ISSN 1898-1143

MANAGERIAL ECONOMICS

SEMIANNUAL

vol. 27 ◆ no. 2 ◆ 2026

formerly Ekonomia Menedżerska

AGH

AGH UNIVERSITY PRESS

KRAKOW 2026

MANAGERIAL ECONOMICS

SEMIANNUAL
vol. 27 no. 2 ■ 2026

Wydział Zarządzania Akademii Górniczo-Hutniczej

EKONOMIA MENEDŻERSKA

PÓŁROCZNIK

tom 27 nr 2 ■ 2026

WYDAWNICTWA AGH

KRAKÓW 2026

Faculty of Management
AGH University of Krakow

MANAGERIAL ECONOMICS

SEMIANNUAL
vol. 27 no. 2 ■ 2026

AGH UNIVERSITY PRESS
KRAKOW 2026

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DOI: https://doi.org/10.7494/manage

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ISSN 1898-1143 (paper version), ISSN 2353-3617 (on-line version)

Number of copies 40. The printed version of the journal is the primary one.

Wydawnictwa AGH (AGH University Press)
Al. A. Mickiewicza 30, 30-059 Kraków
tel. 12 617 32 28
e-mail: redakcja@wydawnictwoagh.pl; www.wydawnictwo.agh.edu.pl

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2026, Vol. 27, No. 2, pp. 129–149
https://doi.org/10.7494/manage.2026.27.2.129
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Arsim Gjinovci[1], Dren Gjinovci[2]

Challenges in human resource management and public organizations. The impact of economic, political and organizational factors

1. Introduction

The global economy is experiencing an intensified phase of globalization characterized by technological integration and profound structural changes (Akbari, 2013). Organizations in the southwestern Balkans face legal and ethical challenges, including operations outside the legal system, which contribute to economic informality and hinder sustainable market development. In Kosovo, politically influenced public organizations risk bankruptcy, placing pressure on future governments to address social and financial demands. The sustainability of public organizations is essential to economic development and for increased domestic and foreign investments. Modern business models emphasize knowledge and human resources, requiring new managerial approaches, new ways of thinking, and more flexible organizational structures. The sustainable development of public organizations is therefore essential to the country's economic stability.

The study aims to analyze the impact of several critical factors on human resource management and provide recommendations for policies and practices that increase professionalism, innovation, and organizational efficiency.

[1] RKS, University of Prishtina, Kosovo, e-mail: arsimgjinovci@yahoo.com, ORCID: 0009-0005-3308-0216, Web of Science ResearcherID: KOD-0276-2024.
[2] RKS University of Prishtina, Kosovo, independent Researcher, PhD Candidate, e-mail: dren.gjinovci@gmail.com, ORCID: 0009-0009-8719-8139, Web of Science ResearcherID: ID-6509-2025.

The main factors examined include political influence in manager selection, lack of creativity and innovation, non-transparent tendering practices, unfavorable economic policies, and limited professional human resources.

1.1. Methodology

The study uses a combined approach of primary and secondary research.

- primary data: collected from the analysis of documents from different departments of public organizations;
- secondary data: extracted from the scientific literature on human resource management, challenges of public organizations, and personnel selection practices.

The sample included:

- public organizations in Kosovo;
- documents and reports published by state institutions and international organizations. Data analysis consisted of a literature review, document analysis, and the interpretation of survey results and participant reports.

1.2. Research hypotheses

The following hypotheses were formulated at the outset of the study:

- H1: High unemployment negatively affects the development of public organizations and the ability to invest in human resources.
- H2: The selection of managers under political influence reduces the professionalism and efficiency of public organizations.
- H3: The lack of innovation hinders the development and effectiveness of services.
- H4: Non-transparent tendering practices negatively affect employee motivation and performance.
- H5: Unfavorable economic policies and the lack of reforms hinder the development of organizations and human resources.
- H6: The lack of professional human resources and limited competition within public organizations are negatively associated with service quality and organizational innovation.
- H6 is intended as a specific hypothesis rather than a general statement. For clarity, we have revised its wording to explicitly indicate the negative relationship between the lack of professional human resources and limited competition, on the one hand, and service quality and organizational innovation, on the other hand.

1.3. Research questions

The hypotheses listed in Section 1.2 were formulated in response to the following research questions:

- What are the main obstacles to human resource development in public organizations?
- How do unemployment and a lack of qualifications affect the performance of public organizations?
- How do political factors affect the selection of managers and organizational efficiency?
- How does the lack of innovation affect decision-making and development?
- What are the consequences of non-transparent tendering practices on employee motivation and performance?
- How do economic policy and the lack of reforms affect the capacity of organizations to develop human resources?

2. Results and discussion

This section presents and discusses the main findings related to the economic, political, and organizational factors affecting human resource management and the functioning of public organizations. Particular attention is given to unemployment and its implications for organizational development, human resource quality, and employment opportunities. The subsequent subsections examine these challenges in greater detail and discuss their implications for the efficiency and professionalization of public organizations.

2.1. Unemployment and its impact on organizational development

Human resources are a key factor in economic growth and innovation (Becker 1993; Bontis et al. 1999; Chirtoc 2010; Gjinovci 2025b). Open innovation implies that enterprises can and should exploit both external and internal ideas and use internal and external routes to reach the market in order to advance their technologies (Chesbrough et al. 2006). The quality and flexibility of the workforce directly affect investment decisions. Kosovo has experienced high unemployment and skills shortages, which limit organizational development and the creation of jobs (Central Bank of the Republic of Kosovo 2010; Kosovo Agency of Statistics 2015; World Bank 2021).

Main effects of unemployment:

- decreased purchasing power (Eurostat 2022);
- inability to generate new ideas (OECD 2017);
- limitations in the professional development of human resources (Boselie et al. 2005);
- reduced opportunities for creating new jobs;
- increased demand for social assistance and a negative impact on the state budget.

Recent trends show a substantial decrease in the unemployment rate in Kosovo. The unemployment rate was 35.3% in 2014, declining to 32.9% in 2015 and further to 27.5% in 2016. After an increase to 31.3% in 2021, the unemployment rate subsequently declined, reaching 10.8% in 2024 (Kosovo Agency of Statistics (KAS), 2014–2024). While this decline indicates a substantial improvement in labour-market conditions, the demand for qualified labour remains an important challenge for organizations and the wider economy.

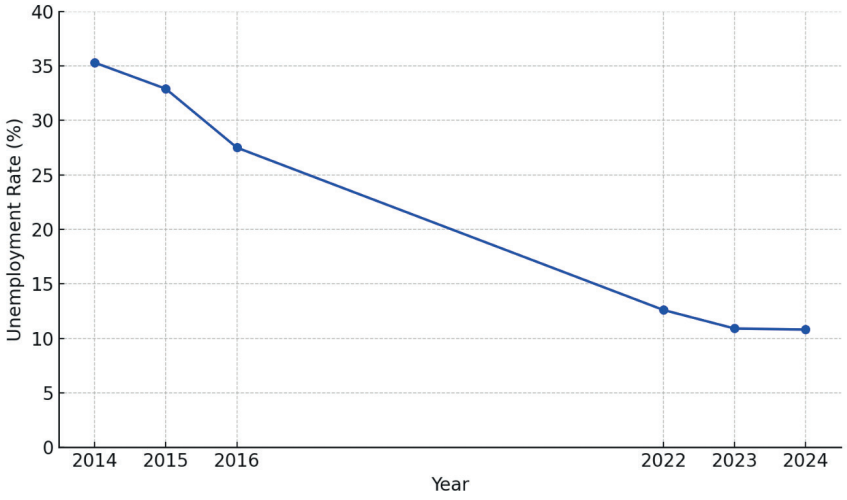

Figure 1. Unemployment rate in Kosovo, 2014–2024

Source: Kosovo Agency of Statistics (KAS), 2014–2024

Figure 1 shows the unemployment rate in Kosovo from 2014 to 2024. The data reported by the Kosovo Agency of Statistics (KAS) indicate a substantial change in the unemployment rate over the last decade. Between 2014 and 2016, the unemployment rate declined from 35.3% to 27.5%. However, the rate increased to 31.3% in 2021. This increase may be associated with methodological changes in

the measurement of unemployment, as well as the effects of the global economic and health crises. After 2021, the unemployment rate declined steadily, reaching 10.8% in 2024. This development indicates significant changes in Kosovo's labour market and highlights the continuing importance of sustainable employment policies and workforce preparation to meet the demand for qualified labour and support organizational and economic development.

2.2. Challenges facing public organizations

Public organizations face several interconnected challenges that can affect their efficiency, adaptability, and capacity to deliver effective services. These challenges include limited innovation, organizational constraints, human resource deficiencies, and institutional factors that may hinder organizational development. The following subsections examine these challenges and their implications for the functioning and professionalization of public organizations.

2.2.1. Lack of innovation

Innovation is essential in many areas, and researching it is equally important; it is impossible to avoid, both literally and figuratively. In a literal sense, it is impossible to read business magazines or newspapers, attend economic conferences, or read annual reports without constantly being confronted with the importance of innovation. In a figurative sense, it is impossible to ignore the fact that corporations must be innovative in order to survive and maintain their competitiveness (Barczak 2012; Chung, Kim, 2017; Eiada et al. 2008; Nelson, Winter, 1977). According to Chesbrough (2003), the impact of innovation lies not only in the creation of new ideas but also in the ability of firms to manage and commercialize them. He emphasizes that "firms must manage the flow of ideas within and across their organizational boundaries to create and capture value". This approach, known as open innovation, has transformed the way companies develop technology and remain competitive in the marketplace. A lack of creativity hinders new investments and the expansion of existing businesses. Investors require state support, quick legal solutions, and infrastructure for sustainable development (Bowen, Lawler 1992; Gjinovci, Gjinovci 2025a).

Key challenges for investors:

- institutional and legal support;
- human resource training and development;
- minimizing investment risk.

Ninety percent of employees in public organizations report a lack of support for advancement based on skills and experience (Gjinovci 2014a; Harusha 2012).

2.2.2. Selection of managers under political influence

The independence of public boards is often compromised by political influence, reducing efficiency, professionalism, and institutional performance (Akbari 2013; Edlira, Gjinovci, 2012). The independence and development of public boards and organizations are essential for the efficient functioning of public administration and sustainable economic development. However, Gjinovci's research (Gjinovci 2015a; Gjinovci et al. 2018) indicates that political influence and nepotism frequently undermine these principles, reducing the professionalism, effectiveness, and overall performance of public organizations. The stability and development of the public sector depend on respect for professional criteria in staff recruitment and promotion, including professional training, practical experience, and demonstrated results in previous positions (Gjinovci 2014b). In practice, political influence favors individuals with political connections over candidates with the required qualifications and performance records, creating an unfair and non-meritocratic environment. This process has clear consequences for human resource management: staff become overburdened, motivation declines, and opportunities to develop professional skills remain limited. Favoring politically connected individuals for board and management positions not only undermines decision-making processes but also adversely impacts organizational performance and the country's economic development. The research highlights that, despite some employees' efforts to advance professionally and improve their qualifications, their potential remains undervalued due to non-meritocratic practices. Public administration reform requires an integrated approach involving not only the government but also civil society and institutional monitoring mechanisms. Active participation by citizens and monitoring organizations can help ensure transparency, accountability, and adherence to professional criteria. Such a system promotes meritocracy, increases employee motivation, improves public sector performance, and contributes to long-term economic and social development (Gjinovci 2018, Gjinovci et al. 2018). Gjinovci's research (Gjinovci 2015b; Gjinovci et al. 2018) further shows that political influence and nepotism in the selection of boards and managing directors often hinder public-sector development and independence. These practices favor politically connected individuals regardless of their qualifications or professional performance, thereby reducing the motivation, effectiveness, and development of public organizations.

2.2.3. Public-sector staffing and average wages

Political influence and the limited number of public sector positions reduce employee motivation. As shown in Table 1, the average gross wage in Kosovo increased from €383 in 2014 to €650 in 2025. The net wage increased from €350 to €620 (Kosovo Agency of Statistics 2025), however the levels remain below European Union standards (Eurostat 2022; World Bank 2021).

Table 1

Regional comparison of average gross salaries (EUR)

Country	2014	2025
Kosovo	383	650
Albania	350	620
North Macedonia	400	670
Montenegro	600	820
Bosnia & Herzegovina	800	1,350
Serbia	1,000	1,550

Key influencing factors include fiscal policy, foreign investment, and employee qualifications (Becker 1993; World Bank 2021). Table 2 presents a regional comparison of average gross salaries in 2014 and 2025, providing an overview of differences in wage levels across the selected countries.

2.2.4. Consequences of privatization and tendering

Privatization has brought partial benefits, while a lack of foreign investment, corruption, and financial crises have had a negative impact (Institute for Advanced Studies GAP, 2015; Privatization Agency of Kosovo, 2012). Recommendations include performance reporting, contract enforcement, and increased transparency.

2.3. Human capital and its importance for development

Human capital, consisting of the intelligence, skills, and experience of individuals, is a key component of economic growth and innovation (Becker 1993; Bontis 1999a; Chirtoc 2010). In Kosovo, the lack of skills and high unemployment rates remain obstacles to economic development and attracting foreign investment (OECD 2017; World Bank 2021).

2.4. Practical implications

The key challenges facing public institutions include:

- high unemployment and skills gaps;
- political influence in staff and managerial selection;
- non-transparent privatization, tendering processes, and limited innovation.

These challenges have direct negative implications for policy and management in the areas of:

- professional development programs,
- meritocratic systems for employee promotion,
- increasing transparency and accountability,
- encouraging innovation and new investments.

These policy and management implications lead to the following academic and practical conclusions:

- Employee responsibility and accountability must be increased.
- Political influence on decision-making must be minimized.
- Promotions must be strictly based on education, experience, and performance.
- Civil society must actively participate in monitoring and ensuring international standards are adhered to (Boselie et al. 2005; OECD 2017).

Table 2

Recommendations for improving public organizations and economic development in Kosovo

Area	Key challenge	Recommendations
Human capital	high unemployment, lack of advanced skills and training	develop structured professional advancement programs, specialized training, alignment with market and international standards
Recruitment and promotion	political influence in hiring and promotions	implement merit-based recruitment and promotion systems; establish clear criteria based on performance and qualifications
Governance and transparency	non-transparent privatization and procurement, corruption	increase accountability, publish annual and financial reports, ensure independent institutional monitoring
Innovation and investment	lack of new ideas, limited investment	support innovative projects and scientific research; encourage new technologies and a diversity of ideas
Civil society participation	weak monitoring of public institutions	actively engage civil society in performance evaluation and public policy monitoring

Table 2 links the principal challenges to specific measures to address them, making the material more structured and readable for academic publications.

Based on the analysis of the challenges faced by public organizations and businesses in Kosovo, an integrated approach is recommended that focuses on developing human capital, promoting meritocracy, increasing transparency, and encouraging innovation. Workforce development should be made a priority by creating structured programs for professional advancement and specialized training that align with market needs and international standards. This will help reduce unemployment and increase the capacity of organizations to innovate and expand their economic activities. Recruitment and promotion of staff should be performed based on merit, setting clear criteria for performance and qualifications. This measure aims to minimize political influence and increase the motivation of professional employees, ensuring efficiency and professionalism within public institutions. Furthermore, increasing transparency and accountability in resource management and privatization processes is essential. The publication of annual and financial reports and information on decision-making will strengthen the credibility of institutions and reduce the opportunities for non-transparent practices. Another important element is to encourage innovation and new investment. Organizations should support creative projects, scientific research, and technological development, creating an environment that facilitates competition and diversity of ideas. This approach not only increases productivity but also contributes to long-term economic sustainability. Active participation of civil society is also essential for monitoring public institutions and ensuring that implemented policies are effective and sustainable. This will ensure compliance with international standards of good governance and will foster human resource development and innovation within organizations. In summary, these recommendations aim to create an integrated, transparent, and innovative environment where human capital development, a meritocratic system, and good governance practices combine to foster sustainable economic and organizational development in Kosovo. Their implementation will contribute to increasing the efficiency, professionalism, and competitiveness of public and private organizations, maximizing the potential of human resources and providing a strong foundation for long-term economic development.

2.5. Empirical results

The demographic data of the respondents provide an important overview of the sample structure and support a more accurate interpretation of the results concerning the effects of non-meritocratic practices, particularly nepotism, in public and private organizations. The study was conducted from September 2025 to January 2026, and the sample comprised $N = 150$ respondents from public and private organizations (Tab. 3).

Table 3

Structure of respondents by age and gender

Variable	Category	Percentage [%]
Age	25–34 years	20
	35–45 years	40
	45–54 years	20
	over 55 years	20
Gender	male	60
	female	40

The research was conducted in central and local public organizations operating in the Kosovo market, including managers and employees of human resources departments. The aim was to analyze the impact of various factors, such as politicization, lack of qualifications, tendering practices, economic policies, and competition, on organizational performance and development. This population was selected because managers and human resource personnel are directly involved in recruitment processes, staffing decisions, and organizational governance. Therefore, they are the most appropriate and reliable respondents for assessing the influence of political interference and non-meritocratic practices on organizational efficiency and professionalism.

As outlined in Table 4 the organizational characteristics show that 48% of the respondents work in public organizations with 11–50 employees, while 52% are part of organizations with 10 or fewer employees. Managers account for 70% of the sample, while human resource employees account for 30%.

Table 4

Distribution of respondents by organization size and position

Characteristic	Category	Percentage [%]
Organization size	11–50 employees	48
	≤10 employees	52
Position in organization	manager	70
	HR staff	30

The organizational characteristics show that 48% of the respondents work in public organizations with 11–50 employees, while 52% work in organizations with 10 or fewer employees. Managers account for 70% of the sample, while human resource (HR) staff account for 30%. The results indicate that most respondents

work in small or medium-sized organizations, while the high proportion of managers in the sample provides direct insight into decision-making and management processes.

2.5.1. Perceptions of organizational factors

The findings presented in Table 5 indicate that respondents perceive political influence in employee and managerial selection as an important organizational issue, with all respondents reporting a high impact on organizational processes.

Table 5

Respondents' perceptions of the impact of key factors on organizational performance and development

Factor assessed	Dominant Response	Percentage [%]
Lack of qualifications	no impact	80
	high impact	20
Political influence in employee selection	high impact	100
Political influence in managerial selection	high impact	100
Efficiency/professionalism	high impact	100
Creativity/innovation	no impact	50
	moderate impact	50
Non-transparent procurement practices	moderate impact	100
Economic policies and lack of reforms	no impact	48
	moderate impact	52
Professional human resources and competition	no impact	62
	impact	38

The results also suggest that non-transparent tendering practices and the lack of creativity and innovation may affect employee motivation, performance, and organizational development, although the perceived intensity of these effects varies across respondents. In contrast, perceptions regarding the impact of employee qualifications and professional human resources on organizational performance are more diverse. Overall, the findings highlight the relevance of merit-based selection, transparent organizational procedures, professional human resource management, and support for innovation in improving the functioning of public organizations. The results show complete agreement among respondents that political influence affects the selection of employees and managers. A lack of qualifications and professional resources is perceived as less important, whereas

creativity and innovation are divided. Non-transparent practices and economic policies have a moderate impact, suggesting that the principal challenges for organizations are structural and institutional.

2.5.2. Descriptive analysis

The main variables were measured on a Likert scale of 1–5. The mean and standard deviation are presented in Table 6.

Table 6

Mean and standard deviation of key variables

Variable	Mean (*M*)	*SD*
Impact of the lack of qualifications	2.10	0.85
Political influence on employee selection	4.90	0.31
Political influence on managerial selection	4.92	0.28
Efficiency/professionalism	4.85	0.40
Lack of creativity and innovation	2.55	0.96
Non-transparent procurement practices	3.00	0.00
Economic policies and lack of reforms	2.60	0.78
Professional resources and competition	2.20	0.70

Political influence is perceived as having a consistently high impact on employee and managerial selection, with mean scores of 4.90 and 4.92, respectively, and relatively low standard deviations. Efficiency and professionalism also received a high mean score ($M = 4.85$, $SD = 0.40$). In contrast, the lack of qualifications ($M = 2.10$, $SD = 0.85$), professional resources and competition ($M = 2.20$, $SD = 0.70$), and the lack of creativity and innovation ($M = 2.55$, $SD = 0.96$) received lower mean scores. Non-transparent procurement practices showed a mean of 3.00 and a standard deviation of 0.00, indicating no variation in the recorded responses for this variable. Overall, the findings suggest that respondents perceive political influence as a particularly prominent factor in employee and managerial selection, while the other measured factors received lower mean scores. These descriptive statistics provide an overview of the response patterns and do not, by themselves, establish causal relationships between the variables.

