix

Solution algorithm

This appendix represents the detailed solution method to our general equilibrium model.

We solved this model for equilibrium by numerical methods. The solution to this recursive dynamic problem was backward induction. The household's problem included two state variables: housing assets and savings. We first discretized the state variables and used the grid search method to find the optimal (*h, s*) combination at the end of the period. For each grid point of the end-of-period housing asset h_j, we calculate the optimal financial asset combination $\{h_J$ and $s_j\}$ that maximizes the value function. Then, we stored all the combinations ($h_j S_j$). Given $\{h_j, s_j, V_j\}$, we then calculated the optimal decisions $\{h_j, h_{J-1}, s_j, s_{J-1}, V_{J-1}, V_j\}$ for age *J−1* using the Bellman equation. Iterate this process until we reach the age of 1.

The steady-state equilibrium was solved by the following steps:

(1) Guess the prices $\{r_t, p_t^h, tr_t\}$. The wage can be written as a function of interest rate: $w_t = z_t^c(1-\alpha)\left(\frac{\alpha}{r_t+\delta}\right)^{\frac{\alpha}{(1-\alpha)}}$.

(2) Then, plug in the price value set and solve the household's problem by backward recursion from time *J* to 1. Using forward simulation to obtain the household's optimal decision rules $\{c_t, h_t+1, s_{t+1}\}$, compute the aggregate variables such as $\{K_t, H_t, N_t\}$. The aggregated housing service demand of all households is $H_t = \sum_{j=1}^{j=J}(\prod_{i=1}^{i=j}\pi_i P_t^j h_t^j)$, and the population size of all working-age cohorts is $N_t = \sum_{j=1}^{j=Jr}(\prod_{i=1}^{i=j}\pi_i P_t^j)$.

(3) Use market clearance conditions to update $\{\widehat{r_t}, \widehat{p^h}, \widehat{tr_t}\}$. Interest rate and labor in the non-durable goods sector can be obtained by solving the following equation set:

$$\begin{cases} 0 = z_t^c\left(\frac{\alpha}{r_t+\delta}\right)^{\frac{\alpha}{1-\alpha}}\left[N_t^c - \frac{(1-\phi)(1-\alpha)}{\phi(1-\nu)}\left(N_t - N_t^c\right)\right] - C_t - I_t \\ 0 = H_{t+1} - (1-\delta_h)H_t - (z_t^h)^{1-\nu\phi}\left[\frac{1-\phi}{\phi(1-\nu)}\frac{1}{p_l}\right]\left(\frac{\nu}{1-\nu}\frac{1}{r_t+\delta}\right)^{\phi\nu}\left(N_t^l - N_t^c\right)\left[z_t^c(1-\alpha)\left(\frac{\alpha}{r_t+\delta}\right)\right]^{1-\phi+\phi\nu} \end{cases}$$

Government transfers and house prices can be solved using Equations III and VII (in the main article).

(4) Compare the old and new guesses. If the distance of two sets is smaller than a tolerance level, then equilibrium is found. Otherwise, update the guesses and repeat step 3, until they converge.

ACCSCIENCE PUBLISHING

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RESEARCH ARTICLE

Health-related quality of life and survival of older adults in Campinas, São Paulo, Brazil: A retrospective analysis from 2008 to 2018

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Abstract

As the average life expectancy continues to rise, the prevalence of multimorbidity is also expected to increase, potentially leading to outcomes such as functional decline, a higher risk of premature death, and adverse effects on overall health and well-being. This study aimed to estimate the survival rates of older adults with varying levels of health-related quality of life (HRQoL) and to assess the association between the domains and components of the 36-item Short Form Health Survey and all-cause mortality over a 10-year period in Brazil. We conducted a retrospective longitudinal study using baseline data from 1,520 elders (aged 60 years and older) who participated in the Health Care Survey of the Municipality of Campinas, São Paulo, Brazil (ISACamp 2008/2009). A linkage was established between the ISACamp databases and the Mortality Information System. An active search was performed for individuals whose data could not be paired to confirm the death status. Survival functions were calculated using the Kaplan–Meier method, while hazard ratios (with 95% confidence intervals) were determined using Cox regression analysis. All HRQoL domains showed proportional hazards and statistically significant differences ($p < 0.05$) between survival curves, except for the bodily pain domain. In the multivariate analysis, lower scores in physical functioning and role-physical were associated with a 74% and 42% increased risk of death, respectively. In addition, impairments in role-emotional, mental health, and general health heightened the risk of mortality by approximately 36%. Notably, the lowest score in the physical component emerged as a significant predictor of mortality, increasing the probability of death by 47%, while the mental component showed no significant association. Our findings provide compelling evidence of the predictive capacity of HRQoL in evaluating mortality risk among older people in low- and middle-income countries.

Keywords: Quality of life; Health-related quality of life; Mortality; Survival analysis; Cohort studies; Elderly

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1. Introduction

Estimates suggest that the world population aged 60 years and older will nearly double between 2015 and 2050, rising from 12% to 22% (World Health Organization, 2021).

In Brazil, this age group currently represents 13% of the population (United Nations, 2017), with projections indicating that this percentage may increase to 29.3% by 2050 (United Nations, 2015).

This increase in longevity is accompanied by a significant rise in chronic non-communicable diseases (CNCDs), which affect vulnerable populations (Marmot & Bell, 2019). CNCDs are the leading cause of mortality in Brazil, accounting for 72% of all deaths in this country (Inês Schmidt *et al*., 2011) and 63% globally (World Health Organization., 2011). By 2019, approximately 47.6% of the elderly reported having one or more CNCDs (Malta *et al*., 2021). With the rise in life expectancy, the prevalence of multimorbidity is also expected to increase (De Melo & De Lima, 2020), resulting in consequences such as functional decline, increased risk of premature death (Fortin *et al*., 2004; Jani *et al*., 2019), and adverse effects on quality of life (QoL) (Nunes *et al*., 2015). Health-related quality of life (HRQoL) serves as a critical indicator of chronic disease management, capturing how these diseases affect individuals' lives. HRQoL encompasses a range of self-reported measures that address physical, psychological, social, and functional aspects, thereby providing insights into the impact of health conditions on daily living (Ware, 2007; Karimi & Brazier, 2016).

According to Idler & Benyamini (1997), self-assessments of health are dynamic and encompass not only an individual's current health status but also their health trajectory over time. Individuals integrate past health changes into their current health evaluations, and self-rated poor health serves as an indicator of perceived decline or impending mortality. Thus, self-reported health measures can anticipate future health outcomes (Idler & Benyamini, 1997; Miller & Wolinsky, 2007). The authors found that responses to a simple question, "How do you assess your health?" were highly correlated with objective clinical measures of morbidity and could predict mortality (Idler & Benyamini, 1997; Miller & Wolinsky, 2007). This raises the question of how this relationship might extend to other self-reported dimensions of health, such as functional capacity, emotional aspects, social aspects, and pain.

Few studies have evaluated this correlation between HRQoL and mortality in the general population, and to our knowledge, no study has been conducted in Brazil or Latin America to evaluate HRQoL as a predictor of mortality in older individuals. On the other hand, existing studies have demonstrated that poor HRQoL is associated with a higher mortality rate among patients with serious conditions, including heart failure (Erceg *et al*., 2019), pulmonary embolism (Chuang *et al*., 2019), cancer (DuMontier *et al*., 2018; Ediebah *et al*., 2014; Sitlinger & Zafar, 2018), and femoral fractures (Campenfeldt *et al*., 2020). A systematic review of 47 studies concluded that higher HRQoL is associated with a reduced risk of all-cause mortality (Phyo *et al*., 2020). However, less than two-thirds of the included studies (28 articles) focused exclusively on elders aged 65 years and older, and only 13 were published in the last 5 years. In addition, 14 studies had sample sizes of fewer than 1,000 individuals, and only seven provided a minimum follow-up of 10 years. Notably, 98% of the studies (46 articles) were conducted in high- or upper-middle-income countries (Phyo *et al*., 2020).

This retrospective cohort study utilizes a representative sample of the elderly population, offering groundbreaking findings for Brazil and Latin America regarding various facets of health and QoL. By employing a globally validated standardized instrument, the study assessed these dimensions as predictors of mortality in the elderly. Global health organizations highlight the importance of measuring QoL as a prospective screening tool in routine clinical practice (Centers for Disease Control and Prevention, 2019; World Health Organization, 2007). The adoption of self-assessed QoL metrics can assist healthcare professionals in promptly identifying signs of impending health decline and increased risk of mortality in the elderly. This contribution not only enhances our understanding of the challenges faced by the elderly but also provides valuable information for clinical and policy interventions aimed at supporting the health of this population.

With projections indicating that 80% of older individuals will reside in low- or middle-income countries by 2050 (World Health Organization, 2021), the predictive power of HRQoL concerning mortality outcomes among non-institutionalized, healthy elders in these regions remains largely unexplored. Therefore, this study aims to assess the probability of survival among older adults with varying HRQoL statuses and to investigate the association of the 36-item Short Form Health Survey (SF-36) domains and components with all-cause mortality over a 10-year follow-up period in Brazil, from 2008 to 2018.

2. Methods

This retrospective longitudinal study utilized baseline data from 1,520 elders aged 60 years and older who were interviewed as part of the Health Care Survey of the Municipality of Campinas (ISACamp) in 2008 – 2009. These participants were subsequently tracked over a 10-year period. The ISACamp 2008 – 2009 employed a complex sampling design based on cluster probability sampling conducted in two stages – territorial and household sectors. In the first stage, 50 territories were randomly selected with a probability proportional to the number of households. In the second stage, households within each selected sector

were systematically drawn, ordered by the percentage of heads of households with higher education.

To identify deaths among participants from the 2008 survey, we linked the ISACamp data with the Mortality Information System maintained by the Municipal Health Department of Campinas (São Paulo, Brazil) from 2008 to 2018. This linkage involved both deterministic and probabilistic methods executed using STATA 15.0 (Stata Corp., College Station, USA), using variables such as name, gender, and date of birth. Death information was matched with records that satisfactorily paired, while non-deaths were assigned to unmatched records. In instances where death status could not be determined, an active search was conducted via telephone calls. If necessary, home visits were conducted to validate each participant's status.

The tracking of patients was carried out by a team of trained interviewers, who received guidance on effectively approaching older adults, both in person and over the telephone, to minimize data loss. During home visits where selected participants could not be located, interviewers were instructed to consult other household members or neighbors. Participants who could not be contacted after three telephone attempts and three home visits were classified as losses and excluded from the study.

The tracking system successfully identified 1,311 of the 1,519 individuals from the 2008 to 2009 survey. An additional 11 participants were excluded for failing to complete the SF-36 survey, resulting in an analyzed sample of 1,300 older adults, representing 85.58% of the initial cohort. Of these, 34.23% (n = 445) had died by 2018. This participant information is illustrated in Figure 1.

2.1. Variables

The dependent variable was time to death, measured from the baseline interview date to the date of death, encompassing all causes of mortality. For participants who were still alive at the end of the study (December 31, 2018), their time was censored.

The independent variables included eight domains and two components of HRQoL. HRQoL was assessed using the SF-36 (Ware, 2007). A slightly modified version of the Quality Metric Incorporated (IQOLA - SF-36v2™ Health Survey Standard, Brazil - Portuguese) was utilized to adapt to the ISACamp questionnaire. The SF-36 has been translated and validated for the Brazilian population (Ciconelli, 1997), with normative data established by Laguardia *et al.* (2013). The SF-36 consists of 36 questions grouped into eight scales – physical functioning, role-physical, bodily pain, general health, vitality, role-emotional, social functioning, and mental health. Scores from these questions were aggregated to create a scale ranging from 0 to 100, with higher scores indicating better QoL (Ware, 2007).

The instrument enables the calculation of two summary components – the physical component (PC) and the mental component (MC). The PC score includes the scales of bodily pain, physical functioning, and role-physical, while the MC score comprises role-emotional, social functioning, and mental health scales. In addition, the vitality and general health scales correlate with both components. This approach reduces the number of statistical comparisons required in SF-36 analyses, condensing eight scales into two summary measures. To calculate the component scores, we utilized average scores from the American population, following recommendations in the manual, as no Brazilian population data were available during the study period (Ware, 2007).

The analyses were performed with dichotomous variables. First, we divided the instrument scores into tertiles – tertile 3 comprised the category zero (best QoL

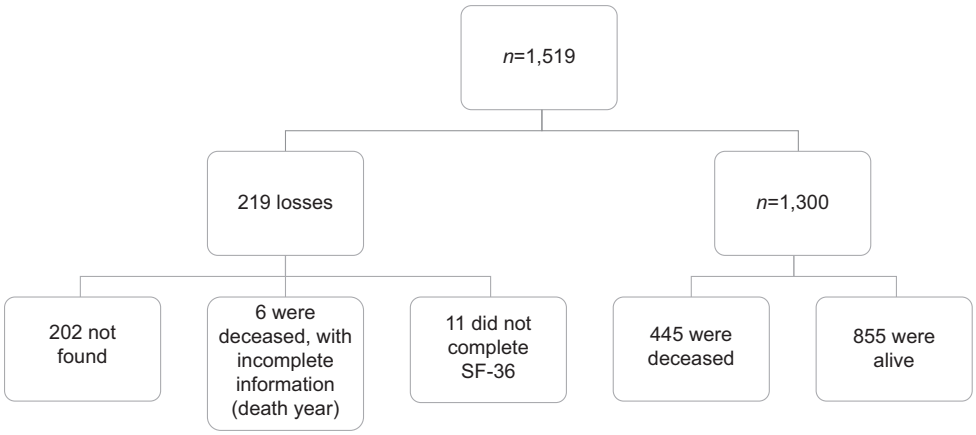

Figure 1. Sample losses and distribution of participants in the study
Abbreviation: SF-36: 36-item Short Form Health Survey.

and health status), and tertiles 1 and 2 comprised the category one (worst QoL and health status). Then, we evaluated the scales of physical functioning (0 ≥ 90; 1 ≤ 85), role-physical (0 ≥ 99; 1 ≤ 93.75), bodily pain (0 ≥ 80; 1 ≤ 74), general health (0 ≥ 75; 1 ≤ 72), vitality (0 ≥ 81.25; 1 ≤ 75), role-emotional (0 ≥ 99; 1 ≤ 92), social functioning (0 = 100; 1 ≤ 99), and mental health (0 ≥ 80; 1 ≤ 75). The cutoff scores for the physical (0 ≥ 50.2117; 1 ≤ 50.2109) and mental (0 ≥ 55.6867; 1 ≤ 55.6861) components were also defined.

Additional independent variables included gender, age (60 – 69 years, 70 – 79 years, and ≥80 years), race/color (white and black/brown), education (0 – 3, 4 – 7, and ≥8 years), income (<1 minimum wage (MW), 1 – 3 MWs and ≥3 MWs), with 415.00 Brazilian real as the reference MW in 2008 (Law 11709/2008), number of chronic diseases (none, one, or two, or more), and physical activity (active, insufficiently active, and inactive).

All independent variables were collected at baseline; in other words, there were no time-dependent variables included in this study.

2.2. Data analysis

Survival functions were calculated using the Kaplan–Meier method for each SF-36 domain and component, with comparisons made using the log-rank test at a significance level of 5%. Crude and adjusted hazard ratios (HRs) for gender, age, income, education, chronic diseases, and physical activity were estimated using Cox semi-parametric regression models. In addition, multivariate Cox regression models were stratified by sex. Simple and multiple regression models were estimated separately for each domain and component of SF-36, along with their respective 95% confidence intervals (CIs). The multiple regression model was adjusted for gender, age, income, education, physical activity, and chronic diseases.

To assess the model fit, Schoenfeld residuals were calculated, and the global proportionality test was applied ($p < 0.05$).

All analyses were performed using STATA 15.0 (Stata Corp., College Station, USA), with regression models estimated using the survey module to account for the complex sampling plan of ISACamp.

3. Results

The median age of the study population was 69 years. Among the 855 older individuals who were not deceased, 61.75% were female, while of the 455 who had died, 53.25% were female. In the total sample (n = 1,300), more than half (52.0%) were aged 60 – 69 years, with 79.9% identifying as white. Only 17.7% of participants earned three or more minimum wages, and 29.2% had more than 8 years of education (Table 1).

Utilizing the Kaplan–Meier method, we found that all HRQoL domains exhibited proportional risks and statistically significant differences ($p < 0.05$) between the survival curves, except for bodily pain. The lowest survival rates were observed in individuals reporting lower scores in physical functioning and role-physical, followed by role-emotional, social functioning, and general health (Figures 2 and 3). Both PC and MC displayed proportional risks and significant differences, with lower survival associated with PC (Figure 4).

In terms of physical functioning, 50% of deaths in the tertile with the highest score (THS) occurred at 5.91 years, while in the tertile with the lowest score (TLS), this occurred at 5.06 years. The survival times for other domains were as follows: role-physical (5.84 THS vs. 4.97 TLS), bodily pain (5.56 THS vs. 5.15 TLS), general health (5.33 THS vs. 5.28 TLS), vitality (5.60 THS vs. 5.08 TLS), role-emotional (5.77 THS vs. 4.47 TLS), social functioning (5.58 THS vs.

Table 1. Characteristics of the Health Care Survey of the Municipality of Campinas, São Paulo, Brazil Cohort (2008 – 2018) by survival status

Variables	Non-death		Death		Total	
	n[a]	%	*n*[a]	%	*n*[a]	%
Sex						
Male	327	61.4	208	38.6	535	41.2
Female	528	69.2	237	30.8	765	58.8
Age group						
60 – 69	538	79.8	138	20.2	676	52.0
70 – 79	266	60.2	177	39.8	443	34.1
80 and older	51	27.5	130	72.5	181	13.9
Race/skin color						
White	671	66.3	342	33.7	1013	79.9
Black	183	64.2	102	35.8	285	22.1
Income (MMW)[b]						
<1 MMW	335	60.9	213	39.1	548	42.2
≥1 – ≤3 MMW	347	66.7	174	33.3	521	40.1
≥3 MW	173	74.7	58	25.3	231	17.7
Education (years)						
0 – 3	281	59.0	193	41.0	474	36.5
4 – 7	293	65.6	152	34.4	445	34.3
8 and more	281	74.0	99	26.0	380	29.2

Notes: [a]*n*=Number of individuals in the unweighted sample. [b]Family income per capita in relation to MMW.
Abbreviation: MW: Minimum wage.

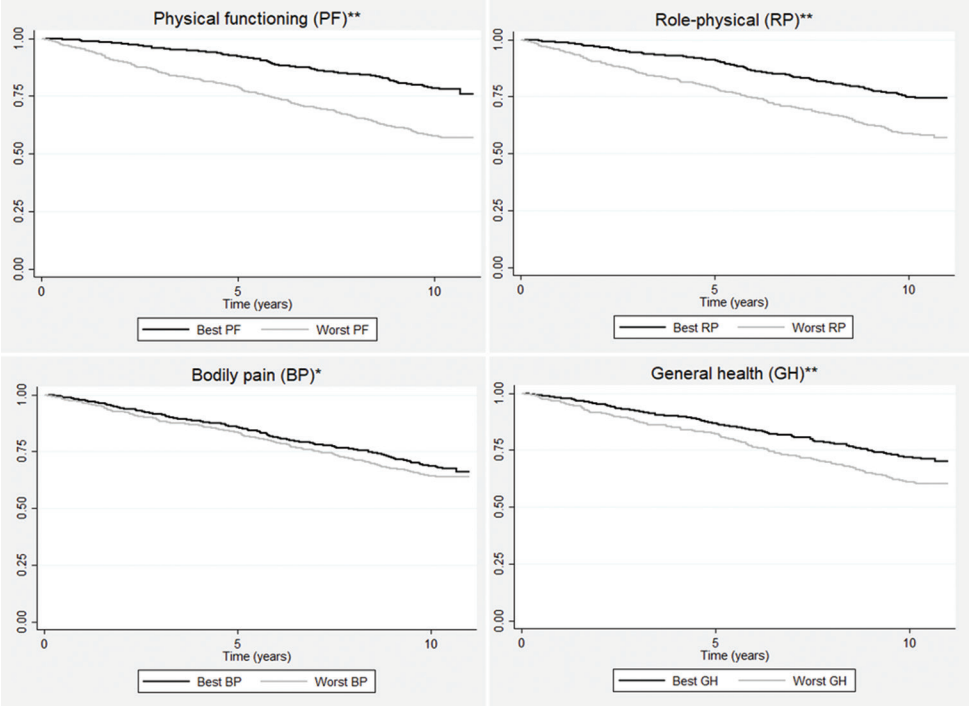

Figure 2. Survival analysis of the Health Care Survey of the Municipality of Campinas, São Paulo, Brazil Cohort elders (60 years and older) with better and worse Health-Related Quality of Life based on the 36-item Short Form Health Survey domains: Physical functioning, role-physical, bodily pain, and general health (2008 – 2018). Notes: $^{**}p < 0.05$, $^{**}\ p < 0.01$
Abbreviations: BP: Bodily pain; GH: General health; PF: Physical functioning; RP: Role to physical.

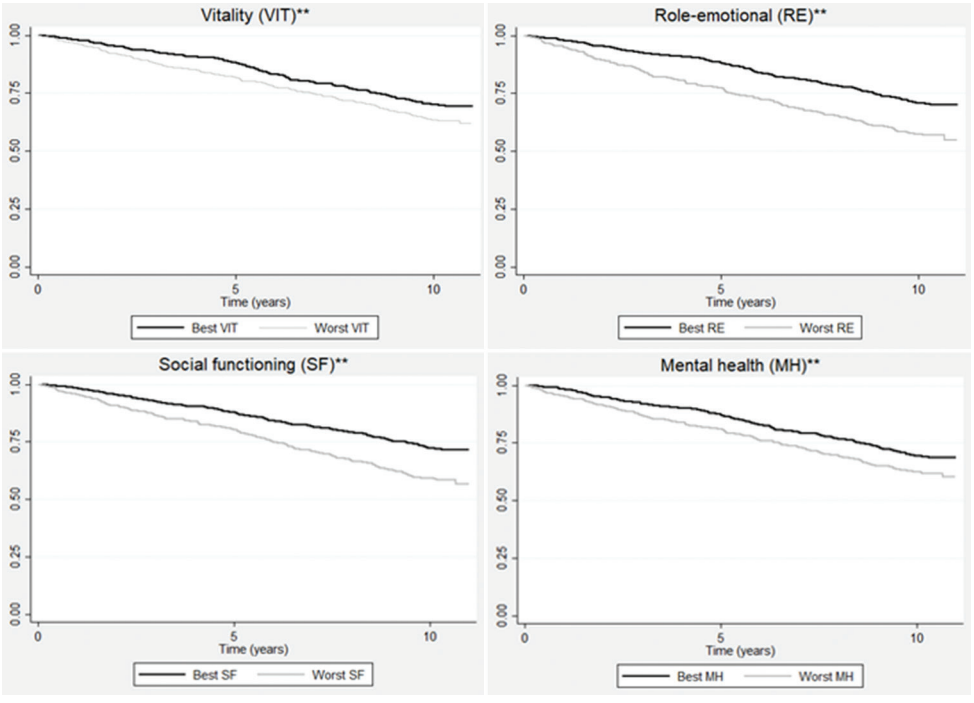

Figure 3. Survival analysis of the Health Care Survey of the Municipality of Campinas, São Paulo, Brazil Cohort elders (60 years and older) with better and worse Health-Related Quality of Life based on the 36-item Short Form Health Survey domains: vitality, role-emotional, social functioning, and mental health (2008 – 2018). Note: $^{**}p < 0.01$
Abbreviations: MH: Mental health; RE: Role-emotional; SF: Social functioning; VIT: Vitality.

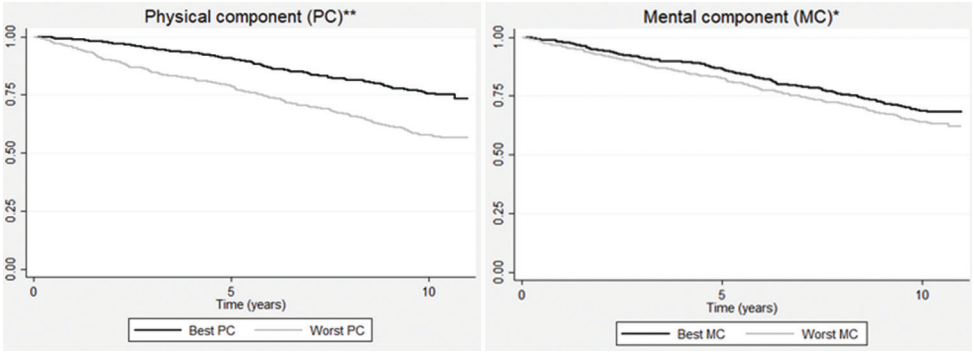

Figure 4. Survival analysis of the Health Care Survey of the Municipality of Campinas, São Paulo, Brazil Cohort elders (60 years and older) with better and worse Health-Related Quality of Life based on the 36-item Short Form Health Survey physical and mental components (2008 – 2018). Note: *$p < 0.05$, **$p < 0.01$
Abbreviations: MC: Mental component; PC: Physical component.

5.15 TLS), and mental health (5.64 THS vs. 5.04 TLS). In PC, 50% of deaths in THS occurred at 5.81 years, while in TLS, this occurred at 5.04 years. In MC, the corresponding times were 5.59 years for THS and 5.11 years for TLS.

Table 2 illustrates the crude analysis, indicating that the risk of death in individuals with lower physical functioning was over twice as high (HR = 2.35; 95% CI 1.79 – 3.09) compared to those with higher scores. Similarly, individuals with greater impairment in role-physical exhibited nearly double the risk (HR = 1.92; 95% CI 1.50 – 2.45). Notably, bodily pain did not demonstrate a significant association with mortality. After adjustments, the risk of all-cause mortality was found to be 74% higher in older adults with lower scores in physical functioning and 42% higher in those with lower scores in role-physical, relative to the reference category of THS. In addition, impairments in role-emotional, along with lower scores in mental health and general health domains increased the risk of mortality by approximately 36% when compared to THS. The highest risk of death (HR = 1.28) was observed in the group exhibiting greater impairment in social functioning compared to the reference category. Importantly, a low score in PC significantly predicted all-cause mortality over 10 years, increasing the probability of death by 47% relative to THS group. In contrast, MC did not show a significant association with mortality risk.

Stratified analyses by sex revealed similar associations between HRQoL and mortality among both men and women. Evaluation of Schoenfeld residuals and the overall proportionality analysis showed satisfactory results (Supplementary File 1 - Figures S1-S7).

4. Discussion

This study utilized a cohort of older adults drawn from a representative sample of Campinas, a city in the state of São Paulo with over 1 million inhabitants. Our findings reveal an inverse dose-response relationship between HRQoL and all-cause mortality over a 10-year follow-up period. Specifically, lower PC scores were associated with a higher risk of premature death among the older adult population. Within the SF-36 domains, physical functioning emerged as a robust predictor of mortality, remaining significant even after adjustments. We also observed significant associations with role-physical, self-rated general health status, role-emotional, social functioning, and mental health. These findings corroborate the theoretical perspectives posited by Idler & Benyamini (1997), emphasizing the predictive power of self-reported physical, emotional, and social dimensions of health for future health events.

Our results align with a recent systematic review and meta-analysis (Phyo *et al.*, 2020) that analyzed 47 studies, of which 43 (91.5%) reported that better QoL was linked to a lower risk of mortality in at least one of the evaluated domains. In addition, the strong association between PC and all-cause mortality in our study corroborates findings from this systematic review and other research conducted in developed countries (Haring *et al.*, 2011; Phyo *et al.*, 2021; Ul-Haq *et al.*, 2014). However, the relationship between MC and mortality exhibited variability across studies (Haring *et al.*, 2011; Otero-Rodríguez *et al.*, 2010; Tsai *et al.*, 2007).

In the systematic review and meta-analysis by Phyo *et al.* (2020), of the 33 studies that evaluated the physical dimension of HRQoL, 30 confirmed the association between improved HRQoL and decreased risk of premature mortality. On the other hand, among the 23 studies assessing the mental dimension, only 13 found a significant association with reduced mortality risk.

