Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669, Print ISSN: 2980-9460
Research Article
DOI: 10.22067/jstinp.2026.96998.1194
JSTINP 2026; Vol. 5, No. 3

Design and Validation of a System Dynamics Model for Attracting and Leveraging Industrial Elites in Iran's Industrial Production System

Ali Shoobi [a], Rouhollah Bagheri [b]*, Jalal Haghighatmonfared [a]

a Department of Management, Central Tehran Branch, Islamic Azad University, Tehran, Iran

b Department of Management, Ferdowsi University of Mashhad, Mashhad, Iran

How to cite this article

Shoobi, A., Bagheri, R. and Haghighatmonfared, J., 2026. Design and Validation of a System Dynamics Model for Attracting and Leveraging Industrial Elites in Iran's Industrial Production System. *Journal of Systems Thinking in Practice*, *5*(3), pp. 110-140. Doi: 10.22067/jstinp.2026.96998.1194.
URL: https://jstinp.um.ac.ir/article_47803.html

ABSTRACT

This paper designs and validates a system dynamics model to explain the mechanisms of attracting, retaining, and leveraging industrial elites in Iran's industrial production system. Given the strategic role of industrial elites in developing a knowledge-based economy and improving industrial competitiveness, a range of policies and institutions have been established in recent years; however, a meaningful gap remains between the emerging capacity of industrial elites and their realised impact on industrial production. Based on the literature on human capital, elite migration, national innovation systems, and science and technology policy and relevant upstream policy documents, key variables and feedback relationships across higher education, elite support, industrial R&D units, industrial knowledge-based companies, the elite labour market, and the policy/institutional environment were identified and formalised as causal-loop and stock and flow structures and implemented in Vensim. Using official time-series data for 2012–2021 (1391–1400), the model was calibrated and evaluated using structural tests (e.g., boundary adequacy and dimensional consistency) and behavioural tests (historical behaviour reproduction, extreme-condition tests, and sensitivity tests). The results indicate that the proposed model reproduces the historical trends of key variables with acceptable accuracy and exhibits robust behaviour under reasonable parameter changes. The model can serve as a policy laboratory for ex ante evaluation of interventions to increase industrial absorption capacity, strengthen industrial R&D, and reduce persistent elite outflows.

Keywords

System dynamics; Industrial elites; Industrial R&D; Industrial knowledge-based companies; Elite migration;

Article history

Received: 2025-12-15
Revised: 2026-01-10
Accepted: 2026-01-20
Published (Online): 2026-09-28

Number of Figures: 12 **Number of Tables: 3** **Number of Pages: 31** **Number of References: 15**

****Corresponding author***
Email: rbagheri@um.ac.ir

1. Introduction

In recent decades, the role of scientific and technological elites in industrial development and in the transition towards a knowledge-based economy has been increasingly emphasised. In this context, industrial elites can be viewed as specialists, often with postgraduate education in engineering and industrial management, who possess distinctive capabilities in research and development (R&D), process and product design, systems analysis, innovation management, and complex problem-solving. Because such capabilities translate into higher-quality R&D, improved productivity, technology development, and the creation and growth of industrial knowledge-based companies, industrial elites can play a decisive role in increasing industrial value added and in realising the objectives stated in national upstream policy documents (Amsden et al., 2012).

In Iran, the quantitative expansion of higher education, the growth of postgraduate programmes in industrial and engineering fields, and the establishment of institutions and policies such as the National Elite Foundation and support programmes for knowledge-based companies have created an institutional and educational basis for strengthening the industrial elite system (Moghimi and Memarzadeh Tehran, 2021).

The number of elites employed in industrial R&D units, influenced by the expansion of higher education and certain support programmes, has shown an upward trend in some years. As shown in Figure 1, based on statistics from the Statistical Center of Iran, this variable increased over the historical period examined. Nevertheless, if the absorption capacity of industry and related institutions is limited, if institutional problems and administrative barriers intensify, or if elite unemployment increases, the growth trajectory may gradually slow and eventually exhibit a 'slowing growth' pattern or even a state of 'relative stagnation' in later years (Statistical Center of Iran, 2022; Sterman, 2000).