2.5.3. Spearman's correlations

Spearman's rank-order correlation analysis revealed strong associations between political influence and perceived professionalism and efficiency. Table 7 provides details on analysis of Spearman's rank-order correlation.

Table 7

Spearman's r correlation matrix

Variable 1	Variable 2	*r*	*p*
Political influence	professionalism	0.71	0.001
	lack of qualifications	0.12	0.210
Lack of qualifications	innovation	0.18	0.080
Non-transparent practices	motivation	0.45	0.005

The results show that the higher the perception of political influence, the lower the perceived level of professionalism. Lack of qualifications has no statistically significant relationship with the main variables.

2.5.4. Linear regression

The linear regression model with professionalism/efficiency as the dependent variable was statistically significant, $F(3, 96) = 15.72$, $p < 0.001$, with $R^2 = 0.32$. The regression coefficients are presented in Table 8.

Table 8

Linear regression results

Predictor variable	β (Beta)	*p*
Political influence (managers)	0.62	0.001
Non-transparent procurement practices	0.28	0.014
Lack of qualifications	0.07	0.410

The results show that political influence in managerial selection was the strongest predictor of professionalism and efficiency ($\beta = 0.62$, $p < 0.001$), followed by non-transparent procurement practices ($\beta = 0.28$, $p = 0.014$). Lack of qualifications was not a statistically significant predictor ($\beta = 0.07$, $p = 0.410$). These findings suggest that organizational performance is more strongly associated with institutional and structural factors than with employees' qualifications alone.

Improving the performance of public organizations requires:

- depoliticizing staff and managerial selection processes,
- increasing transparency in tendering and administrative practices,
- developing clear policies for human resource development and promoting innovation.

2.5.5. Study limitations

This study has several limitations. The findings are based on self-reported perceptions, which may involve subjective bias. The sample is limited to public organizations in Kosovo, reducing generalizability, while the cross-sectional design limits causal interpretations. The secondary data may also contain inconsistencies due to differences in institutional reporting standards.

2.5.6. Focus of the study

This study investigates the impact of structural and institutional determinants – political influence, deficient innovation, human capital constraints, and opaque procurement practices on organizational performance within Kosovo's public sector. It aims to identify their effects on professionalism, efficiency, decision-making, and organizational development.

2.5.7. Future research directions

Future studies should include private-sector organizations and international institutions to enable broader comparisons. Longitudinal and qualitative research is recommended to examine changes over time and causal relationships and to provide deeper insights into political influence, innovation, and human resource development. Cross-country studies could further enhance the understanding of governance and institutional performance in developing economies.

2.5.8. Contribution of the study

This study contributes to the academic literature by providing empirical evidence on the role of political influence in shaping organizational efficiency and professionalism in public institutions. It highlights how structural and institutional barriers, rather than individual qualifications, affect performance. In practical terms, the study provides recommendations for promoting meritocracy, transparency, and human capital development, while supporting public administration reforms and future comparative research.

3. Conclusions and recommendations

This section summarizes the main findings of the study and discusses their implications for public organizations and economic development in Kosovo. Based on the empirical results, it also presents practical recommendations concerning human resource management, merit-based recruitment and promotion, transparency, innovation, and institutional development.

3.1. Conclusions

The analysis conducted on public organizations and businesses in Kosovo shows that sustainable economic and organizational development faces several interrelated challenges. High unemployment and shortages of qualified labor remain major problems that directly affect job creation, innovation, and the expansion of existing businesses. This situation reduces purchasing power, limit opportunities for professional development, increases social costs, and negatively affects the state budget. The lack of innovation within public and private organizations is another important obstacle to economic development. Many organizations prefer to invest in familiar, proven projects to minimize risk, but this approach limits the diversity of ideas and hinders the development of innovative capacity. Investors require institutional support, efficient legal solutions, and sustainable infrastructure to ensure the success of their investments, but structural constraints and insufficient support make investment more difficult. Political influence in the selection of managers and professional staff further undermines institutional efficiency. Recruitment and promotion are often based on political connections rather than merit, creating internal dependencies and reducing the motivation of professional employees. This practice adversely affects human capital development and the effectiveness of organizational decision-making. The privatization of public enterprises and tendering processes also pose major challenges. A lack of transparency, corruption, and conflicts of interest adversely affect expected economic outcomes. These processes are not always accompanied by effective monitoring and accountability, which weakens the credibility and performance of the public and private sectors. An integrated approach to addressing these challenges is therefore needed. Human capital development should be prioritized by establishing structured programs for professional advancement and specialized training aligned with current market needs and international standards. These measures would help reduce unemployment and increase organizations' capacity to innovate and expand their economic activities. Staff recruitment and promotion should be merit-based, with clear performance and qualification criteria designed to minimize political influence and increase the motivation of professional employees.

Increasing transparency and accountability in resource management and privatization processes is essential to guarantee the fair and effective functioning of institutions. The publication of annual and financial reports and the inclusion of independent monitoring will strengthen the credibility of institutions and minimize non-transparent practices.

Another important element for increasing economic sustainability is encouraging innovation and new investments. Organizations should support creative projects, scientific research, and technological development, creating an

environment that facilitates competition and a diversity of ideas. This approach not only increases productivity but also contributes to long-term economic development. Active participation of civil society is also important for monitoring public institutions and ensuring that implemented policies are effective and sustainable. Compliance with international standards of good governance and continuous monitoring of institutions will promote human resource development, innovation, and the sustainability of organizations. In summary, improving public organizations and supporting Kosovo's economic development require an integrated approach that combines human capital development, meritocracy, greater transparency, and innovation. Only by implementing these measures can sustainable and economically viable development be achieved, thereby maximizing the potential of human resources and creating a favorable environment for investment and growth. The findings indicate that political influence is the dominant factor in the selection of managers and employees and directly affects professionalism and efficiency in public organizations. By contrast, most respondents do not perceive staff qualifications as an important factor. Structural and institutional problems, including political influence, non-transparent tendering, and the absence of economic reforms, are therefore perceived as more serious than individual factors such as education or professional qualifications.

3.2. Recommendations

Based on the research conducted, it is recommended that specialized programs for training and professional advancement be designed in accordance with market needs and international standards, while innovation should be promoted to increase competitiveness and productivity.

Clear, merit-based criteria should also be established for staff recruitment and promotion. The assessment methodology and biographies of candidates for managerial positions should also be published, independent recruitment companies should participate in the process, boards should include independent members, transparency and accountability should be strengthened, and good-governance standards should be applied to the management of public resources. Annual financial reports should be published, independent monitoring mechanisms should be established, and integrity in tendering and privatization processes should be strengthened to help prevent corruption and conflicts of interest. It is also essential to support innovation and investment by encouraging creative projects, scientific research, and technological development. Creating a favorable environment for long-term investment and a diversity of ideas requires the active involvement of civil society in monitoring public institutions. This participation ensures that implemented policies are effective, transparent, and in line with international standards.

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Summary

Public organizations face a number of economic and non-economic challenges that directly affect the performance and development of human resources. These challenges include excessive bureaucracy, political influence in the selection of managers, high unemployment, lack of sustainable economic reforms, and non-transparent tendering practices. This study aims to identify the main obstacles to human resource management and to analyze the impact of economic, political, and organizational factors on the efficiency and professionalism of public organizations. The use of a combined approach of primary data, collected from institutional documents and organizational reports, and secondary data, extracted from scientific literature and surveys, allows for a comprehensive analysis of the current situation. The results of the study provide practical recommendations for improving organizational and human resource management, contributing to sustainable economic development and the professionalization of public institutions. This study is particularly relevant to human resource professionals and policymakers aimed at increasing efficiency and innovation in the public sector.

JEL codes: H83, J21, J24, M12, O15

Keywords: *employment, political influence, human resources, professionalization*

Received: 21.07.2026
Accepted: 17.09.2026

Managerial Economics
2026, Vol. 27, No. 2, pp. 151–191
https://doi.org/10.7494/manage.2026.27.2.151
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Jerzy Rydlewski[1], Przemysław Jaśko[2]

Goodwin model for France's business cycles. A functional data analysis approach

1. Introduction

In our work, we focus on the application of ODE (ordinary differential equations) systems with measurement error in economic research, exemplified by the empirical version of the Goodwin model of business cycles (Goodwin 1967), involving two state variables: labor's share of income, and employment ratio. We present an ODE system structural parameter estimation method from data with measurement noise, called the parameter cascade method, introduced by Ramsay and colleagues (Ramsay et al. 2007), which is a generalized profiling estimation procedure (Cao, Ramsay 2007), in which a subset of parameters are estimated as a function of the remaining parameters. This parameter cascade method of estimating the ODE parameters belongs to the group of collocation or functional basis expansion methods. The parameter cascade method takes a functionally oriented approach, in which approximation functions (defined by coefficients of basis functions defining a finite-dimensional functional space) are used to approximate the solutions of the ODEs. The estimation procedure involves two objective functions: inner, and outer. The inner objective function, from which the basis expansion coefficients (nuisance parameters) are obtained by minimization (conditionally on the current values of the ODE system structural parameters), involves a penalty that regularizes the approximations by controlling the extent to which the approximation functions fail to satisfy the ODEs. In turn, the outer objective function is minimized with respect to the ODE system structural parameters, and the fact that the basis expansion coefficients are implicit functions of the structural parameters is taken into account in the gradient-based iterative

[1] AGH University of Krakow, Krakow, Poland, e-mail: ry@agh.edu.pl, ORCID: 0000-0002-2071-0646
[2] Krakow University of Economics, Krakow, Poland, e-mail: jaskop@uek.krakow.pl, ORCID: 0000-0002-5534-9096

procedure. We briefly consider ODE system structural identifiability, which is the theoretical ability to uniquely recover model parameters from ideal, noise-free data, and is a prerequisite for reliable parameter estimation in empirical modeling. Structural parameters of the two-equation ODE system in the standard form of the Goodwin model are not identifiable (we present results on the global identifiability of the structural parameters, obtained with use of the procedure proposed by Dong and colleagues (Dong et al. 2023), called "differential elimination for dynamical models via projections with applications to structural identifiability"). So, to make it possible to estimate the structural parameters of the parameter cascade method, we propose to extend the Goodwin model to a three-equation ODE system, with one additional differential equation involved in the Goodwin model's derivation, representing labor productivity growth. Next, we briefly present a formal statement of the parameter cascade method for estimating ODE system structural parameters, comparing it to the NLS (nonlinear least squares estimator), which belongs to the estimation methods involving time discretization of ODEs.

The structure of the paper is as follows: in Section 2, we present a brief formal statement of the Goodwin model. In Section 3, we consider the structural parameter identifiability problem in the two-equation ODE system of the Goodwin model and propose a possible solution to it. Section 4 briefly describes the estimation procedure of the empirical version of the Goodwin model with the parameter cascade method, with comparison to the NLS estimation. Section 5 presents a simulation and empirical study of the Goodwin model estimation. For the simulation study, we present results on the finite-sample properties of the parameter cascade method and the NLS estimator for the three-equation ODE system of the extended Goodwin model. In the empirical part, we estimate the structural parameters of the three-equation ODE system Goodwin model with additive measurement noise using the parameter cascade method and NLS. It is based on the annual time series data for France over the period 1962–2009, representing three variables: labor productivity, labor's share of income, and employment ratio. The paper concludes with a conclusion section.

2. The Goodwin model

The Goodwin model (proposed in Goodwin 1967) is an economic growth cycle model consisting of two nonlinear ODE equations for two state variables: u and v, which are, respectively, the wage share in the national GDP, and the employment ratio. In the empirical version of the model, measurement noise is added to the two state variables, resulting in measurement equations.

The formal Goodwin model is a reparameterization of the Lotka–Volterra system of differential equations. The differential equations are rewritten such that they can be inferred from the differential and balancing equations, which are assumed on the grounds of economic theory.

The Goodwin model describes a single-sector, non-monetary economy in which there are only two groups: capitalists and workers. They produce a single good, which they can either consume or invest. The price of the good is normalized and equal to one. A description of the Goodwin model from the perspective of mathematical economics can be found, among others, in literature (Jakimowicz 2003).

Following Guzowska (Guzowska 2011), we present a sketch of the derivation of the Goodwin model as a two-equation ODE system from the assumed economic theory equations.

The following variables are involved in the derivation of the model: Y: output, K: capital stock, S: savings, L: employment, $a = Y/L$: labor productivity, n: labor supply, u: workers' share in the output (called labor's share of income), $v = L/n$: employment ratio, w: wage rate.

The main hypotheses defining the Goodwin model structure are described in the following points.

1. There are two homogeneous factors of production: labor and capital. Technological progress is neutral in the Harrod sense, with a constant coefficient:

$$\frac{\dot{a}}{a} = \alpha, \alpha > 0 \tag{1}$$

2. There is constant growth of the labor force:

$$\frac{\dot{n}}{n} = \beta, \beta > 0 \tag{2}$$

All wages are consumed, and all income is invested; all quantities are real and net:

$$S = I = \dot{K} = Y - wL \tag{3}$$

3. Real wages change in accordance with the Phillips curve, which represents the bargaining equation in the labor market:

$$\frac{\dot{w}}{w} = \rho v - \gamma, \rho, \gamma > 0 \tag{4}$$

4. A fraction of income is transferred to employees according to the formula:

$$u = \frac{wL}{Y} = \frac{w}{a} \tag{5}$$

After some straightforward transformations, we arrive at the final Goodwin model, which is the following two-equation ODE system:

$$\begin{cases} \dfrac{du}{dt} = u\left(\rho v - \gamma - \alpha\right) \\ \dfrac{dv}{dt} = v\left(-\dfrac{1}{\sigma}u + \dfrac{1}{\sigma} - \alpha - \beta\right) \end{cases} \tag{6}$$

where u is the wage share in the national GDP (called labor's share of income), and v is the employment ratio, i.e. the number of employed divided by the size of the labor force. All model parameters, i.e. α, β, γ, σ and ρ, should be positive and for the system to be economically meaningful, they also need to satisfy the following requirements: $\alpha + \beta < 1/\sigma$ and $\alpha + \gamma < \rho$. The productivity growth rate, denoted by α, is the rate of growth of labor productivity (e.g., the ratio of increase in output per worker per year). The parameter β describes the labor force growth rate. The parameter γ represents autonomous or institutional wage pressure, i.e. wage inflation expectations. The parameter ρ describes sensitivity of wage growth to employment, i.e. wage bargaining strength. The parameter σ is the capital-to-output ratio, which is also interpreted as the inverse of capital productivity.

To calculate the two-equation ODE system fixed points, we set:

$$\begin{cases} 0 = u\left(\rho v - \gamma - \alpha\right) \\ 0 = v\left(-\dfrac{1}{\sigma}u + \dfrac{1}{\sigma} - \alpha - \beta\right) \end{cases} \tag{7}$$

As solutions, we obtain two fixed points of the system of the state variables u and v:

- a hyperbolic fixed point at the origin (0, 0),
- a stable fixed point (u^*, v^*), which is the center of the closed orbits in the local vicinity

$$\begin{cases} u^* = 1 - \left(\alpha + \beta\right)\sigma \\ v^* = \dfrac{\alpha + \gamma}{\rho} \end{cases} \tag{8}$$

Orbits around this fixed point are closed and elliptical, thus the solutions are periodic, oscillating on an ellipse centered at the point (u^*, v^*).

To formalize these orbits, time is eliminated from the system's two differential equations to produce a single differential equation:

$$\frac{dv}{du} = \frac{v}{u}\frac{-\dfrac{1}{\sigma}u + \dfrac{1}{\sigma} - \alpha - \beta}{\rho v - \alpha - \gamma} \tag{9}$$

relating the variables u and v. The solutions of this equation are closed curves. It can be solved using the method of separation of variables, i.e. integrating:

$$\frac{\rho v-\alpha-\gamma}{v}dv+\frac{\frac{1}{\sigma}u-\frac{1}{\sigma}+\alpha+\beta}{u}du=0 \tag{10}$$

yields the implicit relationship:

$$C=\frac{1}{\sigma}u+\left(-\frac{1}{\sigma}+\alpha+\beta\right)\ln(u)+\rho v-(\alpha+\gamma)\ln(v) \tag{11}$$

where C is a constant value determined by the initial conditions and remains conserved along each curve.

The stability of the fixed points can be determined using ODE system linearization, which involves partial derivatives.

The Jacobian matrix of the two-equation system for state variables u and v is:

$$\mathbf{J}(u,v)=\begin{bmatrix}\rho v-\alpha-\gamma & \rho u\\ -\frac{v}{\sigma} & \frac{(1-u)}{\sigma}-(\alpha+\beta)\end{bmatrix} \tag{12}$$

When evaluated at the fixed point (0, 0), the Jacobian matrix **J** becomes:

$$\mathbf{J}(0,0)=\begin{bmatrix}-\alpha-\gamma & 0\\ 0 & \frac{1}{\sigma}-(\alpha+\beta)\end{bmatrix} \tag{13}$$

The eigenvalues of this matrix are: $\lambda_1=-\alpha-\gamma,\ \lambda_2=\frac{1}{\sigma}-(\alpha+\beta)$.

Taking into account the parameter restrictions assumed in the model, which imply that $\alpha+\gamma$ and $1/\sigma-(\alpha+\beta)$ are always greater than zero, the signs of the eigenvalues always differ. Hence the fixed point at the origin is a saddle point.

Evaluating the Jacobian **J** at the second fixed point, which is:

$$(u^*,v^*)=\left(1-(\alpha+\beta)\sigma,\frac{\alpha+\gamma}{\rho}\right) \tag{14}$$

results in:

$$\mathbf{J}(u^*,v^*)=\begin{bmatrix}0 & \rho-(\alpha+\beta)\sigma\rho\\ -\frac{\alpha+\gamma}{\sigma\rho} & 0\end{bmatrix} \tag{15}$$

The matrix considered here has the following conjugated complex eigenvalues:

$$\lambda_1=i\sqrt{(\alpha+\gamma)\left(\frac{1}{\sigma}-(\alpha+\beta)\right)},\ \lambda_2=-i\sqrt{(\alpha+\gamma)\left(\frac{1}{\sigma}-(\alpha+\beta)\right)}$$

As a result, orbits about the fixed point are closed and elliptic, the solutions are periodic, oscillating on an ellipse around the fixed point with frequency:

$$\omega = \sqrt{\lambda_1 \lambda_2} = \sqrt{(\alpha+\gamma)\left(\frac{1}{\sigma} - (\alpha+\beta)\right)} \text{ and period of } T_G = \frac{2\pi}{\sqrt{\lambda_1 \lambda_2}}$$

Thus, the period T_G of these oscillations is given by:

$$T_G = \frac{2\pi}{\left[(\alpha+\gamma)\left(\frac{1}{\sigma} - (\alpha+\beta)\right)\right]^{1/2}} \tag{16}$$

As mentioned earlier, the two-equation ODE system of the Goodwin model can be seen as a reparameterization of the Lotka–Volterra model in its standard form.

The Lotka–Volterra model is defined as:

$$\begin{cases} \dfrac{du}{dt} = -(a_1 - b_1 v)u \\ \dfrac{dv}{dt} = (a_2 - b_2 u)v \end{cases} \tag{17}$$

This model is related to the Goodwin model by the following parameter relations:

$$a_1 = \alpha + \gamma, b_1 = \rho, a_2 = \frac{1}{\sigma} - (\alpha + \beta), b_2 = \frac{1}{\sigma} \tag{18}$$

3. Structural parameters identifiability problem in the Goodwin model two-equation ODE system

In this work, we consider linear and nonlinear dynamic state-space ODE models, depending on unknown parameters. Usually, these parameters are unknown and cannot be pre-specified and need to be estimated from data obtained by measuring the observable model variables (inputs and outputs). Output variables are given by the so-called measurement equations of the system, which are functions of the system's state variables and measurement noise (possibly additive). In order to solve the estimation problem, input–output data are collected.

In the case of the Goodwin model, the state variables of the ODE system consist of no input variables; only state variables. The measurement equation system involves the identity function, and an independent stationary Gaussian process is added to each equation.