Moreover, studies in high- and upper-middle-income countries reinforce the conclusions drawn by Phyo *et al.* (2020) (Hart, 2019; Nevarez-Flores *et al.*, 2023). Research

Table 2. Hazard ratios and 95% confidence intervals for 10-year mortality based on the eight domains and two components of the 36-item Short Form Health Survey in older adults with better and worse Health-Related Quality of Life in Campinas, São Paulo (2008 – 2018)

HRQoL (SF-36)	Model 1[a]	Model 2[b]	Model 3[c]
Physical functioning			
Best status	1	1	1
Worst status	2.35 (1.79 – 3.09)	1.80 (1.34 – 2.40)	1.74 (1.30 – 2.34)
Role-physical			
Best status	1	1	1
Worst status	1.92 (1.50 – 2.45)	1.47 (1.12 – 1.92)	1.42 (1.09 – 1.85)
Bodily pain			
Best status	1	1	1
Worst status	1.16 (0.92 – 1.44)	1.03 (0.80 – 1.32)	0.98 (0.76 – 1.26)
General health			
Best status	1	1	1
Worst status	1.51 (1.18 – 1.93)	1.41 (1.10 – 1.79)	1.36 (1.06 – 1.74)
Vitality			
Best status	1	1	1
Worst status	1.29 (1.02 – 1.63)	1.18 (0.92 – 1.51)	1.13 (0.88 – 1.45)
Role-emotional			
Best status	1	1	1
Worst status	1.69 (1.35 – 2.11)	1.38 (1.12 – 1.70)	1.35 (1.10 – 1.65)
Social functioning			
Best status	1	1	1
Worst status	1.66 (1.31 – 2.10)	1.32 (1.04 – 1.68)	1.28 (1.01 – 1.63)
Mental health			
Best status	1	1	1
Worst status	1.35 (1.09 – 1.66)	1.40 (1.09 – 1.82)	1.36 (1.06 – 1.75)
Physical component			
Best status	1	1	1
Worst status	2.04 (1.62 – 2.55)	1.53 (1.20 – 1.95)	1.47 (1.16 – 1.88)
Mental component			
Best status	1	1	1
Worst status	1.22 (0.98 – 1.50)	1.20 (0.96 – 1.50)	1.17 (0.94 – 1.45)

[a]Crude hazard ratios and 95% confidence intervals.
[b]Adjusted by gender, age, income, education, and physical activity.
[c]Adjusted by sex, age, income, education, physical activity, and the number of chronic diseases.
Abbreviations: HRQoL: Health-related quality of life; SF-36: 36-item short-form health survey.

conducted in France (Singh-Manoux *et al.*, 2006), Italy (Cavrini *et al.*, 2012), and North America (Brown *et al.*, 2015; Hart, 2019) consistently demonstrates a correlation between higher levels of HRQoL and reduced mortality risk. This consistency across diverse regions suggests that interventions aimed at improving HRQoL could yield substantial public health benefits on a global scale. Furthermore, the observed discrepancies between the physical and mental dimensions of HRQoL underscore the complexity of these relationships, warranting further investigation to elucidate the underlying mechanisms and inform targeted interventions.

A study in the United States with 2,166 participants aged 65 and older, monitored over 28 months, found that individuals in the lowest quartile of PC scores faced a significantly higher risk of death from all causes compared to those in the highest quartile (HR = 5.99; 95% CI 1.90 – 18.95) (Dorr *et al.*, 2006). A similar trend was observed for MC (HR = 2.30; 95% CI 1.64 – 3.22). A longitudinal study in Taiwan with 4,424 participants aged 65 and older followed for 3 years reported that a 10-point reduction in PC and MC scores was associated with increased risk of mortality (HR = 1.60; 95% CI 1.39 – 1.83 and HR = 1.16; 95% CI 1.01 – 1.34, respectively) (Tsai *et al.*, 2007).

In Germany, a study with 4,259 participants aged 20 – 79, monitored over a mean follow-up of 9.7 years, identified the lowest quartile of PC as an independent predictor of mortality (HR = 1.64; 95% CI 1.19 – 2.27), while MC did not significantly predict premature mortality (HR = 0.97; 95% CI 0.74 – 1.28) (Haring *et al.*, 2011). Similarly, a study in Spain with 2,343 older adults (6-year follow-up) found no association between MC and mortality (Otero-Rodríguez *et al.*, 2010).

Previous research has indicated that the PC score is a more critical measure than the MC score for predicting mortality (Der-Martirosian *et al.*, 2010; Liang *et al.*, 2017). Variability in the association between MC and all-cause mortality may reflect specific sociodemographic or cultural factors, underscoring the need for context-specific analysis (Phyo *et al.*, 2021).

A systematic review conducted in 2020 (Phyo *et al.*, 2020) noted that only five studies employing the SF-36 or SF-20 assessed all domains of the instrument, rather than focusing solely the summary components. These studies identified associations of mortality with general health, bodily pain, vitality, and social functioning. In contrast, our study found no associations with bodily pain or vitality but identified significant relationships with physical functioning, role-physical, role-emotional, mental health, general health, and social functioning. The discrepancies may arise from the predominance of studies (98% of the total) in high- or upper-middle-income countries included in the review. By analyzing the individual domains of SF-36, we have gained insights into which aspects of QoL are most adversely affected by comorbidities in the older population,

providing a more comprehensive understanding than that afforded by summary components alone.

Physical functioning exhibited the strongest association with mortality. A decline in physical functions can stem from various health conditions, potentially explaining the increased risk of premature death. However, our study adjusted for the number of chronic diseases at the beginning of the follow-up, which mitigated this effect. Lower physical functioning at baseline may have contributed to increased sedentary behavior, increased risk of falls, as well as diminished social interactions, autonomy, and independence among older individuals. These combined factors can exacerbate health issues and lead to premature mortality. This association reinforces Evans and Stoddart's (1990) model, highlighting functionality as a critical component of health, influenced by disease, behavioral, and biological aspects.

A prospective cohort study involving 30,043 participants (Shishehbor *et al*., 2006) found that physical functioning accounted for 47% of the relationship between socioeconomic status and mortality. This underscores the importance of analyzing HRQoL as a predictor of mortality in Brazil, where approximately 70% of older individuals had an individual monthly income of <420 United States dollars in 2020 (Brazil, 2020).

In addition, our study identified associations between mortality and social, emotional, and mental health domains. A systematic review conducted in Asia found that strong social support, having a spouse or partner, living with family, maintaining a large social network, frequent contact with family and friends, emotional support, and satisfaction with social connections were linked to fewer depressive symptoms among non-institutionalized older adults (Mohd *et al*., 2019). Furthermore, a cohort study with a 20-year follow-up demonstrated a significant association between social isolation/loneliness and mortality (Beller & Wagner, 2018). Two systematic reviews and meta-analyses in low- and middle-income countries also revealed an association between depression and premature death among older adults (Brandão *et al*., 2019; Wei *et al*., 2019). These findings highlight the importance of considering social and emotional aspects when assessing the health of the elderly population.

In a large cohort study of women who initially reported poor physical and mental health but improved during follow-up, the risk of mortality was similar to that of women whose HRQoL remained consistently good (Kroenke *et al*., 2008). Positive lifestyle changes, particularly increased physical activity, were associated with improvements in both PC and MC scores. Adopting healthier lifestyles and pursuing preventive measures can enhance health, improve QoL, and reduce the risk of premature mortality.

Our results indicate that HRQoL can serve as a significant indicator of future adverse health outcomes, supporting clinical, social, and policy decisions. For instance, in Australia, the SF-12 has been integrated into the routine application of Patient Reported Outcome Measures as a strategic goal for the Australian health system (Williams *et al*., 2016). As an abbreviated version of SF-36, SF-12 assesses health-related QoL across physical and mental health dimensions. Improved prediction of premature death risk among older individuals facilitates better clinical monitoring and targeted interventions aimed at reducing this risk. Reducing the testing costs can alleviate the economic burden linked to health issues, in the context of a rapidly aging population (Phyo *et al*., 2021). These possibilities align with Evans and Stoddart's (1990) model, which transcends traditional healthcare boundaries to incorporate health status and functionality as key elements in understanding and delivering healthcare.

Previous studies conducted across different countries have generally shown that healthy aging does not adversely affect HRQoL, suggesting that it is feasible to enjoy a high QoL and well-being over extended periods (Tourani *et al*., 2018). Maintaining a healthy lifestyle in old age is essential to prevent chronic diseases, improve physical functioning and well-being, as well as support independence, autonomy, and active aging (Lima *et al*., 2011). Understanding which aspects of QoL are most affected by comorbidities in the older population is crucial for developing strategies to minimize these impacts and promote dignified aging with good health and well-being.

A high score in PC indicates minimal physical limitations, high energy levels, and health rated as "excellent." Meanwhile, a high score in MC reflects frequent positive feelings, absence of psychological distress, and no impairment in social activities due to emotional issues, along with health rated as "excellent" (Ware & Gandek, 1998). Therefore, HRQoL serves as a measure of the impact of diseases on individual lives, and lower HRQoL scores indicate impaired well-being and predict all-cause mortality. Consequently, clinical, social, and policy interventions are essential to manage CNCDs.

The strengths of this study include its retrospective cohort design with a representative sample of the older population, along with comprehensive information and variables that enabled adjustments for potential confounders. These findings are unprecedented in Brazil and Latin America concerning various dimensions of health and QoL assessed using a validated and widely employed standardized instrument that serves as a predictor of mortality in older adults. Although this study has limitations, they were minimal and did not compromise the validity of the results.

While HRQoL measurement scales may exhibit a ceiling effect, the response categories of SF-36 version 2 have been expanded to mitigate this issue.

5. Conclusions

This retrospective cohort study, featuring a sample of non-institutionalized older adults, reinforces the evidence that higher HRQoL is associated with a reduced risk of all-cause mortality, particularly in the physical dimension of health. Our findings provide further evidence of the predictive capacity of SF-36 for mortality risk among older adults in low- and middle-income countries. Future research is recommended to explore the mediating and moderating factors influencing the association between HRQoL and mortality. These findings can inform policymakers about the importance of integrating self-assessed QoL measures into routine clinical practice, facilitating early detection of health deterioration and increased mortality risk among older adults. This approach would support targeted interventions to enhance the health and well-being of seniors in society.

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Conflict of interest

The authors declare that they have no competing interests related to the conduct of this research.

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Ethical approval and consent to participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the University of Campinas (Research Ethics Committee of the Faculty of Medical Sciences - UNICAMP) (CAAE 72380223.5.0000.5404 – No. 6.276.539/2023). The ISACamp 2008/09 and ISACamp Cohort projects received approval (certificate numbers: 079/2007 and 1,650,093/2018, respectively). Informed consent was obtained from all participants.

Consent for publication

All participants signed the statement of informed consent, authorizing the use of their data for publication.

Availability of data

The data are available through the following link: https://www.synapse.org/#!Synapse: syn53072108

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RESEARCH ARTICLE

Cultural value orientation and attitudes toward workplace gender equity across generations: Insights from Delhi and National Capital region, India

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Abstract

The present research aims to explore the role of Hofstede's cultural values and conformity in shaping people's attitudes toward workplace gender equity (WGE). Furthermore, it explores the mediating role of conformity between cultural values and WGE using the Hayes Process Macro. Results reveal that both cultural values and conformity significantly predict employees' preference for gender equity, and conformity significantly mediates the relationship between ones' cultural orientation and their attitudes toward gender parity. Furthermore, gender, sector, and generation-based comparisons on the aforementioned variables indicate significant differences. The study has important implications as it proffers a theoretical model that explains the various contextual factors responsible for employees' gender-related attitudes.

Keywords: Cultural value orientation; Workplace gender equity; Conformity; Hayes Process Macro; Mediation

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1. Introduction

The last few decades have witnessed a drastic change in the gender composition of the working population. Gender-based division of labor remained in practice well after the Industrial Revolution, continuing until the 1960s when the second wave of the feminist movement began, resulting in a surge of female workforce (Brunell & Burkett, 2002; Rosenthal, 1973). While this movement influenced European societies to challenge gender-based boundaries, Asian countries were still far from initiating a change toward gender-balanced participation in paid work.

In non-Western societies, including India, the participation of women in the workplace is a relatively recent development (Frayer & Kumar, 2023; Verick & International Labour Organization [ILO], 2014). While the change itself was positive, it came with its own set of challenges. Speaking specifically of India, gender disparities have long been embedded in the local culture, and with women entering the workplace, these disparities extended into organizations as well. However, given the recent transformation in gender roles, there is a shortage of research on gender-related issues in the workplace in non-Western societies. Stark cultural differences limit the generalizability of findings from Western studies to non-Western contexts. In an attempt to fill this existing knowledge gap, the

current research aims to explore the cultural underpinnings of workplace gender equity (WGE) in India.

1.1. Cultural value orientation and gender equity

Culture is known to be an important determinant of gender equity within a given society. As put by Ștefanovici (2009, p. 632), "sexual inequity is rooted within the social structure itself, through the allocation by society of segregated roles for each sex. The very existence of activities and responsibilities maintain an imbalance of power between the sexes." Therefore, culture can be considered a significant predictor of gender equity. Several frameworks have been proposed to elucidate cultural values, with Hofstede's model (1980) standing out as one of the most prominent. Hofstede's model includes six distinct cultural value orientations: individualism/collectivism, power distance, uncertainty avoidance, masculinity/femininity, long-term versus short-term orientation, and indulgence/restraint. Individualism/collectivism, the two dichotomies exist across a continuum, where individualism is defined as a "loosely-knit social framework," while collectivism refers to a "tightly-knit social framework." Power distance is the extent to which people are unconcerned with functional and/or structural inequities within society. Uncertainty avoidance refers to how individuals cope with uncertainties about the future and their tolerance levels for such uncertainties. Within the dimension of masculinity/femininity, masculine values include attributes such as competitiveness, achievement, success, and heroism, while a feminine orientation embodies values such as cooperation, care, and concern for others. Furthermore, a long-term orientation includes a more future-oriented perspective alongside a pragmatic approach that emphasizes belief in future planning, saving, and fostering social change. In contrast, a short-term orientation places greater significance on the past and present, focusing on normative approaches and the pursuit of quick results. The final dimension pertains to indulgence/restrain. Indulgence refers to the degree to which a culture allows for the free gratification of basic needs and desires, embracing the enjoyment of life and freedom from various restrictions. In contrast, restraint characterizes the extent to which a culture or society attempts to limit basic needs and desires, imposing restrictions that curtail the fulfillment of these desires.

1.2. Cultural value orientation and conformity

While these values are shared within cultures, the individual proclivities to internalize them depend on conformity. Conformity represents a form of social influence by which we transmit and preserve the values of our culture, fostering a network of shared cultural norms and common values. In simpler terms, conformity refers to the potential change in individuals' overt behavior in situations involving others, contingent on the degree to which individuals succumb to societal or group pressures. Consequently, conformity holds the potential to significantly influence people's behavior and attitudes, including their attitudes toward women's participation in paid work and gender equity as a whole. In the present study, we aim to explore whether the tendency to conform significantly mediates the relationship between cultural values and individuals' attitudes toward WGE.

2. Literature review

Research evidence suggests that the cultural values identified by Hofstede (1980) are predictive of people's attitudes toward gender equity (Bertsch & Warner-Søderholm, 2012; Holmberg & Akerblom, 1998; Malaquias *et al.*, 2022; Plueddemann, 2009). In the present study, attitudes toward WGE are operationally defined in terms of two key factors: employment skepticism and traditional roles preference. Employment skepticism refers to the degree of skepticism regarding women's ability to work outside of home, while traditional roles preference is the extent to which individuals believe that women are naturally suited for household chores. Gender equity, in this context, is defined as the absence of cognitive biases and skepticism toward women and their capacity to engage in work outside the home.

The existing body of research demonstrates that cultures characterized by greater individualism (Davis & Williamson, 2019; Dohi & Fooladi, 2008; Malaquias *et al.*, 2022) and lower power distance (Lee *et al.*, 2020; Malaquias *et al.*, 2022; Plueddemann, 2009) tend to exhibit higher levels of gender egalitarianism. However, the findings concerning uncertainty avoidance, future orientation, and masculinity/femininity have yielded inconclusive results. With regard to uncertainty avoidance, some studies reveal that it can coexist with (Holmberg & Akerblom, 1998) or even promote (Malaquias *et al.*, 2022) gender equality, while others equate higher degrees of uncertainty avoidance with a greater preference for traditional gender norms that discourage gender parity (Bertsch & Warner-Søderholm, 2012; Lee *et al.*, 2020; Terzi *et al.*, 2022). Similarly, with respect to future orientation, certain studies have found a positive association with greater gender egalitarianism (Bertsch & Warner-Søderholm, 2012), while others have demonstrated the opposite (Lee *et al.*, 2020). Likewise, some studies have identified high femininity scores as positively correlated with gender equity (Carrasco *et al.*, 2012; Lee *et al.*, 2020; Milner & Collins, 2000), while other studies have not discovered a significant association between masculinity and gender egalitarianism (Terzi *et al.*, 2022).

The extent to which individuals embrace cultural values, and, subsequently, their appraisal of gender equality, is contingent upon the society's inclination for conformity (Markus & Kitayama, 1991). Research

indicates that collectivistic cultures exhibit a high emphasis on conformity (Kim & Markus, 1999). Some scholars even consider conformity as a behavioral manifestation of collectivistic values (Fincher *et al.*, 2008). Due to the close alliance between conformity and collectivism, conformist cultures are arguably less gender egalitarian (Long, 2011).

Furthermore, as previously noted, people's propensity to conform to societal norms varies across cultures, and the interaction between culture and conformity determines their attitudes toward non-conventional gender roles. This relationship is depicted in Figure 1.

In alignment with these findings, we propose the following hypothesis: (H1) cultural values and conformity tendencies would significantly predict attitudes toward WGE, and conformity tendencies would significantly mediate the relationship between cultural value orientation and WGE.

However, the preference for conformity and cultural values is not fixed; it tends to evolve over generations (Twenge, 2010). A generation is defined as a group of people born in the same general time span who share some life experiences, including significant historical events, pastimes, heroes, and early work experiences (Weston, 2001; Blauth *et al.*, 2011). It is imperative to emphasize that the classification of generations is deeply rooted in their shared life experiences, common values, and sociocultural, political, and economic context. For this very reason, the classification of Indian generations differs from the Western taxonomies. In the West, five generational cohorts have been recognized, according to Steelcase Workspace Futures (2011b). These include Traditionalists (born between 1922 and 1944), Baby Boomers (born between 1945 and 1964), Generation X (born between 1965 and 1979), and Generation Y or Millennials (born between 1980 and 2000). In India, Steelcase Workspace Futures (2011a) has identified four cohorts, namely, Freedom Fighters (born between 1900 and 1946), Traditionals (born between 1947 and 1964), Generation X (same age cohort as Western Gen X), and Generation Y (same age cohort as Western Gen Y).

Research indicates that Millennials exhibit lower levels of collectivism (Sverko, 1999; Teck & Hennessy, 2011)

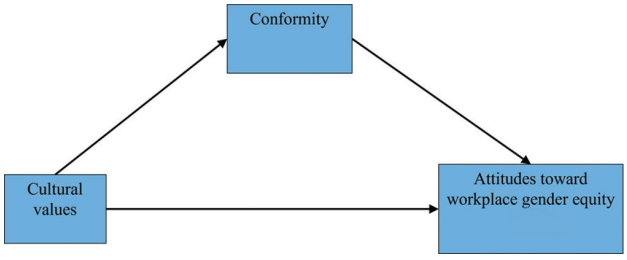

Figure 1. Proposed model depicting the relationship among cultural values, conformity, and workplace gender equity

and conformity (Tolbize, 2008) in comparison to their immediate predecessors. With respect to power distance, generational differences are not conclusive. Some studies suggest that Gen Y requires strong supervision and prefers authoritative leadership, reflecting a higher power distance orientation (Twenge, 2010), while others reveal a strong tendency among this generational cohort to question authority, indicating a lower power distance inclination (Teck & Hennessy, 2011). Moreover, with increased diversity, Gen Yers can be expected to display greater comfort in handling ambiguous situations and tend to score lower on uncertainty avoidance in comparison to previous generations (Clarey, 2009).

With respect to generational variations in conformity tendencies, there is a paucity of evidence. Nevertheless, by considering research findings that indicate a constant decrease in collectivism in India (House *et al.*, 2004) and following the premise that collectivism is positively correlated with conformity (Triandis, 1994), we can tentatively infer that conformity has substantially decreased over generations in the Indian cultural context. Consequently, it can be anticipated that Generation Y is the least conforming among all generations in India.

Regarding gender parity, Parry (2014) has asserted that Gen Y has grown up in a more gender-egalitarian atmosphere, making them more supportive of gender equality. Recent global trends have also shown a narrowing of the gender pay gap across three generations (Pew Research Center, 2013). This observation clearly signifies a substantial decrease in workplace gender inequalities, explaining why younger female employees perceive greater parity at work and view discrimination as a *concept of the past* (Eisner & Harvey, 2009).

These research findings suggest that cultural values, ideologies, and preferences change across generations. Consequently, each generational cohort can be expected to possess a different set of values and cultural orientations, even within the same cultural milieu. In light of these findings, the present study aims to investigate differences in cultural values, conformity tendencies, and preferences for WGE across three generations: traditionals, Gen Xers, and Gen Yers in India. Informed by the aforementioned research findings, we propose the following hypotheses: (H2) There would be significant differences between Traditionals, Gen X, and Gen Y employees on the dimensions of cultural values, conformity tendencies, and WGE.

In addition to generational differences, gender-based variations also exist with respect to individuals' cultural orientations (Kashima *et al.* 1995), preferences for conformity (Griskevicius, 2006), and acceptance of egalitarian gender norms (Ellis *et al.*, 2008). The

interactional effect of generation and gender has also been explored in relation to these aspects, revealing that Millennial women tend to be more future-oriented and make career choices that prioritize work-life balance, while Millennial men tend to take more risks and focus on individual growth and success (Jobvite, 2017). Similarly, more female Millennials aspire to hold positions of power than their male counterparts (Pew Research Center, 2013).

Several studies have demonstrated that women tend to outscore men on collectivism (Hofstede, 2001; Venkatraman & Reddy, 2012) and long-term orientation (Nurmi *et al.*, 1994). In contrast, the pattern is reversed when it comes to power distance (Désert & Leyens, 2006). Regarding uncertainty avoidance, no significant gender differences have been found so far (Stedham & Yamamura, 2002; Budin & Wafa, 2013). Moreover, gender differences on the masculinity/femininity index are inconsistent, with some studies showing an absence of any gender differences (Stedham & Yamamura, 2002), while others suggest that men outscore women (Budin & Wafa, 2013).

With respect to gender differences in conformity tendencies, research has consistently found that women tend to exhibit greater conformity than their male counterparts (Eagly & Chrvala, 1986; Bond & Smith, 1996). Likewise, women tend to hold more positive attitudes toward gender equality (Prasad & Baron, 1996) and also have greater awareness of women's issues, such as domestic violence, than men do (Alazmy *et al.*, 2011). Guided by these research findings, we hypothesized that: (H3) There would be significant differences between male and female employees on the dimensions of cultural values, conformity tendencies, and WGE.

Since organizations served as the context for this research, it was essential to consider organizational characteristics. Therefore, we also explored sector-based differences with respect to the variables of interest. The previous studies offer evidence of sectoral differences in cultural values (Venkatraman & Reddy, 2012), indicating that public sector employees tend to be more collectivistic (Badarch, 2013), while private sector employees are more comfortable in situations involving uncertainty (Granrose, 1997). With regard to sector differences in power distance, although no empirical evidence has been found, power distance tends to be higher in organizations where power is centralized (Investopedia, n.d.). Consequently, it can be expected that public sector employees would score higher on power distance due to the bureaucratic structure and unequal distribution of power in such organizations (Andrews *et al.*, 2009). Sector differences in long-term orientation are not consistent, as some studies suggest that public sector employees are more long-term oriented (Pimpa, 2012), while others suggest otherwise (Mathur *et al.*, 1996). In contrast, private sector employees, being more achievement-oriented and competitive, tend to score higher on the masculinity index (Haussman & Sauer, 2007; Karl & Sutton, 1998) than their public sector counterparts. However, no empirical evidence could be found regarding sector-based differences in conformity tendencies. Nevertheless, given that collectivism has been found to be strongly and positively related to conformity (Kim, 2005), one can expect that public sector employees might be more conforming due to their collectivistic orientation (Badarch, 2013).

Furthermore, sector differences have also been observed in people's preference for gender equity. The World Development Report (2012) highlights that public sector employees generally hold more positive attitudes toward WGE than their counterparts in the private sector. However, interestingly, in India, the pattern appears to be contrary to the aforementioned finding. Women's inclusion rate on the boards of companies has been found to be relatively better in private sector organizations (Zehra & Sarim, 2017). Therefore, we propose that: (H4) there would be a significant difference between public and private sector employees on the dimensions of cultural values, conformity tendencies, and WGE.

3. Methods

3.1. Participants

The participants for the present investigation consisted of 300 employees within the age group of 20 – 60 years, each of whom possessed a minimum of 1 year of experience working in IT companies, whether in the public or private sectors, located within the Delhi National Capital Region (Delhi-NCR). The selection of participants was carried out using a purposive sampling technique. An unequal proportion of participants were drawn from three generational cohorts, further bifurcated on the basis of gender and sector (Figure 2). During the data collection

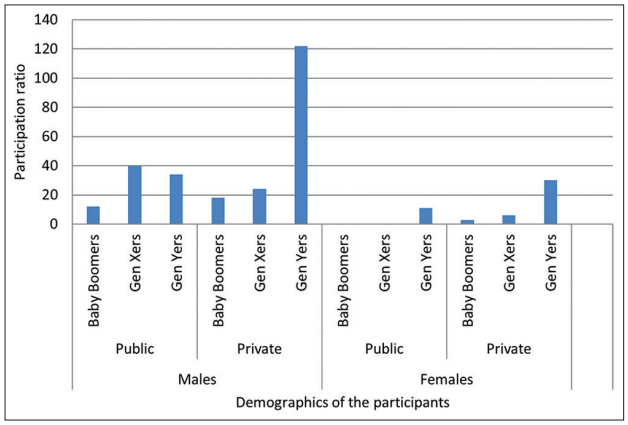

Figure 2. Group-wise representation of participants

phase (March – December 2014), participants from the Traditionals, Gen X, and Gen Y cohorts fell within the age ranges of 50 – 60 years, 35 – 49 years, and 20 – 34 years, respectively. The participants exclusively consisted of permanent employees and were derived from a total of 13 companies, with four operating within the public sector and nine within the private sector.

3.2. Design

The present study employs a 2 × 2 × 3 factorial design to draw comparisons across gender, sectors, and generational cohorts.

3.3. Psychometric tools

The psychometric tools utilized in this study are detailed as follows:

a) Cultural Value Scale (CVSCALE): developed by Yoo *et al.* (2011), CVSCALE was designed to assess employees' cultural values. This instrument measures five of the six core cultural values identified by Hofstede, including Individualism/Collectivism, Low/High Power Distance, Low/High Uncertainty Avoidance, Masculinity/Femininity, and Long/Short-Term Orientation. It comprises 26 items rated on a 5-point scale. The CVSCALE has exhibited satisfactory reliability (Paul *et al.*, 2006) and validity (Patterson *et al.*, 2006).

b) Generalized Conformity Tendency Test (GCTT): to assess employees' conformity tendency, the GCTT developed by Rao (1968) was used. This 14-item situational test yields higher scores for individuals displaying a high inclination toward conformity. The split-half reliability for this tool is reported to be 0.50 (Rao, 1968).

c) Multidimensional Aversion to Women Who Work Scale (MAWWWS): the MAWWWS, developed by Valentine (2001), was employed to assess employees' attitudes toward WGE. This 10-item measure assesses two dimensions: Employment skepticism and traditional roles preference, with items rated on a 4-point scale. Higher scores on this instrument indicate a stronger aversion to gender equity. The tool exhibits an alpha reliability of 0.88 and demonstrates sufficient Criterion and Convergent Validity (Valentine, 2001).

All of the employed tools underwent rigorous standardization and validation procedures. Reflective tools (CVSCALE and MAWWWS) were subjected to tests for convergent and divergent validity (Appendices I and II), while the GCTT, which is a formative tool, was standardized using indicators of both relative and absolute contribution (Appendix III).

3.3.1. Validation of psychometric tools on the study subjects

To validate the psychometric tools on the participants, Confirmatory Factor Analysis was conducted using SmartPLS (version 2.0). In the first round of analysis, it was discovered that the CVSCALE is a first-order formative-second-order reflective construct (Thien *et al.*, 2013), while MAWWWS, with composite scores, is a reflective measure (Valentine, 2001). The GCTT was found to be a formative measure due to its situational and non-interchangeable items (Bledow & Frese, 2009). Subsequently, the outer model was created and tested based on these revelations. Following the recommendations of Hair *et al.*'s (2014) recommendations, eight items (item number 4: masculinity; item number 2: power distance; item numbers 2 and 5: uncertainty avoidance; item numbers 1, 2, 3, and 4: long-term orientation vs short-term orientation) with factor loadings < 0.6 were removed from the CVSCALE, resulting in a refined CVSCALE with a total of 18 items that indicated satisfactory validity on the participants. All items of the MAWWWS were retained, as they exhibited satisfactory levels of individual and composite reliability. The average variance extracted values confirmed the convergent validity of the two tools, and discriminant validity was established using Cross-loadings and Fornell-Larker criteria. Finally, GCTT was validated using measures of collinearity, such as tolerance and Variance Inflation Factor (VIF) values, as well as outer weights and outer loadings.