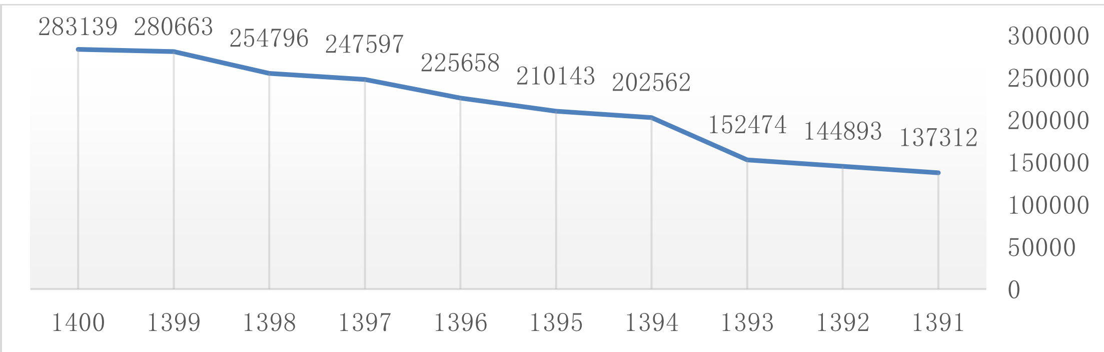

Figure 1. Trend of the number of elites employed in workshops with R&D activities (Statistical Center of Iran, 2022).

 DOI: 10.22067/jstinp.2026.96998.1194

In other words, while the country has invested heavily in training postgraduate human capital in industrial fields and while the number of programmes, graduates, and support instruments has expanded, the expected outcomes in the industrial sector, including sustainable growth in industrial R&D capacity, stable employment of elites in R&D and innovation roles, and increased industrial knowledge-based output, have not fully materialised. This indicates that policy success cannot be assessed solely by the number of graduates or by the announcement of support programmes; instead, the dynamic interactions among subsystems and the quality of implementation must be examined (Moghimi and Memarzadeh Tehran, 2021; Moghimi, 2018).

However, official statistics and expert assessments indicate that a non-trivial share of industrial elites are employed in activities only partially aligned with their specialised expertise, or face pressures to migrate or withdraw from the domestic production cycle. At the same time, many industrial firms experience shortages of elite personnel in their R&D units and in innovation management roles. This coexistence of underutilisation on one side and unmet demand on the other suggests that the system is shaped by complex mechanisms rather than a single factor (Shahabadi et al., 2020; Safaie et al., 2023).

This situation implies that the industrial elite system, as a complex system, faces challenges in its structural design, policy coordination, and interactions among its subsystems. Multiple factors, including the structure and outcomes of higher education, mechanisms for identifying and supporting elites, the capacity and incentives of industrial R&D units, labour-market conditions for specialised human capital, the institutional and regulatory environment, and the flows of elite migration and return, jointly influence the long-term behaviour of this system through reinforcing and balancing feedback loops (Sterman, 2000; Barlas, 1996).

In addition, the system has significant time delays: the effects of policies that influence higher education quality, elite trust, or industrial R&D expenditures may take several years to appear in measurable outcomes such as value added, firm entry, or migration/return flows. Therefore, an approach that explicitly represents accumulations and delays is required to avoid misleading short-term interpretations. Such analysis requires an approach capable of representing causal–feedback relationships, stocks and flows (accumulations and rates), and time delays in an integrated manner. System dynamics is therefore an appropriate approach for understanding the behavioural roots of the problem and for designing, evaluating, and forecasting policies in feedback-rich systems (Forrester, 1961; Sterman, 2000).

Accordingly, the aim of this paper is to design and validate a system dynamics model for Iran’s industrial elite system constructed from the ground up and grounded in empirical data and expert knowledge that can capture the causal–feedback structure of the problem, reproduce the historical behaviour of key variables, and be usable as a policy laboratory for ex ante policy assessment.