A fundamental prerequisite for parameter estimation to be well-posed is the global identifiability of the parametric model. It should be noted that global identifiability assumes an ideal scenario with a perfect, error-free model structure and noise-free measurements. Therefore, while it is a necessary condition, it does not guarantee that accurate parameter identification from real-world input–output data will be achievable; factors such as measurement noise or poor problem conditioning can still impede successful identification (see Denis-Vidal and colleagues (Denis-Vidal et al. 2003). If there are at most a finite number of indistinguishable parameter values, the system is called locally (or nonuniquely) identifiable from the input–output data. Meanwhile, if there is an infinite number of different indistinguishable parameter values, the system is commonly called non-identifiable or unidentifiable.

Approaches used in the ODE structural parameter identifiability analysis include:

- Taylor series method,
- generating series method (GenSSI),
- similarity transformation approach,
- direct test method,
- differential algebra approach (implemented in DAISY, COMBOS, and Structural Identifiability Toolbox).

In this work, we make use of a differential algebra approach to assess the identifiability of the Goodwin model ODE system, by employing the method proposed by Dong and colleagues (Dong et al. 2023), referred to as differential elimination for dynamical models via projections with applications to structural identifiability. Differential algebra involves structures such as differential rings and fields, differential polynomials, rings of differential polynomials, differential ideals, and fields of definition, which are outside the scope of this work. The algebraic apparatus of differential algebra permits one to deal with polynomials which may involve derivatives of some variables (typically the state), and allows polynomials themselves to be differentiated, still keeping a formal similarity with classical commutative algebra. Formal treatments of differential algebra approaches in the context of the global or local identifiability of ODE systems can be found in literature (Hong et al. 2020; Dong et al. 2023; Sedoglavic 2002). A general treatment of differential algebra concepts can be found in Kolchin' work (Kolchin 1973).

The differential algebra approaches involve the idea of finding the input–output representation, which is to eliminate all state variables to derive equations that involve only model parameters, inputs, and observable outputs (and their derivatives). Ideally, a minimal set of such equations is derived. This approach also provides insights into how model parameters interact with each other. For

differential algebra approaches, structural identifiability reduces to a field membership problem: determining whether each parameter lies in the differential field generated by the observed outputs and their derivatives.

In the first phase of the procedure based on differential algebra, a set of generators is computed of the field of definition F of the ideal of the input–output relations; that is, the minimal subfield of the field of rational functions in parameters sufficient to write down the generators of this ideal. These generators are typically taken to be the coefficients of a finite set of input–output relations, which can be computed using:

- a characteristic set, as in DAISY (Differential Algebra for Identifiability of SYstems),
- a Gröbner basis (as in COMBOS),
- elimination by hand.

After this, in the second phase, the identifiability of a parameter is assessed by testing whether it belongs to F.

As already mentioned, to assess the structural identifiability of ODE systems, we use differential elimination for dynamical models via projections, as proposed by Dong and colleagues. (Dong et al., 2023). This algorithm computes a description of the set of differential-algebraic relations between the input and output variables of a dynamical system model. Based on this elimination procedure, a randomized algorithm is constructed to assess the structural identifiability of a parameter in a parametric model. The algorithm is implemented in the `Julia` package named `StructuralIdentifiability.jl`. A description of the usage of this package can be found in literature (Liyanage et al. 2025).

4. Estimation of the empirical version of the Goodwin Model with the parameter cascade method, with comparison to the NLS estimation

Procedures for estimating the parameters of an ODE from noisy data generally fall into three broad categories:

- linearization methods,
- discretization methods,
- collocation methods (basis function expansion methods).

In linearization methods, the ODE is initially approximated by a linear equation around a fixed point. Solutions derived from exponential basis functions are then obtained from this linearized form, serving as the foundation for estimating the model parameters.

The main representatives of estimation procedures involving discretization methods for obtaining approximate solutions to ODE systems are:

- NLS (Nonlinear Least Squares),
- MLE (Maximum Likelihood Estimation).

In discretization approaches, estimating the parameters of an ODE model involves iteratively solving the system numerically and updating the ODE parameters based on the resulting solution. This updating process aligns with the nonlinear regression framework. Specifically, the goal is to find the parameter vector $\boldsymbol{\theta}$ that minimizes the sum of the squared differences between the observed data and the solutions generated by the ODE model. The initial conditions – values of the state variables at the starting time – determine the unique solution obtained through numerical integration. However, in practical scenarios, these initial conditions are often unknown and need to be estimated prior to solving the ODEs. When the initial conditions are unavailable, they are incorporated into the parameter vector and estimated simultaneously with the ODE parameters.

When assumptions other than a stationary Gaussian process are made about the measurement error process, which is superimposed on the solution of the ODE system for state variables, the NLS can be replaced with the MLE estimation. The MLE procedure, when constructing the likelihood function, takes into account the specific distribution of variables in the measurement error process.

The NLS and MLE methods for ODE structural parameter estimation are implemented in the `fitode` package for `R` developed by Park (Park 2022). To obtain approximate time-discretized solutions of the considered ODEs, it makes use of ODE numerical solving procedures implemented in the `deSolve` package of `R` (authored by Soetaert and colleagues (Soetaert et al. 2010)).

In turn, collocation methods express the approximation of the ODE solution in terms of a basis function expansion.

In the initial phase of the development of collocation methods, a two-stage approach was proposed by Varah (Varah 1982), which employed nonparametric techniques to interpolate the derivatives of state variables over time. In the second stage, the parameters are estimated within a nonlinear regression framework, treating these interpolated derivatives as responses. Replacing numerical solutions with nonparametric estimates significantly reduces the computational demands; however, this substitution introduces estimation errors during the interpolation of derivatives, since direct observations of these derivatives are unavailable. Additionally, Cao and colleagues (Cao et al. 2012) demonstrated that such derivative estimation errors can cause bias in the estimation of ordinary differential equation (ODE) parameters. In contrast to the two-step method, Ramsay and colleagues

(Ramsay et al. 2007) proposed an alternative approach known as the parameter cascade method.

The parameter cascade method for ODE structural parameter estimation based on data with measurement noise was implemented in the following `R` packages: `pCODE` by Wang and Cao (Wang, Cao, 2019) (see also (Wang Cao 2023)) and `CollocInfer` by Hooker and colleagues (Hooker et al., 2016). As an alternative approach, Bayesian inference methods on the ODE system parameters are implemented in the `R` package `BayesianFitForecast` by Karami and colleagues (Karami et al. 2025).

Now we briefly describe the NLS and parameter cascade method of the ODE system structural parameter estimation. These methods are, respectively, representatives of the discretization and collocation methods.

4.1. NLS estimation of ODE structural parameters

In the NLS estimation procedure, first, numerical approximate solutions to the ODE initial value problem are obtained for given values of the structural parameters. From this approximate solution, values of the ODE state variables are taken at time points for which empirical time series data is available, and the sum of the squared errors between the approximate and observed values are calculated. The resulting sum of squared errors is an objective function, which is subject to minimization over ODE structural parameters (and optionally also over initial value parameters). Iterative procedures such as Levenberg–Marquardt can be used to minimize the objective function of the NLS estimator.

For an approximate numerical ODE solution, procedures based on linear multistep methods, such as LSODA introduced in literature (Petzold 1983), can be used.

Numerical methods for ODE approximate the solutions to initial value problems of the form:

$$\dot{\mathbf{x}} = \mathbf{f}\left(t, \mathbf{x}\right), \mathbf{x}\left(t_0\right) = \mathbf{x}_0 \tag{19}$$

where $\mathbf{x}\left(t\right) = \left(x_1\left(t\right), \ldots, x_I\left(t\right)\right)'$, and $\mathbf{f}\left(t, \mathbf{x}\right) = \left(f_1\left(t, \mathbf{x}\right), \ldots, f_I\left(t, \mathbf{x}\right)\right)'$

The result is approximations for the value of $\mathbf{x}(t)$ at discrete times t_j: $\mathbf{x}(t) \approx \mathbf{x}(t_j)$ where $t_j = t_0 + jh$, where h is the time step and j is an integer.

Multistep methods use information from the previous s steps to determine the next value. Specifically, a linear multistep method combines linear combinations of past solution values x_j and their derivatives $\mathbf{f}(t_j, \mathbf{x}_j)$ to compute the current step's value.

The objective function for the ODE system can be written as:

$$S(\mathbf{y};\boldsymbol{\theta}) = \sum_{i=1}^{I}\sum_{j=0}^{n}\left(y_{ij} - x_i\left(t_{ij};\boldsymbol{\theta}\right)\right)^2 \tag{20}$$

where $x_i(t_{ij}; \boldsymbol{\theta})$ are the numerical approximate solutions of the ODE for the i-th state variable x_i, at the time moment t_{ij}, calculated under the structural parameter vectors $\boldsymbol{\theta}$, and y_{ij} is the j-th value of the i-th state variable, observed under additive measurement noise at time t_{ij}.

In an iterative procedure such as Levenberg–Marquardt, the gradient $\frac{\partial S}{\partial \boldsymbol{\theta}}$ of the objective function is used, which in turn, by the chain rule, involves the term $\frac{d\mathbf{x}}{d\boldsymbol{\theta}}$, which can be numerically approximated using LSODA numerical ODE solutions calculated under $\boldsymbol{\theta}_k$ (which are the parameter values from the k-th iteration), and under a slightly perturbed version.

Alternatively, gradients $\frac{d\mathbf{x}}{d\boldsymbol{\theta}}$ may be approximated by solving the sensitivity differential equations:

$$\frac{d}{dt}\left(\frac{d\mathbf{x}}{d\boldsymbol{\theta}}\right) = \frac{\partial \mathbf{f}}{\partial \boldsymbol{\theta}} + \frac{\partial \mathbf{f}}{\partial \mathbf{x}}\frac{d\mathbf{x}}{d\boldsymbol{\theta}},\ with \quad \frac{d\mathbf{x}}{d\boldsymbol{\theta}}|_{t=0} = \mathbf{0} \tag{21}$$

In the event that $\mathbf{x}(0) = \mathbf{x}_0$ must also be estimated, the corresponding sensitivity equations are:

$$\frac{d}{dt}\left(\frac{d\mathbf{x}}{d\mathbf{x}_0}\right) = \frac{\partial \mathbf{f}}{\partial \mathbf{x}}\frac{d\mathbf{x}}{d\mathbf{x}_0},\ with \quad \frac{d\mathbf{x}}{d\mathbf{x}_0}|_{t=0} = \mathbf{I} \tag{22}$$

4.2. Parameter cascade method estimation of ODE structural parameters

The parameter cascade method proposed by Ramsay and colleagues (Ramsay et al. 2007) belongs to the family of collocation methods that express the approximation $\hat{x}_i$ of x_i in terms of a basis function expansion. The parameter cascade method provides an estimation of ODE parameters from the noisy observations.

In the parameter cascade method, there is a member of basis function expansion or collocation methods. From such methods, the finite-dimensional function space L_p on [0,T] is first chosen. Approximation functions to the solutions of the ODEs will be chosen from L_p (this is equivalent to choosing the coefficients of the basis functions). For example, using a spline basis to approximate an initial value problem ODE solution is equivalent to the use of an implicit Runge-Kutta method for stepping points located at the knots defining the basis (see (Deuflhard, Bornemann 2012).

A general overview of functional data analysis (FDA) can be found in literature (Ramsay, Silverman 2005; Rydlewski 2025) also presents FDA applications in economic research. The topic of functional data smoothing is treated there in detail. A software implementation of FDA is covered, among others, in work of Ramsay and colleagues (Ramsey et al. 2009). The FDA procedures considered there are implemented in the `R` package `fda` and related family of packages.

In the case of the parameter cascade method, two groups of parameters can be distinguished: structural parameters $\boldsymbol{\theta}$ of the ODE system, and basis function expansion coefficients of the smoothed approximations $\hat{x}_i$ (for each i-th state variable of the ODE system), embraced in the vector $\mathbf{c}$, which are called the nuisance parameters since they are not essential for estimating the ODE model but rather interpolate the observations. For each given set of ODE parameters $\boldsymbol{\theta}$, the basis coefficients $\mathbf{c}$ are estimated by minimizing the inner objective function $J(\boldsymbol{c} \mid \boldsymbol{\theta})$. Thus, the estimate for the basis coefficients becomes an implicit function of the ODE parameters $\boldsymbol{\theta}$ as $\mathbf{c}(\boldsymbol{\theta})$. The amount of regularization is controlled by smoothing parameters in vector $\boldsymbol{\lambda}$. Structural parameters are estimated by minimizing the outer objective function $H(\boldsymbol{\theta}; \boldsymbol{\lambda})$ over $\boldsymbol{\theta}$.

Now we present the main aspects of the parameter cascade method, following Ramsay and colleagues. (Ramsey et al. 2007) and Wang and Cao (Wang, Cao 2023).

We consider the ODE system in the following form:

$$\dot{\mathbf{x}}(t) = f(\mathbf{x}, u, t \mid \boldsymbol{\theta}) \tag{23}$$

where $\mathbf{x}(t)$ denotes the fully or partially observed states of the system at time t.

The considered ODE system links the first derivative over time of the states with $\mathbf{x}$ itself and other influencing components u through some function f defined by the parameter vector $\boldsymbol{\theta}$.

Each of $x_i(t)$ is expressed as a linear combination of basis functions:

$$x_i(t) = \sum_{k}^{K_i} c_{ik}\phi_{ik}(t) = \mathbf{c}_i'\boldsymbol{\phi}_i(t) \tag{24}$$

where K_i is the number of basis functions, and $\boldsymbol{\phi}_i(t)$ is the vector of basis functions evaluated at a time point t.

We define the joint vector of all involved basis coefficients as $\mathbf{c} = (\mathbf{c}_1', \mathbf{c}_2', \ldots, \mathbf{c}_I')'$, and accordingly, the joint vector of all involved basis function values at time t as $\boldsymbol{\phi}(t) = (\boldsymbol{\phi}_1'(t), \boldsymbol{\phi}_2'(t) \ldots, \boldsymbol{\phi}_I'(t))'$.

Let $y_{ij} = x_i(t_{ij}) + e_{ij}$ be the j-th noisy observation of the i-th state variable at time t_{ij}, where e_{ij} is the measurement error or noise, $j = (1, \ldots, n_i)$. It is assumed that vector $\mathbf{e}_i = (e_{i1}, \ldots, e_{in_i})$ of random errors has a distribution function $g(\mathbf{e}_i)$ with

the distribution parameter σ_i. The ODE system structural parameters need to be estimated from noisy observations of the system.

The inner objective function is defined as:

$$J(\mathbf{c}\,|\,\boldsymbol{\theta}) = \sum_{i=1}^{I}\left[-\ln g(\mathbf{e}_i) + \lambda_i \int \left(\dot{x}_i(t) - f_i(\mathbf{x}(t), t\,|\,\boldsymbol{\theta})\right)^2 dt\right] \tag{25}$$

where $\int \left(\dot{x}_i(t) - f_i(\mathbf{x}(t), t\,|\,\boldsymbol{\theta})\right)^2 dt$ is the smoothness penalty defined by the discrepancy between the time derivatives of the smoothed functions and the ODE model equations, for each state variable x_i. Each penalty is multiplied with a respective smoothing parameter λ_i, and they are combined over all dimensions.

For each given set of ODE parameters $\boldsymbol{\theta}$, the basis coefficients $\mathbf{c}$ is estimated by minimizing $J(\boldsymbol{c}\,|\,\boldsymbol{\theta})$ over $\mathbf{c}$. The estimate for the nuisance parameters $\mathbf{c}$ becomes an implicit function $\mathbf{c}(\boldsymbol{\theta})$ of the structural parameters $\boldsymbol{\theta}$. The inner objective function needs to be optimized whenever $\boldsymbol{\theta}$ is updated.

The upper-stream estimation of the parameter cascade method is focused on the structural parameter $\boldsymbol{\theta}$. To carry out this estimation, the outer objective function $H(\boldsymbol{\theta})$ is optimized with respect only to the structural parameters $\boldsymbol{\theta}$. By default, the outer objective function is defined as the negative log-likelihood function or the sum of the squared errors, given the distributions of random errors, namely:

$$H(\boldsymbol{\theta}) = -\sum_{i=1}^{I} \ln g(\hat{\mathbf{e}}_i\,|\,\boldsymbol{\theta}) \tag{26}$$

where $\hat{\mathbf{e}}_i = \boldsymbol{y}_i - \hat{x}_i(\mathbf{t}_i\,|\,\boldsymbol{\theta})$. Here, $\hat{x}_i(\mathbf{t}_i\,|\,\boldsymbol{\theta}) = \hat{\mathbf{c}}_i'(\boldsymbol{\theta})\boldsymbol{\phi}_i(\mathbf{t}_i)$, where $\hat{\mathbf{c}}_i'(\boldsymbol{\theta})$ is the optimizer of $J(\boldsymbol{c}\,|\,\boldsymbol{\theta})$, given the current $\boldsymbol{\theta}$.

In the considered profiling procedure, the nuisance parameter estimates, as already mentioned, are defined to be implicit functions $\hat{\mathbf{c}}_i(\boldsymbol{\theta}, \boldsymbol{\sigma}; \boldsymbol{\lambda})$ of the structural parameters, such that, each time $\boldsymbol{\theta}$ and $\boldsymbol{\sigma}$ are changed, an inner fitting objective $J(\hat{\boldsymbol{c}}\,|\,\boldsymbol{\theta}, \boldsymbol{\sigma}, \boldsymbol{\lambda})$ is reoptimized with respect to $\hat{\mathbf{c}}$ alone. The estimating function $\hat{\mathbf{c}}_i(\boldsymbol{\theta}, \boldsymbol{\sigma}; \boldsymbol{\lambda})$ is regularized by incorporating a penalty term in J that controls the size of the extent that $\hat{\boldsymbol{x}} = \hat{\mathbf{c}}'\boldsymbol{\phi}$ fails to satisfy the differential equation exactly, in a manner that is specified below. The amount of regularization is controlled by smoothing parameters in vector $\boldsymbol{\lambda}$. This is a process of eliminating the direct effect of the nuisance parameters on the fit of the model.

Finally, the data fitting outer criterion $H(\boldsymbol{\theta}, \boldsymbol{\sigma}; \boldsymbol{\lambda})$ is optimized solely with respect to the structural parameters. The outer objective H's dependence on $(\boldsymbol{\theta}, \boldsymbol{\sigma})$ is twofold: direct, and indirect through the involvement of the regularized estimates $\hat{\mathbf{c}}_i(\boldsymbol{\theta}, \boldsymbol{\sigma}; \boldsymbol{\lambda})$, which define the fitted values $\hat{x}_i$. Since $\hat{\mathbf{c}}_i(\boldsymbol{\theta}, \boldsymbol{\sigma}; \boldsymbol{\lambda})$ are already regularized, the criterion H does not need additional regularization and serves as

a straightforward measure of fit, such as the sum of squared errors, log-likelihood, or another appropriate metric based on the error distribution e_{ij}.

Hyperparameter $\boldsymbol{\lambda}$ may be adjusted manually by using numerical and visual heuristics. Alternatively, $\boldsymbol{\lambda}$ may be automatically estimated through the use of a measure $F(\boldsymbol{\lambda})$ of model complexity or mean-squared error, such as the generalized cross-validation criterion often used in least squares spline smoothing. In such a situation, the vector $\boldsymbol{\lambda}$ defines a third level of parameters and leads to the extended parameter cascade, in which structural parameter estimates are in turn defined to be functions $\hat{\boldsymbol{\theta}}(\boldsymbol{\lambda})$ and $\hat{\boldsymbol{\sigma}}(\boldsymbol{\lambda})$ of regularization or complexity parameters, and nuisance parameters now also become functions of $\boldsymbol{\lambda}$ by their dependence on structural parameters.

We now define the form of the gradient $\frac{dH}{d\boldsymbol{\theta}}$, which is used in the optimization of H with respect to $\boldsymbol{\theta}$. To simplify the notation, the dependence of objective H on $\boldsymbol{\sigma}$ and $\boldsymbol{\lambda}$ is dropped, and parameter $\boldsymbol{\lambda}$ is treated as fixed. The following results can be readily generalized to incorporate the joint estimation of the system parameters $\boldsymbol{\theta}$ and the error distribution parameters $\boldsymbol{\sigma}$. We assume that H is twice continuously differentiable with respect to both $\boldsymbol{\theta}$ and $\mathbf{c}$, and that the second partial derivative or Hessian matrices $\partial^2 H/\partial\boldsymbol{\theta}^2$ and $\partial^2 H/\partial\hat{\mathbf{c}}^2$ are positive definite over a non-empty neighborhood $\mathcal{N}$ of y in data space.