3.4. Procedure

The investigator obtained permission from the HR personnel of various IT companies in Delhi-NCR for the purpose of data collection. Individuals who met the study's specific criteria were purposively selected for inclusion. Before data collection, all selected participants were provided with a comprehensive briefing regarding the study's objectives, and any questions or concerns were addressed to ensure clarity. After being given all the necessary instructions, participants were requested to complete the questionnaire battery. In addition, a substantial portion of the data was collected through online surveys using Google Forms. Following the data collection phase, the collected data underwent statistical analysis using the SPSS software.

3.5. Statistical analysis

The normality of the data and homogeneity of variance were assessed using the Kolmogorov–Smirnov test and Levene's test of equality of variance, respectively. Moreover, mediation analysis was performed using Hayes Process Macro (Model 4) to evaluate the direct and indirect effects of cultural values on attitudes toward WGE. Comparative analyses based on sector, generation, and gender were conducted

using mean-comparison techniques, complemented by descriptive statistics. *Post hoc* analysis was applied for intragroup comparisons, wherever applicable.

4. Results

As depicted in Figure 2, the distribution of participants across the three groups is notably imbalanced, which can pose a potential challenge to the robustness of statistical analyses. Furthermore, the Kolmogorov–Smirnov test revealed a departure from the normal distribution in the data, while the non-parametric Leven's test of equality of variance (Nordstokke & Zumbo, 2010) indicated that the variance across different groups was not homogeneous. Therefore, Welch's *t* and *F* tests, which are well-suited for non-normally distributed data with unequal group sizes and heterogeneous variance, were carried out for mean comparisons. Moreover, adjusted omega square (Adj. ω^2), as a measure of effect size, was calculated, and the Games-Howell test was employed for post-hoc analysis. Effect size was computed using the formula by Olejnik and Algina (2000):

$$Adj\grave{u}^{\,2} = \frac{df_{(bet)}\left(F-1\right)}{df_{(bet)}\left(F-1\right)+N_T} \quad \text{(I)}$$

In addition, Hayes Process Macro was employed to explore regression and mediation effects.

As represented in Table 1, it was found that collectivism emerged as a significant predictor of conformity (Path coefficient = 0.0640, $p < 0.05$), but not gender inequity (Path coefficient = 0.0060). On the other hand, conformity demonstrated a significant predictive association with gender inequity (Path coefficient = 0.4920, $p < 0.01$). Moreover, the 95% confidence interval for the indirect effect of collectivism on gender inequity (0.0315), which ranges from 0.0054 to 0.0788, does not include zero. This indicates that the indirect effect is statistically significant. This implies that conformity significantly mediates the relationship between collectivism and gender inequity.

Table 1 provides additional insights into the relationships between various cultural values and gender equity. It is evident that masculinity significantly predicts gender inequity (Path coefficient = 1.0094, $p < 0.01$) but does not predict conformity (Path coefficient = 0.0774). On the other hand, conformity demonstrates a significant predictive association with gender inequity (Path coefficient = 0.3640, $p < 0.01$). Importantly, with regard to the mediation effect, conformity emerges as a significant intermediary variable between masculinity and gender inequity (Indirect effect = 0.0282, 95% CI = 0.0001 – 0.0832). This positive predictive relationship between masculinity and gender inequity is consistent with the previous research evidence, as demonstrated by Milner & Collins (2000), who found feminine cultures to be more gender-egalitarian. Along the same line, Hofstede (2003) also noted that, as compared to masculine cultures, women's participation in the workforce is greater in feminine cultures.

Moreover, power distance is found to be a significant predictor of both conformity (Path coefficient = 0.1950,

Table 1. The mediation effect of conformity in the relationship between different cultural values and the absence of gender equity

Predictor	Dependent variable	Path coefficient	*p*-value	Indirect effect of X on Y	95% confidence intervals	
					Lower limit	Upper limit
Collectivism (X)	Conformity (M)	0.0640	0.0347*	0.0315	0.0054	0.0788
Collectivism (X)	Gender inequity (Y)	0.0060	0.9344			
Conformity	Gender inequity	0.4920	0.0005**			
Masculinity (X)	Conformity (M)	0.0774	0.0885	0.0282	0.0001	0.0832
Masculinity (X)	Gender inequity (Y)	1.0094	0.0000**			
Conformity	Gender inequity	0.3640	0.0021**			
Power distance (X)	Conformity (M)	0.1950	0.0000**	0.0643	0.0080	0.1386
Power distance (X)	Gender inequity (Y)	0.3870	0.0001**			
Conformity	Gender inequity	0.3300	0.0194*			
Long-term orientation (X)	Conformity (M)	0.3089	0.0000**	0.1161	0.0263	0.2574
Long-term orientation (X)	Gender inequity (Y)	0.6371	0.0006**			
Conformity	Gender inequity	0.3759	0.0074**			
Uncertainty avoidance (X)	Conformity (M)	−0.0489	0.4596	−0.0234	−0.1052	0.0390
Uncertainty avoidance (X)	Gender inequity (Y)	−0.3372	0.0322*			
Conformity	Gender inequity	0.4779	0.0006**			

Notes: *Significance at 0.05 level; **Significance at 0.01 level.

$p < 0.01$) and gender inequity (Path coefficient = 0.3870, $p < 0.01$). Furthermore, conformity not only significantly predicts gender inequity (Path coefficient = 0.3300, $p < 0.05$) but also serves as a mediator in the relationship between power distance and gender inequity (Indirect effect = 0.0643, 95% CI = 0.0080 – 0.1386). The observed relationship between higher power distance and greater gender inequality is consistent with previous research outcomes (Plueddemann, 2009). The underlying reason is that cultures characterized by high Power Distance tend to legitimize unequal power distribution between the two sexes.

The findings of this study suggest that long-term orientation significantly predicts both conformity (Path coefficient = 0.3089, $p < 0.01$) and gender inequity (Path coefficient = 0.6371, $p < 0.01$). Furthermore, conformity has been revealed as a significant predictor of gender inequity (Path coefficient = 0.3759, $p < 0.01$). Moreover, the mediating effect (Indirect effect = 0.1161, 95% CI = 0.0263 – 0.2574) reveals that conformity significantly mediates the relationship between long-term orientation and gender inequity.

The significant predictive relationship between long-term orientation and gender inequity, as observed in this study, contradicts previous research that suggests cultures with a futuristic orientation tend to be more egalitarian (Bertsch & Warner-Søderholm, 2012). However, the present study aligns with the assertion made by Ahn & Cunningham (2017), indicating that long-term oriented cultures may exhibit lower gender parity due to the core characteristics of this cultural value being rooted in Confucius' teachings (Hofstede & Bond, 1988), which place greater emphasis on social status. Consequently, this may "reflect an endorsement of the status quo (i.e., power imbalance), and thereby reify men's dominant roles in society and in organizations" (Ahn & Cunningham, 2017, p. 863).

Both uncertainty avoidance (Path coefficient = −0.3372, $p < 0.05$) and conformity (Path coefficient = 0.4779, $p < 0.01$) significantly predict gender inequity. However, conformity does not mediate the relationship between uncertainty avoidance and gender inequity significantly (Indirect effect = −0.0234, 95% CI = −0.1052 – 0.0390). The finding that uncertainty avoidance has a negative predictive association with gender inequity implies that high uncertainty avoidance leads to low gender inequity, aligning with the existing literature (Keating & Martin, 2007; Amin & Sogra, 2014). Holmberg & Akerblom (1998) have suggested a positive relationship between gender equality and uncertainty avoidance, as careful planning to avoid future ambiguities can enhance gender egalitarianism. Overall, four out of five cultural dimensions significantly predict attitudes toward gender equity.

Similarly, conformity is a significant predictor of gender inequity, consistent with the previous empirical findings suggesting that cultures encouraging traditional gender role attitudes and exerting pressure to conform tend to exhibit greater gender disparity (Smith & Bond, 1999). Long (2011) has explained gender inequality in terms of contextual factors, arguing that individuals within specific cultural contexts experience strong pressure to conform to certain gender roles, often resulting in gender disparity. To contextualize this finding, one might argue that in Indian society, which operates on patriarchal norms strengthening male hegemony (Chhokar *et al.*, 2007), high normative conformity predicts greater gender inequality.

Furthermore, this study's findings also suggest that, with the exception of the cultural value of uncertainty avoidance, conformity significantly mediates the relationship between the remaining four cultural values and gender inequity. This outcome is consistent with previous research findings (Smith & Bond, 1999; Long, 2011), which have confirmed that conformity mediates the relationship between cultural values and gender equality. It implies that a society's cultural values and the societal pressure to abide by these norms cumulatively determine the degree of preference given to gender equity within that cultural context. Our finding confirms that despite its detrimental impact on social structure, gender inequity remains highly prevalent in cultures where it is socially acceptable and in line with existing sociocultural norms (Demographic and Health Survey, 2007). India, being a highly patriarchal society that adheres to conventional gender roles (Chhokar *et al.*, 2007), exhibits lower gender equity due to the readiness of individuals to conform to these traditional gender norms. In this context, gender inequity is often perceived as "normal" because of its historical presence in society. Therefore, the findings partially support H1, which posits that "cultural values and conformity tendency would significantly predict attitudes toward WGE, and conformity tendency would significantly mediate the relationship between cultural value orientation and WGE."

As observed in Table 2, the three generations exhibit significant differences in their acceptance of the cultural value of power distance (Welch's $F_{(2,76.7)} = 3.547$, $p < 0.05$, Adj. $\omega^2 = 0.01$). The results indicate that Gen Xers (M = 9.9) are the most likely to accept unequal power dissemination, followed by Gen Yers (M = 8.8), while Traditionals remain the least accepting of centralized power (M = 8.1). Furthermore, as shown in Table 3, *post hoc* comparisons suggest that Traditionals and Gen Xers significantly differ on this dimension, with a mean difference of 1.8 ($p < 0.05$).

While there is no empirical support for the current finding due to the dearth of research in this area, one

Table 2. Mean values, standard deviation, Welch's *F* statistics, and effect size (adjusted ω^2) for generation-based mean comparisons (N=300)

Variables	Generation	n	Mean values	Standard deviation	Welch's *F* test				Adjusted ω^2
					Statistic	df1	df2	*p*-value	
Conformity	Traditionals	33	2.6	2.1	5.252	2	82.8	0.007**	0.02
	Gen X	70	3.9	1.9					
	Gen Y	197	3.4	2.3					
Power distance	Traditionals	33	8.1	2.9	3.547	2	76.7	0.034*	0.01
	Gen X	70	9.9	3.9					
	Gen Y	197	8.8	3.0					
Uncertainty avoidance	Traditionals	33	12.2	1.8	2.846	2	76.4	0.064	N.S.
	Gen X	70	12.6	2.3					
	Gen Y	197	11.8	1.8					
Collectivism	Traditionals	33	19.8	4.4	5.375	2	76.6	0.007**	0.02
	Gen X	70	22.6	4.4					
	Gen Y	197	20.9	4.1					
Masculinity	Traditionals	33	6.5	2.9	6.827	2	79.2	0.002**	0.03
	Gen X	70	6.1	2.6					
	Gen Y	197	7.4	2.8					
Long-term orientation	Traditionals	33	6.4	1.6	3.789	2	81.4	0.027*	0.01
	Gen X	70	7.3	1.5					
	Gen Y	197	7.1	1.7					
Employment skepticism	Traditionals	33	8.5	2.9	6.085	2	82.6	0.003**	0.03
	Gen X	70	8.6	2.2					
	Gen Y	197	9.7	3.1					
Traditional gender roles	Traditionals	33	10.2	2.5	0.031	2	86.7	0.969	N.S.
	Gen X	70	10.1	2.5					
	Gen Y	197	10.2	3.2					

Notes: *Significance at 0.05 level; **Significance at 0.01 level; N.S.: Not significant.

plausible explanation could be that Traditionals, having been born right after Indian's independence, grew up in a culture that glorified equity and condemned unequal power dissemination. Moreover, they witnessed the dawn of democratization in India, which may explain their inclination toward parity. Furthermore, the higher score on power distance for Gen Xers might result from their presence in powerful positions. According to Hofstede, power distance is "the extent to which the less powerful members of a society expect and accept that power is distributed unequally" (Hofstede, 1980, p. 45). In a culture where subordinates expect the leader to have more power, individuals in leadership positions have to exert authority, possibly explaining why Gen X population, which currently occupies top leadership positions, demonstrates a greater preference for power distance.

Furthermore, scores on collectivism vary significantly across the three generational cohorts (Welch's $F_{(2,76.6)} = 5.375$, $p < 0.01$, Adj. $\omega^2 = 0.02$). Traditionals (M = 19.8) appear to be the least collectivistic, followed by Gen Yers (M = 20.9) who exhibit a slightly greater preference for collectivism, while Gen Xers have the highest score (M = 22.6) on this dimension. This implies that Gen Xers are the most group-oriented generational cohort. *Post hoc* comparisons revealed that Gen Xers scored significantly higher than Traditionals (Mean difference = 2.75, $p < 0.05$) as well as Gen Yers (Mean difference = 1.65, $p < 0.05$) on the measure of collectivism.

These findings are consistent with the research of Putney & Bengtson (2004), who found that Gen X is more collectivistic than previous generations. In addition, Putney *et al.* (2007) described the increase in collectivistic and humanistic values among Gen X people as a consequence of egalitarian family structure. Moreover, Robbins *et al.* (2010) argued that Gen X's inclination toward collectivism can be attributed to their current position in the organizational hierarchy. Gen X employees have mostly

Table 3. Results of Games-Howell *post hoc* multiple comparison test for the three generational cohorts

Dependent variables	Generation	Generation	Mean difference	*p*-value
Conformity	Traditionals	Gen X	1.37	0.006**
		Gen Y	0.80	0.124
	Gen X	Gen Y	0.57	0.113
Power distance	Traditionals	Gen X	1.80	0.031*
		Gen Y	0.71	0.426
	Gen X	Gen Y	1.09	0.090
Collectivism	Traditionals	Gen X	2.75	0.013*
		Gen Y	1.09	0.390
	Gen X	Gen Y	1.65	0.019*
Masculinity	Traditionals	Gen X	0.46	0.724
		Gen Y	0.87	0.265
	Gen X	Gen Y	1.33	0.001**
Long-term orientation	Traditionals	Gen X	0.94	0.021*
		Gen Y	0.70	0.077
	Gen X	Gen Y	0.24	0.522
Employment skepticism	Traditionals	Gen X	0.09	0.984
		Gen Y	1.2	0.003**
	Gen X	Gen Y	1.1	0.004**

Notes: *Significance at 0.05 level; **Significance at 0.01 level.

reached top management positions, where they have an obligation to maintain and monitor group cohesiveness and interpersonal relations at the organizational level, which is why they turn out to be more group-oriented than other generations.

Furthermore, Traditionals' low score on collectivism indicates that this cohort is the most individualistic generation. This is consistent with Twenge & Campbell's (2009) explanation, who initially proposed that Baby Boomers were the first generational cohort to develop individualistic traits. While this argument was originally applied to Western Baby Boomers, our findings indicate that Indian Traditionals also exhibit similar traits. This highly individualistic orientation of Indian Traditionals can be described in the light of socio-historical context. They were the first generation to witness an independent India after years of colonization, and this significant nation-level transition was manifested at the individual level as well. Consequently, "independence" at the individual level began to gain social acceptance, giving impetus to the rise of individualistic values.

In addition, our investigation reveals a decline in collectivism among the Gen Y population, supported by Teck & Hennessy's (2011) findings, which demonstrate that Millennials have a strong inclination toward uniqueness and aspire to be independent and different from others. Thus, they tend to score high on individualism. This trend is consistent with the findings offered by Sverko (1999), who discovered that early and late Gen Xers differed significantly in terms of individualistic values, with late Gen Xers displaying stronger individualistic values than early Gen Xers. This demonstrates that collectivism decreased over time, and by the time Gen Y entered the workforce, individualism had already become predominant.

Regarding the dimensions of masculinity (Welch's $F_{(2,79.2)} = 6.827$, $p < 0.01$, Adj. $\omega^2 = 0.03$), Gen Yers (M = 7.4) have outscored both Traditionals (M = 6.5) and Gen Xers (M = 6.1), indicating that Gen Y employees are more likely to believe that women are inferior to men when it comes to their ability to work as professionals. Post-hoc comparisons further reveal significant differences, particularly between Gen Xers and Gen Yers, in terms of masculinity scores (Mean difference = 1.33, $p < 0.01$).

Although no empirical data could be found to support our findings, one plausible explanation could be that Gen Yers score highest on the measure of masculinity because they are more open, straightforward, and vocal about their opinions (Parment, 2011), unlike previous generations. Especially in the Indian context where gender roles are deeply ingrained, we can expect all three generations to hold similar attitudes toward working women, but Gen Yers express them more openly than other generations.

Finally, significant generational differences were observed regarding long-term orientation (Welch's $F_{(2,81.4)} = 3.789$, $p < 0.05$, Adj. $\omega^2 = 0.01$). Gen X (M = 7.3) emerged as the most future-oriented, while Traditionals (M = 6.4) were identified as the least futuristic cohort (Mean difference = 0.94, $p < 0.05$). While there is a gap in the existing body of knowledge regarding generational variations in long-term orientation, we can explain this finding on theoretical grounds. Gen Xers are currently at a stage where they are required to think and plan for future, while Traditionals are closer to Erikson's (1959) *Ego Integrity* stage and, hence, are more consumed by their past than the future.

However, in terms of uncertainty avoidance, no significant generational differences were observed (Welch's $F_{(2,76.4)} = 2.846$, not significant [N.S.]), which contradicts existing research evidence (Clarey, 2009). One plausible explanation for the absence of generation-related variations in uncertainty avoidance is that all these generations have witnessed ambivalence and volatility in various forms. Ranging from drastic technological changes to unexpected economic downturns, individuals across these generations have collectively experienced uncertainty and have come to perceive it as being inevitable.

With reference to conformity, the three generational cohorts in this study exhibited significant differences (Welch's $F_{(2,82.8)} = 0.252$, $p < 0.01$, Adj. $\omega^2 = 0.02$). Mean values reveal that Gen Xers (M = 3.9) scored highest on conformity tendency, followed by Gen Y employees (M = 3.4), while Traditionals surprisingly scored the lowest (M = 2.6) on this construct. The effect size, however, is small, indicating that merely 2% of variations in conformity scores can be attributed to generational differences. In addition, *post hoc* comparisons (Table 3) indicate a statistically significant difference between Traditionals and Gen Xers in terms of conformity tendency (Mean difference = 1.37, $p < 0.01$).

These results correspond with the observed generational differences in collectivism. It is empirically established that collectivism is positively associated with the tendency of conformity (Triandis, 1994). Therefore, it is evident that Traditionals exhibit the least conformity, as they scored the lowest on collectivism, while Gen Xers, who scored the highest on collectivism, are the most conforming generation. Furthermore, the lower preference for conformity among Gen Y can be supported by previous research by Tolbize (2008) and Pettigrew (2014), who have described this generation as non-conforming.

Regarding generational differences in gender inequity, we found that the three generations exhibit a statistically significant difference in the dimension of employment skepticism (Welch's $F_{(2,82.6)} = 6.085$, $p < 0.01$, Adj. $\omega^2 = 0.03$). Gen Yers (M = 9.7) are most skeptical about women's participation in the workplace, while Traditionals are the least skeptical (M = 8.5). Post-hoc comparisons revealed that Gen Y has outscored both Traditionals (Mean difference = 1.2, $p < 0.01$) and Gen Xers (Mean difference = 1.1, $p < 0.01$) in this dimension. Nonetheless, the practical significance of this difference is relatively small, as only 3% of score variations can be attributed to generational differences. In contrast, when it comes to the preference for traditional gender roles, there are no generational differences (Welch's $F_{(2,86.7)} = 0.031$, N.S.). The framing effect might explain the presence of generational differences in only one dimension of gender equity.

These findings are inconsistent with previous research findings by Parry (2014), who proposed that Gen Y is characterized by a more gender-egalitarian approach compared to the previous generations. This inconsistency can be explained by Millennials' straightforward and highly vocal attitude (Parment, 2011). Therefore, the findings partially support H2, which states that "There would be significant differences between Traditionals, Gen X, and Gen Y employees on the dimensions of cultural values, conformity tendency, and WGE."

As depicted in Table 4, the two genders do not appear to differ significantly on any of the dimensions of cultural

Table 4. Mean values, standard deviation, Welch's *t* statistics, and effect size (adjusted ω^2) for gender-based mean comparisons (N=300)

Variables	Gender	n	Mean values	Standard deviation	Welch's *t*-test				Adjusted ω^2
					Statistic	df1	df2	p-value	
Conformity	Female	50	2.9	2.1	3.712	1	73.4	0.058	N.S.
	Male	250	3.6	2.3					
Power distance	Female	50	8.6	3.3	0.926	1	69.9	0.339	N.S.
	Male	250	9.1	3.3					
Uncertainty avoidance	Female	50	12.3	1.7	0.548	1	78.6	0.461	N.S.
	Male	250	12.1	2.0					
Collectivism	Female	50	20.6	4.1	1.237	1	73.3	0.270	N.S.
	Male	250	21.3	4.4					
Masculinity	Female	50	6.3	3.1	3.823	1	66.6	0.055	N.S.
	Male	250	7.2	2.8					
Long-term orientation	Female	50	6.9	1.7	0.727	1	71.2	0.397	N.S.
	Male	250	7.1	1.7					
Employment skepticism	Female	50	7.3	1.8	58.900	1	109.1	0.000**	0.16
	Male	250	9.7	2.9					
Traditional gender roles	Female	50	8.2	2.7	31.136	1	72.4	0.000**	0.09
	Male	250	10.6	2.8					

Notes: *Significance at 0.05 level; **Significance at 0.01 level; N.S.: Not significant.

value orientation, including power distance (Welch's $t_{(1,69.9)}$ = 0.926, N.S.), uncertainty avoidance (Welch's $t_{(1,78.6)}$ = 0.548, N.S.), collectivism (Welch's $t_{(1,73.3)}$ = 1.237, N.S.), masculinity (Welch's $t_{(1,66.6)}$ = 3.823, N.S.), and long-term orientation (Welch's $t_{(1,71.2)}$ = 0.727, N.S.).

Our findings contradict existing research evidence that supports the existence of gender differences in these cultural orientations (Venkatraman & Reddy, 2012; Désert & Leyens, 2006). This contrast may be attributed to the fact that most of these studies were conducted in Western societies. Since collectivism (Chhokar *et al.*, 2007), power distance (Matsumoto & Kupperbusch, 2001), and long-term orientation (Hofstede, 1984) are deeply ingrained in our social fabric, individuals tend to align with these values, regardless of gender. Moreover, the absence of gender-based differences in uncertainty avoidance and masculinity is supported by research findings obtained by Stedham & Yamamura (2002) and Budin & Wafa (2013), respectively.

Therefore, on the basis of our current findings, we propose that gender differences are not prominent in cultural value orientation, as these values operate at a broader societal level. These findings also lend support to previous research outcomes suggesting that cultural norms tend to overshadow the sense of individual agency among collectivistic societies (O'Connor & Shimizu, 2002; You *et al.*, 2011).

In contrast to previous research, which demonstrated that women tend to conform more than men (Bond & Smith, 1996), our findings indicate that the two genders do not significantly differ in terms of conformity (Welch's $t_{(1,73.4)}$ = 3.712, N.S.). This could be explained in terms of sociocultural differences, as conformity is positively associated with collectivism (Trommsdorff, 1995), and Indian society, being collectivistic as a whole, naturally promotes conformity. Eagly & Chrvala (1986) have opined that conformity proclivity depends more on situational factors than gender differences. Hence, individuals tend to conform less on topics they are knowledgeable about, irrespective of their gender. Moreover, our results suggest that in the Indian context, conformity is not significantly influenced by gender since it is accepted at the societal level, and all individuals face implicit pressure to conform to existing social norms, irrespective of their gender identity.

In terms of attitudes toward gender equity, our study revealed that men outscored women on both dimensions, indicating less favorable attitudes toward WGE. On the dimension of employment skepticism, scores for both genders showed statistically significant variation (Welch's $t_{(1,109.1)}$ = 58.900, $p < 0.01$). Mean values suggest that males (M = 9.7) exhibited greater skepticism regarding women's ability to work efficiently outside the home compared to females (M = 7.3). In addition, men (M = 10.6) expressed a stronger preference for traditional gender roles than women (M = 8.2). This difference is statistically significant (Welch's $t_{(1,72.4)}$ = 31.136, $p < 0.01$). Furthermore, the effect sizes for these gender differences, as indicated by adjusted omega-squared values, demonstrate their practical significance. Gender accounts for approximately 16% of the variation in employment skepticism (Adj. ω^2 = 0.16) and 9% of the variation in traditional gender roles preference (Adj. ω^2 = 0.09) indicate that gender explains about 16% and 9% of the variation in the two dimensions, respectively.

These results underscore the observation that men exhibit less favorable attitudes toward WGE when compared to women, a phenomenon previously corroborated by Budin & Wafa (2013). In the context of Indian society, these findings are unsurprising, given that our culture continues to predominantly assign roles and responsibilities based on gender. However, what is particularly intriguing is that Indian men hold this viewpoint more firmly, while women tend to believe in the equal capabilities of both genders in all aspects of life. This phenomenon aligns with Ridgeway's (1992) argument that, in general, men tend to perceive women as not "good enough" to compete; however, when a woman attains a competitive position, they exhibit greater apprehension toward her than toward a male competitor. This apprehension might be a potential explanation for why men harbor more reservations about working alongside women. Moreover, men tend to endorse traditional gender roles more strongly, as these norms solidify male supremacy by assigning them greater power and authority (Castro & Hernandez, 2004). Consequently, H3, which posits that "There would be significant differences between male and female employees on the dimensions of cultural values, conformity tendency, and WGE," has been partially supported by the research findings.

As presented in Table 5, the two groups exhibit a significant difference in power distance, with a small effect size (Welch's $t_{(1,184.1)}$ = 22.312, $p < 0.01$, Adj. ω^2 = 0.06). Mean values on this dimension suggest that employees in the private sector (M = 8.4) are less inclined to unquestioningly accept the prevailing patterns of power distribution compared to their counterparts in public sector organizations (M = 10.2). It is important to note that these sector-based disparities account for only 6% of the variability in scores on this particular dimension. These findings align with Budhwar & Varma's (2011) argument that employees within conventional public sector organizations in India exhibit greater power distance

Table 5. Mean values, standard deviation, Welch's *t* statistics, and effect size (adjusted ω²) for sector-based mean comparisons (N=300)

Variables	Sector	n	Mean values	Standard deviation	Welch's *t*-test				Adjusted ω²
					Statistic	df1	df2	*p*-value	
Conformity	Private	203	3.2	2.4	10.769	1	228.8	0.001**	0.03
	Public	97	4.0	1.9					
Power distance	Private	203	8.4	3.2	22.312	1	184.1	0.000**	0.06
	Public	97	10.2	3.3					
Uncertainty avoidance	Private	203	12.1	1.8	0.061	1	158.3	0.805	N.S.
	Public	97	12.1	2.3					
Collectivism	Private	203	20.7	4.4	8.585	1	206.4	0.004**	0.02
	Public	97	22.2	3.9					
Masculinity	Private	203	7.5	2.9	7.984	1	222.2	0.005**	0.02
	Public	97	6.4	2.5					
Long-term orientation	Private	203	7.2	1.9	3.087	1	266.8	0.080	N.S.
	Public	97	6.9	1.3					
Employment skepticism	Private	203	9.5	3.1	0.028	1	231.0	0.867	N.S.
	Public	97	9.3	2.5					
Traditional gender roles	Private	203	10.7	2.3	6.159	1	252.9	0.014*	0.016
	Public	97	9.9	3.2					

Notes: *Significance at 0.05 level; **Significance at 0.01 level; N.S.: Not significant.

and a reduced inclination toward active participation. It has been asserted that the landscape of power distance in India is undergoing transformation with the emergence of new sectors (such as IT and Business process outsourcing [BPO]). Nevertheless, in traditional bureaucratic services, power distance remains high, due to a multitude of socio-political and historical factors, including India's "long imperialist history" (Budhwar & Varma, 2011). In addition, the centralization of power and authority in public sector organizations contributes to this difference. Power distance tends to be more pronounced in organizations where power is centralized (Investopedia, n.d.). Consequently, it is more prevalent among public sector employees, given that public sector organizations typically adhere to a strict bureaucratic structure characterized by unequal power distribution (Andrews *et al.*, 2009).