The main research question of the paper is:

Can a feedback-based dynamic model be designed for Iran's industrial elite system that is structurally valid and behaviourally capable of reproducing real historical trends?

The remainder of the paper first reviews the theoretical foundations and relevant literature, then explains the system dynamics methodology and model-building steps. It subsequently presents the causal loop diagrams (CLDs) and stock and flow structure, reports the calibration and validation results, and concludes with recommendations for policy analysis and future research.

2. Theoretical Background and Literature Review

2.1. The concept of elites and industrial elites

In the social sciences and humanities literature, elites are individuals distinguished from the societal average in terms of cognitive ability, professional skills, creativity, and social influence. In the context of economic and industrial development, scientific and technological elites are those who contribute significantly to competitiveness and economic growth through the production of knowledge, the development of technology, and innovation in products and processes (Pareto, 1968; Mills, 1956).

Industrial elites are a subset of national elites whose activities are directly related to industrial production, industrial R&D, engineering and technological design, process improvement, production management, and innovation management. In addition to specialised technical knowledge, they often possess competencies such as systems thinking, complex problem-solving, teamwork, and the ability to operate effectively in complex organisational environments; therefore, they can play key roles in industrial organisations and innovation ecosystems (Amsden et al., 2012).

2.2. The elite system, elite migration, and the national innovation system

The elite system comprises institutions and processes that identify, nurture, support, employ, and retain elites at the national level. In Iran, this system includes components such as higher education, the National Elite Foundation, R&D centers, science and technology parks, knowledge-based companies, and the specialised labour market (Naqi Pourfar, 2013; Moghimi and Memarzadeh Tehran, 2021).

Alongside this system, elite migration is considered a serious challenge for developing economies. The emigration of elites not only represents a loss of the educational investments made in training specialised human capital but also reduces national capacity for R&D and innovation. Recent studies emphasise transforming 'brain drain' into 'elite circulation' and leveraging the capabilities of emigrant elites via scientific networks and targeted return programmes; however, such outcomes require domestic absorption capacity, stable and credible policies, and a supportive institutional environment (Shahabadi et al., 2020; Safaie et al., 2023).

From a policy standpoint, elite migration is not solely a 'flow' to be minimised; it is also an outcome that reflects the perceived relative attractiveness of domestic versus foreign opportunities, including factors such as income, career prospects, research infrastructure, and the institutional quality of the environment. As a result, policies focusing only on short-term incentives may not be sufficient unless the broader institutional setting is also improved (Shahabadi et al., 2020).

Within the national innovation system, industrial and scientific elites are recognised as key actors in the creation, diffusion, and application of knowledge. Industry, universities, policymakers, and intermediary organisations (such as elite foundations and innovation-support funds) interact dynamically in an innovation network. Any disruption, weakness, or misalignment in the feedback loops of this network can lead to inefficiency in the attraction, retention, and utilisation of elites (Freeman, 1987; Lundvall, 1992; Nelson, 1993).

2.3. System dynamics in analysing elite systems

System dynamics is an approach that focuses on 'structure' as the key determinant of system behaviour over time. By representing stocks, flows, feedback loops, and delays, this approach has been widely used in management and public policy, as well as in domains such as education, human resources, and scientific and technological systems (Sterman, 2000).

In the context of elite systems, system dynamics enables modelling the interactions among higher education, elite identification and support policies, specialised labour markets, industrial R&D units, and migration and return flows. This, in turn, enables the estimation of the effects of alternative policies over time while accounting for feedback effects, nonlinearity, and time delays.

Building on this approach, the present study seeks to develop a dynamic, data-informed model for Iran's industrial elite system and to validate its structure and behaviour, so that subsequent studies can apply the model for scenario-based policy analysis.