The gradient or total derivative with respect to $\boldsymbol{\theta}$ is:

$$\frac{dH}{d\boldsymbol{\theta}} = \frac{\partial H}{\partial\boldsymbol{\theta}} + \frac{\partial H}{\partial\hat{\mathbf{c}}}\frac{d\hat{\mathbf{c}}}{d\boldsymbol{\theta}} \tag{27}$$

Since $\hat{\mathbf{c}}(\boldsymbol{\theta})$ is not available explicitly, the implicit function theorem can be used to obtain:

$$\frac{d\hat{\mathbf{c}}}{d\boldsymbol{\theta}} = \left(\frac{\partial^2 J}{\partial\hat{\mathbf{c}}^2}\right)^{-1}\frac{\partial^2 J}{\partial\hat{\mathbf{c}}\partial\boldsymbol{\theta}} \tag{28}$$

$$\frac{dH}{d\boldsymbol{\theta}} = \frac{\partial H}{\partial\boldsymbol{\theta}} - \frac{\partial H}{\partial\hat{\mathbf{c}}}\left(\frac{\partial^2 J}{\partial\hat{\mathbf{c}}^2}\right)^{-1}\frac{\partial^2 J}{\partial\hat{\mathbf{c}}\partial\boldsymbol{\theta}} \tag{29}$$

Regarding the computational aspects, the optimization of the inner objective function follows the non-linear least squares (NLS) framework, which allows the use of the Levenberg–Marquardt algorithm to estimate $\hat{\mathbf{c}}_i(\boldsymbol{\theta})$. While the optimization of the outer objective function also resembles an NLS problem, the incorporation of a parameter cascade strategy introduces an additional layer of optimization at each outer estimation step, resulting in a nested optimization structure. This allows the use of the Levenberg–Marquardt method, but the Jacobian matrix needs to be calculated for each iteration of the update on the structural parameters, and each entry of the Jacobian for the outer objective involves a complete optimization of the inner one.

The variances of the parameter cascade method estimators of the ODE system structural parameters can be assessed using two methods: the bootstrap variance estimator and the Delta variance estimator, for which algorithms are described in detail, respectively, in literature (Ramsey et al. 2007; Wang, Cao 2023). Parameter cascade method estimation of the ODE structural parameters and nuisance parameters, with the two mentioned methods for variance estimations, among other procedures, is employed in the `R` package `pCODE` by Wang and Cao (Wang, Cao 2019). Procedures for optimally selecting the hyperparameter $\boldsymbol{\lambda}$ are implemented in the `R` package `CollocInfer` by Hooker and colleagues (Hooker et al. 2016).

The asymptotic efficiency and finite-sample properties of the parameter cascade method estimators of the ODE system parameters can be found in literature (Qi, Zhao 2010). They present formally derived asymptotic properties of the considered estimator, and the results for a finite sample based on simulations.

An empirical procedure for parameter cascade estimation of parameters of the predator–prey ODE system is shown in the paper by Cao and colleagues (Cao et al. 2008). Zhang and colleagues (Zhang et al. 2015) propose model selection and estimation in situations when there are competing ordinary differential equation (ODE) models (which are special cases of a "full" model). The consistent selection procedure employs statistical estimation of the full model, followed by a combination of a least squares approximation (LSA) and the adaptive Lasso. Selected model parameters are then estimated using the parameter cascade method.

5. Simulation and empirical study of the Goodwin model estimation

In the following section, we present both a simulation study and an empirical application of the Goodwin model. The finite-sample performance of the parameter cascade and nonlinear least squares (NLS) estimators for the three-equation Goodwin ODE system is first evaluated through simulations. Next, the proposed methods are applied to estimate the Goodwin model for the French economy over the period 1962–2009.

5.1. Simulation study comparing the parameter cascade method and NLS estimators for the three-equation ODE Goodwin model

We consider the Goodwin model represented by the four-state ODE system with additive *iiN* measurement noise with a standard deviation of 0.05. The four state variables of the ODE system are: (a, n, u, and v), which can be associated

with the following economic phenomena: a: labor productivity, n: labor force, u: labor income share, and v: employment rate. The assumed values of the structural parameters of the considered ODE system are as follows: $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$, initial values: $a_0 = 1$, $n_0 = 1$, $u_0 = 0.4$, $v_0 = 0.4$.

The orbit cycle period, calculated using the assumed parameter values of the considered ODE system, is $T_G = 28.0993$.

The (u, v) subsystem has two fixed points: (0,0) and (0.5,0.5). We simulate $N_{rep} = 100$ replications from the four-equation ODE system of the Goodwin model, with additive measurement noise. For ODE parameters, $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$ are assumed, and additive measurement noise is specified for each of the four equations in the form of the following processes: $iiN(0, \sigma_j = 0.05)$, $j = a, n, u, v$. The following initial values for the trajectories are assumed: $u_0 = 0.4$, $v_0 = 0.4$. The length of the simulated trajectories is $T = 100$. In the following figures, for the 100 replicated simulations with additive measurement noise, we present the time series of a, n, u, v (Fig. 1), and (u, v) phase-space portraits (Fig. 2).

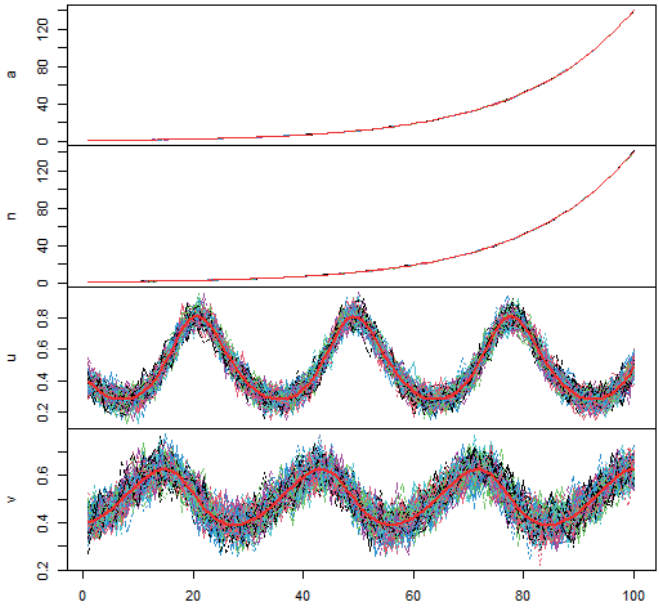

Figure 1. 100 simulated trajectories (of length $T = 100$) from the Goodwin model represented by the four-state equation ODE system with additive $iiN(0, 0.05)$ measurement noise; ODE system parameters: $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$; initial values: $a_0 = 1$, $n_0 = 1$, $u_0 = 0.4$, $v_0 = 0.4$

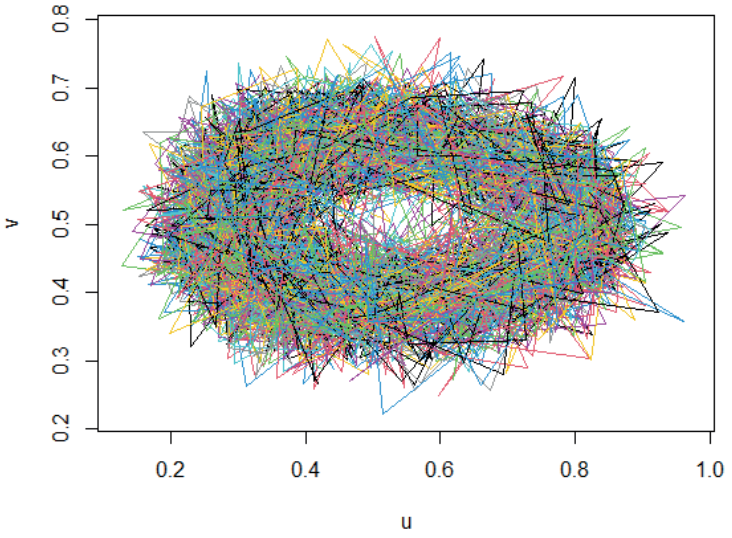

Figure 2. Phase plot in (u, v) space of the 100 simulations from the Goodwin model represented by the four-state equation ODE system with additive $iiN(0, 0.05)$ measurement noise; ODE system parameters: $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$; initial values: $u_0 = 0.4$, $v_0 = 0.4$

5.2. Estimation settings for structural parameters of the Goodwin ODE system based on simulated trajectory data

From each of the 100 simulated replications, the values of the following estimators are calculated: the simplified estimator, the NLS (nonlinear least squares) estimator, and the parameter cascade estimator. For the iterative procedures used to obtain the NLS and cascade parameter method estimators, the simplified estimator is used as the starting value.

The NLS and the parameter cascade method estimators are based on the data from the three-equation subsystem of state variables (a, u, v), with additive measurement noise $iiN(0, \sigma_j)$, $j = a, u, v$. Therefore to compute its values, we used 100 simulated trajectories of length $T = 100$ for (a, u, v). For the parameter cascade method estimator, we experimentally arrived at the following settings: B-spline bases for the smoothed functional representations of the trajectories for each of the three state variables a, u and v. For each of the three trajectories a, u and v, the assumed B-spline basis functions are of order four and have four knots, which implies there are 6 B-splines basis functions (number of B-splines basis functions is equal to: number of knots + order of basis functions – 2) in each basis.

Moreover, estimates for the cycle period T_G and for the coordinates of the fixed point (u^*, v^*) of the (u, v) subsystem, using the obtained values for the considered estimators, are provided.

In the following subparagraphs, we provide graphical presentations of the distributions of the mentioned estimates based on the simulation data from 100 replications.

5.3. Simplified estimator distribution from the simulation

The simplified estimates are generally not considered estimators *per se*, but more a starting point for iterative procedures of NLS and parameter cascade method estimation, based on the four-equation differential system for the state variables a, n, u, v:

$$\begin{cases} \dfrac{da}{dt} = \alpha a \\ \dfrac{dn}{dt} = \beta n \\ \dfrac{du}{dt} = u\left(\rho v - \gamma - \alpha\right) \\ \dfrac{dv}{dt} = v\left(-\dfrac{1}{\sigma}u + \dfrac{1}{\sigma} - \alpha - \beta\right) \end{cases} \tag{30}$$

Simplified estimate for the α parameter is:

$$\tilde{\alpha} := \frac{1}{T-1}\sum_{t=2}^{T}\frac{a_t - a_{t-1}}{a_{t-1}} \tag{31}$$

Simplified estimate for the β parameter is:

$$\tilde{\beta} := \frac{1}{T-1}\sum_{t=2}^{T}\frac{n_t - n_{t-1}}{n_{t-1}} \tag{32}$$

To obtain simplified estimates for the other parameters, we use the derivative equations for $u(t)$ and $v(t)$.

In the case of the derivative equation for $u(t)$:

$$\frac{du}{dt} = u\left(\rho v - \gamma - \alpha\right) \tag{33}$$

we rearrange it into the form:

$$\rho v - \gamma = \frac{1}{u}\cdot\frac{du}{dt} + \alpha \tag{34}$$

In the case of the derivative equation for $v(t)$:

$$\frac{dv}{dt} = v\left(-\frac{1}{\sigma}u + \frac{1}{\sigma} - \alpha - \beta\right) \tag{35}$$

we rearrange it into the form:

$$-\frac{1}{\sigma}u + \frac{1}{\sigma} - \alpha - \beta = \frac{1}{v}\cdot\frac{dv}{dt} \tag{36}$$

To obtain a simplified estimate of $\frac{1}{\sigma}$, we perform the following rearrangement:

$$\frac{1}{v}\cdot\frac{dv}{dt} + \alpha + \beta = \frac{1}{\sigma}\cdot(1-u) \tag{37}$$

The dependent variable for the linear regression without a constant, used for the initial guess of $\widetilde{\frac{1}{\sigma}}$, has the form:

$$\frac{v_t - v_{t-1}}{v_t} + \tilde{\alpha} + \tilde{\beta} \tag{38}$$

The independent variable for the linear regression without a constant, used for the simplified estimate of $\widetilde{\frac{1}{\sigma}}$, has the form: $1 - u_t$.

Simplified estimate for the σ parameter is:

$$\tilde{\sigma} := \frac{1}{\widetilde{\frac{1}{\sigma}}} \tag{39}$$

To provide the simplified estimates of ρ and $-\gamma$, we use the already established relation:

$$\frac{1}{u}\cdot\frac{du}{dt} + \alpha = \rho v - \gamma \tag{40}$$

The dependent variable for the linear regression used for the initial guess of $\tilde{\rho}$ and $\widetilde{-\gamma}$ has the form:

$$\frac{u_t - u_{t-1}}{u_t} + \tilde{\alpha} \tag{41}$$

The independent variable for the linear regression used for the initial guess of $\tilde{\rho}$ and $\widetilde{-\gamma}$ is: v_t.

OLS estimates of the linear regression considered here are: $\tilde{\rho}$ (intercept) and $\widetilde{-\gamma}$ (slope).

Thus, we take:

$$\tilde{\gamma} := \widetilde{--\gamma} \tag{42}$$

A high degree of caution is needed when proposing simplified estimates based on a time discretization of the Goodwin model system equations because, for example, the system resulting from the simple Euler time discretization of the Lotka–Volterra system can have different dynamic properties than the original continuous-time one (see Guzowska 2011).

In the following figures, we present the distribution of the simplified estimator values obtained from 100 simulated trajectories from the four-equation ODE system (for the state variables (a, n, u, v) with additive measurement noise. Figure 3 presents the boxplot of the simplified estimator values obtained from the simulated time series.

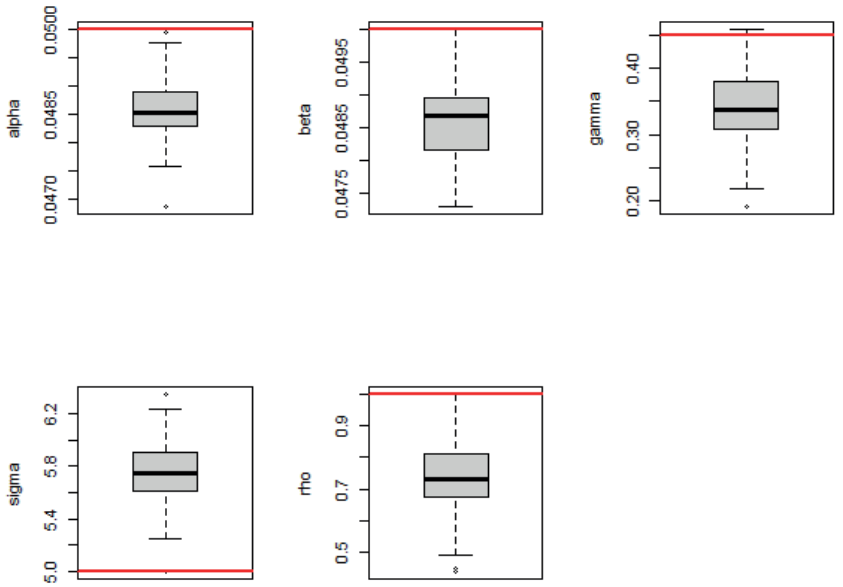

Figure 3. Boxplot of the simplified estimator values for the parameters α, β, γ, σ, ρ, for the ODE system of four equations for the state variables a, n, u, v, obtained from 100 simulated replications, with assumed parameter values: $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$; initial values: $u_0 = 0.4$, $v_0 = 0.4$ with trajectory length $T = 100$. True values of the parameters are represented by horizontal red lines

5.4. NLS (nonlinear least squares) estimator distribution from the simulation

In the NLS estimation procedure of the three-equation ODE system of the Goodwin model structural parameters, we combine the LSODA numerical ODE approximate solution procedure, implemented in the function `ode` from the `R` package `deSolve`, with the Levenberg–Marquardt algorithm (implemented by the function `nls.lm` from the `R` package `minpack.lm` by Elzhov et al. (2016)) for iteratively minimizing the nonlinear residual sum of squares objective function.

In the following figures, we present the distribution of the NLS estimator values obtained from 100 simulated trajectories from the three-equation ODE system (for the state variables (a, u, v) with additive measurement noise. Figure 4 presents the phase portrait for the (u, v) subsystem with parameters equal to the NLS estimator values obtained from the simulated trajectories. Figure 5 presents the boxplot of the NLS estimator values obtained from the simulated time series. Figure 6 presents the scatterplot of the fixed points of the (u, v) subsystem calculated using NLS estimator values.

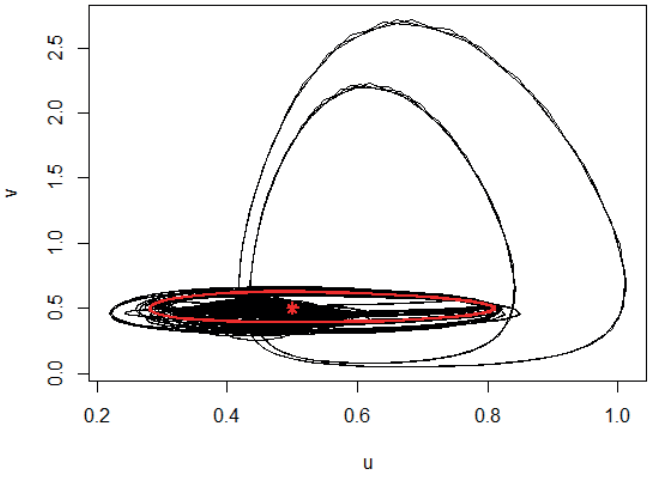

Figure 4. Phase plots for (u, v) generated from the two-equation ODE subsystem for state variables u and v, with parameter values obtained using NLS estimator from each of the 100 simulated replications, trajectories start from the observed values of u and v for each replication. Red bolded curves represent trajectories from the noiseless ODE system with the assumed parameters of $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$, and the initial values $u_0 = 0.4$ and $v_0 = 0.4$ assumed in the simulation study. The red asterisk represents the true fixed point (0.5, 0.5), which is the center of the red orbit

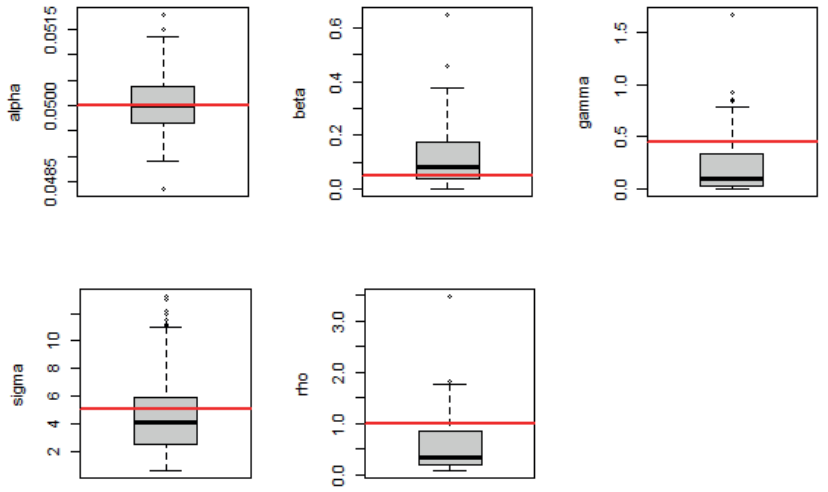

Figure 5. Boxplot of the NLS estimator values of the parameters α, β, γ, σ, ρ, for the three-equation ODE system for the state variables a, u, v, obtained from 100 simulated replications, with assumed parameter values: $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$; initial values $u_0 = 0.4$, $v_0 = 0.4$; with trajectory length $T = 100$. True values of the parameters are represented by horizontal red lines

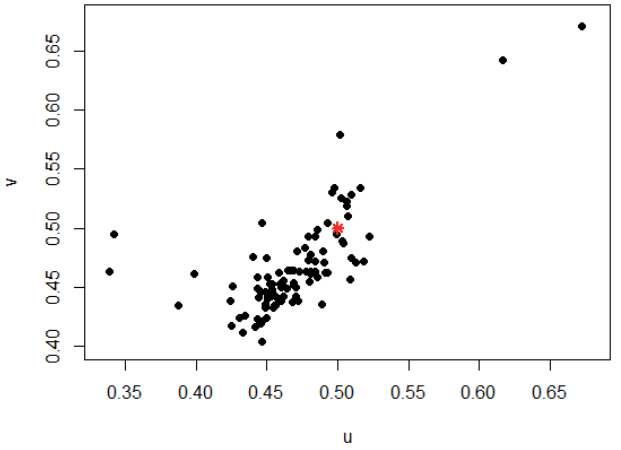

Figure 6. Scatterplot of the (u, v) subsystem fixed points calculated using NLS estimator values of parameters of the considered three-equation ODE system, obtained from 100 simulated replications. The true coordinates of the non-zero fixed point (0.5, 0.5) are represented by the red asterisk

5.5. Parameter cascade estimator distribution from the simulation

We take the following settings for the parameter cascade method estimation for the structural parameters of the three-equation ODE Goodwin system model for the state variables a, u and v, based on each of the 100 simulated trajectories starting from $(a_0, u_0, v_0) = (1, 0.4, 0.4)$ with additive $iiN(0, 0.05)$ measurement noise:

- times: $t \in [0, \ldots, 100]$,
- basis functions: B-splines,
- basis function order: 4,
- number of knots: 4,
- number of basis functions: number of knots + basis function order – 2 = 6,
- penalty hyperparameter λ (assumed jointly for all state variables) from the inner objective function: 10^{-2} (selected based on an experiment with λ from the grid: 10^k, $k \in [-5, \ldots, 5]$).