Moreover, a significant difference is evident between the two groups in terms of masculinity (Welch's $t_{(1,222.2)} = 7.984$, $p < 0.01$, Adj. $\omega^2 = 0.02$). Private sector employees score higher (M = 7.5) than their public sector counterparts (M = 6.4), suggesting that individuals employed in private sector organizations tend to hold more conservative views regarding the equal capabilities and competence of women, while their public sector counterparts are less likely to believe in gender stereotypes. Nevertheless, it is important to note that the effect size of this difference indicates that sector-based disparities can account for only 2% of the variation in masculinity scores, which is too small to draw practical inferences. These findings align with previous research (Haussman & Sauer, 2007; Karl & Sutton, 1998) that established the tendency of private sector employees to score higher on the masculinity index compared to their public sector peers.

In terms of collectivism, a significant difference is observed between the two sectors (Welch's $t_{(1,206.4)} = 8.585$, $p < 0.01$, Adj. $\omega^2 = 0.02$), where private sector employees exhibit lower levels of collectivism and group orientation (M = 20.7) compared to their counterparts in the public sector (M = 22.2). However, it is worth noting that the effect size remains small, signifying that a mere 2% of the variation in collectivism scores can be attributed to sector differences. These findings are consistent with prior research conducted by Venkatraman & Reddy (2012) and Badarch (2013), both of whom reported that public-sector employees tend to be more collectivistic than their private-sector counterparts. This difference can be attributed to the longevity of association with one's employing organization. According to data from the Bureau of Labor Statistics, in 2016, the average job tenure for public-sector employees was 7.7 years, while private-sector employees had an average job tenure of only 3.7 years. Similarly, research conducted in the Indian context indicates that private-sector employees exhibit lower commitment to their organizations (Sharma & Bajpai, 2010) and tend to change

employers more frequently. In contrast, public-sector jobs offer greater career stability, leading to less job-hopping among employees (Sharma & Bajpai, 2010). Consequently, one plausible explanation for the greater emphasis on group belongingness among public sector employees is the longer period of their association with the organization, which fosters stronger bonds with the organization and its members. Private-sector employees, on the other hand, often change organizations in pursuit of better personal growth and opportunities for success. As a result, they identify themselves less with their employing organization and prioritize personal benefits over group achievements.

Moreover, when considering the dimensions of uncertainty avoidance (Welch's $t_{(1,158.3)} = 0.061$, N.S.) and long-term orientation (Welch's $t_{(1,266.8)} = 3.087$, N.S.), the two groups did not exhibit any significant differences. While research in this area is scant, these inter-sector similarities can be attributed to the provision of similar training programs by both sectors. These programs instill a futuristic vision in employees and equip them to tackle ambivalence. This commonality explains why employees in both sectors display resemblances in their inclination toward a futuristic orientation and their tendency to avoid situations involving uncertainty and risk.

With regard to conformity tendency (Welch's $t_{(1,228.8)} = 10.769, p < 0.01$), the two groups exhibit a statistically significant difference, with private sector employees demonstrating lower conformity (M = 3.2) than their public sector counterparts (M = 4.0). Nevertheless, it is crucial to note that the effect size for this observed difference is very small (Adj. $\omega^2 = 0.03$), implying that only 3% of the variance in conformity scores can be attributed to the sector in which one is employed. Although no prior research specifically addresses sector-related differences in conformity proclivity, the current finding can be explained on theoretical grounds. Public-sector employees' inclination toward conformity can be attributed to the collectivistic values practiced and fostered within public-sector organizations (Badarch, 2013). Conversely, private sector employees are less inclined toward conformity due to their adherence to more individualistic values, which drive them to strive for personal growth and success rather than seeking group acceptance.

Significant differences between sectors were observed regarding the dimension of traditional gender role preference (Welch's $t_{(1,252.9)} = 6.159, p < 0.05$, Adj. $\omega^2 = 0.016$). Mean scores indicate that private-sector employees exhibit greater support for traditional gender roles (M = 10.7) in comparison to their counterparts working in public-sector organizations (M = 9.9). However, it is essential to note that the effect size for this sector difference is rather small and lacks practical significance, with a meager 1.6% of the variation in scores on traditional gender role preference being attributed to sector differences. These findings are consistent with existing evidence suggesting that public sector employees tend to harbor more positive attitudes toward WGE than their private sector counterparts (World Development Report, 2012). Furthermore, given the higher levels of competition prevailing in the private sector (Rocheleau & Wu, 2002) and the perception of women as strong competitors (Ridgeway, 1992), employees' preference for traditional gender roles can be viewed as a defensive strategy employed to deter women competitors from entering the workforce and exacerbating an already intense competitive environment.

Moreover, concerning employment skepticism (Welch's $t_{(1,231)} = 0.028$, N.S.), no significant difference was observed between the two sectors. This finding can be explained in the light of the *Framing Effect* (Scott, 1993), which postulates that participants' responses are, to a great extent, determined by the way questions are framed. In addition, the Social Desirability Effect (Meehl & Hathaway, 1946) may have played a role in shaping participants' responses. Given that our culture promotes conventionality, particularly with respect to gender roles, participants may have perceived it as more socially acceptable to express a preference for traditional gender roles rather than explicitly expressing their skepticism regarding women's participation in paid employment. Consequently, the results in this study offer partial support for H4, which postulates that "There would be significant differences between public and private sector employees on the dimensions of cultural values, conformity tendency, and WGE."

5. Conclusions

The present research aimed to explore the influence of individuals' cultural orientation and conformity tendencies on their attitudes toward WGE. It also examined the mediating role of conformity in connecting cultural values and the inclination toward gender equity. The findings from the mediation analysis revealed that, among the five cultural values identified by Hofstede, four significantly predicted individuals' attitudes concerning gender equity in the workplace. Moreover, conformity emerged as a significant predictor of gender equity and also acted as a mediator in the relationship between cultural values and WGE. With respect to inter-group comparisons, no significant gender differences were observed in the realms of cultural values and conformity. However, a significant observation was made in the comparison between men and women, with men displaying a significantly lesser preference for WGE. On investigating sector-based differences, it became evident that the two sectors exhibited disparities in specific

cultural values and conformity tendencies. Moreover, a significant difference was observed between public and private sector employees in just one dimension of gender equity, namely traditional gender roles. Finally, an examination of the three generations indicated distinctions in certain cultural values, conformity tendencies, and the employment skepticism associated with gender equity.

In summary, the present study highlights the sociocultural and attitudinal impediments that hinder gender parity, and it carries tremendous implications by introducing a framework that underscores the importance of contextual factors, such as cultural orientation, conformity, and generational effects. These factors are often overlooked by organizational management and policymakers while chalking out strategies for reinforcing and fostering gender parity in the workplace. Existing research indicates that countries in the Asia-Pacific region rank second in terms of gender disparity, surpassed only by Middle-Eastern nations (Gupta *et al.*, 2019). These differences are undoubtedly influenced, at least in part, by broader socio-cultural factors, such as conformity, gender role expectations, and other cultural practices. Addressing such inequalities necessitates macro-level, research-driven reforms. The findings presented here lay a foundation for further empirical investigations in this domain and offer key insights into the intricate nexus of factors that curtail holistic gender parity in the workplace. They throw light on the urgent need for organizations to conduct gender-sensitivity training programs to address biased attitudes toward women in the workplace.

Despite the valuable implications of this study, it is important to acknowledge several methodological limitations that should be considered when generalizing the findings. One notable limitation is the use of a small, unequal, and non-representative sample size. The results should be interpreted with caution in light of these sample characteristics. In addition, due to the non-normal distribution of the obtained data, the application of MANOVA was not feasible, which prevented us from examining the potential interaction effect of gender, sector, and generation. Furthermore, the current research did not account for extraneous variables (e.g., organizational culture and values), which may have impacted the responses received from participants. It is essential to recognize ththe data that were exclusively collected from the IT sector, limiting the generalizability of the findings to other employment sectors. Therefore, researchers are recommended to collect data from various sectors such as banking, hospitality, telecommunications, and others in future studies, allowing for a comprehensive analysis of inter-sector differences in cultural values, conformity, and gender equity. Furthermore, it is imperative to acknowledge that this study employed a binary and cis-heteronormative understanding of gender throughout the research. To foster inclusivity and broaden the scope of the literature, it is recommended that future studies strive for a more comprehensive approach by including non-binary individuals in their investigations. This approach will significantly contribute to a more diverse and enriched body of literature.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: Nasrina Siddiqi
Formal analysis: Nasrina Siddiqi
Investigation: Nasrina Siddiqi
Methodology: Nasrina Siddiqi
Writing – original draft: Nasrina Siddiqi
Writing – review and editing: All authors

Ethics approval and consent to participate

The present research has been approved by the research ethics committee of Jamia Millia Islamia (Approval ID: 09-2844), and it is conducted in compliance with the protocol approved by the institution.

Consent for publication

Informed consent was taken from participants for publishing their data.

Availability of data

Data used in this work are available from the corresponding author on reasonable request.

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Appendix

Appendix I. AVE values for reflectively measured constructs

Constructs	AVE
Collectivism	0.50
Masculinity	0.71
Power distance	0.55
Uncertainty avoidance	0.57
Long-term orientation	0.62
Gender inequity	0.51

Abbreviation: AVE: Average variance extracted.

Appendix II. Discriminant validity testing using Fornell-Larcker Criteria

Constructs	Average variance extracted	Collectivism	Conformity	Gender inequity	Long-term oreintation	Masculinity	Power distance	Uncertainty
Collectivism	0.5	0.71*	---	---	---	---	---	---
Conformity	---	0.206	---	---	---	---	---	---
Gender inequity	0.51	0.052	0.280	0.71*	---	---	---	---
Long-term orientation	0.62	0.230	0.225	0.238	0.79*	---	---	---
Masculinity	0.71	0.165	0.365	0.558	0.264	0.84*	---	---
Power distance	0.55	0.261	0.315	0.285	0.216	0.290	0.74*	---
Uncertainty	0.57	0.251	0.043	−0.119	0.153	0.045	0.147	0.75*

Note: *Square root of average variance extracted.

Appendix III: Table indicating the outer weights, *t*-values, *p*-values, and outer loadings of Generalized Conformity Tendency Test

Indicators	Outer weights	*t*-value	*p*-value	Outer loadings
CON1	0.603	4.648	0.00**	0.550
CON2	0.049	0.367	0.71	0.189
CON3	0.428	2.612	0.01**	0.336
CON4	−0.175	1.269	0.21	0.298
CON5	0.563	4.245	0.00**	0.493
CON6	0.030	0.185	0.85	0.224
CON7	0.191	1.217	0.22	0.394
CON8	0.388	2.814	0.01**	0.301
CON9	0.015	0.099	0.92	0.198
CON10	−0.231	1.344	0.18	0.090
CON11	0.245	1.976	0.05*	0.215
CON12	0.110	0.905	0.37	0.268
CON13	−0.123	0.947	0.34	0.034
CON14	−0.208	1.666	0.10	−0.144
Collinearity assessment	Tolerance		>0.2	
	Variance Inflation Factor (VIF)		<5	

Note: **Significance at 0.01 level; *Significance at 0.05 level.

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RESEARCH ARTICLE

Should women in logistics stay or switch? An application of the moderating effect of work-life balance in the self-determination theory to Malaysian young women

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Abstract

The transport and logistics sector is described as non-traditional for women because the industry mostly employs men and the tasks undertaken are viewed as masculine. Therefore, the difficulties that women face when working in the transport and logistics sector are recognized as different from women working in traditional areas. Women continue to be under-represented, especially in the transport and logistics sector. Inequity and career barriers continue to be an issue within this sector. A lack of interest toward the issue of inequality of genders in the logistics industry in Malaysia will further worsen the disinterest in the issue. The challenges faced by women in the logistics industry are framed by the community which sees the industry as not belonging to women. However, the number of women involved in this industry increases on a yearly basis. Despite the issue of work-life balance due to round the clock working conditions, women remain in this challenging industry. Hence, to address this issue, the authors unearth the factors influencing the intention to stay among women in the logistics industry by extending the self-determination theory with job satisfaction and family supervisor supportive behavior as additional predictors, and work-life balance as a moderator. By adapting a purposive sampling method, a total of 248 usable questionnaires were gathered from women in the logistics industry in Malaysia. The findings indicate that extrinsic motivation, intrinsic motivation, job satisfaction, and family supportive supervisory behavior have a positive relationship with the intention to stay in the logistics industry. Furthermore, work-life balance moderates the relationship between job satisfaction and extrinsic motivation toward the intention to commit to the logistic industry. The present study provides a foundation for human resource departments to reduce the prevalence of retention issues and decrease the number of talented employees who leave their work, especially women in the logistics field.

Keywords: Women in logistics; Intention to stay; Self-determinant theory; Work-life balance

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1. Introduction

Advancement in technology has made the logistics industry attractive not only for men but also for women who start to play a role in this field. The logistics industry is labeled as a male-dominated industry and is not seen as women-friendly due to several factors. These include dirtiness, high physical requirements (Maloni *et al*., 2019), and the limited number of women who elect to pursue a career in this industry. Although it was demonstrated that women have equivalent competencies as men in the logistics industry (Vo *et al*., 2023), this industry suffers from a gender bias as women represent only 35% of the workforce. Moreover, they receive lower pay and suffer from a lack of career progress (Maloni *et al*., 2019a; Nix & Stifler, 2016).

Despite multiple challenges such as hardship (Vo *et al*., 2023), gender inequalities, lack of opportunities to reach top management positions (Zinn *et al*., 2018), lower salaries (Ruel & Jaegler, 2021), the number of women in logistics industries increases on a yearly basis. The percentage of women in the industry was 36% in 2016 and reached 41% in 2021 (Gartner, 2021). The nature of the industry and the global supply chain requires round the clock working hours. This is at odds with the Malaysian traditional family-centered role of women which affects their work-life balance (Nix & Stifler, 2016) and creates conflicts within their home environments (Maloni *et al*., 2019). In the Malaysian setting, women have more obligations regarding family roles than men. These include taking care of household work, raising children, and other tasks related to the family. Meanwhile, men are more concerned with the financial burden and house-hold requirements (Malaysia Population Research Hub, 2023). Although most women tend to choose their family over their career in the logistics industry, statistics highlight a different situation, suggesting that studies are required to unearth factors influencing the retention among women in logistics. Most studies are focused on factors influencing the intention to stay or turnover intention in general, but there is a lack of research focusing on women in the logistics industry. Furthermore, only a handful of publications had women at their core (Hazeen Fathima & Umarani, 2023; Kuvaas *et al*., 2017; Maloni *et al*., 2019; Ruel & Fritz, 2021), thus resulting in a lack of understanding on their behavior in the logistics industry (Azlin *et al*., 2023), especially in term of their work-life balance through the lens of the self-determination theory (SDT).

Hence, to fill the gap in the literature, the researchers identify in the current study the factors that influence the intention to continue to commit among women in the logistics industry in Malaysia using the SDT theory and introduce work-life balance as a moderator in the research model. Besides variables representing the SDT, job satisfaction and family supervisory support behavior are included as additional predictors to enhance the predictive power of the model. This is a novel approach as there is a scarcity of studies where work-life balance is employed as a moderator in the SDT to explain the intention to stay in the logistics industry. Furthermore, since the logistics industry is colossal and different from other industries, it is crucial to conduct a study based on women's perception of this industry. Moreover, as the purpose of the study is to prevent women from leaving this field, it is pertinent to unearth the factors influencing them to stay.

It is vital to discover factors that promote awareness among logistics companies in Malaysia to address women's issue in the logistics industry. Besides contributing to the body of knowledge, this study benefits the logistics industry which is challenged by turnover problems in various ways. One of these, which is extremely important for human resource management in the logistics industry, is to understand the factors that could influence the intention of women to stay in the logistics industry. By identifying the predictors, human resource departments could address the intention to leave this industry by crafting better policies supporting their requirements. The study provides a foundation to reduce the prevalence of retention issues and decrease the number of talented employees leaving their work in the logistics field.

1.1. Literature review

1.1.1. Self-determination theory

The self-determination theory (SDT) developed by Ryan & Deci (2017) is a macro theory of human motivation that is successfully applied across domains including parenting, education, healthcare, sports and physical activity, psychotherapy, and virtual worlds, as well as in the fields of work motivation and management. The SDT specifically suggests that both employees' performance, well-being, and future behavior are affected by the type of motivation they have in their job activities (Deci *et al*., 2017). The theory is centered on two types of motivation that influence employees' goals in their work setting. First, intrinsic motivation relates to employees' actions as inherently interesting or pleasurable. Second, extrinsic motivation relates to external factors which produce different outcomes (Deci & Ryan, 2000). The SDT theory, commonly used to determine human need, is widely employed across the field to predict employees' intention to leave.

1.1.2. Intention to stay

Continuance of commitment or the intention to stay refers to the assumption or the likelihood of individuals staying

in their current jobs or remaining with their current organizations (Pressley & Garside, 2023). Based on the context of the current study, continuance of commitment refers to the willingness of women to remain employed in the logistics industry. Besides the importance of revealing employee future commitment, most studies are concerned with the intention to quit, and few studies address the issue of continuance of commitment or the intention to stay (Bolt *et al.*, 2022). This is especially true for the logistics industry where employees should overcome a variety of industry-specific difficulties. Moreover, since the introduction of new technologies should raise the ability for women to work in this men-oriented field, the low numbers of women employed, and their retention should not be taken lightly by the industry and academics.

1.1.3. Intrinsic motivation

Intrinsic motivation is a form of autonomous motivation which refers to an individual's intention to perform a task for its own sake, as opposed to completing it for any other external reason (Gagné & Deci, 2005). Intrinsic motivation includes fun, enjoyment, interest, novelty, aesthetic value, and challenges and is opposed to external pressures or monetary rewards. Employees whose autonomy and competency are supported are more likely to develop intrinsic motivation. While women are greatly intrinsically motivated to work in the logistics industry, they should have a higher willingness to stay in this field. Maryam *et al.* (2021) highlight that intrinsic motivation has a positive effect on the continuance of commitment to stay in a specific industry. Based on that, the authors propose that:

H1: Intrinsic motivation of women in logistics has a positive relationship toward the intention to stay in the logistics industry.

1.1.4. Extrinsic motivation

In SDT, externally motivated people may become self-determined through the internalization and integration of externally motivated tasks (Ryan & Deci, 2000). Extrinsic motivation is a form of controlled motivation which refers to an individual's intent to perform a task when triggered by an external influence or outcome distinct from the task (Gagné & Deci, 2005). Since extrinsically motivated behavior is externally prompted, the primary reason people are willing to perform in a particular way is to feel valued by important people in their surroundings (Ryan & Deci, 2000).

According to Kuvaas *et al.* (2017), extrinsic motivation has varying employee outcomes based on the study setting. Higher extrinsic motivation can produce positive outcomes. A past study (Maryam *et al.*, 2021) revealed that extrinsic motivation has a positive relationship with the continuance of commitment. Based on this postulation, the authors propose that:

H2: Extrinsic motivation of women in logistics has a positive relationship toward the intention to stay in the logistics industry.

1.1.5. Job satisfaction

Job satisfaction (JS) refers to affective responses on multiple aspects of a job (Ladelsky & Lee, 2022). Several authors claim that JS plays a major role in employees' future behavior. Furthermore, JS is also considered a powerful predictor of the intention to stay. According to Buitendach & Rathmann (2009), satisfied employees are motivated to perform better in their jobs and stay longer with their organizations. Studies in fields sharing traits with the logistics industry, such as long or unspecified working hours, as in the medical field (Chen & Zhou, 2016) and in the construction industry (Xie *et al.*, 2022), confirm that job satisfaction positively relates to the intention to stay. Thus, the authors propose that:

H3: Job satisfaction has a positive relationship toward women's intention to stay in the logistics industry.

1.1.6. Family supportive supervisory behavior

Family-supportive supervisory behavior refers to supervisors or managers empathizing with the requirements to find balance between work and family responsibilities (Thomas & Ganster, 1995). Despite the importance of family-supportive supervisory behavior, Schorsch *et al.* (2017) claim that the work culture of the supply chain management (SCM) is not well understood due to limited research exploring organizational support for employees and their retention. The core value of family-supportive supervisory behaviors is to serve family-friendly behavior for an employee to perform their family commitments. For women, being cared for by their management, fulfills their psychological needs to cope with their role as family members (Rofcanin *et al.*, 2018), especially in problematic families. Women with family-supportive supervisory behavior deal better with family issues and thus can focus on their jobs' responsibilities without diversions (Zhang *et al.*, 2020). Researchers highlight that family-supportive supervisory behavior has a negative relation with turnover intention (Liu *et al.*, 2020; Zhang *et al.*, 2020).

Based on this postulation, the authors propose that:

H4: Family-supportive supervisory behavior of women in logistics has a positive relationship toward the intention to stay in the logistics industry.

1.1.7. Moderating effect of work-life balance

Moderating effect has been used by several scholars in social science to justify their contribution to their studies (Hafaz

Ngah *et al*., 2020). To enhance the model's predictive power, the authors introduce work-life balance as a moderator within the research framework. Figure 1 illustrates the research framework of the study with work-life balance as a moderator. Work-life balance refers to the degree with which individuals manage diverse roles in their daily lives, such as job requirements, family's responsibilities, and any other roles to balance their professional requirements and personnel responsibilities (Aloulou *et al*., 2023). For women, having a work-life balance is crucial to ensure they can meet the expectations of family members and work requirements. Women want to perform at their offices and as mothers, wives, and daughters in their families. In the Malaysia context, women play a leading role in ensuring that their families are in an ideal situation. However, working in the logistics industry, which is known as a day-and-night working environment, has the potential to strain the work-life balance, as more time is spent on professional requirements. Work-life balance leads not only to greater productivity but also improves company loyalty and reduces the level of intent to leave the organization (Moore, 2007). As mentioned by Dousin *et al.* (2021), work-life balance improves employees' emotional well-being and reduces turnover intention. Moreover, Vo *et al.* (2023) suggest that based on institutional logic, a good work-family balance helps to retain women talent. Hence, the authors believe that work-life balance could increase the intention to commit in the logistics industry among women. As such:

H5a: Work-life balance moderates the relationship between intrinsic motivation and the intention to stay in the logistics industry, and the relationship between intrinsic motivation and the intention to stay will be stronger when work-life balance is high.

H5b: Work-life balance moderates the relationship between extrinsic motivation and the intention to stay in the logistics industry, and the relationship between extrinsic motivation and the intention to stay will be stronger when work-life balance is high.

H5c: Work-life balance moderates the relationship between job satisfaction and the intention to stay in the logistic industry and the relationship between JS and the intention to stay will be stronger when work-life balance is high.

H5d: Work-life balance moderates the relationship between family-supportive supervisory behavior and the intention to stay in the logistics industry, and the relationship between family-supportive supervisory behavior and the intention to stay will be stronger when work-life balance is high.

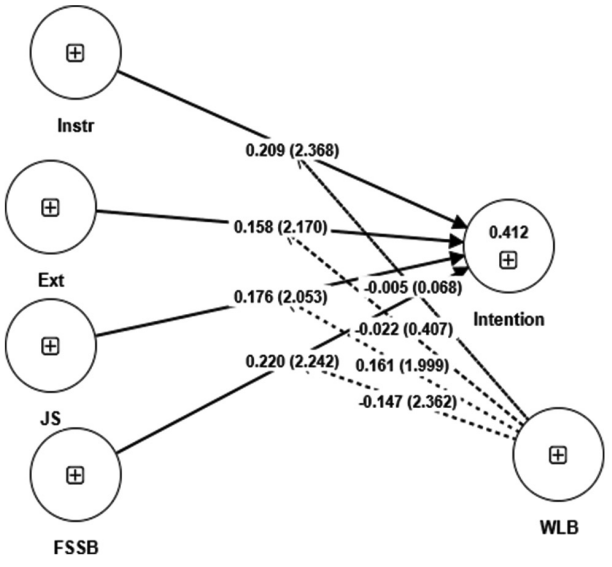

Figure 1. Structural model
Abbreviations: Ext: Extrinsic motivation; FSSB: Family supportive supervisory behavior; Intention: Intention to stay; Instr: Intrinsic motivation; JS: Job satisfaction; WLB: Work-life balance.

2. Data and methods

2.1. Sampling method and data collection

A purposive sampling method was applied in this study as the authors focus on recruiting women in the logistics industry. Moreover, besides the specific criteria of the respondents, unavailability of the sampling frame also forced the authors to employ this sampling technique (Hassan *et al*., 2023; Rowley, 2014). An online survey was used to collect the data in the present study. To ensure sufficient sample size, the authors used numerous channels to share a link to the questionnaire. In the early stage, the link was shared through Facebook and Instagram to seek women respondents from logistics companies. Using personal contacts, the authors also used WhatsApp to distribute the link to the questionnaire. Last, the authors also contacted logistics companies by approaching their human resource departments to share the link with women in their organizations. From these contacts, the authors managed to collect 280 completed questionnaires. However, after screening, only 248 answers were valid and usable for the data analysis. The reasons for discarding respondents included the inclusion of men respondents, high missing values, and respondents with the same score from the beginning till the end (Ngah *et al*., 2023).

In determining the minimum sample size as suggested by Albtoosh & Ngah (2022) and Hair *et al.* (2019), the authors conducted power analysis. In the case for nine predictors, 80% power, and a medium effect size as suggested by Gefen *et al.* (2011) and Ngah *et al.* (2021), the minimum sample size of our research is 114. Since

248 samples were collected, the sample size was considered sufficient to test the research model of the study.

2.2. Research instruments

To ensure item validity, all items used to measure the constructs in the study were adopted from established sources in the field. Items for extrinsic motivation and intrinsic motivation were adopted from Kuvaas *et al.*, (2017), job satisfaction and family-supportive supervisor behavior from Maloni *et al.* (2019b), work-life balance from Fontinha *et al.* (2018), and items for intention to stay from Presbitero & Teng-Calleja (2020). Details are provided in Table A1 of the Appendix. Since the authors gathered the data from a single source, the risk of common method variance could arise (Ngah *et al.*, 2022; Tuan Mansor *et al.*, 2022). As suggested by Podsakoff *et al.* (2012) and Syafiq *et al.* (2023), the authors employed different anchor scales. The exogenous variables were measured using 5-point Likert scales, whereas the endogenous variable was measured with a 7-point Likert scale.

2.3. Statistical analysis

The authors employed the Statistical Package for the Social Science (SPSS) to illustrate the respondent's profile and structural equation modeling (SEM) with smart partial least squares (PLS) (Ringle *et al.*, 2022) for hypotheses testing. Since the nature of the study was solely for predictive purposes, Smart PLS was deemed appropriate for the study (Hair *et al.*, 2019; Ngah *et al.*, 2021).

Furthermore, it has been evidenced that using a single source of data may result in common method variance (CMV) (Tuan Mansor *et al.*, 2022), which may have an impact on the quality of the findings (Halimi *et al.*, 2021). To address this problem, both procedural and statistical methods of analysis were applied. A different anchor scale to measure constructs for the procedural method (Ngah *et al.*, 2021; Podsakoff *et al.*, 2012) was used. As such, a 7-point Likert scale was employed to determine the intention to commit. Meanwhile, 5-point Likert scales were used to determine the other constructs. For the statistical method, the authors utilized full collinearity analysis (Albtoosh & Ngah, 2022; Kock, 2015) to remedy the potential issue of CMV. A VIF value less than or equal to 3.3 indicates that there is no bias in a single source of data. The analysis revealed VIF values lower than 3.3, indicating that the CMV was not a serious problem in the present study. Table A2 of the Appendix depicts a summary of full collinearity testing for each construct.

2.3.1. Validity tests

For the analysis, the authors followed the two-step approach proposed by Hair *et al.* (2017) and Ngah *et al.* (2022) with a measurement model and a structural model. For the measurement model, the convergent validity and discriminant validity needed to be established before developing the structural model. According to Ngah *et al.* (2022), convergent validity is a test that determines whether the items used can measure the same construct. The loading and composite reliability must be ≥0.7, while average variance extracted must be ≥0.5 to confirm the convergent validity (Hair *et al.*, 2017). Table A3 of the Appendix shows the results of convergent validity.

The heterotrait – monotrait ratio of correlations (HTMT) was used to establish the discriminant validity, as recommended by Henseler *et al.* (2015). As shown in Table A4 of the Appendix, all HTMT values were lower than 0.85, indicating that the discriminant validity was established (Franke & Sarstedt, 2019).

The authors proceeded to the structural model to test the hypotheses after the measurement model was established. As shown in Figure A1 of the Appendix, a bootstrapping procedure (Hair *et al.*, 2017) with a 5,000 resampling technique was used to test the hypotheses developed. A hypothesis is considered supported if the beta value is aligned with the hypothesis, with a t-value of ≥1.645, a *p*-value of ≤0.05, and no null values for the confidence interval between lower and upper levels (Ngah *et al.*, 2021).

3. Results

Based on the data obtained from the 248 usable responses, most respondents are between the ages of 26 and 33 years old (39.1%), and 71.4% of respondents are single women. Most respondents have a degree (61.3%). The majority of respondents in the survey are Malays (60.6%). In terms of income levels, the highest proportion of income level is between MYR 1,000 and MYR 3,000, (50%). Exactly 46.8% of the respondents have between 1 and 3 years of experience. Table 1 shows the characteristics of the 248 respondents in terms of their demographic background.

The authors developed four direct hypotheses and four moderating hypotheses. The results of the direct effect in Table 2 show that intrinsic motivation ($\beta = 0.209$, $p < 0.01$), extrinsic motivation ($\beta = 0.158$, $p < 0.05$), JS ($\beta = 0.176$, $p < 0.05$), and family-supportive supervisory behavior ($\beta = 0.220$, $p < 0.05$) have a positive relationship with the intention to stay in the logistic industry, thus supporting H1 – H4 of the study. This indicates that these four variables are crucial factors to increase the intention to commit in the logistics industry among women in Malaysia. For the moderating effect, the analysis revealed that two hypotheses were unsupported, and another two hypotheses were supported.

Table 1. Respondent's characteristics

Characteristic	Frequency	%
Age		
18–25 years	95	38.3
26–33 years	97	39.1
34–41 years	35	14.1
42–49 years	18	7.3
>50 years	3	1.2
Marital status		
Single	177	71.4
Married	70	28.2
Other	1	0.4
Qualification		
High school education	10	4.0
Certificate	7	2.8
Diploma	73	29.4
Degree	152	61.3
Master	4	1.6
PhD	2	0.8
Race		
Malay	200	80.6
Chinese	34	13.7
Indian	9	3.6
Other	5	2.0
Income (MYR)		
1000–3000	124	50
3001–6000	108	43.5
6001–9000	8	3.2
>9001	8	3.2
Experience in logistics industry		
1–3 years	116	46.8
4–6 years	82	33.1
7–9 years	26	10.5
More than 10 years	24	9.7

The result shows that work-life balance moderates the relationship between job satisfaction and intention to stay ($\beta = 0.161$, $p < 0.05$), and for the relationship between family-supportive supervisory behavior → intention to stay ($\beta = 0.147$, $p < 0.01$), thus supporting H7 and H8 in the study. Meanwhile, for H5 intrinsic motivation → intention to stay ($\beta = -0.005$, $p = 0.473$) and extrinsic motivation → intention to stay ($\beta = -0.022$, $p = 0.342$), work-life balance failed to moderate these relationships; hence, H5 and H6 were unsupported. Thus, confirming that two moderation hypotheses were supported, and another two moderation hypotheses were unsupported. Table 2 and Figure 1 illustrates the analysis for the hypotheses of the study; meanwhile, Figures 2 and 3 illustrate the Dawson (2014) plots for the supported moderating effect.

3.1. PLS prediction

In accordance with Rashid *et al.* (2022) and Shmueli *et al.* (2019), the nature of the current study was focused on the predictive purpose. As such, PLS prediction analysis with a holdout sample-based procedure that generates case-level predictions on an item or construct level using the PLS Predict was performed to assess predictive relevance. This analysis was based on the root mean square error. A low level of error indicates a strong predictive power (Ngah *et al.*, 2023). Shmueli *et al.* (2019) indicate that a strong predictive power is obtained when all item differences (PLS-LM) have negative values, thus indicating a lower error level from PLS modeling when compared to linear modeling (LM). As illustrated in Table 3, the data indicate that the results of PLS minus LM are all negative values, consequently indicating lower error from the PLS modeling. This indicates that the model has a strong predictive power.

4. Discussion

The authors aimed to unearth factors influencing women's intention to stay in the logistics industry. To enhance the

Table 2. Hypotheses testing

Hypothesis	Relationship	Beta	SE	T value	p values	LLCI	ULCI	VIF	f2
H1	Instr -> Intention	0.209	0.088	2.368	0.009	0.071	0.356	1.979	0.025
H2	Ext -> Intention	0.158	0.073	2.170	0.015	0.034	0.272	1.279	0.053
H3	JS -> Intention	0.176	0.086	2.053	0.020	0.054	0.328	1.741	0.004
H4	FSSB -> Intention	0.220	0.098	2.242	0.013	0.068	0.397	1.533	0.028
H5	WLB×Instr -> Intention	−0.005	0.072	0.068	0.473	−0.121	0.105		
H6	WLB×Ext -> Intention	−0.022	0.053	0.407	0.342	−0.100	0.078		
H7	WLB×JS -> Intention	0.161	0.080	1.999	0.023	0.022	0.282		
H8	WLB×FSSB -> Intention	0.147	0.062	2.362	0.009	0.028	0.236		

Abbreviations: Ext: Extrinsic motivation; FSSB: Family supportive supervisory behavior; Intention: Intention to stay; Instr: Intrinsic motivation; JS: Job satisfaction; WLB: Work-life balance.

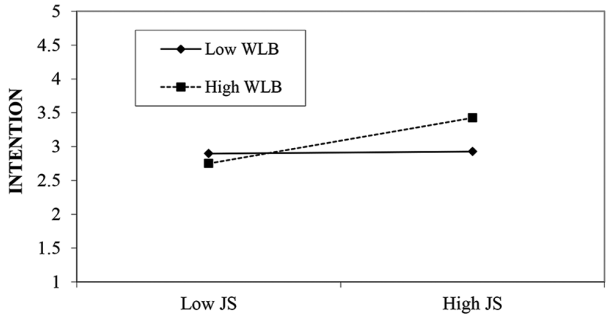

Figure 2. Moderating effect of work-life balance (WLB) for the relationship between job satisfaction (JS) and intention to stay (Intention).

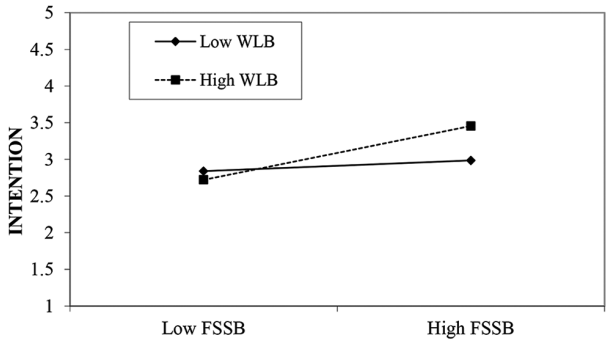

Figure 3. Moderating effect of work-life balance (WLB) for the relationship between family supportive supervisory behavior (FSSB) and intention to stay (Intention).

Table 3. PLS prediction

Item	Q^2predict	PLS-SEM_ RMSE	LM_RMSE	PLS-LM	Decision
CI1	0.35	0.923	0.983	−0.06	Strong
CI2	0.248	0.987	1.081	−0.094	
CI3	0.264	0.985	1.055	−0.07	

Abbreviation: RMSE: Root mean square error.

predictive power, the authors introduced the moderation effect of work-life balance as a moderator for intrinsic motivation, extrinsic motivation, job satisfaction, and family support supervisory behavior on the intention to stay. The findings indicate that intrinsic motivation has a positive relationship with intention, which is consistent with Maryam *et al.*'s (2021) conclusions. The findings confirm the importance of intrinsic motivation to enhance the intention to stay in the logistics industry for women in Malaysia. Consequently, three basic psychological needs that promote intrinsic motivation (relatedness, competency, and autonomy) (Deci et al., 2017) should not be neglected by logistics companies that truly value the role of women staff in their organization.

The analysis also reveals that extrinsic motivation has a positive effect on the intention to stay in the logistics industry for women in Malaysia. The findings support a previous study by Maryam *et al.* (2021), thus suggesting the prominent role of extrinsic motivation towards the intention to stay in the logistics industry. Despite tough challenges faced by women in the logistics industry, either in their daily routine tasks or in their career growth, extrinsic motivation factors, including good salaries and appropriate recognition, contribute to women having a higher intention to stay in this industry.

The analysis also reveals that job satisfaction has a positive effect on women's intention to stay in the logistics industry. The results are similar to a past study conducted by Xie *et al.* (2022) who found that construction workers are also willing to stay if they are satisfied with their jobs. It also indicates that despite the perceived difficulties inherent to an industry, job satisfaction is an important factor promoting employee retention. Thus, it is the role of all stakeholders to ensure that not only women, but all employees remain satisfied with their jobs. It should be noted that salary is not the only enhancing factor. A good work environment and compatible colleagues are also essential to enhance job satisfaction.

Family-supportive supervisor behaviors are found to have a positive effect on the intention to stay in the logistics industry for women in this field. Positive family-supportive supervisor behaviors negatively affect the intention to quit (Liu *et al.*, 2020), thus suggesting that it positively influences the intention to stay. Besides their positions in their office, having a good management that is concerned with women's roles in their families creates a positive incentive to stay with the same management, organization, or industry. Women who feel that they are looked after by their supervisors do not hesitate to contribute further to ensure their organizations' success.

Besides the direct effect, the authors also looked at the effect of work-life balance as a moderator within the model. There are mixed findings on this issue since work-life balance only moderates the relationship between job satisfaction and family-supportive supervisor behaviors and fails to moderate for intrinsic motivation and extrinsic motivation toward women's intention to stay in the logistics industry. Work-life balance strengthens the relationship between job satisfaction and intention and between family-supportive supervisor behaviors and the intention to stay in the logistics industry. This suggests the level of prominence of work-life balance in strengthening the relationship between these factors. However, even though work-life balance fails to moderate the relationship between intrinsic

motivation and extrinsic motivation toward the intention to stay in the logistics industry, it indicates that women have a good level of intrinsic motivation and extrinsic motivation and that work-life balance does not have any moderating effect on the intention to stay in this industry. This scenario can be explained by the fact that women are already aware of the situation in the logistics industry when joining. Due to good understanding, preparation, and pertinent knowledge gained from lectures and industrial experiences, women's commitment to this industry can prevail. This can explain why the number of women in this industry is continuously on the rise.

4.1. Strengths

The present study is a pioneering effort to explore the influence of the SDT theory with the extension of job satisfaction and family-supportive supervisor behaviors on women's intention to stay in the logistics industry. On a theoretical level, examining the factors influencing the intention of women to stay in the logistics industry will benefit academics and logistics organizations to better understand the factors influencing the intention to stay among women in the logistics industry. The present publication contributes to the body of knowledge on the factors influencing women to stay in the logistics industry. The results also confirm the capability of the SDT theory to explain future commitment of women in this industry, which could also be applicable to other industries. Moreover, the results also confirm the role of job satisfaction and family-supportive supervisor behaviors to enhance women's commitment to the logistics industry. Furthermore, the present article enriches the literature in this field of study by introducing the role of work-life balance as a moderator in SDT and for job satisfaction and family-supportive supervisor behaviors.

4.2. Managerial implications

The findings of the study provide meaningful information for organizations. It is the duty of human resource departments to tackle this issue to ensure that women play a role in the logistics industry. The literature shows the value of women, their capabilities, and their role in supporting the development of the logistics industry. Thus, human resource managers should craft better policies to ensure that women who have been trained in this field will not shift to another industry due to the limitations of the logistics industry.

4.3. Limitations

Although this study was carefully designed, several limitations remain. First, since the researchers employed a non-probability sampling method with a purposive sampling technique, representativeness and generalizability are generally not achieved. Hence, it is strongly suggested that this study be replicated to provide better generalizability (Sarstedt *et al.*, 2018). Furthermore, the same model should be tested in different contexts, either in Malaysia or outside Malaysia, to ensure the model is further validated and the findings can be generalized in other settings. Second, the study was limited to the variables from the SDT theory, and an extension of job satisfaction, family-supportive supervisor behavior, and the moderating effect of work-life balance. Other potential pertinent variables were excluded in the study, and thus future studies could extend their model with compensation and personnel job-fit factors since these variables also have a significant impact on women staying in the logistics industry. Last, the sample comprises nearly 40% of respondents under the age of 25. This is a group which might face fewer work-life balance issues. This can be explained by how the data were collected with a survey method, and how responding to the questionnaire was voluntary in nature. Control over this aspect of the study was limited. Hence, future studies should be designed to focus further on older women working in this industry who have different responsibilities in their families. This would provide insightful information on how work-family conflicts play a role in the intention to stay in logistics industry, and how work-life balance is more crucial for more mature women.

5. Conclusions

To ensure that the onus on women staying in this industry is not solely placed on them, all parties, such as families, managers, and regulations, should follow the same direction to protect women's rights and support their career and capability to strengthen the logistics industry. If all parties play their role professionally, there is no reason why women should leave the logistics industry. Although the study sheds light on this issue, limitations remain. The study is limited to the SDT theory which is extended with job satisfaction and family-supportive supervisor behaviors. Other crucial variables such as industry commitment, personnel job-fit, and justice should be explored to provide better explanatory power to the model and to better understand women's behavior in the logistics industry. Besides work-life balance as a moderator, work-life conflicts or work-family conflicts, which are commonly used as predictors, are also potential moderators. This should be investigated in future studies on this issue. Having a different setting such as in Western or in developed countries could also be important and provide different perspectives. Hence, it is the role of academics in other countries and regions to explore this

issue and provide meaningful information for the logistics industry and researchers in the field.

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Conflict of interest

The authors declare that they have no competing interest.

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Appendix

Table A1. Measurements of the study

No.	Intrinsic motivation
1.	The job I carry out is itself a driving force in my career.
2.	The tasks that I do at work are enjoyable
3.	My job is meaningful
4.	My job is very exciting
5.	My job is so interesting that it is a motivation in itself
6.	Sometimes I get so motivated by my work that I almost forget about everything else around me.
No.	**Extrinsic motivation**
1.	If I have to put extra effort into my job, I need to get extra pay.
2.	It is important for me to have an external incentive to strive for a good job.
3.	External benefits, such as rewards and provisions are important to how well I do my work.
4.	If I were offered better pay, I would have done a better job.
No.	**Work-life balance**
1.	I could achieve a healthy balance between work and home life.
2.	My current working hours/patterns are in keeping with my personal circumstances.
No.	**Job satisfaction**
1.	Generally speaking, I'm very satisfied with my job.
2.	Most of the day, I'm excited about my work
3.	I consider my job to be rather unpleasant.
No.	**Intention to stay**
1.	I intend to continue to work in logistics industry in the future.
2.	I will always try to apply my knowledge in logistics in my career life.
3.	I plan to continue to work in logistics industry in the future.
No.	**Family supportive supervisory behavior**
1	My supervisor makes me feel comfortable talking to him/her about conflicts between work and non-work
2	My supervisor demonstrates effective behaviors in how to juggle work and non-work issues
3	My supervisor works effectively with employees to creatively solve conflicts between work and non-work
4	My supervisor organizes the work in my department or unit to jointly benefit employees and the company

Table A2. Full collinearity testing

Construct	Ext	JS	WLB	Instr	Intention	FSMB
VIF	1.258	1.577	1.587	1.729	1.498	1.485

Abbreviations: WLB: Work-life balance; JS: Job satisfication.

Table A3. Convergent validity

Construct	Item	Loading	CR	AVE
Commitment intention	CI1	0.945	0.960	0.889
	CI2	0.934		
	CI3	0.950		
Extrinsic motivation	Ext1	0.831	0.911	0.720
	Ext2	0.873		
	Ext3	0.852		
	Ext4	0.837		
Family support supervisor behavior	FSMS1	0.865	0.917	0.734
	FSMS2	0.840		
	FSMS3	0.863		
	FSSB4	0.860		
Intrinsic motivation	Instr1	0.767	0.927	0.680
	Instr2	0.821		
	Instr3	0.875		
	Instr4	0.851		
	Instr5	0.869		
	Instr6	0.756		
Job satisfaction	JS1	0.919	0.932	0.821
	JS2	0.872		
	JS3	0.926		
Work-life balance	WLB1	0.885	0.908	0.767
	WLB2	0.883		
	WLB3	0.860		

Abbreviations: Ext: Extrinsic motivation; FSSB: Family supportive supervisory behavior; Intention: Intention to stay; Instr: Intrinsic motivation; JS: Job satisfaction; WLB: Work-life balance.

Table A4. Discriminant validity HTMT

Construct	Ext	FSMB	Instr	Intention	JS	WLB
Ext						
FSMB	0.352					
Instr	0.327	0.493				
Intention	0.446	0.523	0.410			
JS	0.268	0.213	0.540	0.290		
WLB	0.274	0.268	0.567	0.285	0.622	

Abbreviations: Ext: Extrinsic motivation; FSSB: Family supportive supervisory behavior; Intention: Intention to stay; Instr: Intrinsic motivation; JS: Job satisfaction; WLB: Work-life balance.

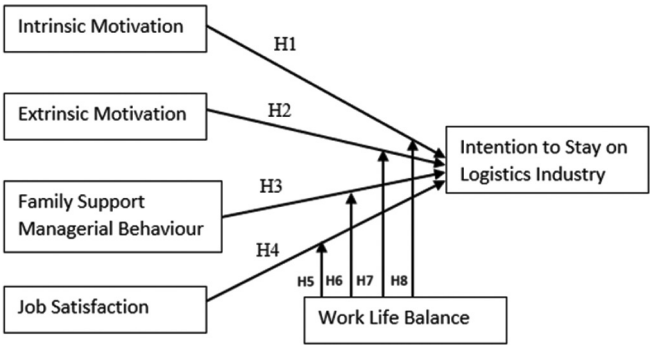

Figure A1. Research framework

ACCSCIENCE PUBLISHING

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RESEARCH ARTICLE

Measuring active aging: Development of a active aging measurement tool

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Abstract

In recent years, various debates have emerged in the literature regarding the conceptualization of active aging. However, there is a lack of tools to assess active aging at the individual level. The aim of this paper is to develop a measurement tool and procedure for assessing active aging focused on an individual level, encompassing different elements of people's lives, and providing an individual quantitative result for each person. To achieve this aim, a representative sample of 404 community-dwelling older adults (aged ≥ 60 years) from Galicia, Spain, was interviewed using a structured survey guided by a questionnaire. The tool is based on an empirically validated model of active aging, which comprises two broad categories (health and participation) as well as a measurement tool. The results presented demonstrate how a region in Spain is actively aging. The discussion highlights the potential of this tool, which integrates different approximations of the concept and underscores its importance in people's lives.

Keywords: Active aging; Model; Index; Measurement; Individual level

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1. Introduction

1.1. Origin of the concept of active aging

The construct of active aging is framed as a concept belonging to the new paradigm of aging, which focuses more on a positive approach to studying older ages and aging (Foster & Walker, 2021). Successful aging theory is usually considered the origin of this new paradigm (Rowe & Kahn, 1987; 1997), whose roots can be traced to the sociogerontological literature of the fifties, such as the activity theory (Havighurst, 1953; 1963). The concept of successful aging has received criticism, but it has influenced the perspective in which older age has been conceived and researched in the past decades (Foster & Walker, 2021). Some other concepts have been defined afterward, focusing on positive aging as an alternative to expected dependence and passivity in older ages, such as productive aging or healthy aging (Foster & Walker, 2015). These share some commonalities, namely, the use of gerontological knowledge to build a positive conception of older age and aging and the challenge to negative stereotypes of advanced stages of life (Lassen & Moreira, 2014).

Compared to healthy aging or productive aging, which focused on one unique element, either health or social productivity, active aging was formulated to transmit

a broader concept (Foster & Walker, 2013; World Health Organization [WHO], 2002). Some references to active aging can be traced back to the late 1970s, whereas other authors consider the International Year of Older Persons (1999) as the launch of this concept when it was developed in an editorial written by Kalache (1999). Nonetheless, different elaborations about how activity is linked to the opportunities to be healthy in later life raised in articles before the 2000s. Later, the worldwide definition of "active aging" was presented in the document "Active Aging: A Political Framework" (WHO, 2002), elaborated as a result of the Madrid International Plan of Action on Aging and the Political Declaration adopted at the Second World Assembly on Aging of the United Nations held in 2002. This plan is the turning point in the focus of the WHO to address the challenge of building a society for all ages by integrating into the new political concept the scientific tradition developed in the past decades of the 20th century. While the need to create and maintain opportunities for older people to remain active is highlighted, other important factors in the aging process beyond health, such as activity and participation, are also recognized (Fernández-Ballesteros, 2005; Kalache & Kickbusch, 1997; WHO, 2002).

Active aging was defined as "the process of optimizing opportunities for health, participation, and security to enhance the quality of life as people age" (p. 12). Three basic pillars are identified to promote active aging: participation, health, and security, to which a fourth pillar was subsequently added, that is, lifelong learning (International Longevity Center Brazil, 2015). The aim is that people can develop their full potential for physical, social, and mental well-being throughout their lives and participate in society according to their needs, desires, and abilities while providing adequate protection, security, and care when they need assistance (WHO, 2002). Activity is, thereby, represented by continuous participation in diverse activities in terms of social, economic, cultural, physical, and routine activities. Active aging, therefore, unifies the ideas of activity and participation, health, independence, and good aging but provides participation with a main role (Van Malderen *et al.*, 2013).

Hence, active aging is a broader and more inclusive concept than the previous ones embedded in this paradigm (Bowling, 2008; Mendes, 2013; Van Malderen *et al.*, 2013; Stenner *et al.*, 2011). By definition, it gathers individual elements of productive and healthy aging from a multidimensional perspective (Foster & Walker, 2013; Kalache & Kickbusch, 1997; WHO, 2002; Van Malderen *et al.*, 2013). In addition, the importance of an active and proactive attitude from people in their own aging process is added instead of focusing on results. Based on the conceptualization, it defends an active lifestyle while respecting the possibilities of each individual, including fragile people or people with disabilities, frequently excluded in other operationalizations (Sidorenko & Zaidi, 2013; WHO, 2002).

Some principles have been outlined to preserve the ambition of the concept (Foster & Walker, 2021; Walker, 2002). Here, activity is considered a broad concept, including all significant activities that improve the well-being of individuals and families, the local community, and society. In addition, it argues that all older people should be included in the concept – not only young, independent, and healthy people but also fragile, dependent older people. Third, it is conceived as a preventive concept with a whole-life course perspective, whereas the fourth principle claims the enhancement of intergenerational solidarity and opportunities. The fifth point is that both rights and responsibilities are implied in terms of social protection and lifelong education and learning, insisting on the obligation to take advantage of these opportunities. Sixth, empowerment and participation are important effects of active aging, given that they promote citizens' active attitudes in terms of bidirectional communication between society and policies. This approach is fostered to avoid imposition from high hierarchies and to prevent the conversion into a coercive strategy. The seventh principle suggests that active aging must respect national and cultural diversity regarding ways of participation without falling into valuing judgments about which activity is the best. The latter refers to the need to integrate flexibility into this approach. The individual perspective of active aging defends the existence of variation among individuals and their available sources to age well, which, in addition to the changes in limitations and preferences that occur during the life course, give rise to differences in the individual aging process.

From a political perspective, active aging refers to both individual and collective strategies to optimize economic, social, and cultural participation during the life course to manage current and future aging populations (Kalache & Kickbusch, 1997; Lassen & Moreira, 2014; WHO, 2002). However, this term has spread in society, and older people have their own conceptions of active aging. Some studies have researched how older adults define it, concluding that positive terms are used in the definition, referring to both health as a global concept (Bowling, 2008; 2009; Lucena *et al.,* 2010) and activity and participation (Clarke & Warren, 2007; Lucena *et al.,* 2010; Stenner *et al.,* 2011; Townsend *et al.,* 2006). Health includes multiple dimensions, such as maintaining good physical health

and body functioning, mental functioning and activity, and social relationships and contact (Bowling, 2008; 2009; Stenner *et al*., 2011). References to activity or participation are also found in their own perspectives, in which physical, mental, and social activities are mixed, alluding to a general active lifestyle in which all these are included. In doing so, they highlight leisure, family care, volunteering, learning, traveling, or physical activity (e.g., Bowling, 2008; Hasmanová, 2011; Stenner *et al.,* 2011; Townsend *et al.,* 2006; Venn & Arber, 2011), whereas employment was not clearly included (Venn & Arber, 2011). A complete representation covering the main dimensions, highlighted by the different approaches and debates around active aging, is less frequently found in the research (Montero *et al*., 2011; Paúl *et al*., 2012; Perales *et al.,* 2014).

1.2. Literature on measurements of active aging

At present, there is still an absence of a gold standard for rating active aging. This concept has been partially assessed by considering some specific elements such as employment, social participation, and, less frequently, leisure time, and activities (Marsillas, 2016), whereas relatively few studies have measured it from a broad conception. In those cases, items or scales were used separately when measuring the components of the concept (Caprara *et al.,* 2013), or they were measured through the compliance of a list of criteria to create a dichotomous variable representing active aging (Bélanger *et al.,* 2017; Fernández-Ballesteros *et al*., 2007). This measurement procedure is too strict because it generally delimits active aging to a specific group of people and is not sufficiently flexible to depict the evolution of people. Another approach was the summative measurement of dichotomous variables and the creation of a continuous variable for active aging (Perales *et al.,* 2014).

In the past few years, instruments have been developed to quantitatively measure active aging, with the Active Aging Index (Zaidi *et al*., 2013) being the most acknowledged. It was developed based on the population perspective, with the collaboration of the European Commission's Employment, Social Affairs, and Inclusion Directorate General and the United Nations Economic Commission for Europe (UNECE). This toolkit is developed as an index targeted at policymakers and aimed at measuring the potential of active aging at a country level based on 22 indicators organized in four domains: (i) employment; (ii) participation in society; (iii) independent, healthy, and secure living; and (iv) capacity and enabling environment for active aging. The information for each indicator comes from secondary data sources for 28 European countries, such as the European Social Survey. The index sheds light on the effectiveness of existing strategies and points out the environmental elements that can be improved to increase opportunities to age actively. The concept of the Active Aging Index (AAI) incorporates an economic dimension that involves the inclusion of older persons in the labor market and other productive activities. However, it cannot be used to measure active aging at an individual level since its indicators are macrolevel-oriented, such as healthy life expectancy, and the result provided is based on the aggregate number of older people that meet different indicators.

In academic literature, some attempts to measure active aging at an individual level can also be found. In recent years, empirical models have been developed, but tools to measure this concept with a multidimensional and inclusive conception are scarce. Existing measurements are focused either on specific dimensions of active aging or have been developed through a closed list of criteria, which may exclude some people and do not represent older people's ways of engaging. Therefore, in contrast to the intentions when conceptualizing active aging as a broad concept, measurement in studies has been made through dichotomous and criteria variables created when all its elements were met (e.g., Fernández-Ballesteros *et al*., 2007; Lucena *et al.,* 2010; Montero *et al.,* 2011). The inclusion criteria tend to be relatively high, and the compulsory fulfillment of them creates rigid ways of active aging (Perales *et al*., 2014). This operationalization can also result in the exclusion of people with some disabilities, which contradicts the statements of WHO (2002). Conversely, engagement in life should be promoted even when constraints are present by adapting the forms to each person's situation (Boudiny, 2013), such as the assessment method developed to measure active aging (Rantanen *et al.*, 2019). In the case of the AAI, population- and macrolevel approaches focusing on productive participation and health variables do not cover the gap of a tool that contributes to quantifying active aging in older adults. For this reason, it is necessary to measure the concept of active aging, which represents inter- and intra-individual variability as a continuum (Bowling, 2008).

1.3. Aims of this study

The aims of this study were threefold. First, we developed a new measurement tool based on a tested model of active aging (Marsillas *et al.,* 2017), focusing on the individual level. This tool was developed considering the debates about active aging and by combining the most important dimensions found in the scientific literature regarding the elements enhanced by policy, research, and lay approaches. By including both health, conceived as a global concept, and participation, as a broad variety of alternative ways to actively age, it intends to represent more diverse population groups sometimes excluded by measurement procedures.

In doing so, a recurrent problem in the literature will be overcome, namely, the partial study of the concept of active aging. Second, it aims to construct a personal active aging index that allows quantification of this concept. The goal is to achieve a procedure that allows us to create a quantitative continuous variable, which can provide richer information than only establishing if somebody ages actively or not (Perales *et al.*, 2014). For instance, this could help evaluate the efficacy of initiatives related to active aging promotion. In doing so, an individual measuring tool will be provided that allows the quantification of the active aging of people, the value of the dimensions composing the index, and the identification of the improvement areas of each person. Thus, an efficacy assessment of the initiatives implemented to promote active aging was conducted and improved with the information provided. Third, the descriptive results for older adults living in Galicia (Spain) in terms of active aging are shared.