The following two plots present trajectories simulated from the (u, v) subsystem of the Goodwin model starting, respectively, from the observed initial values of u and v, and from the smoothed basis-expansion values of these initial conditions. To obtain each of the 100 trajectories, we use parameter cascade estimates based on a particular replication of simulated time series data (see Figures 7 and 8).

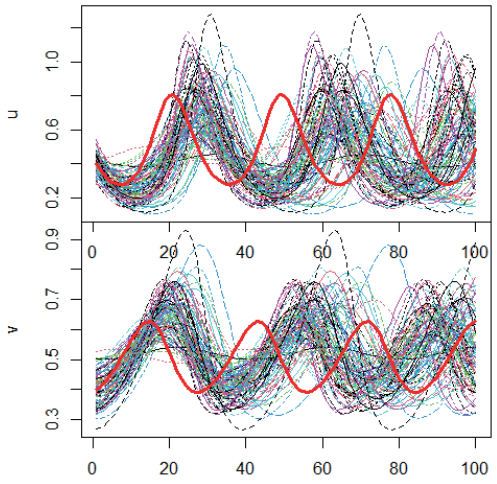

Figure 7. Trajectories (of length $T = 100$) generated from the two-equation ODE subsystem for state variables u and v, with parameter values estimated using the parameter cascade method, from each of the 100 simulated replications. Trajectories start from the observed values of u and v for the each replication. Red bold curves represent trajectories from the noiseless ODE system with the assumed parameters $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$, and initial values of $u_0 = 0.4$, $v_0 = 0.4$

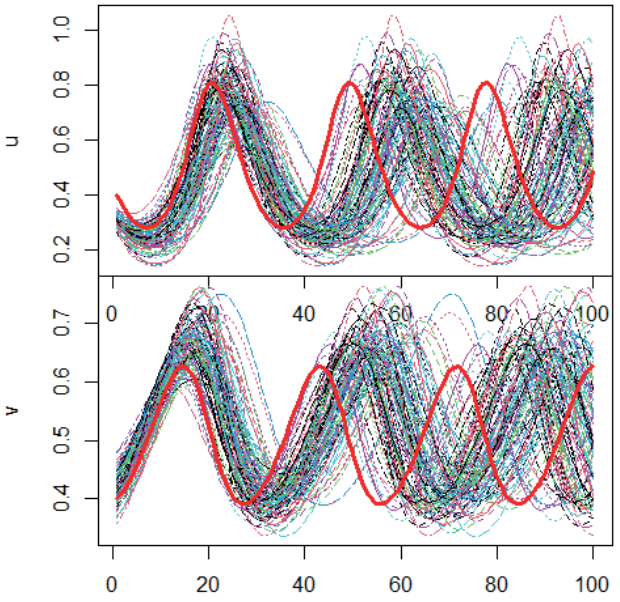

Figure 8. Trajectories (of length $T = 100$) generated from the two-equation ODE subsystem for state variables u and v, with parameter values estimated using the parameter cascade method, from each of the 100 simulated replications. Trajectories start from the smoothed values of u and v for the each replication. Red bold curves represent trajectories from the noiseless ODE system with the assumed parameters $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$, and initial values of $u_0 = 0.4$, $v_0 = 0.4$

The following two plots show phase portraits simulated from the (u, v) subsystem of the Goodwin model starting, respectively, from the observed initial values of u and v and from smoothed basis-expansion values of these initial values (see Figures 9 and 10). To obtain each of the 100 trajectories, we use parameter cascade estimates based on a particular replication of simulated time series data.

In both figures, red curve represents the true orbit obtained from the noiseless ODE system with parameters of $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$, and initial values of $u_0 = 0.4$, $v_0 = 0.4$, assumed in the simulation study. Red asterisk represents the true fixed point (0.5, 0.5), which is the center of the red line orbit.

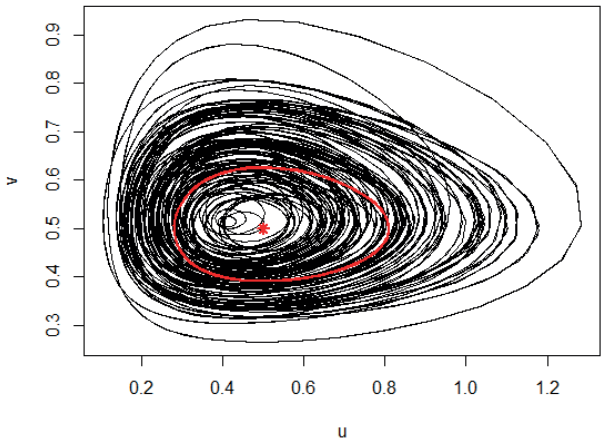

Figure 9. Phase plots for (u, v) generated from the two-equation ODE subsystem for state variables u and v, with parameter values estimated using the parameter cascade method, from each of the 100 simulated replications. Trajectories start from the observed values of u and v for the replication. The red curve represents the true orbit obtained from the noiseless ODE system with parameters of $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$, and initial values of $u_0 = 0.4$, $v_0 = 0.4$, as assumed in the simulation study. The red asterisk represents the true fixed point (0.5, 0.5), which is the center of the red orbit

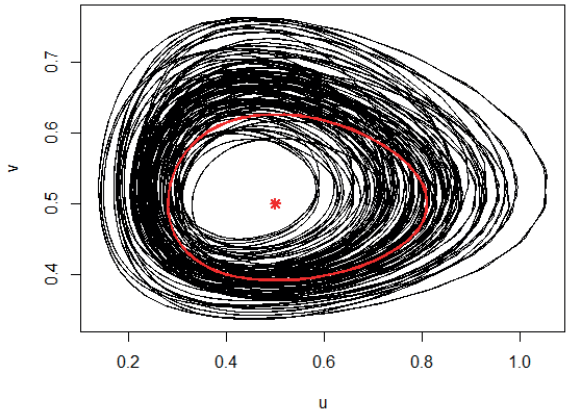

Figure 10. Phase plots for (u, v) generated from the two-equation ODE subsystem for state variables u and v, with parameter values estimated using the parameter cascade method, from each of the 100 simulated replications. Trajectories start from the smoothed values of u and v for each replication. The red curve represents the true orbit obtained from the noiseless ODE system with parameters of $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$, and initial values of $u_0 = 0.4$, $v_0 = 0.4$, as assumed in the simulation study. The red asterisk represents the true fixed point (0.5, 0.5), which is the center of the red orbit

Next, we present a boxplot of the parameter cascade estimator values obtained from the simulated time series (see Figure 11).

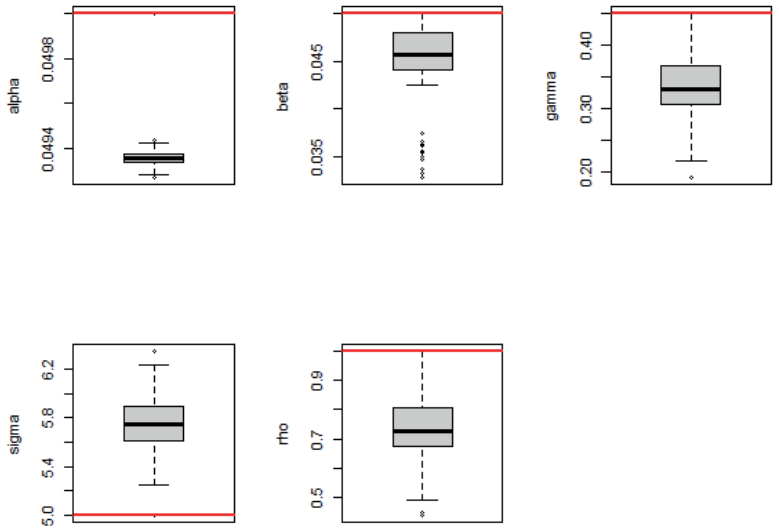

Figure 11. Boxplot of the parameter cascade method estimator values for the parameters α, β, γ, σ, ρ, for the three-equation ODE system for the state variables a, u, v obtained from 100 simulated replications, with assumed parameter values $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$; initial values $u_0 = 0.4$, $v_0 = 0.4$; with trajectory length $T = 100$. True values of the parameters are represented by horizontal red lines

5.6. Descriptive statistics for the values of the considered estimators obtained in a 100-replication simulation study

Using each of the 100 simulated replications of trajectories of length $T = 100$, from the (a, n, u, v) ODE system with additive *iiN* measurement noise, we computed values of the considered structural parameter estimators, i.e. the simplified estimator, the NLS estimator, and the parameter cascade method estimator (the latter two estimators are based on the three-variables subsystem a, u, v). Descriptive statistics are calculated for these 100 values of the considered structural parameter estimators for the Goodwin ODE model system. They are provided in the following tables, along with descriptive statistics for T_G and the fixed point (u^*, v^*) estimates, based on the three considered structural parameter estimators (see Tables 1–3).

Table 1

Estimates of the three-equation ODE system for the state variables a, u, and v of the Goodwin model, obtained using the simplified estimator, the NLS estimator, and the parameter cascade method estimator. The true values of the considered ODE system parameters are: $\alpha = 0.05$, $\beta = 0.05$, $\gamma = 0.45$, $\sigma = 5$, $\rho = 1$

Parameter	n	Mean	Standard deviation	Median	Trimmed	MAD	Min	Max	Range	Skewness	Kurtosis	Standard error
Simplified parameter estimator												
α	100	0.05	0.00	0.05	0.05	0.00	0.05	0.05	0.00	–0.03	0.35	0.00
β	100	0.05	0.00	0.05	0.05	0.00	0.05	0.05	0.00	–0.09	–0.49	0.00
γ	100	0.34	0.06	0.34	0.34	0.05	0.19	0.46	0.27	–0.24	0.01	0.01
σ	100	5.76	0.21	5.75	5.75	0.22	5.25	6.35	1.10	0.17	–0.15	0.02
ρ	100	0.73	0.11	0.73	0.74	0.10	0.44	0.97	0.54	–0.23	0.02	0.01
Nonlinear least squares estimator												
α	100	0.05	0.00	0.05	0.05	0.00	0.05	0.05	0.00	0.25	0.15	0.00
β	100	0.13	0.12	0.08	0.11	0.09	0.00	0.65	0.65	1.40	2.27	0.01
γ	100	0.22	0.27	0.10	0.16	0.13	0.00	1.66	1.66	2.24	6.82	0.03
σ	100	4.71	3.23	3.96	4.27	2.39	0.55	13.23	12.68	1.06	0.10	0.32
ρ	100	0.55	0.53	0,34	0.46	0.31	0.07	3.47	3.39	2.23	7.48	0.05
Parameter cascade method estimator												
α	100	0.05	0.00	0.05	0.05	0.00	0.05	0.05	0.00	–0.11	0.31	0.00
β	100	0.04	0.00	0.05	0.05	0.00	0.03	0.05	0.02	–1.59	1.91	0.00
γ	100	0.33	0.05	0.33	0.33	0.04	0.19	0.45	0.26	–0.21	0.09	0.01
σ	100	5.76	0.21	5.75	5.75	0.22	5.25	6.35	1.10	0.17	–0.15	0.02
ρ	100	0.74	0.11	0.73	0.74	0.10	0.44	0.97	0.53	–0.24	0.04	0.01

Table 2

Estimates of the cycle period obtained using the values of the simplified estimator, the NLS estimator, and the parameter cascade method estimator.
The true value of the cycle period is $T_G = 28.0993$

Estimation method	n	Mean	Standard deviation	Median	Trimmed mean	MAD	Min	Max	Range	Skew-ness	Kur-tosis	Stan-dard error
Simplified parameter estimation	100	36.75	2.97	36.45	36.5	2.99	30.7	46.87	16.18	0.91	1.22	0.3
Nonlinear least squares estimation	100	44.25	14	46.14	43.33	2.76	21.8	128.67	106.87	2.58	13.08	1.4
Parameter cascade method estimation	100	36.46	3.25	36.27	36.23	3.12	30.15	46.89	16.73	0.72	0.72	0.32

Table 3

Fixed-point estimates obtained using the values of the empirical estimator (mean values of u and v), the simplified estimator, the NLS estimator, and the parameter cascade method estimator. The true coordinates of the fixed point in the (u, v) subsystem are $(u^*, v^*) = (0.5, 0.5)$

Coordinate of variable	n	Mean	Standard deviation	Median	Trimmed	MAD	Min	Max	Range	Skew	Kurtosis	Standard error
Fixed point estimate using: empirical method												
u	100	0.48	0.00	0.48	0.48	0.00	0.46	0.49	0.02	–0.09	–0.13	0.00
v	100	0.50	0.00	0.50	0.50	0.00	0.49	0.51	0.02	–0.39	–0.07	0.00
Fixed point estimate using: simplified parameter estimator												
u	100	0.44	0.02	0.44	0.44	0.02	0.38	0.49	0.10	–0.26	–0.16	0.00
v	100	0.53	0.01	0.53	0.53	0.01	0.50	0.55	0.04	0.18	–0.38	0.00
Fixed point estimate using: nonlinear least squares estimator												
u	100	0.47	0.04	0.47	0.47	0.03	0.34	0.67	0.33	1.05	7.81	0.00
v	100	0.47	0.04	0.46	0.46	0.03	0.40	0.67	0.27	2.28	7.68	0.00
Fixed point estimate using: parameter cascade method estimator												
u	100	0.46	0.03	0.45	0.46	0.03	0.39	0.53	0.15	0.49	0.08	0.00
v	100	0.52	0.01	0.52	0.52	0.01	0.50	0.55	0.05	0.54	0.61	0.00

5.7. Finite-sample properties of the considered estimators of the Goodwin ODE model system observed in the simulation

Taking into account the simulation results in a finite sample, all three considered estimators of the structural parameters of the Goodwin model ODE system, i.e. the simplified estimator, the NLS estimator, and the parameter cascade estimator, exhibit bias relative to the known parameters of the data-generating process (DGP) of the simulation (see Tables 1–3 and the boxplots for particular estimator values: Figures 3, 5 and 11). Moreover, the iterative procedure of the NLS estimator, for a fraction of simulated time series, tends to converge to parameter values distant from the "real" DGP values. This is clearly visible in the (u, v) phase portrait of trajectories, with parameter values equal to the NLS estimates (see Figure 4). Some problems in recovering the cycle period T_G (overestimation) and the stable fixed point also appear for the considered estimators (see Table 3).

5.8. Empirical study: Goodwin model for the French economy (1962–2009)

Empirical data for France for the period 1962–2009 $T = 48$, extracted from the paper of Grasselli and Maheshwari (Grasselli, Maheshwari 2018), include:

- a: labor productivity,
- n: labor force,
- u: labor income share,
- v: employment rate.

Time series plots for a, n, u, v for France over the period 1962–2009 are shown in Figure 12.

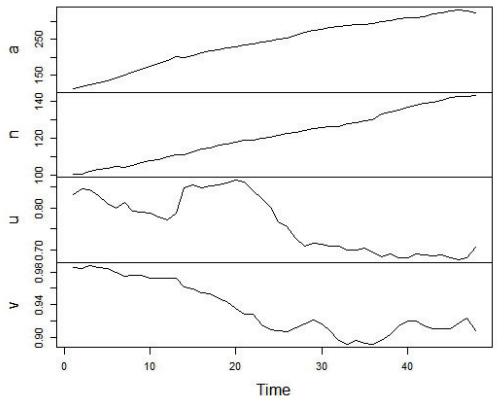

Figure 12. Time series, where u is labor income share, and v is employment rate. Data for France (1962–2009, $T = 48$)

Phase plot in the (u, v) space for empirical annual data for France for the period 1962–2009 (T = 48) is shown in Figure 13.

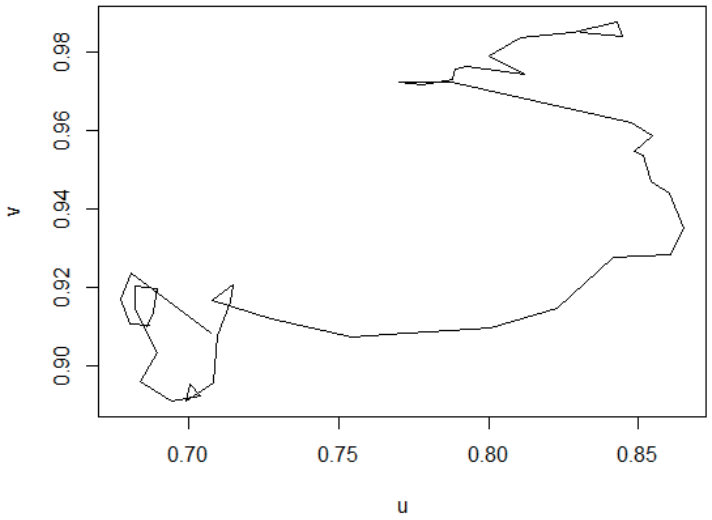

Figure 13. Phase portrait for (u, v), where u is labor income share, and v is employment rate.
Annual data for France (1962–2009, T = 48)

5.9. Simplified estimator of the four-equation ODE system (for *a*, *n*, *u*, *v*) of the Goodwin model for the French data (1962–2009)

First, we estimated the four-equation ODE system for the a, n, u and v state variables. We present results of the simplified estimator values for the structural and nuisance parameters for the four-equation ODE system for a, u and v, with the $iiN(0, \sigma_j)$, $j = a, u, v$, measurement noise process assumed for each of the state variables.

Values of the simplified estimator of the parameters of the four-equation ODE system of the Goodwin model, based on annual data for a, n, u, v for France for the period of 1962–2009 are:

$$\tilde{\alpha} = 0.0223,\ \tilde{\beta} = 0.0075,\ \tilde{\gamma} = 0.0738,\ \tilde{\sigma} = 8.9867,\ \tilde{\rho} = 0.0991.$$

The period of oscillation from the simplified estimates is $\tilde{T}_G = 70.9946$ years.

The fixed point, which is the center of the periodic ellipsoid from the simplified parameter estimates $(\tilde{u}^*, \tilde{v}^*) = (0.7325, 0.9698)$.

The time series plot for u and v with predicted values from the Goodwin model, based on the four-equation ODE model for the state variables a, n, u and v is shown in Figure 14.

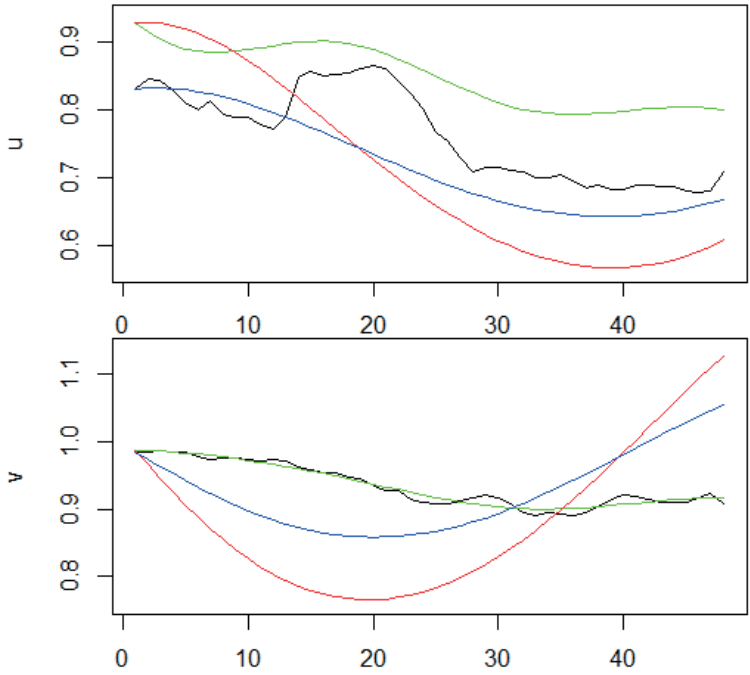

Figure 14. Time series plot of predicted values of the trajectories of u and v of the length $T = 48$, from the four-equation ODE system with structural parameter values obtained using the simplified estimator for the French data over the period 1962–2009, i.e. $\tilde{\alpha} = 0.0223$, $\tilde{\beta} = 0.0075$, $\tilde{\gamma} = 0.0738$, $\tilde{\sigma} = 8.9867$, $\tilde{\rho} = 0.0991$. The black curves represent empirical time series, while blue and red curves represent trajectories from the considered ODE model starting, respectively, from the empirically observed and (weighted by nuisance parameters in the B-spline basis) smoothed trajectories (green curves) as initial values of u and v; see below in the parameter cascade estimation subparagraph

The phase portrait for (u, v) with the ellipsoid and its center, based on the initial simplified estimates of the Goodwin model parameters (four-equation ODE model for the state variables a, n, u, v), is shown in Figure 15.