2. Methods

2.1. Study sample

The study methodology was based on a survey of a representative sample of community-dwelling residents aged 60 years and over in Galicia, Spain. In Galicia, 804,403 inhabitants are aged ≥ 60 years, representing 29.2% of the total population. Structured interviews were conducted by experienced psychologists using a questionnaire. The sample size was calculated based on the population size and a 95% confidence level with a 5% margin of error. The sampling selection was made through the county register, and a two-stage sampling was chosen: conglomerates for the selection of the first-level units (municipalities) and quotas according to the habitat (urban/semi-urban vs. rural/semi-rural), gender, and age group (60 – 74 years *vs.* 75 or older) for the selection of the second-level units (individuals). No personal data were requested, and anonymity and confidentiality were guaranteed. Ethical review and approval were waived for this study because the data collected in the study were anonymous and according to the Organic Law on Personal Data Protection and Guarantee of Digital Rights (Article 2.2. LOPD 3/2018). The participants were informed about the aim of the research and provided verbal consent. Participation in the study was voluntary.

Based on the population distribution, the final sample was composed of 404 individuals (176 men and 228 women; mean age = 72.6 years and range = 60 – 94 years), recruited directly by interviewers in different community facilities regarding those venues where people of different profiles usually attended. In this sense, we included social centers, which are oriented toward older people to meet to have coffee, perform exercise, read newspapers, or arrange issues related to the municipality, as well as clinics, around hospitals, or markets. Regarding the habitat, 59.2% are residents of a rural/semi-rural area, whereas 40.8% are from an urban/semi-urban area. Thirty percent of the respondents did not complete primary studies, 32.9% completed primary education, 21.0% completed secondary education, and 16.1% completed tertiary education. In terms of marital status, 9.2% were single, 58.1% married, 3.0% divorced, and 29.7% widowed.

2.2. Variables and measures

The variables included in the questionnaire were chosen based on a literature review (Marsillas, 2016) and assessed the ten broad dimensions of: (i) health (objective and subjective health), (ii) functionality (basic and instrumental daily activities), (iii) cognitive state, (iv) affective state, (v) social state (social and family perceived support, frequency of outdoor social contact), (vi) Information and Communication Technologies (ICT) use, (vii) lifelong learning, (viii) employment, (ix) participation in society, and (x) leisure activities, as well as sociodemographic variables (age, gender, habitat, marital status, education, and income).

The dimensions of active aging were measured using different scales. Functionality was evaluated using the Barthel Index (Cronbach's alpha = 0.83) (Mahoney & Barthel, 1965) and Lawton and Brody Scale (Cronbach's alpha = 0.92) (Lawton & Brody, 1969); cognitive status was measured using the Mini-Examen Cognoscitivo, the Spanish version of the Mini-Mental State Examination (Cronbach's alpha = 0.73) (Lobo *et al.,* 1999); affective status as part of mental health was measured using the positive affect scale of the Affective Balance Scale (Cronbach's alpha = 0.76) (Godoy-Izquierdo *et al*., 2008); different leisure activities were measured using items from Scarmeas *et al.* (2003) and by adding two more items; participation in society and employment were assessed with several items from the Active Aging Index (Zaidi *et al.*, 2013). Health was assessed using seven items created for this study, ICT use was measured using three items, including one from Zaidi *et al.* (2013), and social state was evaluated using a scale created for this study (Cronbach's alpha = 0.83) by combining selected items from Zaidi *et al.* (2013), the Spanish version of the Duke-UNC-11 scale (Bellón *et al.,* 1996a), and modified items from the Spanish version of the Family APGAR (Bellón *et al.,* 1996b).

2.3. Statistical analysis

Based on the statistical model of active aging that has already been tested and published (Marsillas *et al.,* 2017), a composite index was constructed following the

methodology and steps proposed by the OECD (2008). Some of the original scales used to measure the dimensions of active aging had range scores starting at values different from 0. Therefore, after scoring each scale following the corresponding instructions, the individual scores were recoded to be added to the index. The minimum score in each item and scale was represented as 0, corresponding to the lack of presence of the dimension assessed, instead of having a minimum score of 5, which could correspond depending on the correction procedure, for instance. As leisure was scored based on frequency regarding a large number and variety of activities, it would be difficult to fulfill all the leisure activities at the highest level. For this reason, these variables were recoded before calculating the leisure dimension index (Table 1).

The values of each subdimension and subscale are detailed in Tables 2 and 3. The indexes for the subscales were first calculated by summing all the responses and then standardizing each subscale score using the minimum-maximum method (OECD, 2008) (Equation I). The result was a score for each dimension on a scale from 0 to 1, where 0 is the worst result, and 1 is the best result possible.

$$\text{Index} = \frac{\text{Real score} - \text{minimum score}}{\text{Maximum score} - \text{minimum score}} \quad \text{(I)}$$

To obtain a higher dimension, the mean of all indices composing the upper dimension was determined, providing the same weight to all subdimensions. As an example, to calculate the physical health subdimension, the subscales of objective health and subjective health were calculated following the steps indicated above for standardization, and then, the arithmetic average of the indicators was calculated. Each index can be classified into three levels based on the criteria of the Program of the United Nations for Development (2006), where <0.5 means low level, between 0.5 and 0.79, moderate level, and >0.80, high level.

Table 1. Scores of leisure dimension

Subscale	Subscale range	Recoded values
Artistic	0 – 4	0: 0 1 – 2: 0.5 3 – 4: 1
Productive	0 – 4	0: 0 1 – 2: 0.5 3 – 4: 1
Recreative	0 – 4	0: 0 1 – 2: 0.5 3 – 4: 1
Social	0 – 6	0: 0 1 – 2: 0.5 3 – 4: 1
Solitary	0 – 4	0: 0 1 – 2: 0.5 3 – 4: 1
Outdoors	0 – 6	0: 0 1 – 3: 0.5 4 – 6: 1

After the index was determined, a data analysis was conducted using SPSS 21.0 for Windows (IBM Corporation, New York, USA). A descriptive analysis was carried out, in which means and standard deviations were calculated. Moreover, the Pearson correlation coefficient was calculated to quantify the degree and direction of the relationships between the variables comprising the health and participation dimensions.

3. Results

After assessing the psychometrics, the index was constructed, and descriptive results were extracted. The mean and standard deviation were calculated for all dimensions and sub-dimensions comprising the active aging index (Table 4).

The level of active aging in this sample was moderate ($M = 0.66$). The dimension of global health ($M = 0.77$) had a higher value than the participation variables ($M = 0.45$). Health, functionality, and social state achieved the highest means ($M = 0.94$) and ($M = 0.91$), respectively, and goals and positive emotions achieved the lowest values ($M = 0.33$) and ($M = 0.43$), respectively. Regarding participation, leisure had the highest value ($M = 0.51$), followed by ICT and lifelong learning ($M = 0.42$). Employment had the lowest value ($M = 0.08$).

4. Discussion

This study was carried out to develop an individual measurement instrument that quantifies the degree of active aging of a person and summarizes it into one unique continuous score. This tool is based on an empirically supported model of active aging. This study contributes to the empirical literature in the field of active aging paradigm with a more comprehensive approach based on a multidimensional perspective and the development of a tested measurement instrument for active aging aimed at the individual level. For this, a tool was constructed based on an empirical model (Marsillas *et al.*, 2017), following the steps recommended by experts to construct composite indices (OECD, 2008; United Nations for Development, 2006). The instrument presented here facilitates the achievement of an individual continuous score not only in each of the dimensions or subdimensions comprising active aging but also in the concept as a whole. The scores provided show not only the performance in each

Table 2. Subscale values to calculate the active aging index

Dimension	Subdimension	Subscale	No. of items	Items	Range of items	Range of subscale
Health	Physical	Objective health	3	(i) Presence of symptoms in the past two weeks. Recoded 0/1 based on average. (ii) Absence/presence of chronic disease. (iii) Absence/presence of non-chronic disease or psychological stress in the past 3 months.	0 – 1	0 – 3
		Subjective health	4	(i) Perceived limitations in daily activities. (ii) Perception of daily activity limited by cognitive state. (iii) Satisfaction with health. (iv) Perceived on health compared to peers.	0 – 4	0 – 16
	Functionality	Functionality	2	(i) Independence in Basic Life Activities. (ii) Independence in Instrumental Life Activities.	0 – 4	0 – 8
	Cognitive	Cognitive	1	(i) Mini-examen cognoscitivo. Well-cognitive state versus possible cognitive decline.	0 – 1	0 – 1
	Affective	Situation in life	4	(i) Feeling things are going well. (ii) Feeling glad for having people to count on. (iii) Feeling full of energy. (iv) Feeling confident about the future.	0 – 2	0 – 8
		Emotions	3	(i) Joy. (ii) Cheer or happiness. (iii) Euphoric.	0 – 2	0 – 6
		Goals	2	(i) Interest. (ii) Achievement.	0 – 2	0 – 4
	Social	Friends	3	(i) Frequency of contact with friends and family. (ii) Satisfaction with relationship with neighbors. (iii) Satisfaction with relationship with friends.	0 – 4	0 – 12
		Family	9	(i) Visits. (ii) Having people who care about oneself. (iii) Possibility to talk to someone about problems. (iv) Receiving invitations to entertain or going out. (v) Receiving help when being ill. (vi) Receiving love and affection. (vii) Satisfaction with help from family. (viii) Satisfaction with time spent with family. (ix) Feeling loved by family.	0 – 4	0 – 36

dimension but also the improvement areas to enhance in the intervention, according to individual preferences. This approach solves one relevant gap in this field, namely, the absence of a personal measurement tool that unifies all the components in the same score and quantifies active aging as a continuous variable (Bowling, 2008; Fernández-Ballesteros, 2009).

Both concept and measurement tool development were aimed at the individual after reviewing different approaches to active aging to extract the main subdimensions linked to not only the theoretical definitions (e.g., WHO, 2002) but also according to the debates found in the literature (Marsillas *et al.,* 2017). Components included allude to personal conditions, such as physical, functional, cognitive, affective, and social dimensions, as well as participation in terms of social participation, employment, leisure, lifelong learning, and use of ICT. Taking into consideration also the ambient and socioeconomic aspects would imply assessing another construct called quality of life (Fernández-Ballesteros, 2009), so they were proposed as external conditions of life influencing active aging (Boudiny, 2013; Fernández-Ballesteros, 2009). Here, this concept was addressed in terms of objective and subjective variables to capture the personal perspective (Stenner *et al.,* 2011). Both are necessary given that the subjective variables refer to older people's perceptions of their conditions, whereas the objective ones impede the consideration of a situation as a good one when it is not so (objective and subjective health). In some cases, self-assessments are better predictors of mortality than objective evaluation (Fernández-Ballesteros, 2009; Schoenfeld *et al.,* 1994), but by including objective variables, the "wellbeing paradox" is softer.

Table 3. Subscale values to calculate the active aging index

Dimension	Subdimension	Subscale	No. of items	Items	Range of items	Range of subscale
Participation	Employment	Employment	1	Paid work.	0–1	0–1
	Participation in society	Participation in society	3	(i) Caring for children and grandchildren. (ii) Political participation. (iii) Volunteering.	0–1	0–3
	Use of ICT	Use of ICT	3	(i) Use of mobile phone. (ii) Use of computer. (iii) Use of the Internet.	0–4	0–12
	Lifelong learning	Lifelong learning	2	(i) Attendance to lectures. (ii) Attendance to courses within/outside the regular education system. (iii) Reading.	0–1	0–1
	Leisure	Artistic	2	(i) Singing/playing instruments. (ii) Drawing or crafts.	0–2	0–1
		Physical	2	(i) Walking. (ii) Sports, exercise, or dancing.	0–2	0–1
		Productive	2	(i) Gardening. (ii) Cooking.	0–2	0–1
		Recreative	2	(i) TV watching. (ii) Games: Crosswords, Sudoku, etc.	0–2	0–1
		Social	2	(i) Playing cards/other games with people. (ii) Visiting friends/relatives/neighbors.	0–2	0–1
		Solitary	2	(i) Time for oneself. (ii) Collect things.	0–2	0–1
		Outdoors	3	(i) Cinema/Theater. (ii) Traveling. (iii) Associations or clubs.	0–2	0–1

Abbreviation: ICT: Information and communication technologies.

Results corroborated that active aging can be measured at an individual level. Active aging has been proposed as a higher-order construct composed of two broad categories of variables: (i) Health and (ii) participation. The first group includes elements related to health as a multidimensional concept, considering physical, mental, and social variables. These findings are consistent with those of authors who study active aging, such as Bowling (2008), Montero *et al.* (2011), and Perales *et al.* (2014). However, some academics have rejected the inclusion of health in active aging (Boudiny, 2013). This omission may be due to the frequent restriction of physical components and the absence of diseases, as well as becoming the center of the concept and neglecting other important elements, such as participation. Moreover, the common consideration of active aging as a criteria list where an absence of chronic diseases and disability is included contributes to restricting this concept to specific groups (Strawbridge *et al.*, 2002). However, physical health cannot be the only axis of the concept, as it is neither sufficient nor indispensable to actively age (Clark & Warren, 2007; Stenner *et al.*, 2011). Social variables represent the most important variables within this dimension. Older people highlight the value of social relationships, and a trend is detected in which older people prefer emotionally close relationships, in which the quality of social contacts prevails over quantity (Berg, 2008). Although the affective state represents a less contributing component compared, for instance, to social variables or cognitive state, the results can be comparable to those of Bowling *et al.* (2008), in which psychological functioning represents a response less provided when referring to active aging.

Participation variables represent different types of activities, including both productive and leisure activities, following the preferences and perceptions of older adults (Boudiny, 2013; Clarke & Warren, 2007; Stenner *et al.*, 2011). In doing so, a more inclusive approach to active aging is addressed, which unifies the policy, scientific, and lay perspectives. It supports the mainstream ideas about productive activities as defended by policymakers in terms of employment, social participation, and leisure activities, mainly defended by researchers (Boudiny, 2013; Foster & Walker, 2013; Hasmanová, 2011) and older people's definitions (Bowling, 2008; Stenner *et al.*, 2011). Without

Table 4. Descriptive results of active aging and dimensions

Indices	Median	S.D.	Minimum	Maximum
Physical health index	0.65	0.20	0.03	0.97
Objective physical health index	0.60	0.32	0	1
Subjective physical health index	0.70	0.16	0.06	0.94
Functionality index	0.94	0.15	0	1
Cognitive index	0.86	0.35	0	1
Affective index	0.47	0.23	0	1
Affective index: Goals	0.33	0.35	0	1
Affective index: Emotions	0.43	0.30	0	1
Affective index: Situation in life	0.65	0.26	0	1
Social index	0.91	0.14	0	1
Social index: Family	0.91	0.16	0	1
Social index: Friends	0.92	0.16	0	1
Employment index	0.08	0.28	0	1
Participation in society index	0.38	0.49	0	1
Use of ICT index	0.42	0.35	0	1
Lifelong learning index	0.42	0.28	0	1
Leisure index	0.51	0.17	0.07	0.93
Global health index	0.77	0.13	0.27	0.99
Global participation index	0.45	0.25	0.02	1.00
Global active aging index	0.66	0.15	0.18	1.00

Abbreviations: ICT: Information and communication technologies; S.D.: Standard deviation.

the combination of these elements, active aging would be restricted to health, and even from a multidimensional perspective, it would omit active and involved lifestyles (Boudiny, 2013). Leisure activities contributed the most to the participation variables. This result is in agreement with the authors, who argue that leisure activities indirectly increase life satisfaction (Boudiny & Mortelmans, 2011; Bowling, 2008; Clarke & Warren, 2007). Different types of leisure activities were included, even those traditionally excluded from being considered rather passive, such as watching TV, solving crosswords, or gardening, since they are important to the oldest (Avramov & Moskova, 2003; Clarke & Warren, 2007; Pettigrew & Roberts, 2008; Townsend *et al.*, 2006). Home-based and solitary leisure activities were also considered part of the index. The rationale for including them was to count the diversity of activities that embrace the changing preferences and selection of activities derived from constraints in health and physical abilities, which tends to lead to more home-based leisure (Gauthier & Smeeding, 2003; Venn & Arber, 2011; Verbrugge *et al.*, 1996). The importance of ICT use is shown as a participation variable and part of the concept of active aging, which agrees with Boudiny & Mortelmans (2011). Subsequently, as stated by previous authors who referred to ICT's benefits (Boudiny & Mortelmans, 2011; Small *et al.,* 2009), these results are in line with the current encouragement of their use to promote older people's inclusion, and they provide empirical support for their inclusion as constituents of the concept of active aging. We found lifelong learning to be another important dimension that influences older people's well-being (Walker, 2002). Productive activity, both in terms of employment and social participation, contributed relatively little to the active aging construct. The reasons behind this may be related to the fact that the proportion of older people in working age was small in relation to the total age range, both for the current unemployment trend, the retirement schemes, and the lower labor opportunities at older ages (Avramov & Maskova, 2003; Boudiny, 2013; Hirsch, Macpherson, & Hardy, 2000; Walker, 2006; WHO, 2002). A relatively low level of social participation was found, for instance, in the case of volunteering, due to the frequent existence of upper age limits (Foster & Walker, 2013; Gauthier & Smeeding, 2003). Another factor that could explain this result is the share of people living in suburban environments, where the attendance at volunteer organizations or the distance to relatives make participation difficult (Monreal, 2008). Moreover, sometimes tension exists among work, care responsibilities, volunteering, and leisure; thus, certain patterns of leisure can impede social participation (Dury *et al.,* 2015).

Despite these findings, this study also has some inherent limitations. First, the cross-sectional nature of the research does not permit the verification of the causal relationship among variables. On this topic, each component of active aging could act as a predictor as well (Hasmanová, 2011). However, the proposed tool had a good representation of the different components of active aging presented in the literature according to different approaches. Second, there is a lack of a gold standard for measuring and rating active aging (Rantanen *et al.,* 2019), which makes the complete validation process difficult. Although this study was developed in an attempt to provide a new index based on an empirically supported model that covers a wide range of indicators, a future validation study should include alternatives for testing the criterion-based validity as well to prove if the new index is more inclusive as intended. Third, although one of the aims was to determine the influence of active aging on the cognitive and subjective components of well-being and life satisfaction, it could also be interesting to add quality of life as an outcome variable (WHO, 2002). Fourth, most of the variables are assessed by self-

reporting; thus, subjective perception may influence the results. Nevertheless, in future research, validity could be tested by comparing it to objectively measured equivalent variables, such as the specification of social networks in the case of perceived social support. Finally, by including more antecedents or predictor variables with long-term effects and covering a multilevel model (Fernández-Ballesteros, 2008), more complete information can be provided. Future research could take these considerations into account. This study, however, was performed to develop an empirically supported individual measurement instrument for active aging based on a broad and inclusive individual concept and the theory of active aging, which integrates the different approaches addressing this concept. The final aim was to complement the population perspective of active aging by focusing on individual variables that are likely to be modified by individual-level interventions.

Based on the results hereby presented, the next steps to promote active aging in our region could be done simultaneously from a double perspective, both at the micro level, focused on older people, and at the meso- and macrolevels, related to neighborhoods and communities, public policies, and institutional environments (Sidorenko & Zaidi, 2013). A focus on enhancing health and participation should be expanded, always according to older adults' preferences, and adapting to the environment and contextual elements while maximizing individual conditions. For this, the coordination of health and social measures, education, employment, economy, social security, living arrangements, transport, and urban and rural development is crucial (Lassen & Moreira, 2014; Walker & Maltby, 2012; WHO, 2002). In addition, the benefits of the active aging process need to be more disseminated, enhancing the active participation of older people in society and in decisions that have an impact on their lives. More programs promoting active aging components should be built and assessed to prove their efficacy on active aging during the course of life (Boudiny, 2013; Fernández-Ballesteros *et al.*, 2004). However, it is necessary to prevent this discourse from transmitting a compulsory strategy as well as unique self-responsibility to individuals. In these cases, negative consequences would be produced, such as personal discomfort, blaming, and the oppression of older people, stepping back to narrower concepts such as successful aging or productive aging (Boudiny, 2013; Hasmanová, 2011; Ranzijn, 2010).

In addition, it is necessary to be aware that some critiques about active aging point out that the activities and values promoted by policy and research are mainly associated with first stage of old age (the young-old) or functionally independent old people (Boudiny & Mortelmans, 2011; Van Dyk, 2014), whereas activities not linked to middle-aged people usually result in stigmatization (Venn & Arber, 2011). Another source of critical thinking is that the lifestyle promoted in the current discourse of active aging is easy to follow by people who can afford it, who have the physical or mental ability to do so, and who can participate in the institutions where it is promoted (Biggs, 2001; Bowling, 2005; Hasmanová, 2011). It means that this rhetoric may become coercive, as the social images promoted are being interiorized by older people (Foster & Walker, 2015; Katz, 2000; Townsend *et al.,* 2006), with high expectations placed on them (Boudiny, 2013). Those expectations can be assumed as a challenge or a threat depending on personal circumstances in terms of health, educational level, or income (Pavlova & Silbereisen, 2012). In addition, this paradigm is not fully prepared to incorporate the notion of decline (Foster & Walker, 2015; Moulaert & Paris, 2013), and it ignores the barriers of certain social groups to meet the ideals of older ages (Hasmanová, 2011). Thus, active aging may be presented as unattainable for a large group of people who are old or who live with a disability and cannot join active aging as it is being promoted (Holstein & Minkler, 2003). This situation results in subtle or overt social discrimination or exclusion of old-old people, as well as vulnerable, fragile, and dependent people who do not meet the criteria in terms of health, independence, productivity, and activity (Boudiny, 2013; Ranzijn, 2010; Van Dyk, 2014). For those reasons, policies and programs should increase the opportunities to remain active, adapting them when necessary, such as in the case of dependent people (Boudiny, 2013; WHO, 2002). This issue is also related to how active aging has been presented in practice, narrower than the theorical conceptualization (Boudiny, 2013; Foster & Walker, 2015). Unless changes are made to include new alternative ways to age actively, it will result in a new categorization of older ages as being narrow, oppressive, excluding, and normative, with an excessive idealization of older ages (Foster & Walker, 2015; Holstein & Minkler, 2007). Thus, the same mistakes from active theory (Boudiny, 2013) and successful aging (Pruchno *et al.,* 2010; Strawbridge *et al.*, 2002) could be made. Future research on this concept may evolve toward meaningful (active) aging, focusing more on what is meaningful for aging people and linking this paradigm of activity to what is relevant and generates subjective well-being for older adults.

5. Conclusions

In this study, a tool that can assess active aging in an integral, quantitative, and continuous way is tested and shared. Due to its operationalization, people who otherwise could not

meet the exigent criteria of active aging were included, taking into account the various dimensions, abilities, and activities present in their lives. It provides some progress toward a broader version of active aging. Moreover, this tool is aimed at an individual level and could contribute to meeting the need to provide empirical evidence regarding the effectiveness of intervention programs (Bowling & Iliffe, 2006). In doing so, the recommendations about incorporating the heterogeneity of older people as a continuum are incorporated (Fernández-Ballesteros, 2009). Its importance is reflected in the manifest concern about the transformation of this paradigm into an excessively idealized one, which may result in a negative impact on older people's well-being by presenting an extremely positive image of active aging and neglecting the reality faced by older adults (Hasmanová, 2011; Holstein & Minkler, 2007). The results obtained support the hypothesis of including two big types of variables as components of active aging: Those referring to global health and those alluding to different ways of participation. All these variables are proposed from a multidimensional perspective by matching different spheres of people's lives. Thus, the triangle created by the three approximations found in the literature (political, scientific, and social) is reconciled in a certain manner.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: Sara Marsillas, Jesús Varela
Formal analysis: Sara Marsillas, Antonio Rial
Investigation: Sara Marsillas, Antonio Rial
Methodology: All authors
Writing – original draft*:* Sara Marsillas
Writing – review & editing*:* All authors

Ethics approval and consent to participate

The acquisition of ethical approval is not necessary, as participants have given their verbal consent.

Consent for publication

Informed consent was provided verbally.

Availability of data

The data used in this work are available from the corresponding author on reasonable request.

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RESEARCH ARTICLE

Analysis of age-specific fertility in India: Deterministic and non-deterministic modeling approaches

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Abstract

The main objective of this study is to investigate the pattern of age-specific fertility rates (ASFRs) in India using deterministic and non-deterministic approaches. Toward this end, we proposed statistical polynomial regression models to study the distributional pattern of ASFRs for total, rural, and urban women in India. Further, a comparative study considering selected skewed regression models was undertaken. For this study, secondary data on ASFR were collected from Sample Registration System, Statistical Report-2020, and from National Family Health Survey 5 (NFHS-5; 2019 – 2021). It was found that all three subcategories of ASFRs, namely, the total, rural, and urban ASFRs, followed the reciprocal biquadratic polynomial model. On the other hand, all three subcategories of ASFR follow the skew-normal type 2 distribution. Similar findings were also obtained and validated based on NFHS-5 data. Further, the chosen statistical models' validity and stability were tested using various model validation techniques and model selection criteria.

Keywords: Age-specific fertility rate; Polynomial regression model; Skewed regression model; Cross validity prediction power; Shrinkage; Coefficient of determination

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1. Introduction

Like in many other developing countries, fertility is an essential issue with significant social, economic, and demographic consequences in India. The fertility rate is an important metric that describes changing patterns of the demographic configuration of a nation concerning its population size, composition, and growth rate. The age of women is an essential factor affecting fertility levels. Further, age-specific fertility rates (ASFRs) provide a clear picture of the fertility behavior of women in different age groups. ASFR is defined as total number of babies born per 1000 women in a specific age group in a particular region. To monitor and detect the change in population in any region, *for example*, district, state, or country, it is crucial to study its fertility and, more specifically, its age-specific fertility behavior.

According to Sample Registration System (SRS-2020) in the states of Andhra Pradesh and West Bengal, fertility reached its peak in the age group 20 – 24. In Jammu and

Kashmir, fertility reached its peak in the age group 30 – 34. In all other bigger states or union territories, the highest fertility has been attained in the age group 25 – 29. Fertility, however, declines from age 30 in all the bigger states or union territories, except Jammu and Kashmir where it declines from age 35. The ASFR in the younger age group 15 – 19 varies from 2.6 in Delhi to 22.3 in West Bengal. In the age group 30 – 34, the variation in the level of ASFR is from 41.9 in West Bengal to 147 in Bihar (SRS, 2020).

Another important measure of fertility that has been used to measure the replacement level of fertility in any region is the total fertility rate (TFR). TFR is measured by summing up all the ASFRs. According to SRS-2020, TFR for the country decreased to 2.0 in 2020 from 2.1 in 2019. During 2020, Bihar reported the highest TFR (3.0), while Delhi, Tamil Nadu, and West Bengal reported the lowest TFR (1.4). At present, the TFR among rural women is 2.2 at the national level, which is higher than that of urban India (having a TFR of 1.6). At the national level, there is an increasing trend in fertility in the more advanced age group 30 – 44, while there is a decrease in fertility in the younger age group 15 – 29 (SRS, 2020).

ASFRs offer a clear picture of the fertility patterns, as they provide information on the likelihood of a woman giving birth within a specific age range. In the Indian context, analyzing the ASFRs can offer insight into the country's fertility trend, including factors such as women's education, healthcare, and family planning (Singh *et al.*, 2022). By examining the ASFR, policymakers can make informed decisions regarding population policies, healthcare, and education policies since regions with high ASFRs will cause significant population growth and other health-related issues. Verma *et al.* (2019) proposed various age-specific contraceptive policies to reduce fertility and population growth rates in different age groups. Therefore, a thorough analysis of ASFRs in India is crucial in understanding and addressing the country's demographic challenges. Considering the importance of ASFRs, several studies conducted to observe their pattern and trend are discussed below.

In the existing literature, various fertility models have been proposed and implemented to study the behavior of ASFRs. Some researchers have proposed deterministic models, and others proposed stochastic models. Hoem *et al.* (1981) performed the curve fitting to the ASFR using cubic spline, Hadwiger, Coal-Trussel, Beta, Gamma, Brass, and Gompertz functions. Similarly, a generalized Hadwiger model was used to fit the ASFRs of Hungary and Norway (Gilje, 1969). However, the Hadwiger two-component mixture model was used to study the fertility pattern in the United Kingdom, Ireland, and the United States of America (Chandola *et al.*, 1999). In Pakistan, ASFR was studied using the Makeham curve fitting method (Luther, 1984). Similarly, Azzalini (2003; 2005) applied skew-normal distribution and skew-t distribution to study the pattern of ASFR. Mazzuco & Scarpa (2011) used a skew-symmetric model to fit the fertility pattern of different countries by uni-modal and bimodal-fertility schedules. Skew-logistic model was also used to study the ASFRs of Italy (Asili *et al.*, 2014) and India (Mishra *et al.*, 2017). Gaire & Aryal (2015) proposed the Invers Gaussian model; Gaire *et al.* (2019) used the skew-log-logistic model; and Gaire *et al.*, (2022) formulated the polynomial models to fit the ASFRs of Nepali mothers. Islam (2011) used a polynomial model to fit the ASFRs and forward cumulative ASFRs of Indonesia and found that ASFRs follow the third-degree polynomial model and forward cumulative ASFRs follow the second-degree polynomial model. Singh *et al.* (2015) fitted a third-degree polynomial for different ages and their reciprocal for the ASFRs of India.

In India, the ASFR has been declining steadily in recent decades. However, there are still significant gaps in fertility levels between different states and socioeconomic groups. To achieve such a target, a better understanding of the current pattern of ASFRs is required. Statistical models, when well-constructed, can aid in this understanding as they provide better insight into some characteristics of the distributional pattern of fertility. A few studies have highlighted the use of polynomial model in ASFR modeling in India, but the available evidence is either restricted to single method or outdated and thus a comprehensive analysis of ASFR using both deterministic and stochastic model is necessary.

In general, the ASFR follows a bell-shaped curve that depends on various factors, such as the age of women at marriage, the proportion of married women at a specific age, the proportion of widowhood and separated women, post-partum abstinence and the level of contraceptive use (Balasubramanian, 1980).

In demographic studies, deterministic and non-deterministic (stochastic) modeling techniques are employed. Deterministic models are generally used to describe the functional relationship between the variables under consideration. However, in non-deterministic models, the variables rely on probability distributions (Islam, 2009). In this study, we proposed deterministic and non-deterministic models to study the recent pattern of ASFRs in India. We considered eight deterministic models (viz. linear, second-degree, third-degree, fourth-degree, and their reciprocal polynomial models), and six non-deterministic models (viz. skew-normal (type-1 and -2), skew-t (type-3, -4, and -5) and skew-logistic model) to

study the pattern of ASFRs. Modeling fertility behavior is also beneficial for estimating fertility and facilitating population projections. In this study, both types of modeling techniques, *that is*, deterministic and non-deterministic, were explored, and a comparative study was also undertaken.

This paper is organized into five important sections. In the first section, the background of the study is discussed. The second section deals with the information on the data source and a detailed description of the methodologies used in this study. The results of this study are given in the third section. The discussion and conclusion are narrated in the fourth and fifth sections, respectively.

2. Data source and methodology

2.1. Data source

For this study, secondary data were collected from SRS-2020. SRS provides estimates of various demographic, fertility, and mortality indicators based on the data collected through annual sample surveys for both state and national levels under the Ministry of Home Affairs, Government of India. In this study, we considered ASFRs for different age groups, viz. 15 – 19, 20 – 24, 25 – 29, 30 – 34, 35 – 39, 40 – 44, and 45 – 49, among total, rural, and urban women in India and considered TFRs of some bigger states of India for the year 2020. To validate the proposed best-fitted model, an additional data set on ASFR was collected from the recent National Family Health Survey (NFHS-5) 2019 – 2021, which is the fifth survey in a row conducted by the International Institute for Population Sciences (IIPS), Mumbai under the Ministry of Health and Family Welfare (MoHFW), Government of India. Here ASFR is interpreted as the number of children born per 1000 women in the respective age groups, and TFR refers to the total number of children born by a woman during her reproductive span.

2.2. Polynomial regression model

A polynomial relationship between age (x) and ASFR (y) of degree "k" is defined as (Van Der Waerdem, 1948; Spiegel, 1992):

$$y = f(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + \ldots + a_k x^k \qquad \text{(I)}$$

where a_0 ($\neq 0$) is a constant, a_i (>0) is the coefficient of x^i (i=1,2,3,…,k)

The above functional relationship can also be rewritten as k^{th} degree polynomial model as:

$$f(x) = a_0 + \sum_{i=1}^{k} a_i x^i + \epsilon \qquad \text{(II)}$$

The general form of inverse k^{th} degree polynomial model can be written as:

$$f(x) = a_0 + \sum_{i=1}^{k} a_i x^{-i} + \epsilon \qquad \text{(III)}$$

where $\in$ is an error term follows $(0,\sigma^2)$, and here the aim is to choose a suitable value for k, which minimizes the error sum of square (Gupta & Kapoor, 1997).

From Equations II and III, we can obtain zero-degree (constant), first-degree (linear), second-degree (quadratic), third-degree (cubic), fourth-degree (bi-quadratic) polynomial regression models and their reciprocal form by putting the value of "k" as 0, 1, 2, 3, 4, −1, −2, −3, and −4, respectively.

Age is a monotonic increasing function but probability of bearing children in the later ages is lower than the probability of childbearing for females in the younger ages. Therefore, we considered inverse of female age in the polynomial to examine notable changes (if any) in the predicted values of ASFR. The inverse of age of mother was used as a variable in the polynomial model as it captures the declining trend of the fertility rate with increasing age (Pandey & Kour, 2019). Therefore, the inverse of age is a better predictor of fertility than only age. Using the inverse of age in polynomial models can improve the accuracy of these models and make them more useful for understanding and forecasting fertility trends.

2.3. Model validation techniques

The model validation for the deterministic model can be obtained using various measures such as cross-validation prediction power (CVPP), shrinkage, F-test, velocity, and elasticity curve. These techniques are discussed below in detail.

2.3.1. Cross-validation prediction power

Here, we use CVPP to check the stability of the proposed polynomial models, which is defined as (Stevens, 1996):

$$\rho^2_{cvpp} = 1 - \frac{(n-2)(n^2-1)}{n(n-k-1)(n-k-2)}(1-R^2) \qquad \text{(IV)}$$

where n is the total number of classes, k is the number of regressors in the model, and R^2 is the square of the correlation between observed and predicted values of the dependent variable (*i.e.*, ASFR) obtained from the fitting of the different polynomial regression model.

2.3.2. Shrinkage

In general, the higher the value of the coefficient of determination (R^2), the better the model fits the data. To

measure the stability of R^2 of the model, we can evaluate (1-shrinkage), which is defined as:

$$1-\text{shrinkage}=1-\left|\rho^2_{cvpp}-R^2\right| \quad \text{(V)}$$

where $\text{shrinkage}=\left|\rho^2_{cvpp}-R^2\right|$.

2.3.3. F-test

The F-test is used to verify the significance of R^2 as well as the significance of the proposed model. The F-test statistic is given by (Gujarati, 1998);

$$F=\frac{ESS/(m-1)}{RSS/(n-m)}=\frac{R^2/(m-1)}{(1-R^2)/(n-m)} \quad \text{(VI)}$$

where m is the total number of parameters of the fitted model, n is the number of cases, ESS is the error sum of square, RSS is the regression sum of square, and R^2 is the coefficient of determination of the model.

Further, we considered six selected skewed distributions, viz. skew-normal (type-1, type-2), skew-t (type-3, type-4, and type-5), and skew-logistic distribution, to study the pattern of ASFRs of women in India. The parameters of the proposed models were estimated by the Rigby & Stasinopoulos (2005) method. The models with their probability density functions (PDFs) are discussed below.

2.4. Skew-normal distribution

In this study, we considered two types of skew-normal distributions: skew-normal type-1 and skew-normal type-2, which are explained below briefly.

2.4.1. Skew-normal type-1 distribution

The PDF of skew-normal type-1 distribution is defined as (Azzanani, 1986):

$$f\left(y\mid\mu,\sigma,\nu\right)=\frac{2}{\sigma}f\left(z\right)\text{F}(\nu z) \quad \text{(VII)}$$

for $-\infty\ (y,\mu,\nu)<\infty$ and $\sigma>0$; where $z=\frac{(y-\mu)}{\sigma}$, and f (.) and F (.) are the PDF and cumulative distribution function (cdf) of standard normal distribution respectively.

The mean and variance are given by

$E(Y)=\mu+\left\{2\upsilon^2/\pi\left(1+\upsilon^2\right)\right\}^{1/2}$ and

$Var(Y)=\sigma^2\left\{1-2\upsilon^2/\pi\left(1+\upsilon^2\right)\right\}$.

2.4.2. Skew-normal type-2 distribution

The skew-normal type-2 (or two-piece normal) distribution is defined as (Johnson *et al.*, 1994):

$$f\left(y\mid\mu,\sigma,\nu\right)=\frac{c}{\sigma}\left[\begin{array}{l}\exp\left\{-\frac{1}{2}(\nu z)^2\right\}I(y<\mu)\\+\exp\left\{-\frac{1}{2}\left(\frac{z}{\nu}\right)^2 I(y\geq\mu)\right\}\end{array}\right] \quad \text{(VIII)}$$

for $-\infty<(y,\mu)<\infty$ and $(\sigma,\nu)>0$; where $z=\frac{(y-\mu)}{\sigma}$, and $c=\frac{\sqrt{2}\nu}{\sqrt{\pi}\left(1+\nu^2\right)}$. Note that I(.) is an indicator function, where $I(x)=1$ if x is true, and $I(x)=0$ if x is false.

2.5. Skew-t distribution

There are five types of skew-t distributions that are generally used, namely, skew-t type-1, type-2, type-3, type-4, and type-5. Here, we used only three skew-t distributions, *that is*, skew-t type-3, type-4, and type-5. Interested readers may refer to Azzalini (1986) and Azzalini and Capitanio (2003) for skew-t type-1 and type-2 distributions, respectively. Three considered skew-t distributions are briefly discussed below.

2.5.1. Skew-t type-3 distribution

The skew-t type-3 is a spliced scale distribution and the PDF is defined as (Fernández and Steel, 1998):

$$f\left(y\mid\mu,\sigma,\nu,\gamma\right)=\frac{c}{\sigma}\left[1+\frac{z^2}{\gamma}\left\{\upsilon^2 I(y<\mu)+\frac{1}{\nu^2}I(y\geq\mu)\right\}\right] \quad \text{(IX)}$$

for $-\infty<(y,\mu)<\infty$ and $(\sigma,\nu,\gamma)>0$; where $z=(y-\mu)/\sigma$ and $c=\frac{2\nu}{\left\{\sigma\left(1+\nu^2\right)B\left(\frac{1}{2},\frac{\gamma}{2}\right)\gamma^{1/2}\right\}}$. Here μ is the location parameter, σ is the scale parameter, ν is the degree of freedom and γ is the skewness parameter.

Here, the mode of the distribution is μ. The mean and variance are given by $E(Y)=\mu+\sigma\text{E}(z)$ and $Var(Y)=\sigma^2 Var(z)$, where $E(z)=\frac{2\gamma^{\frac{1}{2}}(\nu^2-1)}{\left\{(\gamma-1)B\left(\frac{1}{2},\frac{\gamma}{2}\right)\nu\right\}}$ and $E(z^2)=\frac{\gamma\left(\nu^3+\frac{1}{\nu^3}\right)}{\left\{(\gamma-2)\left(\nu+\frac{1}{\nu}\right)\right\}}$

2.5.2. Skew-t type-4 distribution

This is also a spliced-shape distribution with PDF defined as (Rigby *et al.*, 2019):

$$f\left(Y\mid\mu,\sigma,\nu,\gamma\right)=\frac{c}{\sigma}\left[\begin{array}{l}\left\{1+\frac{z^2}{\nu}\right\}^{-(\nu+1)/2} I\left(y<\mu\right)\\ +\left\{1+\frac{z^2}{\gamma}\right\}^{-(\gamma+1)/2} I(y\geq\mu)\end{array}\right] \quad \text{(X)}$$

for $-\infty<(y,\infty)<\infty$ and $(\sigma,\nu,\gamma)>0$; where $z=(y-\mu)/\sigma$ and $c=\frac{2}{\nu^{1/2}B\left(\frac{1}{2},\frac{\nu}{2}\right)+\gamma^{1/2}B\left(\frac{1}{2},\frac{\gamma}{2}\right)}$.

The mean and variance are given by $E(Y)=\mu+\sigma\mathrm{E}(z)$ and $Var(Y)=\sigma^2Var(z)$, where $E\left(z\right)=c\left(\frac{1}{\gamma-1}-\frac{1}{\nu-1}\right)$ for all $(\nu,\gamma)>1$ and $E\left(z^2\right)=\frac{c}{2}\left[\begin{array}{l}\left\{\gamma^{3/2}B\left(\frac{1}{2},\frac{\gamma}{2}\right)/\left(\gamma-2\right)\right\}\\ +\left\{\nu^{3/2}B\left(\frac{1}{2},\frac{\nu}{2}\right)/\left(\nu-2\right)\right\}\end{array}\right]$ for all $(\nu,\gamma)>2$.

2.5.3. Skew-t type-5 distribution

The PDF of skew-t type-5 distribution is defined as (Jones & Faddy, 2003):

$$f\left(y\mid\mu,\sigma,\nu,\gamma\right)=\frac{c}{\sigma}\left\{1+\frac{z}{\left(a+b+z^2\right)^{1/2}}\right\}^{a+1/2}\left\{1-\frac{z}{\left(a+b+z^2\right)^{1/2}}\right\}^{b+1/2} \quad \text{(XI)}$$

for $-\infty<(y,\mu,\nu)<\infty$ and $(a,b,\sigma,\gamma)>0$; where $=(\mathrm{y}-\mu)/\sigma$, $\nu=\frac{(a-b)}{\left\{ab\left(a+b\right)\right\}^{1/2}}$, $\gamma=\frac{2}{\left(a+b\right)}$, and $c=\left[2^{a+b-1}\left(a+b\right)^{\frac{1}{2}}B(a,b)\right]^{-1}$.

The mean and variance are given by $E(Y)=\mu+\sigma E(z)$ and $Var(Y)=\sigma^2Var(z)$, where $E\left(z\right)=\frac{\left(a-b\right)\left(a+b\right)^{1/2}\Gamma\left(a-\frac{1}{2}\right)\Gamma\left(b-\frac{1}{2}\right)}{2\Gamma(a)\Gamma(b)}$ and $E\left(z^2\right)=\frac{\left(a+b\right)\left\{\left(a-b\right)^2+a+b-2\right\}}{4(a-1)(b-1)}$. When $a=b$, f reduces to t-distribution with $2a$ degrees of freedom. When $a<b$ or $a>b$, f is negatively or positively skewed, respectively.

2.6. Skew-logistic distribution

The generalized logistic has cumulative distribution function as (Shao, 2002):

$$F\left(y\mid\mu,\sigma,\nu\right)=\frac{1}{\left(1+e^{-(y-\mu)/\sigma}\right)^{\nu}};\ \sigma,\nu>0 \quad \text{(XII)}$$

The density function is given by:

$$f\left(y\mid\mu,\sigma,\nu\right)=\frac{\nu}{\sigma}.\frac{e^{-(y-\mu)/\sigma}}{\left\{1+e^{-(y-\mu)/\sigma}\right\}^{\nu+1}};\ \sigma,\nu>0 \quad \text{(XIII)}$$

Applying the Azzalini (2003) method for skewing a symmetric distribution, we have the skew logistic distribution function as follows:

$$f\left(y\mid\mu,\sigma,\nu\right)=2f\left(z\right)F(\nu z)$$

$$\Rightarrow f\left(y\mid\mu,\sigma,\nu\right)=\frac{2\nu}{\sigma}.\frac{e^{-z}}{\left\{1+e^{-\nu z}\right\}\left\{1+e^{-z}\right\}^{\nu+1}} \quad \text{(XIV)}$$

where $=(y-\mu)/\sigma$. The skewness is determined by the power ν.

2.7. Model selection criteria

The model selection criteria, namely, Akaike information criteria (AIC) and Bayes information criteria (BIC), have been widely used in almost all the fields of quantitative research to choose a comparatively best model among other alternative models. The AIC and BIC are defined as (Akaike, 1974; Raftery, 1995; Schwarz, 1978):

AIC = (2 × number of parameters) – (2 × log-likelihood) (XV)

BIC = (log [number of observations] × number of parameters) – (2 × log-likelihood) (XVI)

A model with the lowest value of AIC and BIC is considered the best fit model.

The R software (version 4.2.2) has been used for the analysis and plotting. Various packages such as "gamlss" and "glogis" were used for non-deterministic model fitting and estimation in this study (Rigby *et al.*, 2019).

3. Analysis and results

Detailed analysis and results are furnished in this section, including the diagrammatic visualizations and tables. Figure 1 shows the spatial distribution of TFR among rural (L) and urban (R) women in bigger states of India. The figure demonstrated that the TFR is highest among rural women in Bihar (3.1) and highest among urban women in Bihar (2.3) and Uttar Pradesh (2.3). The lowest TFR is observed among rural women in Delhi (1.4) and Tamil Nadu (1.4) and lowest among urban women in Himachal Pradesh (1.1), Jammu and Kashmir (1.1), and West Bengal (1.1). It is worth noting that 13 bigger states of India have their TFR below the replacement level of fertility, with

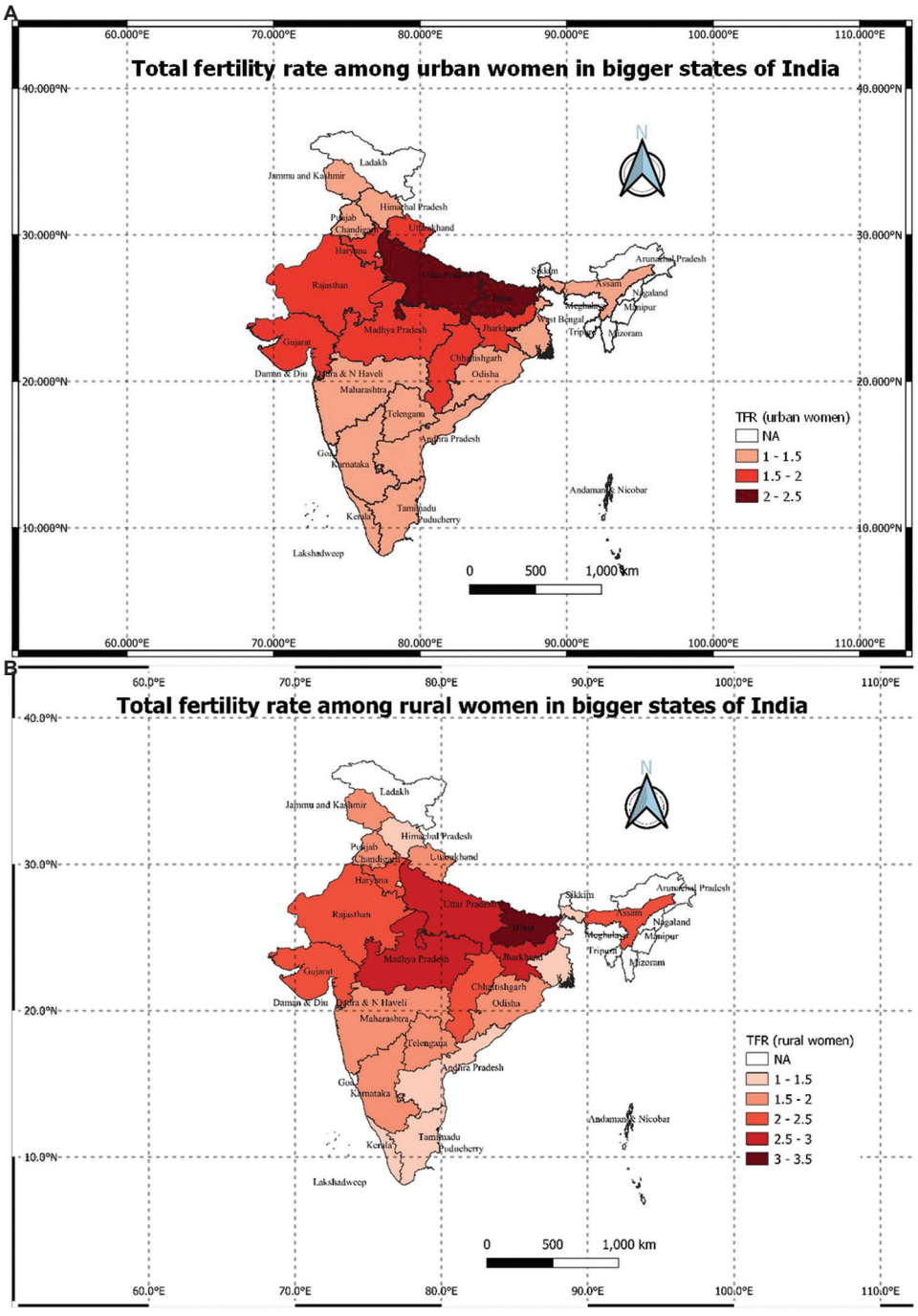

Figure 1. (A and B) Spatial distribution of total fertility rate among rural and urban women in India. Source: SRS-2020.

Andhra Pradesh (1.5), Delhi (1.4), Himachal Pradesh (1.5), Jammu and Kashmir (1.6), Karnataka (1.7), Kerala (1.5), Maharashtra (1.6), Odisha (1.9), Punjab (1.6), Tamil Nadu (1.4), Telangana (1.6), Uttarakhand (1.8), and West Bengal (1.5). All the bigger states of India except Bihar and Uttar Pradesh achieved below the replacement level of TFR among rural women. Figure 1 shows that TFR is comparatively higher in the northeastern part than in other parts of India.

According to the SRS-2020, the replacement level of TFR (*i.e.*, 2.1) has been attained at the national level, along with Delhi (1.4), Tamil Nadu (1.4), West Bengal (1.4), Andhra Pradesh (1.5), Himachal Pradesh (1.5), Jammu and Kashmir (1.5), Kerala (1.5), Maharashtra (1.5), Punjab (1.5), Telangana (1.5), Karnataka (1.6), Odisha (1.8), Uttarakhand (1.8), Gujarat (2.0), Haryana (2.0), and Assam (2.1).

The ASFRs of women in India according to their residential status are given in Table 1. The child-bearing period among women lies between 15 and 49 years, and the fertility rate differs for the different age groups. The ASFR is highest for the age group 25 – 29 years in every category (total, rural, and urban). Similarly, the ASFR is lowest for the age group 45 – 49 years in every category of women in India; this scenario is quite obvious due to the age factor and occurrence of menopause among women. Higher ASFR is observed in rural areas compared to urban areas in all the specified age groups.

Figure 2 shows that the ASFR follows a similar pattern among total, rural, and urban women in India. The pattern starts from very low in the very young age group 15 – 19 years, rising and peaking at the age group 25 – 29 years, and thereafter it gradually declines and approaches zero as the age of the women approaches 50 years. Again, the distribution of ASFRs in the rural population shows a higher peak than in the urban population in India.

Table 1. Age-specific fertility rates of women in India according to their residential status

Age group	ASFRs of women in India		
	Total	Rural	Urban
15 – 19	11.3	13.2	6.6
20 – 24	113.6	128.1	81.8
25 – 29	139.6	152.5	115.2
30 – 34	84.4	89.4	75.5
35 – 39	35.6	38.9	29.5
40 – 44	11.7	13.5	8.5
45 – 49	4.7	5.2	3.9

Note: ASFRs: Age-specific fertility rates.
Source: SRS-2020

By verifying the line plot in Figure 2, it is decided that the ASFRs can be estimated through fitting polynomial models concerning different ages. Initially, we fitted the polynomial of age (x) and reciprocal of x having degrees 1, 2, 3, and 4 for the ASFRs and recorded in Table 2. It is clear from Table 2 that the values of R^2, AIC, and BIC for the cubic, bi-quadratic polynomial regression model for x and reciprocal of x are nearly the same. Therefore, we considered these four polynomial models, and a more detailed comparison was undertaken by taking them as models I, II, III, and IV.

Table 3 reveals the model fit summary of eight polynomial regression models in terms of their AIC and BIC values. Based on the lowest AIC and BIC value, reciprocal bi-quadratic regression model was found to be the best-fitted model for predicting the value of ASFR. The results obtained from the analysis of NFHS-5 data are quite similar to the results obtained from the proposed best-fitted model, thus validating our proposed models.

The considered ASFR can be explained by the third and fourth-degree polynomial model (for age [x] and reciprocal of x) as follows.

Model I: $y = a + bx + cx^2 + dx^3$

Model II: $y = a + b\left(\frac{1}{x}\right) + c\left(\frac{1}{x}\right)^2 + d\left(\frac{1}{x}\right)^3$

Model III: $y = a + bx + cx^2 + dx^3 + ex^4$

Model IV: $y = a + b\left(\frac{1}{x}\right) + c\left(\frac{1}{x}\right)^2 + d\left(\frac{1}{x}\right)^3 + e\left(\frac{1}{x}\right)^4$

where y is the ASFR, x is the mid-point of the age interval, and a, b, c, d, and e are the parameters of polynomial models.

Thus, by applying the proposed model, we can get more reliable estimates of fertility parameters, which can explain the fertility pattern more accurately.

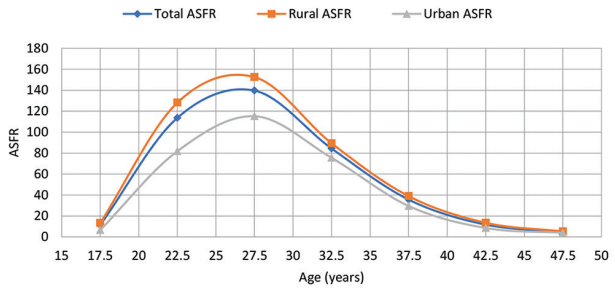

Figure 2. Graphical representation of age-specific fertility rates of women in India according to their residential status. Source: SRS-2020.
Note: ASFR: Age-specific fertility rate.

Table 2. Summary of fitted polynomial regression models for age-specific fertility rates of women in India

Polynomial model	Deg.	Total			Rural			Urban		
		R^2	AIC	BIC	R^2	AIC	BIC	R^2	AIC	BIC
Linear	1	0.211	79.208	79.046	0.220	80.427	80.265	0.172	80.427	80.265
Quadratic	2	0.614	76.194	75.978	0.606	77.657	77.440	0.638	77.657	77.440
Cubic	3	0.981	57.348	57.077	0.976	59.949	59.678	0.979	59.949	59.678
Biquadratic	4	0.987	55.796	55.471	0.989	56.408	56.084	0.979	56.408	56.084
Reciprocal linear	1	0.050	80.513	80.351	0.055	81.769	81.606	0.029	77.751	77.588
Reciprocal quadratic	2	0.928	64.410	64.194	0.928	65.743	65.527	0.913	62.791	62.575
Reciprocal cubic	3	0.942	64.920	64.649	0.947	65.475	65.204	0.914	64.715	64.444
Reciprocal biquadratic	4	0.998	40.447	40.122	0.997	45.187	44.862	0.999	31.842	31.517

Note: AIC: Akaike information criteria; BIC: Bayes information criteria; R^2: Coefficient of determination of the model.
Source: SRS-2020.

Table 3. Summary of fitted polynomial regression models for age-specific fertility rates of women in India

Polynomial model	Deg.	Total			Rural			Urban		
		R^2	AIC	BIC	R^2	AIC	BIC	R^2	AIC	BIC
Linear	1	0.46	28.86	24.86	0.47	29.36	25.36	0.40	27.84	23.84
Quadratic	2	0.54	30.41	24.41	0.53	31.01	25.01	0.55	28.99	22.99
Cubic	3	0.90	27.82	19.82	0.88	28.95	20.95	0.94	28.95	20.95
Bi-quadratic	4	1.00	18.57	8.57	0.99	21.64	11.64	1.00	18.56	8.56
Reciprocal linear	1	0.28	29.75	25.75	0.30	30.23	26.23	0.21	28.69	24.69
Reciprocal quadratic	2	0.82	27.53	21.53	0.80	28.41	22.41	0.86	28.41	22.41
Reciprocal cubic	3	0.99	19.73	11.73	1.00	30.41	22.41	0.97	22.39	14.39
Reciprocal bi-quadratic	4	1.00	18.43	8.43	1.00	19.12	9.12	1.00	16.08	6.08

Note: AIC: Akaike information criteria; BIC: Bayes information criteria; R^2: Coefficient of determination of the model.
Source: NFHS-5, 2019 – 2021

3.1. Analysis of total ASFR of women in India

For fitting the above polynomial model, the variable x is taken as the mid-point of the age group, and the outcome variable is ASFR in that particular age group and defined by y. The coefficients of determination for the models I, II, III, and IV are obtained as 0.981, 0.942, 0.987, and 0.988, respectively (shown in Table 2). This indicates that models I, II, III, and IV explain about 98.1%, 94.2%, 98.7%, and 98.8% variations of the total ASFR among women in India. The fitted polynomial models for estimating total ASFR among women in India are given by:

Model I:

$$y = -1491.8 + 154.49x - 4.6911x^2 + 0.0443x^3$$

Model II:

$$y = -214.4672301 + 6621.998405\left(\frac{1}{x}\right) + 272750.3921\left(\frac{1}{x}\right)^2 - 5601751.365\left(\frac{1}{x}\right)^3$$

Model III:

$$y = -2268.9 + 263.34x - 10.143x^2 + 0.1605x^3 - 0.0009x^4$$

Model IV:

$$y = 2596.734 - 328995\left(\frac{1}{x}\right) + 14677019\left(\frac{1}{x}\right)^2 - 270000000\left(\frac{1}{x}\right)^3 + 1730000000\left(\frac{1}{x}\right)^4$$

The above four models were utilized to predict the total ASFRs of women in India and are given in Table 4.