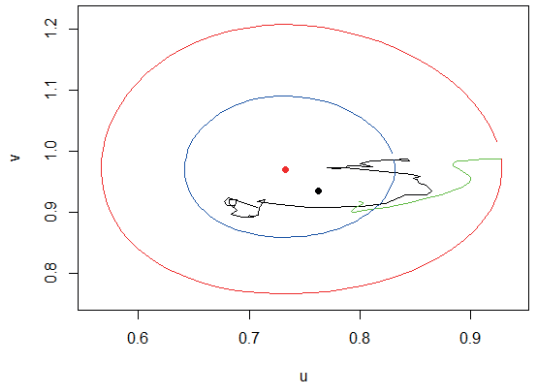

Figure 15. Phase plots in the (u, v) space of predicted trajectories of u and v, of length $T = [\hat{T}_G] = 71$ years, from the four-equation ODE system with structural parameter values obtained using the simplified estimator for the French data over the period 1962–2009, i.e. $\tilde{\alpha} = 0.0223$, $\tilde{\beta} = 0.0075$, $\tilde{\gamma} = 0.0738$, $\tilde{\sigma} = 8.9867$, $\tilde{\rho} = 0.0991$. The black curves represent empirical time series, while blue and red curves represent trajectories from the considered ODE model starting, respectively, from the empirically observed and (weighted by nuisance parameters in the B-spline basis) smoothed trajectories (green curve) as initial values of u and v; see below in the parameter cascade estimation subparagraph. The black point represents the empirically estimated fixed point of the (u, v) subsystem. The red point represents fixed point $(\tilde{u}^*, \tilde{v}^*) = (0.7325, 0.9698)$, calculated using simplified estimates of the structural parameters

5.10. Parameter cascade method estimator of the three-equation ODE system for (a, u, v) of the Goodwin model for the French data (1962–2009)

Here we estimate, using the parameter cascade method, the structural parameters of the Goodwin three-equation ODE system for the state variables a, u and v. The model assumes $iiN(0, \sigma_j)$, $j = a, u, v$ additive noise for each state variable. By experiment, we choose the B-spline functional basis of order 4 and with 4 knots.

We use the previously obtained simplified estimates as starting values for the iterative parameter cascade method procedure:

$$(\tilde{\alpha}_{(init)}, \tilde{\beta}_{(init)}, \tilde{\gamma}_{(init)}, \tilde{\sigma}_{(init)}, \tilde{\rho}_{(init)}) = (0.0223, 0.0075, 0.0738., 8.9867, 0.0991)$$

We use a multiple cross-validation procedure for selecting the hyperparameter λ (joint for all state variables) for the inner criterion of the parameter cascade method.

We assume a grid of λ values of 10^k, for integer values $k = -5, -4, \ldots, 4, 5$.

The value $\lambda = 10^{-2}$ was selected.

Parameter cascade method estimation of the ODE system's structural parameters and nuisance parameters was implemented in the `R` package `pCODE`. The package has been used in this study.

Table 4 presents the results of the parameter cascade method estimation (with $\lambda = 10^{-2}$) for the three-equation ODE system for a, n and v, with the $iiN(0, \sigma_j)$, $j = a, u, v$, measurement noise process assumed for each state variable.

Table 4

Values of the parameter cascade method estimator for structural parameters of the three-equation ODE system and nuisance parameters of the Goodwin model, based on annual data for a, n and v for France over the period 1962–2009

Structural parameters estimates: parameter cascade method									
α		β		γ		σ		ρ	
0.0125		0.0104		0.0761		8.9866		0.0921	
Nuisance parameters estimates: parameter cascade method									
1	2	3	4	5	6	7	8	9	10
0.9644	1.3329	1.9823	2.5418	2.8845	2.9517	0.928	0.8444	0.9688	0.7425
11	12	13	14	15	16	17	18		
0.8151	0.799	0.9875	0.9845	0.9566	0.8779	0.9164	0.917		

The following step is the estimation of variances of the parameter cascade method estimators for the structural parameters of the considered ODE system. To do this, we use the bootstrap method with 50 replications and $\lambda = 10^{-2}$. We also calculate the standard errors of the parameter cascade method estimators as square roots of bootstrap variances (see Table 5).

Table 5

Bootstrap variance and standard error estimates for the parameter cascade method estimators of the structural parameters of the considered three-equation ODE system of the Goodwin model

Statistic	α	β	γ	σ	ρ
Bootstrap variance estimator	9,2328E-05	1,8603E-05	1,8146E-05	7,1171E-06	1,6187E-05
Bootstrap standard errors of variance estimator	0.0096	0.0043	0.0043	0.0027	0.0040

The period of oscillations from the parameter cascade estimates is $\hat{T}_{period} = 71.0001$ years.

The fixed point, which is the center of the periodic ellipsoid from the parameter cascade method estimates, is $(\hat{u}^*, \hat{v}^*) = (0.7940, 0.9621)$.

The time series plot of the predicted values for the model based on the parameter cascade method estimates of the Goodwin model parameters (based on the three-equation ODE model for the state variables a, n and v) is shown in Figure 16.

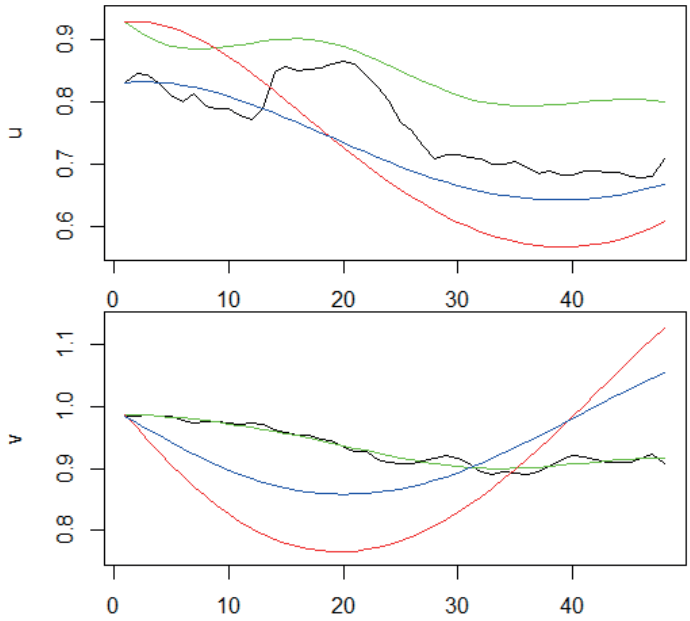

Figure 16. Time series plot of predicted trajectories of u and v, of length $T = 48$, from the three-equation ODE system with structural parameter values estimated using the parameter cascade method for the French data over the period 1962–2009 (with $\lambda = 10^{-2}$ and B-spline bases of order 4 with 4 knots), where $\tilde{\alpha} = 0.0125$, $\tilde{\beta} = 0.0104$, $\tilde{\gamma} = 0.0761$, $\tilde{\sigma} = 8.9866$, $\tilde{\rho} = 0.0921$. The black curves represent empirical time series, while blue and red curves represent trajectories from the considered ODE model starting, respectively, from the empirically observed and (weighted by nuisance parameters in the B-spline basis) smoothed initial values of u and v

The phase portrait showing the ellipsoid and its center, based on the parameter cascade method estimates of the Goodwin model parameters (three-equation ODE model for the state variables a, n and v), is shown in Figure 17.

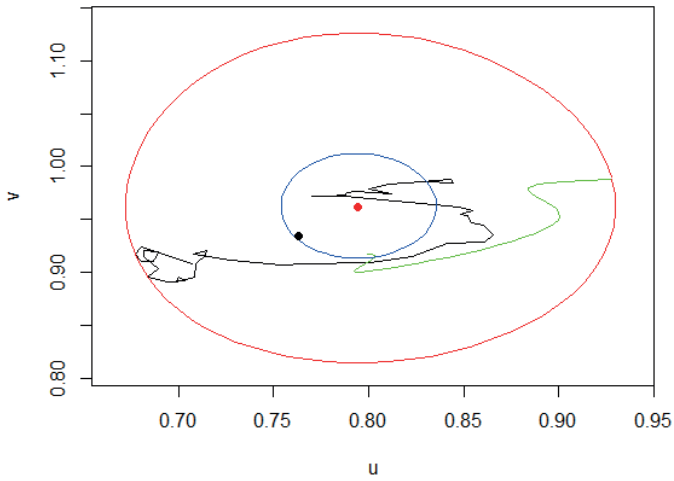

Figure 17. Phase plots in the (u, v) space of predicted trajectories of u and v, of length $T = [\hat{T}_G] = 72$ years, from the three-equation ODE system with structural parameter values estimated using the parameter cascade method for the French data over the period 1962–2009 (with $\lambda = 10^{-2}$ and B-spline bases of order 4 with 4 knots), where $\tilde{\alpha} = 0.0125$, $\tilde{\beta} = 0.0104$, $\tilde{\gamma} = 0.0761$, $\tilde{\sigma} = 8.9866$, $\tilde{\rho} = 0.0921$. The black curves represent empirical time series, while the blue and red curves represent trajectories from the considered ODE model starting, respectively, from the empirically observed and (weighted by nuisance parameters in the B-spline basis) smoothed initial values of u and v. The black point represents the empirically estimated fixed point of the (u, v) subsystem (computed as the mean of the empirical values). The red point represents the fixed-point estimate calculated using parameter cascade method estimators of the structural parameters: $(\hat{u}^*, \hat{v}^*) = (0.7940, 0.9621)$

5.11. NLS (nonlinear least squares) estimator of the three-equation ODE system for (a, u, v) of the Goodwin model for the French data over the period 1962–2009

Here we estimate the structural parameters of the Goodwin three-equation ODE system using the NLS method for the state variables a, u and v. The model assumes $iiN(0, \sigma_j)$, $j = a, u, v$ additive for each state variable.

We use the previously obtained simplified estimates as starting values for the iterative NLS procedure: $(\tilde{\alpha}_{(init)}, \tilde{\beta}_{(init)}, \tilde{\gamma}_{(init)}, \tilde{\sigma}_{(init)}, \tilde{\rho}_{(init)}) = (0.0223, 0.0075, 0.0738, 8.9867, 0.0991)$.

Table 6 presents the results of the NLS estimation of the structural parameters for the three-equation ODE system for a, u and v, with $iiN(0, \sigma_j)$, $j = a, u, v$, and a measurement noise process assumed for each state variable.

Table 6

Values of the NLS estimator for the structural parameters of the three-equation ODE system of the Goodwin model, based on annual data for a, u and v, for France over the period 1962–2009

Parameter	α	β	γ	σ	ρ
NLS estimate	0.0266	0.0247	0.0000	5.9879	0.0201

Based on the obtained NLS estimates of the Goodwin model's structural parameters, the requirement $\alpha + \gamma < \rho$ for economic meaningfulness is not satisfied.

Taking into account that the (u, v) trajectories based on the obtained NLS estimates lie outside of the square $[0,1]\times[0,1]$ most of the time, the NLS estimation results are not reliable.

5.12. Estimation results obtained using the parameter cascade and NLS methods in the empirical study

Values of the parameter cascade estimator for the Goodwin model, based on time series of length $T = 48$ for the French economy, imply a stable fixed point quite close to the empirical one. Plugging the estimated values into the (u, v) ODE subsystem results in a trajectory that remains within the rectangle $[0,1]\times[0,1]$ over the full cycle (estimated by the parameter cascade procedure as 72 years) when started from the empirically observed initial value. When the trajectory is started from the functionally smoothed initial value, it departs from the $[0,1]\times[0,1]$ box. Taking this into account and considering the simulation results presented earlier in this work, the empirical results should be interpreted with caution. Moreover, the available time series for France ($T = 48$) is too short to capture the full cycle ($\hat{T}_G = 48$), so it is not really possible to meaningfully recover the true length of the (u, v) cycle. There is also uncertainty as to whether the Goodwin model in its standard form can even approximately represent the true data-generating process for the considered state variables (model specification uncertainty).

For the NLS approach, the iterative procedure was stopped on the boundary of the feasible parameter set in the dimension of the γ parameter (which was zeroed). Based on the obtained NLS estimates, the requirement $\alpha + \gamma < \rho$ for economic meaningfulness is not satisfied. Problems with the NLS results also become apparent when examining trajectories in the (u, v) phase space, which, regardless of whether started from empirical or parameter cascade–smoothed initial values, remain outside the rectangle $[0,1]\times[0,1]$ during most of the cycle.

Other authors also report poor empirical outcomes in the estimation of structural parameters of the Goodwin model (including the recovery of the cycle length T_G and the fixed point). For example, Grasselli and Maheshwari consider estimators based on a discretization of the ODE system for time series data for 10 Western economies and report difficulties in recovering empirical fixed points as well as empirical trajectories of u and v (Grasselli, Maheshwari 2018). The authors suggest that the standard Goodwin system of ODEs should be respecified or extended to better match real macroeconomic data-generating processes. Similar empirical and theoretical conclusions regarding the estimation of the Goodwin model estimation can be found in literature (Harvie 2000; Basu 2024).

6. Conclusions

Our study of ODE systems with measurement error in economic modeling – focusing on the empirical Goodwin model – reveals both methodological progress and practical challenges. The parameter cascade method offers a functional (basis-function-expansion-driven) approach to handling measurement noise in ODE systems; however the results reveal limitations: in finite samples, all estimators exhibit bias, and the NLS method sometimes produces estimates far from the true parameters values, leading to unrealistic trajectories. The non-identifiability of the standard two-equation Goodwin model leads us to extend it with a third equation for labor productivity, introduced in the derivation of the Goodwin model from macroeconomic dynamic assumptions. Applying the model to French data, we struggle to recover realistic dynamics, which is in line with existing literature, suggesting the need to respecify or extend the model. Overall, while the parameter cascade and related methods are valuable tools for analyzing nonlinear systems with measurement error, their performance depends strongly on model structure, data quality, and underlying economic assumptions.

Acknowledgments

The contribution by Jerzy Rydlewski was supported by the AGH University of Krakow under grants no. 16.16.420.054 and 501.00 10000 2600, funded by the Polish Ministry of Science and Higher Education.

The contribution by Przemysław Jaśko presents the results of Project no. 059/EFP/2025/POT, financed from the subsidy granted to the Krakow University of Economics.

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Summary

This study investigates the application of functional data analysis and the parameter cascade method to the estimation of structural parameters in the Goodwin model of economic growth cycles. The Goodwin model, formulated as a system of ordinary differential equations describing the dynamic interaction between labour's share of income and the employment rate, was initially estimated using functional data representations. However, the model did not yield satisfactory empirical results, which can be partly attributed to its structural non-identifiability and the limited time span of the available data, which do not cover a full business cycle. To address these limitations, an identifiable model based on the Volterra–Lotka system was introduced as an alternative specification. Using annual data for France over the period 1962–2009, both simulation and empirical analyses were conducted to assess the performance of the parameter cascade method relative to the nonlinear least squares estimator and simplified method estimator of the Goodwin model three equation ODE system. The results indicate that the functional-data-based approach, particularly the parameter cascade method, provides a promising framework for the estimation of continuous-time dynamic economic models with measurement error. Although the findings remain preliminary, they demonstrate the methodological potential of combining functional data analysis with ODE-based representations of macroeconomic processes.

JEL codes: JEL E32, C63, C13

Keywords: Goodwin model, ODE systems in economics, functional data analysis, collocation methods, parameter cascade method, France's business cycle

Received: 26.11.2025
Accepted: 26.05.2026

Managerial Economics
2026, Vol. 27, No. 2, pp. 193–220
https://doi.org/10.7494/manage.2026.27.2.193
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Johannes Treu[1], Stephan Otto[2], Okka Zimmermann[3]

Financial literacy among older adults in Germany. Results of a qualitative study

1. Introduction

Demographic change and the growing complexity of the financial system pose increasing challenges for aging societies. Although working life ends with retirement, financial decisions and responsibilities persist. Older adults face new issues related to pensions, assets, future provision, and the management of limited resources, often without adequate support or age-appropriate information and advisory services (Boyle et al. 2025; OECD 2020a, 2023).

This gap stems from several factors. New financial products, tightened regulations, and digital processes present frequently underestimated challenges, especially for people who are retired or approaching retirement. To ensure comprehensive access to financial services, however, the financial sector must reach all social groups (Grohmann, Menkhoff 2020; Ozili 2021). Older adults represent a group that has been only marginally integrated into financial strategies. Yet, financial security and effective management of resources in old age are essential for social participation, independence, and dignity (Bundesministerium für Familie, Senioren, Frauen und Jugend, 2025).

This structural neglect is exacerbated by the absence of a broad-based national financial literacy strategy in Germany. Despite rising poverty risks and comparatively low levels of financial literacy (Klein et al. 2021), there are no educational-policy or academic initiatives that specifically address the needs of

[1] IU International University of Applied Sciences Campus Berlin, Berlin Germany, e-mail: johannes.treu@iu.org, ORCID 0000-0002-6959-3903
[2] IU International University of Applied Sciences Campus Berlin, Berlin Germany, e-mail: stephan.otto@iu.org, ORCID 0000-0002-1313-8768
[3] IU International University of Applied Sciences Campus Braunschweig, e-mail: okka.zimmermann@iu.org, ORCID 0000-0002-1719-1777

older adults. Consequently, this population lacks systematic support to make informed financial decisions in retirement and secure their long-term economic situation. The resulting risk of financial exclusion reduces the chances of a financially secure retirement and raises fundamental questions about fairness, equal opportunity, and age-related justice in access to financial literacy and services. Against this backdrop, the question of how tailored, low-threshold, and trustworthy financial literacy measures should be designed for this target group is becoming increasingly important.

The present paper addresses the research gap described above and focuses on initial findings from an exploratory analysis of twenty qualitative interviews with older adults. It examines the financial knowledge, needs, and access barriers that characterize older adults' financial behavior, and the support formats and financial products the respondents consider appropriate. The findings are intended to make an empirically grounded contribution to the hitherto under-researched intersection of aging, financial literacy, and social participation.

The qualitative study was embedded in the research project "Financial Literacy for Older Adults" (German: Finanzielle Bildung von Senioren – FiBiSen) at IU International University. The project aims to examine the knowledge levels, needs, and barriers that older adults face in financial decision-making. The general aim is to highlight perspectives that have so far received little attention in the financial sector. Three central research questions guide the project:

- Which areas of financial literacy and information are particularly relevant for older adults?
- In which areas do knowledge gaps exist?
- What forms of training, information, and advisory measures do older adults require with respect to financial literacy?

These questions are designed to capture both the individual and structural dimensions of financial literacy in old age, thereby addressing the identified research gap. In the long term, the overall project seeks to develop target-group-specific educational programs that contribute to increasing and maintaining financial well-being in an aging society.

The paper is structured as follows: Section 2 presents the theoretical background and reviews the current state of research, Section 3 explains the research design and the methodological approach, Section 4 presents the results, Section 5 covers limitations and outlook, and Section 6 concludes by summarizing the main findings and their implications.

2. Theoretical background and state of research

The subsequent chapter delineates the conceptual foundations on which the present study is based and situates it within the existing body of research. To this

end, Section 2.1 elaborates the construct of financial literacy and its prevailing operationalisations, whereas Section 2.2 characterises older adults as the target population under investigation.