Table 4 exhibits the predicted value of total ASFRs among women in India with its 95% confidence interval (95% CI) using polynomial models I, II, III, and IV. This table contains the mid-point of the age interval, observed ASFR, predicted ASFR, and its 95% CI. The values of ASFR predicted by model IV are closer to the observed value than those predicted by the other three models, *that is*, models

Table 4. Predicted value of total age-specific fertility rates among women in India with its 95% confidence interval using models I, II, III, and IV

Mid-point	Observed ASFR	Model I			Model II			Model III			Model IV		
		Pred. ASFR	95% CI		Pred. ASFR	95% CI		Pred. ASFR	95% CI		Pred. ASFR	95% CI	
17.5	11.3	12.54	0.00	33.86	9.32	0.00	45.94	9.66	0.00	29.92	11.25	4.48	18.02
22.5	113.6	113.89	92.57	135.21	126.82	90.20	163.44	120.59	100.33	140.85	114.20	107.43	120.97
27.5	139.6	130.16	108.84	151.48	117.64	81.02	154.26	129.20	108.94	149.46	137.43	130.66	144.20
32.5	84.4	94.57	73.25	115.89	84.33	47.71	120.95	88.82	68.56	109.08	86.99	80.22	93.76
37.5	35.6	40.33	19.01	61.65	49.85	13.23	86.47	39.37	19.11	59.63	36.21	29.44	42.98
42.5	11.7	0.65	0.00	21.97	19.38	0.00	56.00	7.36	0.00	27.62	8.62	1.85	15.39
47.5	4.7	8.77	0.00	30.09	--	--	--	5.90	0.00	26.16	6.20	0.00	12.97

Note: ASFR: Age-specific fertility rate; 95% CI: 95% confidence interval.

I, II, and III. Predicted ASFRs show the highest fertility in the age group 25 – 29 years for all four models.

Figure 3 depicts the comparison plot between the observed and estimated values of total ASFR (viz. models I, II, II, and IV). The figure shows that model IV fits the observed values more accurately than others.

3.2. Analysis of ASFR of rural women in India

In this section, models I, II, III, and IV were considered to study the variations in the ASFR for rural women in India. The coefficient of determinations for models I, II, III, and IV are obtained as 0.976, 0.947, 0.989, and 0.997, respectively (shown in Table 2). This indicates that models I, II, III, and IV explain about 97.6%, 94.7%, 98.9%, and 99.7% variations of the ASFR among rural women in India.

The fitted polynomial models for the ASFRs among rural women in India are given by;

Model I: $y = -1635.8 + 169.87x - 5.1709x^2 + 0.0489x^3$

Model II:

$$y = -174.113 + 1857.712\left(\frac{1}{x}\right) + 447227.8\left(\frac{1}{x}\right)^2 - 7402566\left(\frac{1}{x}\right)^3$$

Model III:

$$y = -2732.7 + 323.5x - 12.866x^2 + 0.213x^3 - 0.0013x^4$$

Model IV:

$$y = 2722.746 - 343985.6638\left(\frac{1}{x}\right) + 15290400.8\left(\frac{1}{x}\right)^2 - 278807975\left(\frac{1}{x}\right)^3 + 1785869990\left(\frac{1}{x}\right)^4$$

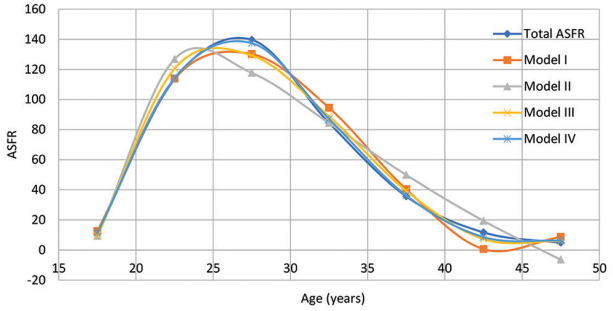

Figure 3. Curve fitting of total age-specific fertility rates among women in India using models I, II, III, and IV.
Note: ASFR: Age-specific fertility rate.

The above four models were utilized to predict ASFRs of rural women in India and are rendered in Table 5.

Table 5 shows the predicted values of ASFR for rural women using polynomials models I, II, III, and IV. This table also contains the mid-point of the age interval, observed ASFRs of rural areas, and 95% CI for corresponding predicted ASFRs. It is observed that model IV gives predicted values closer to the observed ASFRs than other considered models.

Figure 4 displays the comparison plot between the observed and the estimated values of ASFR among rural women (viz. models I, II, II, and IV). The figure suggests that model IV fits the observed values more accurately than others.

3.3. Analysis of ASFRs among urban women in India

Models I, II, III, and IV were used to determine the values of ASFR of urban women in India. Here, the explanatory variable is the mid-point of the age group, *that is*, x, and the explained variable is ASFR, *that is*, y. The coefficient of determinations for the models I, II, III, and IV are obtained

Table 5. Predicted values of age-specific fertility rate among rural women in India with its 95% confidence interval using models I, II, III, and IV

Mid-point	Observed ASFR	Model I			Model II			Model III			Model IV		
		Pred. ASFR	95% CI		Pred. ASFR	95% CI		Pred. ASFR	95% CI		Pred. ASFR	95% CI	
17.5	13.2	15.58	0.00	41.25	11.14	0.00	49.24	11.53	0.00	32.70	13.13	3.63	22.63
22.5	128.1	125.87	100.20	151.54	141.98	103.88	180.08	135.34	114.17	156.51	128.97	119.47	138.47
27.5	152.5	142.76	117.09	168.43	128.87	90.77	166.97	141.41	120.24	162.58	149.26	139.76	158.76
32.5	89.4	102.96	77.29	128.63	90.82	52.72	128.92	94.85	73.68	116.02	93.56	84.06	103.06
37.5	38.9	43.16	17.49	68.83	53.08	14.98	91.18	41.81	20.64	62.98	39.02	29.52	48.52
42.5	13.5	0.07	0.00	25.74	20.77	0.00	58.87	9.54	0.00	30.71	9.69	0.19	19.19
47.5	5.2	10.38	0.00	36.05	--	--	--	6.33	0.00	27.50	7.16	0.00	16.66

Note: ASFR: Age-specific fertility rate; 95% CI: 95% confidence interval.

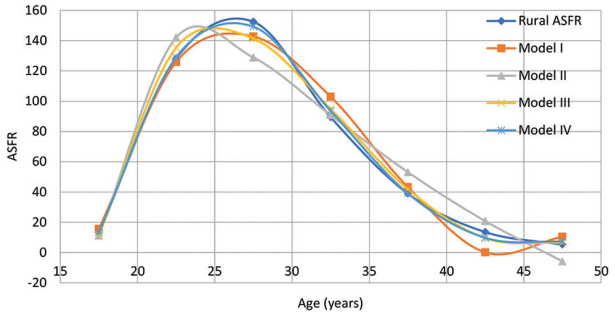

Figure 4. Curve fitting of rural age-specific fertility rate among women in India using models I, II, III, and IV.
Note: ASFR: Age-specific fertility rate.

as 0.979, 0.914, 0.979, and 0.999, respectively (shown in Table 2). This indicates that the models I, II, III, and IV explain about 97.9%, 91.4%, 97.9%, and 99.9% variations of the ASFRs among urban women in India.

The fitted polynomial models for the ASFR among urban women in India are given below:

Model I: $y = -1204.4 + 123.42x - 3.712x^2 + 0.0347x^3$

Model II:

$$y = -333.393 + 19597.5\left(\frac{1}{x}\right) - 171573\left(\frac{1}{x}\right)^2 - 1187388\left(\frac{1}{x}\right)^3$$

Model III:

$$y = -1219.7 + 125.56x - 3.8192x^2 + 0.037x^3 - 0.00002x^4$$

Model IV:

$$y = 2459.395 - 313821.301\left(\frac{1}{x}\right) + 14138352.6\left(\frac{1}{x}\right)^2 - 262842440.1\left(\frac{1}{x}\right)^3 + 1721711842\left(\frac{1}{x}\right)^4$$

The above four models were utilized to predict ASFR of urban women in India and are given in Table 6.

Table 6 provides the predicted values of ASFR for urban women in India using polynomials model-I, II, III, and IV. This table also contains the midpoint of the age interval, observed ASFRs of rural India, and 95% CI for corresponding predicted ASFRs. It is observed that the difference between the predicted and observed values of ASFRs is lesser in model-IV compared to the other considered models.

Figure 5 shows the comparison plot between the observed and estimated values of ASFR among urban women (viz. models I, II, II, and IV). The figure shows that model IV fits the ASFR values more accurately than other models.

Table 7 explains the comparative study of models I, II, III, and IV fitted to the total, rural, and urban women in India. The model superiority was checked using the value of the coefficient of determination, CVPP, and shrinkage for each model. The findings suggested that model IV provides better estimates of ASFRs for total, rural, and urban women in India.

3.4. Modeling of ASFR using skewed regression models

In this section, six selected fertility models are fitted to the ASFRs data of three categories, *i.e.*, total, rural, and

urban women in India. Table 8 shows the performance summary of six fitted models in terms of Log-likelihood Log-likelihood (LL), AIC, and BIC values. We found that the skew-normal (type-2) model has the smallest

Table 6. Predicted value of age-specific fertility rate among urban women in India with its 95% confidence interval using model I, II, III, and IV

Mid-point	Observed ASFR	Model I			Model II			Model III			Model IV		
		Pred. ASFR	95% CI		Pred. ASFR	95% CI		Pred. ASFR	95% CI		Pred. ASFR	95% CI	
17.5	6.6	4.87	0.00	22.58	4.67	0.00	36.61	4.82	0.00	26.50	6.59	0.00	28.27
22.5	81.8	89.08	71.37	106.79	94.45	62.51	126.39	89.21	67.53	110.89	81.91	60.23	103.59
27.5	115.2	102.91	87.20	122.62	95.28	63.34	127.22	104.89	83.21	126.57	114.94	93.26	136.62
32.5	75.5	78.41	60.70	96.12	72.58	40.64	104.52	78.30	56.62	99.98	75.23	53.55	96.91
37.5	29.5	35.64	17.93	53.35	44.68	12.74	76.62	35.62	13.94	57.30	31.13	9.45	52.81
42.5	8.5	2.64	0.00	20.35	17.27	0.00	49.21	2.77	0.00	24.45	6.59	0.00	28.27
47.5	3.9	5.46	0.00	23.17	--	--	--	5.40	0.00	27.08	4.61	0.00	26.29

Note: ASFR: Age-specific fertility rate; 95% CI: 95% confidence interval.

Table 7. Estimated cross-validation prediction power and shrinkage of the proposed polynomial models of age-specific fertility rate for women according to their residential status

ASFR	Polynomial model	n	k	R^2	ρ^2_{cvpp}	Shrinkage	F-value	S.E.	*p*-value
Total	Model I	7	3	0.981	0.891	0.090	50.01	10.878	0.004
	Model II	7	3	0.942	0.669	0.273	16.29	18.683	0.023
	Model III	7	4	0.988	0.794	0.194	41.87	10.337	0.023
	Model IV	7	4	0.999	0.983	0.016	379.12	3.453	0.002
Rural	Model I	7	3	0.976	0.863	0.113	41.35	13.099	0.006
	Model II	7	3	0.948	0.703	0.245	18.23	19.438	0.020
	Model III	7	4	0.989	0.811	0.178	46.22	10.799	0.021
	Model IV	7	4	0.997	0.962	0.036	231.63	4.845	0.004
Urban	Model I	7	3	0.979	0.880	0.099	47.78	9.034	0.004
	Model II	7	3	0.915	0.514	0.401	10.75	18.411	0.041
	Model III	7	4	0.980	0.657	0.323	23.90	11.063	0.041
	Model IV	7	4	0.999	0.983	0.016	855.42	1.868	0.001

Note: CVPP: Cross-validation prediction power; R^2: Coefficient of determination of the model; S.E.: Standard error.

Table 8. Model fit summary of skewed regression models.

Model	Total			Rural			Urban		
	LL	AIC	BIC	LL	AIC	BIC	LL	AIC	BIC
Skew-normal (type-1)	−37.43	80.87	80.71	−38.08	82.17	82.01	−35.98	77.96	77.79
Skew-normal (type-2)	**−35.52**	**77.04**	**76.88**	**−36.17**	**78.35**	**78.19**	**−33.96**	**73.93**	**73.77**
Skew-t (type-3)	−35.52	79.04	78.82	−36.18	80.37	80.15	−33.96	75.93	75.72
Skew-t (type-4)	−37.43	82.87	82.65	−38.08	84.17	83.95	−35.97	79.95	79.74
Skew-t (type-5)	−36.16	80.32	80.10	−36.83	81.67	81.45	−34.33	76.67	76.45
Skew-logistic	−36.93	79.87	79.70	−37.56	81.11	80.95	−35.51	77.02	76.86

Note: AIC: Akaike information criteria; BIC: Bayes information criteria; LL: Log-likelihood; Values in boldface used for best fit model with the lowest AIC and BIC values.
Source: SRS-2020

AIC and BIC value compared to all other considered models for rural, urban, and total population of India. This indicates that skew-normal (type-2) model is the best-fit model to explain the distribution of ASFRs of women in India and its rural and urban regions. Further results obtained from the analysis of NFHS-5 data given in Table 9 are quite similar to the results obtained from the proposed best-fitted model, thus validating our proposed models.

Table 10 depicts the outcomes of the skew-normal (type-2) model in terms of their parameter estimates, standard error, t-value, and *p*-value. It is clearly observed that the skewness parameter written in the logarithmic form comes out to be positive for each category, which means the age-specific fertility curves are positively skewed for all the categories, *that is*, total, rural, and urban.

Figure 6 represents the histogram and the fitted skew-normal type-2 distribution to the ASFRs among total, rural, and urban women. This figure confirms that the fertility rates among all the residential categories and India are positively skewed.

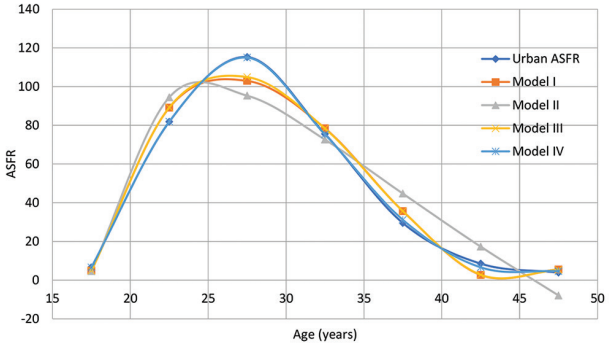

Figure 5. Curve fitting of age-specific fertility rates among urban women in India using models I, II, III, and IV.
Note: ASFR: Age-specific fertility rate.

It is clear from Table 11 that the observed and predicted fertility rates for various age groups in all three categories are very close to each other. This shows a good fitting of the skew-normal type-2 model for the Indian fertility schedule. The table also shows that the highest fertility rate is predicted for the women of age group 25 – 29 (mid 27.5) years, and the lowest is predicted for the women of age group 45 – 49 (mid 47.5) years in all three categories. Among all three categories, rural women have a higher level of fertility compared to urban women in India.

3.5. Comparison between deterministic and non-deterministic approaches

Both the deterministic and non-deterministic models fit well in the considered ASFR data for total, rural, and urban women in India. However, a critical examination was performed by plotting the observed values of ASFRs with respect to the predicted values, namely, two best-fit models, one from deterministic models (*i.e.*, reciprocal bi-quadratic) and another from non- deterministic models (*i.e.*, skew-normal type-2). The comparison plot of observed and predicted ASFRs for total, rural, and urban women is shown in Figures 7-9, respectively.

Based on Figures 7-9, we can notice that both the models, *that is*, reciprocal bi-quadratic (M-IV) and skew-normal type-2 (SN2) model provide the predicted ASFRs which are very close to the observed ASFRs. However, by observing closely, it can be said that the SN2 model provides better estimates than the M-IV model.

4. Discussion

The tendency of fertility rates may vary among different age groups, so it is pertinent to consider a modeling approach that can describe the fertility profile more accurately and in a compact form. Therefore, we attempted to model the pattern of ASFRs in India using deterministic and non-

Table 9. Model fit summary of skewed regression models.

Model	Total			Rural			Urban		
	LL	AIC	BIC	LL	AIC	BIC	LL	AIC	BIC
Skew-normal (type-1)	−39.25	82.85	82.69	−37.79	76.85	82.85	−37.75	82.69	76.85
Skew-normal (type-2)	**−36.97**	**78.28**	**78.12**	**−35.51**	**72.28**	**78.28**	**−35.47**	**78.12**	**72.28**
Skew-t (type-3)	−37.24	80.28	80.06	−35.29	72.28	80.28	−35.24	80.06	72.28
Skew-t (type-4)	−39.12	84.03	83.82	−37.17	76.03	84.03	−37.12	83.82	76.03
Skew-t (type-5)	−37.83	81.46	81.25	−35.88	73.46	81.46	−35.83	81.25	73.46
Skew-logistic	−37.42	79.40	78.82	−38.00	80.37	80.15	−35.78	75.93	75.72

Note: AIC: Akaike information criteria; BIC: Bayes information criteria, LL: Log-likelihood; Values in boldface used for best fit model with the lowest AIC and BIC values.
Source: NFHS-5, 2019-2021

deterministic modeling approaches and propose a better model that explains the ASFRs more accurately. A similar study was conducted by Srivastava *et al.* (2021) to compare existing models with the Hadwiger model for the national and sub-national fertility pattern in India.

In this study, all the proposed models are very flexible and fitted to the age-specific fertility patterns of total, rural, and urban women in India. The observed ASFRs obtained from the SRS-2020 are very close to the values estimated by the reciprocal bi-quadratic model among the deterministic models. Similar findings are seen concerning the skew-normal type-2 model among the non-deterministic models. By comparing all the fitted ASFRs, we concluded that the skew-normal type-2 model is the best-fit model among all the considered models.

Pandey & Kaur (2019) suggested that the fifth-degree polynomial model better describes the varying fertility patterns of India and its sub-regions. Some recent studies suggested that the inverse of age is a more accurate and reliable predictor of fertility than age alone. Singh *et al.* (2014) found that the third-degree polynomial with the inverse of age gives better estimates of ASFRs among women in Uttar Pradesh. Mishra *et al.* (2017) and Gaire *et al.* (2022) also discovered the superiority of inverse of age over age alone in four states of India (Meghalaya, Uttar Pradesh, West Bengal, and Kerala) and Nepal, respectively.

In a recent study, it was found that skew-logistic model is suitable for studying the pattern of state-wise fertility in India (Mishra *et al.*, 2017). It is worthwhile to mention that the skew-logistic model incorporates estimating four parameters, but the proposed model used in this study, *that is*, skew-normal type-2 model, deals with only three

Table 10. Skew-normal (type-2) model outcomes for total, rural, and urban age-specific fertility rate.

Region	Coefficients	Estimate	Std. error	t-value	Pr(>|t|)
	μ	6.255	8.397	0.745	0.498
Total	$\log(\sigma)$	2.948	1.143	2.579	0.061
	$\log(\nu)$	1.377	1.141	1.207	0.294
	μ	8.160	16.46	0.496	0.638
Rural	$\log(\sigma)$	3.043	0.308	9.850	<0.001
	$\log(\nu)$	1.377	0.332	4.149	0.006
	μ	4.329	3.736	1.159	0.311
Urban	$\log(\sigma)$	2.675	0.909	2.940	0.042
	$\log(\nu)$	1.438	0.879	1.634	0.178

Table 11. Observed and predicted values of ASFR of total, rural, and urban women in India using the skew-normal type-2 model

Mid-point	Total			Rural			Urban		
	Observed	Predicted	Residual	Observed	Predicted	Residual	Observed	Predicted	Residual
17.5	11.3	12.537	−1.237	13.2	14.397	−1.197	6.6	8.059	−1.459
22.5	113.6	112.550	1.050	128.1	127.005	1.095	81.8	80.952	0.848
27.5	139.6	138.149	1.451	152.5	151.063	1.437	115.2	113.708	1.492
32.5	84.4	83.829	0.571	89.4	88.883	0.517	75.5	74.781	0.719
37.5	35.6	36.006	−0.406	38.9	39.311	−0.411	29.5	29.892	−0.392
42.5	11.7	12.916	−1.216	13.5	14.683	−1.183	8.5	9.806	−1.306
47.5	4.7	6.418	−1.718	5.2	6.907	−1.707	3.9	5.659	−1.759

Abbreviation: ASFR: Age-specific fertility rate.

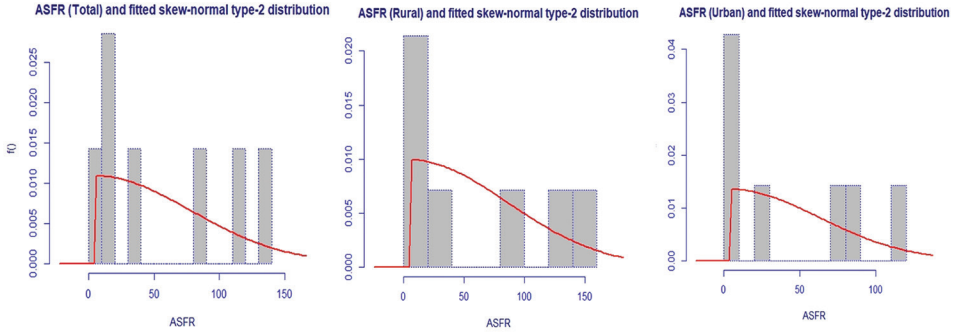

Figure 6. Fitted skew-normal type 2 distribution to total, rural, and urban age-specific fertility rates in India.

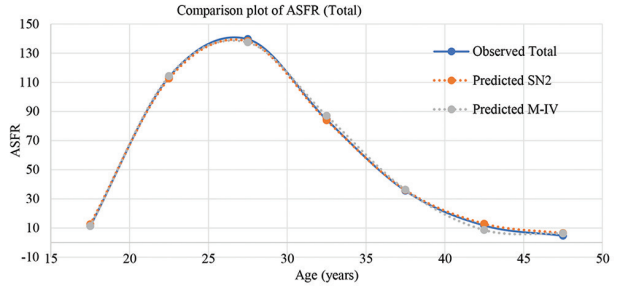

Figure 7. Comparison between observed and predicted values of total age-specific fertility rates.
Note: ASFR: Age-specific fertility rate; M-IV: Reciprocal bi-quadratic model; SN2: Skew-normal type-2 model.

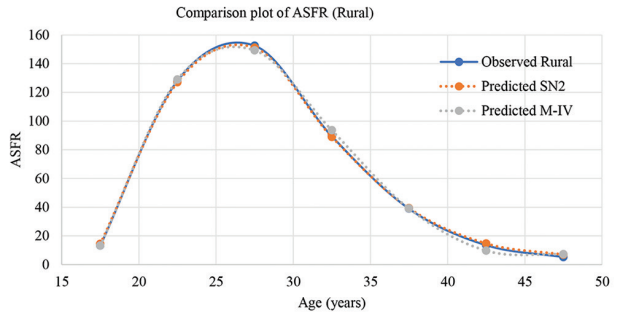

Figure 8. Comparison between observed and predicted values of rural age-specific fertility rates.
Note: ASFR: Age-specific fertility rate; M-IV: Reciprocal bi-quadratic model; SN2: Skew-normal type-2 model.

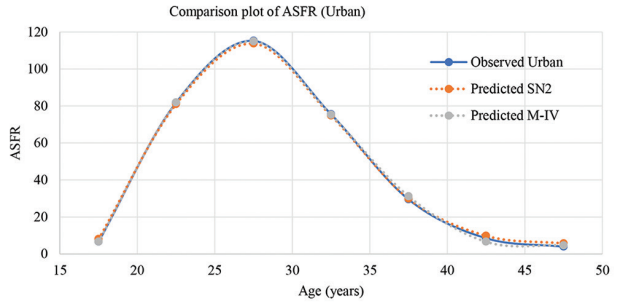

Figure 9. Comparison between observed and predicted values of urban age-specific fertility rates.
Note: ASFR: Age-specific fertility rate; M-IV: Reciprocal bi-quadratic model; SN2: Akew-normal type-2 model.

parameters. Therefore, it is better than the previously proposed models in reducing the complexity of estimating the model parameters and their interpretation.

The variations in the fertility pattern may occur due to various factors, such as differences in age at first marriage, level of contraceptive prevalence, desired family size, the status of women in society, and level of participation of women in employment (Kapoor *et al.*, 2015). Similarly, the lack of correct information about the fertile window (the time of highest chance of conception during the menstrual cycle) also significantly causes a rise in fertility due to the high prevalence of traditional contraceptives in India. It has been observed that only 20% of the urban population has the correct information about the fertile window (Verma *et al.*, 2017). Therefore, this study may be extended by considering various factors that affect fertility in India.

Monitoring the fertility behavior in a population is crucial in terms of safeguarding the reproductive health of women, as many studies have pointed out that the fertility behavior of women affects their reproductive health significantly.

For the validation of our results, we fitted all the considered model to the NFHS-5 data. It is found that the same model emerges as the best-fit model as we proposed based on the SRS data empirically.

Several limitations of this study should be noted. First, the SRS is a sample survey, restricting us to make inferences about the entire population of India. Second, the NFHS is a cross-sectional survey, so it is not possible to track changes in ASFR over time. Third, both data sources are subject to non-response bias, which can affect the accuracy of the estimates. This study does not consider the potential impact of other factors on ASFR, such as socioeconomic status, education level, and access to healthcare. These factors can also affect ASFR, and their omission from the study may lead to biased estimates.

This study can further be extended to the sub-national level. Fitting models for sub-national ASFR can be helpful to identify the factors that are associated with fertility at the sub-national level. This information can be used to develop policies and interventions to improve fertility outcomes in specific regions or populations.

5. Conclusions

The objective of this study was to study the pattern of ASFRs in India using both deterministic and non-deterministic approaches. After carefully undertaking the study, we found that the estimates yielded by both approaches were close to the national ASFRs. Further, through critical examination, we can conclude that the skew-normal (type-2) model best describes India's fertility pattern. Therefore, more accurate projections of ASFR can be made at a particular point of time between two surveys using the skew-normal (type-2) model in India. In a nutshell, this study provides insight, knowledge, and essential tool for the government authorities and researchers to project fertility rates and understand the fertility transitions in India. The study also provides a basis for policymakers to perform interventions to control fertility in a specific age group in the Indian population.

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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

Not applicable.

Consent for publication

Not applicable.

Availability of data

The datasets used for the analysis in this study are available in the public domain, *i.e.*, SRS, Statistical Report-2020, and National Family Health Survey (NFHS-5)-2019-21 (http://rchiips.org/nfhs/nfhs5.shtml).

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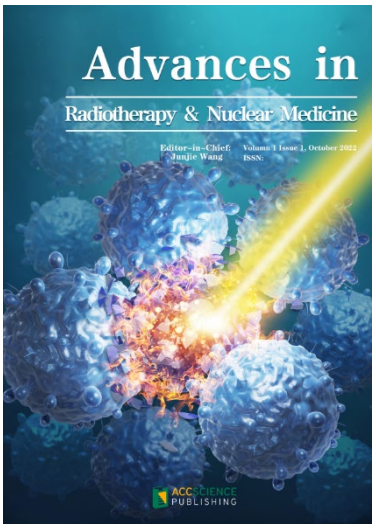

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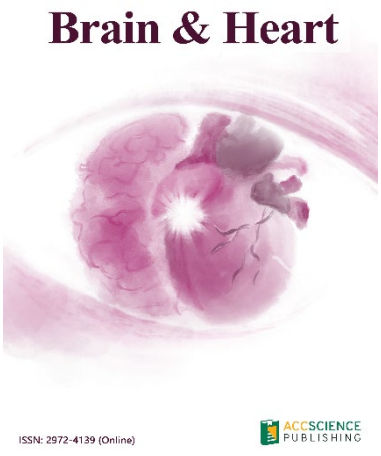

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