2.1. Financial literacy

The concept of financial literacy can be traced back to 1992, when the National Foundation for Educational Research (NFER), in collaboration with NatWest Bank, provided the first explicit definition. This definition emphasized the ability to make informed and sound decisions in managing financial matters. Five years later, the Jump$tart Coalition for Personal Financial Literacy adopted the term in its study "Jump$tart Survey of Financial Literacy Among High School Students" and broadened it to include the practical application of knowledge and skills for the effective management of personal finances and long-term financial stability (Cude 2021; Świecka et al. 2019; Treu 2023, 2024a, 2024b).

In academic discourse, financial literacy is understood as a multidimensional construct encompassing the acquisition of knowledge about financial products, an understanding of fundamental financial concepts, the ability to make sound financial decisions, practical participation in financial activities, and mathematical and computational skills (Świecka et al. 2019). Given this breadth, research faces the challenge of the absence of a universally accepted definition. This is due to the frequent conflation of financial literacy and financial knowledge, the coexistence of divergent conceptual and operational definitions, and the ongoing digitalization, which extends the discourse to include digital financial literacy (Cude 2021; Haupt 2021; Morgan 2021; Treu 2024a, 2024b).

One of the most widely accepted frameworks is the model proposed by Lusardi and Mitchell (2014), which defines financial literacy as possessing the specific skills necessary to access and understand economic information and to make informed decisions in areas such as financial planning, wealth accumulation, debt management, and retirement planning. This concept rests on three key knowledge dimensions commonly known as the "Big Three." The concept serves as a fundamental pillar for financial decision-making (Helmold et al. 2024; Lusardi 2019; Lusardi, Mitchell 2014; Treu, Elss 2024, 2025):

- numeracy skills (interest calculations and compound interest);
- knowledge about inflation;
- understanding of risk diversification.

International comparative studies based on these dimensions suggest that only about 30% of participants possess comprehensive financial literacy, while more than 50% have little or no knowledge (Haupt 2021; Lusardi 2019; Lusardi, Mitchell 2014). Financial literacy also tends to be higher in urban areas than in

rural regions (Klapper, Panos, 2011). Van Rooij et al. (2011) explain this difference by noting that cities have a higher prevalence of formal employment, which often requires a basic level of engagement with financial products.

International institutions have likewise recognized the importance of financial literacy and its measurement. The OECD elevated it to a policy priority (OECD 2013, 2020b) and, as early as 2005, defined financial literacy as: "[…] the process by which financial consumers/investors improve their understanding of financial products and concepts and, through information, instruction and/or objective advice, develop the skills and confidence to become more aware of financial risks and opportunities, to make informed choices, to know where to go for help, and to take other effective actions to improve their financial well-being" (OECD 2005).

Building on the work of Atkinson and Messy (2012) and the OECD/International Network on Financial Education (INFE), a revised definition was adopted in 2012:

"A combination of financial awareness, knowledge, skills, attitudes, and behaviors necessary to make sound financial decisions and ultimately achieve individual financial well-being."

Unlike the primarily knowledge-based framework of Lusardi and Mitchell (2014), this OECD definition incorporates awareness, skills, attitudes, and behavioral patterns. Three dimensions for assessing financial literacy follow from this broader concept (Atkinson, Messy 2012; Haupt 2021; OECD 2022):

- **knowledge** (compound interest, inflation, interest rates, time value of money, risk vs. return, risk diversification);
- **behavior** (assessing affordability, timely bill payment, monitoring personal finances, setting long-term financial goals);
- **attitudes** (spending vs. saving preferences, long-term vs. short-term orientation).

For measurement purposes, the OECD developed the Toolkit for Measuring Financial Literacy and Financial Inclusion, first deployed in 2010 and subsequently updated for approximately 40 countries in 2015/16 (Helmold et al. 2024; Treu 2024a, 2024b; Treu, Elss 2025). A 2018 revision incorporated financial well-being, and a later extension added digital financial literacy. The latest version is the 2026 Toolkit (OECD 2026).

2.2. Target group

This research gap becomes clearer when the target group is viewed through an intersectional lens. Financial vulnerability in later life is not shaped by age alone but by the interaction of gender, migration background, employment history, caregiving responsibilities, self-employment, and regional socioeconomic conditions. Although older adults are less likely to experience poverty than

some other population groups, particularly vulnerable subgroups exist within this demographic (Brettschneider, Klammer 2020). Women with discontinuous employment histories and extended family-care phases often have lower pension entitlements and particularly low financial literacy (Lusardi, Mitchell 2008). Formerly self-employed individuals constitute another at-risk group, as they have frequently made insufficient contributions to the statutory pension system or inadequate private provisions (Kümpers, Alisch 2018). Older migrants are also considered to face an above-average poverty risk, especially if they entered the labor market late or held precarious employment. Finally, older adults in eastern Germany often have low pension entitlements because of the post-reunification transformation, and the same applies to western Germans with repeatedly interrupted employment histories (Klammer, Brettschneider 2016). These vulnerabilities may overlap, meaning that individuals occupying several disadvantaged social and economic positions can face particularly pronounced risks in later life.

These vulnerabilities do not necessarily occur independently. An intersectional perspective suggests that overlapping social positions and life-course disadvantages – such as gender, migration background, employment history, caregiving responsibilities, and region – may interact to produce particularly pronounced financial vulnerability in later life (Brettschneider, Klammer, 2020).

The intersectional perspective (Crenshaw 1991) proves particularly useful for analyzing these overlapping inequalities. It highlights that the categories mentioned do not merely accumulate but can give rise to qualitatively new forms of disadvantage. Such disadvantages intensify over the life course and manifest in old age as heightened financial vulnerability.

A central implication is that older adults are not a homogeneous group. Financial risks stem from the complex interactions of social, biographical, and structural factors, which influence each other rather than acting independently. Therefore, it is essential both methodologically and practically to move beyond seeing older adults as a single group and to carefully consider their diverse life circumstances and different needs.

3. Research design and methodological approach

Given the exploratory character of the research interest, the present study adopts a qualitative research design, the constitutive elements of which are documented in the following chapter. Sections 3.1 and 3.2 set out the procedures of data collection and analysis, whereas Sections 3.3 and 3.4 specify the sampling strategy, field access, and the sociodemographic composition of the realised sample

3.1. Qualitative approach and data collection

The FiBiSen project employs a sequential mixed-methods design in which qualitative interviews first explore key thematic areas, and a subsequent quantitative survey verifies and broadens the findings. This design serves to identify group-specific knowledge gaps, subjective experiences, and factors that hinder or promote participation in financial literacy programs.

A qualitative approach was chosen for the first project phase to gain in-depth insight into the subjective experiences of the target group. This is particularly warranted because standardized instruments alone are insufficient to capture the everyday barriers and group-specific needs of vulnerable populations, including older adults (Strübing 2021). Problem-centered interviews (Witzel 2000) were conducted, supplemented by a short sociodemographic questionnaire. The interviews explored participants' financial knowledge and their subjective perceptions, attitudes, and experiences regarding financial matters.

3.2. Analytical method

The interview material was analyzed using the content-structuring qualitative content analysis developed by Kuckartz and Rädiker (2022). This approach was considered suitable because it systematically combines deductive and inductive category development.

The analysis began with a deductive coding framework derived from the central research questions. This initial framework was used to structure the interview material and guide the first stage of analysis. During the subsequent review of the coded material, the categories were refined and differentiated inductively. This process enabled the development of more specific main and subcategories that reflected both the research questions and themes emerging from the participants' accounts.

The category system and codebook were developed collaboratively by the research team. For each category, binding coding rules were established and supplemented with anchor examples to maximize inter-coder reliability. A two-person team coded the material using a consensus-based procedure; they discussed and resolved discrepancies jointly to ensure both discriminatory power and intersubjective comprehensibility. Each main category was subdivided into four to six subcategories.

3.3. Sampling and field access

Twenty older adults (nine women and eleven men) were recruited for the study. We conducted telephone or face-to-face interviews from October to November 2025. Sampling was initially guided by a criteria-based selection process drawing on characteristics derived from the literature (minimum age 60, gender,

regional location). Organizations such as church parishes and social-work providers working with the target group were approached to identify potential participants. This initial field access was then expanded through snowball sampling, whereby recruited participants recommended further individuals from their personal networks (Przyborski, Wohlrab-Sahr 2021).

A methodologically noteworthy observation emerged during recruitment: clear reservations regarding the topic of finance and financial literacy were apparent. Individuals who declined to participate, predominantly women, stated that they did not wish to comment on financial topics or that they lacked relevant knowledge. This finding is analytically significant because it points to gender-specific participation barriers and self-exclusion mechanisms, which are explored further in the results section.

3.4. Sample description

Despite these recruitment challenges, the resulting sample exhibits a level of heterogeneity appropriate for qualitative research. Participants' ages range from 60 to 84 years, representing various stages of older adulthood. Geographically, the sample spans major cities (e.g., Berlin, Essen), medium-sized cities (e.g., Rostock, Oberhausen), and smaller communities. Living situations range from single-person households to households with a partner or family; most respondents live in owner-occupied housing.

The sample is also diverse in educational attainment and professional background, including individuals with vocational qualifications, university degrees, and doctoral degrees. Professional fields range from commercial occupations to scientific, medical, and architectural roles. Most participants are retired; a few earn supplementary income through property rental or marginal employment, and a small proportion remains employed, in some cases beyond the standard retirement age. Overall, the sample enables a multiperspective analysis of financial literacy needs in later life, although it is not statistically representative.

4. Results. Financial literacy from the perspective of older adults

Based on the methodology and sample described above, this section presents initial findings from the qualitative interviews. The results are organized around the seven main categories identified during the analysis. These categories partially extend beyond the three deductively formulated research questions, as the inductive analysis yielded additional categories, particularly regarding attitudes,

biographical turning points, and family influences, that are analytically significant for a comprehensive understanding of financial literacy in old age.

4.1. Main category I. Acquisition of financial knowledge

The main category, acquisition of financial knowledge, captures how respondents have acquired, expanded, or updated their financial knowledge over the course of their lives, ranging from intentional learning to informal, incidental everyday opportunities (see Table 1). Acquisition of financial knowledge is conceptualized as a continuous, dynamic process in which new information is absorbed, evaluated, linked to personal experience, and integrated into existing knowledge structures.

Table 1

Subcategories, frequency, and prevalence in the sample

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Experiential learning / learning from life events	16	"We invested money once […] and ended up getting neither any interest nor our money back […] that was a learning experience" (FB01, l. 71 ff.)	very common
Family and partner	15	"Apart from that, I naturally discussed these matters extensively with my husband. […] We always talked things through together" (FB01, l. 31 ff.)	very common
Financial institutions (banks / savings banks)	13	"If we want to know anything about our investments, we call our bank" (FB01, l. 256 f.)	frequent
Personal social circle (friends / acquaintances)	7	"I have a good friend […] who worked in banking and was also responsible for real estate matters" (FB02, l. 73 f.)	moderate
Independent research via financial media	5	"We subscribe to a weekend newspaper […] and two newsletters […] and I look at what they have to say" (FB06, l. 168 ff.)	low–moderate
Formal educational programs (courses / seminars)	3	"It was a webinar […] on what one should pay attention to […] and it was presented very nicely" (FB06, l. 213 f.)	rare

Note: FB is the anonymized code assigned to the interviewees

The analysis shows that financial knowledge is acquired predominantly through informal, experience-based, and socially embedded means. The most frequently cited source is experiential learning through life events. In most interviews (16 of 20), respondents indicate that financial competences were primarily developed through specific life situations, e.g., employment, starting a family, separation, or purchasing property. Financial literacy thus appears less as a systematic learning process than as a gradual adaptation to the practical demands of life.

Family and partners constitute an almost equally important source, documented in 15 cases. Financial decisions are often made jointly, and knowledge is transmitted intergenerationally within partnerships and families. Both division-of-labor arrangements based on traditional gender roles and forms of mutual support are evident. The family functions as a central venue for informal learning, whose impact extends well beyond the occasional transfer of knowledge.

Professional financial service providers also prove relevant. More than half of the respondents (13 of 20) cite personal advice from banks, savings banks, or tax advisors as a significant source of knowledge. Tax advisors are perceived as competent, reliable, and often long-standing points of contact who provide important guidance on investment, taxation, retirement provision, and wealth transfer. However, their role is described ambivalently: whereas tax advisors are frequently regarded as independent and trustworthy, some respondents express skepticism toward banks regarding potential sales interests. In this institutional context, financial knowledge is acquired predominantly on an ad hoc basis within specific advisory situations, rather than as neutrally available general knowledge.

Individualized and formalized forms of knowledge acquisition occur considerably less frequently but provide informative indications of the prerequisites and limitations of self-directed financial literacy. Seven respondents report informal conversations with friends or acquaintances in which financial topics are discussed; this exchange serves primarily to compare decisions, contextualize experiences, and reduce uncertainty, yet it remains sporadic and limited in scope. Independent research via financial media (newspapers, guidebooks, digital sources) is mentioned in five interviews. It requires self-confidence and media literacy and is used mainly by respondents who already have basic financial knowledge. Formal educational programs, such as courses or seminars, cited only three times, represent the least frequently mentioned source.

4.2. Main category II. Needs and wishes regarding financial literacy in old age

This category captures the topics, support formats, and learning opportunities respondents consider helpful, necessary, or desirable for managing financial

matters in later life (see Table 2). The focus is on which forms of knowledge transfer are regarded as suitable for strengthening financial security and decision-making competence.

Table 2

Subcategories, frequency, and prevalence in the sample

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Individual personal advice	14	"Women do not really take an active role in this. At least most of them do not. Financial matters have always been considered a man's responsibility. They tend to stay out of it, often to their own disadvantage" (FB06, l. 261 ff.)	very common
Advice tailored to needs and life circumstances	11	"And there is one more thing that concerns me, for example. […] What if we have to dip into our savings? That is our inheritance" (FB06, l. 307 ff.)	frequent
Independent advice (free from sales interests)	9	"What one would really need is an independent advisor – although such a person probably hardly exists – who could clearly explain where one can invest relatively safely while achieving the highest possible returns" (FB16, l. 109 ff.)	frequent
Peer exchange / learning in social settings	6	"Quite often, you talk to colleagues about their investments. For example, one colleague might be actively involved in trading stocks […] You discuss it with him, sometimes even make investments together through his account, and that is where I get my information from" (FB09, l. 151 ff.)	moderate
Women-specific financial literacy	4	"Women are not really actively involved in these matters. At least very few of them are. Financial matters have always been considered a man's responsibility. They tend to stay out of it, often to their own disadvantage" (FB06, l. 261 ff.)	low–moderate

The need for financial literacy in old age is primarily articulated as a desire for individual, personalized advice. In most interviews (14 of 20), financial support is sought in a context-specific way, linked to concrete questions rather than

general information. Clarity, trust, and the opportunity to ask targeted follow-up questions are key priorities.

Closely linked to this is the need for life-situation-oriented advice, expressed by more than half of the respondents (11 of 20). They desire services geared toward specific transitional and decision-making situations in old age, such as retirement, asset transfer, housing decisions, or potential care needs. Financial literacy is understood here not as a continuous process, but as situation-specific support at biographically significant moments.

Another central finding is the wish for independent advice free from sales interests (9 of 20). Respondents repeatedly express skepticism toward commercial providers and emphasize the importance of neutral, non-product-specific information as a prerequisite for trust. This corresponds to the ambivalent perception of banks documented in Section 4.1 and underscores that, from the target group's perspective, credibility and impartiality are key quality criteria for financial literacy programs.

Participatory and target-group-specific formats occur less frequently, yet indicate differentiated needs. Six respondents express a desire for peer exchange in which shared experiences with friends or acquaintances serve as a learning resource. This exchange is described as low-threshold and relevant to everyday life, though it fulfills a complementary function alongside individual counseling. Finally, four interviews point to the need for women-specific programs, especially given traditional gender roles that historically excluded women from financial decisions, resulting in greater support needs in old age.

4.3. Main category III. Attitudes and emotions in financial matters

This category captures respondents' subjective attitudes, feelings, and evaluations in financial matters, highlighting how cognitive orientations and affective reactions interact in financial behavior (see Table 3).

Table 3

Subcategories, frequency, and prevalence in the sample

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Security orientation / caution	17	"When you're retired, I think you need to have a bit of a financial buffer" (FB02, l. 101)	very common
Insecurity / fear of financial loss	9	"I sometimes feel uneasy […] when my financial cushion shrinks" (FB02, l. 130 ff.)	frequent

Table 3 cont.

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Need for control / self-determination	8	"I am perfectly capable of making financial decisions on my own." (FB01, l. 107)	moderate–frequent
Composure / confidence in one's own abilities	7	"I cannot imagine a situation in which I would not make a (most likely) correct decision." (FB05, l. 105 ff.)	moderate

Attitudes and emotions about financial matters are shaped primarily by a pronounced security orientation. In almost all interviews (17 of 20), respondents describe a cautious approach to money, manifested in a desire for reserves, financial security, and the deliberate avoidance of financial products that are not understood or are perceived as risky. Security is viewed as a central prerequisite for financial agency in old age. This finding aligns with the dominance of experience-based learning documented in Section 4.1 and suggests that predominantly situational knowledge acquisition favors avoiding investment forms that are not fully understood.

Complementing this security focus, emotional insecurity emerges in just under half of the interviews (9 of 20), manifesting as worry or fear of financial loss. This insecurity is frequently tied to concrete situations: the depletion of financial reserves, unclear future expenses, or the perception of limited room for correction in old age. In these cases, financial decisions are emotionally charged and accompanied by a heightened need for reassurance. Security orientation and fear of loss thus prove not to be opposites but complementary facets of a preservation-oriented basic attitude.

A pronounced need for control emerges in eight interviews as a response to this tension. Respondents emphasize the importance of making financial decisions independently and retaining control over their money. Self-determination counterbalances uncertainty and safeguards against offers perceived as opaque or externally directed. This finding connects to the desire for independent advice documented in Section 4.2, illustrating that financial autonomy holds not only practical but also emotional significance for the target group.

In contrast, seven respondents report composure and confidence in their own financial abilities. This emotional disposition is frequently accompanied by extensive experience, stable income trajectories, or successfully managed financial decisions. Composure thus appears less like a starting point than the outcome

of biographical learning processes. This confirms the importance of experiential learning at an emotional level.

4.4. Main category IV. Meaning attributions to financial literacy

This category captures the personal relevance respondents attribute to financial literacy, retrospectively across past life stages and prospectively across current and future challenges (see Table 4). It reveals how subjective interpretations of financial literacy shape the willingness to learn, information-seeking behavior, and financial decision-making.

Table 4

Subcategories, frequency, and prevalence in the sample

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Financial literacy as a prerequisite for security and stability	14	"But it was always also about having financial security" (FB02, l. 36 f.)	very common
Financial literacy as a lifelong learning task	12	"It was really an ongoing learning process over 35 years" (FB01, l. 148 f.)	frequent
Call for institutionalized financial literacy (school / university)	8	"I really see this as something that should be addressed in schools and, at the latest, in higher education […]" (FB01, l. 385 f.)	moderate–frequent

Financial literacy is predominantly associated with security and stability. In most interviews (14 of 20), financial knowledge is described as a key prerequisite for leading a financially secure life, limiting risks, and ensuring long-term stability. This finding adds a cognitive dimension to the emotionally grounded orientation towards security documented in Section 4.3: among the interviewees, financial knowledge is not merely an object of affective desire but is conceptualised as a concrete means of securing their own future.

Beyond this stability-related interpretation, more than half of the respondents (12 out of 20) view financial literacy as a lifelong learning task; an ongoing engagement across different life stages, closely linked to personal experiences,

mistakes, and professional contexts. This interpretation aligns with the finding that financial knowledge is primarily acquired through experience and embedded in one's biography.

Notably, just under half of the interviews (8 of 20) also contain an explicit call for financial literacy to be institutionally anchored in the education system. Respondents advocate compulsory programs in schools or higher education to impart basic financial competences early and to reduce future uncertainty and poor decision-making. Respondents often justify this call retrospectively and link it to perceived deficits in their own learning histories. The finding deserves particular attention because it reveals a tension between the subjectively preferred mode of learning (experience-based) and the simultaneously expressed demand for formalized education. Respondents thus recognize the limitations of informal learning and advocate a more systematic approach, at least for future generations.

4.5. Main category V. Financial turning points

This category covers significant events, transitions, and changes in respondents' life courses that noticeably affected their financial situation, behavior, or sense of security (see Table 5). These turning points mark moments at which routines were questioned, decisions reassessed, or financial strategies adjusted. The category highlights how such key moments trigger learning processes and either expand or restrict the financial scope for action.

Table 5

Subcategories, frequency, and prevalence in the sample

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Property ownership (purchase, construction, repayment)	15	"I also had to purchase property. In fact, two properties: one for business purposes and one for private use" (FB16, l. 6 f.)	very common
Systemic upheaval and reunification 1989/1990	11	"For instance, when we moved from Berlin to Mannheim in 1990, I was initially unemployed" (FB06, l. 5 f.)	frequent

Table 5 cont.

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Starting a business / self-employment	9	"As a self-employed person, I had to buy a company […]" (FB16, l. 5 f.)	frequent
Transition to retirement	8	"The tax advisor said that he had not seen pension payments like these in a long time" (FB06, l. 15 f.)	moderate–frequent
Family changes	6	"Then, later, came the divorce. Those were the situations that, so to speak, created pressure." (FB16, l. 12 f.)	moderate
Childhood influences	5	"These stories ran throughout my childhood and ultimately shaped the way I lived my daily life, teaching me to use resources and money sparingly." (FB11, l. 26 ff.)	moderate

Financial turning points are mainly associated with significant life changes and structural shifts. The most frequently cited turning point is property ownership (15 out of 20). Purchasing or building a house, taking out a mortgage, or fully repaying a loan are described as phases in which financial decisions carry far-reaching consequences and shape financial freedom of action over extended periods. This aligns with the security-focused mindset discussed in Section 4.3: respondents view property ownership not just as an economic investment but also as a key strategy for ensuring their retirement security.

The systemic upheaval in Germany in 1989/1990 constitutes another major turning point mentioned in more than half of the interviews (11 out of 20). The political and economic transformation process was often accompanied by profound changes in employment trajectories, job losses, career reorientation, internal migration, or the first encounter with market-based income and social-security systems. For many respondents, this phase entailed heightened financial insecurity alongside new opportunities and learning processes. This finding underscores the intersectional perspective outlined in Section 2, in which regional origin and transformation experiences operate as distinct dimensions of financial vulnerability.

Just under half of the respondents (9 out of 20) identify business start-ups and periods of self-employment as defining financial turning points. These are associated with fluctuating incomes, investment risks, and increased financial pressure. Self-employment is portrayed ambivalently; as both a demanding

phase and as a period of intensive financial learning. It adds another layer to experience-based learning: self-employment generates a specific pressure to act that accelerates learning yet also increases susceptibility to error.

The transition to retirement represents a significant turning point for eight respondents. Retirement brings a changed income structure, new spending patterns, and sometimes decisions about relocation or pension arrangements. During this phase, respondents fundamentally reassess financial security, often focusing on long-term planning and maintaining their standard of living. This finding corresponds to the need for life-situation-oriented advice documented in Section 4.2.

The two remaining subcategories occur less frequently but provide further insights into the biographical depth structure of financial turning points. Family changes, e.g., divorce, starting a family, or the renegotiation of financial responsibilities within a partnership, are described as turning points in six interviews, often accompanied by increased economic pressure or changed priorities. Finally, five respondents point to childhood influences as long-lasting turning points in the sense of biographical frames of reference. Early experiences of financial hardship, thrift, or family attitudes toward money shape later attitudes and decision-making practices as continuous influences rather than isolated events.

4.6. Main category VI. Attitudes toward investment risk

This category captures respondents' fundamental attitudes and evaluation patterns regarding uncertainty, potential losses, and opportunities for return in financial investments (see Table 6). It reflects the extent to which respondents accept, avoid, or selectively take risks, supplementing the emotional dispositions and security needs documented in the preceding sections with an action-oriented dimension.

Table 6

Subcategories, frequency, and prevalence in the sample

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Conservative approach / risk avoidance	20	"We were very conservative with our money [...] we had no appetite for risk" (FB01, l. 145)	universal
Risk awareness through negative experiences	8	"We invested money … and ended up receiving neither any interest nor our money back [...] that was a learning experience" (FB01, l. 71f f.)	moderate–frequent

Table 6 cont.

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Life-stage-specific risk avoidance	6	"At my age, I am not really going to invest in anything anymore [...] that is something I should have done when I was younger" (FB02, l. 117 f.)	moderate
Selective willingness for low-risk investments	4	"We bought investment funds … diversification is important [...]" (FB06, l. 213 f.)	rare

The analysis reveals consistently pronounced risk aversion. The "conservative approach/risk avoidance" subcategory is the only one in the entire study to appear in all 20 interviews, making it the sole universally shared attitude in the sample. Risk is predominantly perceived as a potential threat to accumulated assets, while return maximization and wealth growth play a subordinate role. This finding consolidates the previously documented security orientation into a concrete behavioral pattern.

The causes of this risk aversion can be differentiated at two levels. At the biographical level, eight interviews reveal risk awareness explicitly attributed to negative experiences: past losses or disappointing investment returns serve as formative learning experiences that lead to a permanent withdrawal from risky investment forms. Participants retrospectively interpret risk as a source of error and subsequently avoid it. This pattern corresponds to the dominance of experience-based learning. Even in the investment context, experiences serve as a central source of financial orientation.

At the life-stage-specific level, six interviews reveal age-related risk avoidance accompanied by characteristic reasoning. Respondents point to a diminishing investment time horizon and uncertainties about care needs, health developments, or maintaining their current standard of living. Risk is thus perceived as no longer worthwhile or justifiable, a reasoning pattern that connects to the financial turning points associated with retirement (Section 4.5).

By contrast, only four interviews show a selective willingness to engage in low-risk investments. Here, risk is not entirely excluded but permitted in a controlled manner, for example, through broadly diversified funds or investment forms perceived as transparent and calculable. Decision-making processes are highly rationalized and often collectively organized. Even these few risk-tolerant

respondents regard transparency and subjective comprehensibility as indispensable prerequisites for investment decisions, echoing the documented need for control (Section 4.3).

4.7. Main category VII. Family influences on financial literacy

This category encompasses all statements in which money-related orientations and behaviors are described as the result of early socialization within the family (see Table 7). The focus is on implicitly conveyed norms, routines, and responsibilities, as well as the ways in which financial matters were discussed or treated as taboo in the family of origin. The category reveals how financial interpretive patterns and responsibility attributions are established early in life and durably shape later financial behavior. It thus provides a socialization-theoretical framework for the attitudes, emotions, and behavioral patterns documented in the preceding sections.

The dominant subcategory is the implicit intergenerational transmission of financial practices and norms (14 out of 20). Respondents report learning financial attitudes, e.g., thrift, cautious consumption, debt avoidance, and budgeting, not through explicit instruction but through everyday family practices and role models. Financial literacy appears here as an implicit socialization process conveyed through recurring routines. This finding deepens the documented dominance of informal learning and anchors it in early childhood socialization: the experience-based acquisition of financial knowledge proves to be a continuation of a pattern already established in the family of origin.

Table 7

Subcategories, frequency, and prevalence in the sample

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Implicit intergenerational financial practices and norms	14	"Back then, it was all cash. It was divided into envelopes for the different expense categories. And, well, when an envelope was empty, it was empty" (FB01, l. 79ff.)	very common
Money as a taboo subject within the family	8	"No, no, no. [...] We had virtually no knowledge of our parents' income or any savings they might have had. [...]) It was simply not discussed" (FB06, l. 38ff.)	frequent

Table 7 cont.

Subcategory	Number of respondents (n = 20)	Example quote	Prevalence
Finances as a "non-issue" in childhood	4	"Not really. [...] We had a fairly sheltered upbringing, and money was not really a topic" (FB06, l. 34)	low–moderate
Gender-specific division of labor in financial matters	5	"I never concerned myself with investments [...] or taxes [...]; that simply was not my area of responsibility. I was more in charge of vacations and our family's cultural activities" (FB04, l. 91ff.)	low–moderate

A further prominent theme is the taboo surrounding money within the family of origin (8 of 20). In these cases, financial matters were rarely discussed explicitly; money was treated as a private affair or left to individual family members. This form of non-communication is often accompanied by uncertainty, a lack of transparency, or engagement with financial topics only later in life. This finding aligns with the emotional insecurity documented in Section 4.3 and suggests that early family communication patterns may contribute to its development.

The remaining two subcategories occur less frequently but provide additional insight. In four interviews, finances are described as a "non-issue" during childhood: respondents characterize their upbringing as financially unremarkable or secure, such that money had little subjective salience. Financial literacy remained in the background of everyday life and gained significance only in later life stages, further supporting the role of biographical turning points as triggers for financial learning (Section 4.5). Five interviews also revealed a gender-specific division of financial responsibilities within the family. Traditional role expectations often meant that one parent, typically within a gendered division of labor, assumed primary responsibility for financial matters, while other family members were less involved in financial decision-making. These arrangements appear to shape not only access to financial knowledge but also later perceptions of competence, responsibility, and confidence in dealing with financial matters. This finding therefore connects with the gender-specific barriers discussed in Section 3.3 and the need for women-specific financial education programs highlighted in Section 4.2. The interviews suggest that such differences in financial participation may begin early in life and be reinforced through processes of socialization.

4.8. Cross-category patterns and correlations

An integrated examination of the seven main categories reveals several overarching patterns that extend beyond the individual findings and highlight the internal coherence of the results.

The first key pattern is the consistent dominance of informal, experience-based knowledge acquisition, which manifests at three levels: socially, in early childhood socialization through family norms and practices (Category VII); biographically, in experiential learning at life-course turning points (Categories I and V); and in terms of expressed needs, in the preference for personal, context-specific advice over formalized educational formats (Category II). Formal educational plays no significant role as either an actual knowledge source or a preferred format. A noteworthy tension arises from the juxtaposition of Categories I and IV: although respondents have predominantly learned informally, eight of the twenty call for the institutional embedding of financial literacy in schools and higher education, thereby acknowledging the limitations of the very learning pattern that shaped them.

A second pattern is security as a cross-category leitmotif. Security emerges as a dominant emotion (Category III), is conceptualized cognitively as an educational goal (Category IV), manifests in investment behavior as universal risk aversion (Category VI), and is applied as a quality criterion to advisory services (Category II). This consistency across emotion, cognition, action, and expressed need points to a deeply rooted, biographically developed disposition.

A third involves a biographical chain of financial influences. Childhood socialization experiences such as implicit norms, taboos, and gender-specific divisions of responsibility (Category VII) continue in the experience-based learning of adulthood (Categories I and V), coalesce into emotional dispositions in later life (Category III), and manifest as concrete behavioral patterns such as risk aversion (Category VI). The gender dimension proves to be a silent yet consistently converging structural feature: from the familial division of labor (Category VII) through gender-specific participation barriers in the recruitment process (Section 3.3) to the articulated need for women-specific services (Category II), a socially entrenched pattern of inequality becomes visible. Finally, a comparison of Categories I and II reveals an institutional ambivalence: banks are used as a knowledge source in the absence of alternatives, yet viewed with skepticism, while independent advice is explicitly desired. This points to a structural gap in the existing advisory system.

4.9. Implications for the design of financial literacy programs

The findings and cross-category patterns yield several empirically grounded implications for designing financial literacy programs for older adults. The

consistent predominance of informal, experience-based, and socially embedded knowledge acquisition – from early childhood socialization (Category VII) through experiential learning at biographical turning points (Categories I and V) to a preference for personal, context-specific counseling (Category II) – suggests that educational provision should not rely exclusively on formalized delivery formats. Rather, it appears more effective to build on existing informal learning practices through facilitated peer-exchange formats, narrative approaches drawing on biographical experiences, or the integration of family networks as learning contexts. Formats that value experiential knowledge and employ dialogical methods are likely to achieve higher acceptance than purely instructional programs.

Closely related is the question of timing and situational context. The finding that financial literacy needs are primarily linked to biographical transition phases, such as retirement, property decisions, wealth transfer, or care needs, argues for a consistently life-situation-oriented program structure: not continuous course programs but situation-specific, readily available support targeted at moments when financial decisions are particularly consequential, and receptivity to learning is heightened.

A further key requirement arises from the emotional disposition of the target group. The pronounced security orientation (Category III), high need for control, and universal risk aversion (Category VI) make clear that financial literacy cannot be conceived solely as cognitive knowledge transfer. Security-seeking, fear of loss, and the need for self-determination are emotional prerequisites that significantly influence access to and processing of financial information. Programs should explicitly account for these dispositions, for instance, through trust-building dialogue settings, normalizing financial uncertainty, and strengthening financial self-efficacy. In investment-related contexts, information should focus less on return optimization and more on comprehensibility, security, and life-stage appropriateness. The documented ambivalence toward banks and the explicit desire for independent, sales-free advice (Category II) point to a structural gap that could be addressed by institutionally independent contact points such as consumer advice centers, local advisory services, or civil-society organizations. Credibility and impartiality emerge as key quality criteria without which the trust of the target group is difficult to secure.

The findings further point to the need for differentiated, diversity-sensitive program design. The cross-category convergence of gender-specific findings, from familial socialization patterns (Category VII) through recruitment barriers to the articulated need for women-specific financial literacy (Category II), illustrates that traditional role attributions remain effective across the entire life course, producing increased support needs and self-exclusion mechanisms in old age. Gender-sensitive formats that actively address this biographically developed

distance through supportive learning environments, role-reflective approaches, and low-threshold entry-level programs appear just as necessary as biographically reflective methods that explore the connection between early influences and current financial behavior. Family-shaped attitudes, taboos, and role models should not be treated as immutable starting conditions, but should be integrated into educational processes as dimensions open to reflection, raising awareness of entrenched patterns and expanding the scope for action.

5. Limitations and outlook

The findings presented above are subject to a number of constraints that must be taken into account when interpreting them. The following chapter therefore first discusses the methodological limitations of the study (5.1) before outlining the resulting avenues for future research (5.2).

5.1. Limitations

This study has several methodological limitations. First, it is an exploratory qualitative study based on only 20 interviews. The findings capture subjective perspectives and interpretive patterns but do not permit conclusions about their distribution within the broader population of older adults in Germany.

Second, despite efforts to achieve a heterogeneous sample, the recruitment strategy introduced some structural biases. Recruitment via church parishes, social-work organizations, and snowball sampling favors socially integrated and comparatively accessible individuals, while isolated, very elderly, or severely health-impaired older adults were scarcely reached. People with a migration background are not represented, although this group was identified as particularly vulnerable in the theoretical framework. The intersectional perspective introduced in Section 2 (Crenshaw 1991) could therefore be only partially realized: while the gender dimension and regional transformation experiences could be analyzed across categories, other dimensions identified as relevant, such as migration history, educational attainment, and family living arrangements, remained empirically under-represented. The systematic investigation of these intersectional constellations is reserved for the quantitative project phase.

Third, gender-specific self-exclusion mechanisms were already evident during recruitment: those who declined to participate were predominantly women, citing a lack of knowledge. This suggests that precisely those perspectives most illuminating for understanding gender-related barriers are under-represented in the present sample.

Finally, the analysis rests on self-reports, which may be subject to social-desirability bias as well as selective recall and retrospective reinterpretation. Particularly regarding financial literacy, risk tolerance, and money management, respondents may overestimate their knowledge, downplay uncertainties, or narratively reconstruct past experiences from the perspective of their current life situation. The qualitative design did not include an objective measure of financial literacy, which will be addressed in the quantitative phase.

5.2. Outlook

The findings of this qualitative study provide the exploratory foundation for the second, quantitative phase of the FiBiSen project. Building on the needs, barriers, and thematic patterns identified in the interviews, a standardized questionnaire for older adults is being developed to examine these findings in a larger sample. The quantitative phase will assess the prevalence and variation of the patterns identified qualitatively, including the predominance of informal financial knowledge acquisition, a strong orientation toward financial security, ambivalent attitudes toward financial institutions, and gender-related differences.

Alongside the survey of subjective needs and attitudes, respondents' actual financial knowledge will be assessed using the OECD/INFE Toolkit for Measuring Financial Literacy. This internationally established instrument enables a standardized assessment of financial knowledge, behaviors, and attitudes while also permitting contextualization within the international research landscape. The combination of subjective needs assessment and objective knowledge diagnostics is intended to reveal where self-assessments and actual financial knowledge diverge and where specific educational needs exist.

To ensure instrument quality, a two-stage pre-test procedure is planned. First, a cognitive pre-test will be conducted in which selected participants complete the questionnaire while thinking aloud, in order to identify comprehension problems, ambiguities, and the cognitive demands of individual items. The instrument will then be revised and subjected to a standard pre-test that assesses practicability, completion time, and reliability under field conditions. This procedure ensures that the survey instrument adequately accounts for the specific cognitive and linguistic requirements of the target group.

6. Conclusion

Based on 20 semi-structured qualitative interviews, this study examined how older adults in Germany acquire financial knowledge, what needs and barriers characterize their financial behavior, and what forms of support they desire. The

content-structuring qualitative content analysis yielded seven main categories that provide a nuanced account of the financial literacy of older adults.

The results show that financial knowledge in later life is acquired primarily informally, through experience, and within a social context. Formal educational programs play no significant role as a knowledge source or a preferred format. Instead, biographical learning opportunities, family influences, and personal advice from financial institutions dominate, though the latter is met with marked skepticism about commercial sales interests. The desire for individual, life-situation-oriented, and independent advice emerges as a central finding, pointing to a structural gap in the existing advisory system.

At the emotional level, respondents' financial behavior is significantly shaped by a focus on security, fear of loss, and the need for control and self-determination. Cross-category analysis reveals that these dispositions are not isolated attitudes but are linked within a biographical continuum. Family socialization patterns, in particular implicit norms, taboos, and gender-specific divisions of responsibility, continue in the experience-based learning of adulthood and manifest in later life as a near-universal risk aversion in the investment context. Security emerges as a cross-category leitmotif, operating emotionally (as a basic attitude), cognitively (as an educational goal), in practice (as an investment-avoidance strategy), and in terms of needs (as a quality criterion for advice). The gender dimension constitutes a silent yet consistently convergent structural feature: from familial role attributions through access barriers in the recruitment process to the articulated need for women-specific services, a socially entrenched pattern of inequality becomes visible. Together with the documented institutional ambivalence toward financial-service providers, this warrants systematic consideration in the design of future educational programs.

Overall, the study shows that older adults' financial literacy is not an isolated knowledge deficit but the result of lifelong, socially embedded, and emotionally charged processes. The design of target-group-specific educational programs should therefore build on informal learning practices, use biographical transition phases as intervention points, ensure institutional independence, and address the emotional and socialization-related prerequisites of the target group. Because most respondents prefer experience-based learning, which cannot be reproduced within formalized educational pathways, case-based learning appears worth considering. It is an established practice in social work education and may be more intuitive for learners than abstract concepts. For example, it could be implemented by describing the financial situations and decisions of older adults in typical life situations, either in brochures or in group discussions in which older adults discuss solutions to such situations. The planned quantitative project phase will test and deepen these exploratory findings on a broader empirical basis.

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Summary

Based on 20 semi-structured qualitative interviews and a content-structuring qualitative content analysis, this study examined how older adults in Germany acquire financial knowledge, what needs and barriers characterize their financial behavior, and what support they desire. Seven main categories emerged. Financial knowledge in later life is acquired primarily informally — through experience, family influences, and personal advice from financial institutions, the latter viewed with marked skepticism regarding commercial interests. Formal educational programs play no significant role. The desire for individual, life-situation-oriented, and independent advice points to a structural gap in the existing advisory system. Emotionally, financial behavior is shaped by a focus on security, fear of loss, and the need for control. Cross-category analysis reveals that these dispositions are linked within a biographical continuum: family socialization patterns — implicit norms, taboos, and gender-specific divisions of responsibility — continue in experience-based learning and manifest in later life as near-universal risk aversion. Security operates as a cross-category leitmotif — emotionally, cognitively, in practice, and in terms of advisory needs. Gender constitutes a silent yet convergent structural feature, from familial role attributions through access barriers to the articulated need for women-specific services. The study demonstrates that financial literacy among older adults should be understood not as an isolated knowledge deficit but as the result of lifelong, socially embedded, and emotionally charged processes. Educational programs should build on informal learning practices, utilize biographical transition phases as intervention points, ensure institutional independence, and address the emotional and socialization-related prerequisites of the target group. Since most respondents prefer experience-based learning, case-based approaches — for example describing typical financial situations in brochures or group discussions — merit consideration. The planned quantitative project phase will test these exploratory findings on a broader empirical basis.

JEL codes: G53, C81

Keywords: *financial literacy, qualitative study, older adult*

Received: 10.06.2026
Accepted: 18.09.2026

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