3. Research Methodology

3.1. System dynamics approach

The methodology of this research is based on Sterman's proposed framework for system dynamics modelling (Sterman, 2000). Accordingly, the research process was conducted through several main steps:

1. Problem formulation and reference behaviours: We identified three historical reference-mode variables for 2012–2021 (1391–1400): (i) industrial knowledge-based companies, (ii) industrial R&D projects awaiting financing, and (iii) elites employed in industrial R&D units.
2. Dynamic hypothesis formulation: We constructed causal loop diagrams to articulate the main reinforcing and balancing feedback mechanisms driving elite attraction, retention, and industrial impact.
3. Simulation model formulation: We translated the CLDs into a stock-and-flow structure and specified the mathematical equations for all variables, implementing the model in Vensim.
4. Testing and validation: We calibrated uncertain parameters against historical data and performed structural and behavioural validation tests (boundary adequacy, dimensional consistency, parameter verification, historical behaviour reproduction, extreme-condition tests, and sensitivity analysis).
5. Preparation for policy scenario analysis: We mapped key policy levers to model parameters (e.g., financial support intensity, administrative bureaucracy, regulatory stability, venture capital investment, migration/return programmes) and ensured that the validated model can serve as a policy laboratory for scenario experiments to the horizon year 1420 (2041).

These steps are iterative rather than strictly linear: insights from testing and validation can lead to revising the dynamic hypothesis and even revisiting the model boundary or reference modes, until the model achieves acceptable structural and behavioural validity.

3.1.1. Problem formulation and reference behaviours

In system dynamics, the first and most important step is to formulate the problem dynamically; that is, instead of focusing on static and cross-sectional states, the modeller focuses on temporal patterns of change in key variables. The goal is to clarify what behaviours the system has exhibited over the relevant horizon, why these behaviours are considered problematic from a policy and managerial perspective, and which variables must be central to the model.

In this study, the main problem is that despite the quantitative expansion of higher education, the establishment of institutions such as the National Elite Foundation, and the growth of knowledge-based companies, the temporal behaviour of attracting, retaining, and leveraging industrial elites has not fully aligned with national development expectations. Observed trends indicate that:

- A considerable share of trained elites has been absorbed into non-industrial pathways.
- Among industrial elites, issues such as unemployment, employment unrelated to specialisation, and emigration are evident.
- Meanwhile, the final impact of these investments on indicators such as industrial value added and the share of knowledge-based products in GDP and industrial exports has been lower than expected.

From the system dynamics perspective, this situation is not the result of a single isolated factor; rather, it is the outcome of interactions among multiple reinforcing and balancing feedback loops. Therefore, the purpose of the dynamic model developed in this paper is to identify and formulate these feedback structures and to analyse their implications for the system's aggregate behaviour.

Accordingly, three reference modes were selected as central behavioural patterns for the model: (i) the number of elites employed in industrial R&D units, (ii) the number of industrial knowledge-based companies, and (iii) the number of industrial R&D projects awaiting financing. These reference modes jointly represent the absorption of elites into industry, the innovation-oriented organisational outcomes, and the financing capacity of the innovation system.

3.1.2. Time horizon

The time horizon in system dynamics should be long enough to (i) explain the causes and mechanisms of the phenomenon through a retrospective view and (ii) observe the delayed and indirect effects of decisions and policies through a forward-looking view. Accordingly, the horizon of this model spans from 2012 (1391) to 2041 (1420). This horizon is justified because: (a) since the early 2010s, relatively regular official statistics have been available for areas such as higher education, labour markets, industrial value added, and knowledge-based companies; (b) the year 1420 is approximately aligned with the horizon of certain national vision documents and long-term plans in science, technology, and industry; and (c) an approximately three-decade horizon enables observation of slow-moving behaviours, accumulations, and structural delays.

3.1.3. Reference behaviours

The required data were collected from official and reliable sources. The most important sources include: (i) statistics from the Statistical Center of Iran regarding the number of elites employed in industrial R&D units and the number of industrial R&D projects; (ii) statistical reports and programme documents in the field of technology policy and industrial development, including data on the number of knowledge-based companies; and (iii) semi-structured interviews with academic and industrial experts.

Time-series data for 2012–2021 (1391–1400) were entered into the model using WITH LOOKUP functions to reproduce the historical behaviour of key variables during the calibration period.

3.1.4. Modelling tool

The system dynamics model was designed and implemented in the Vensim software environment. Stock variables were defined using INTEG functions, and flow variables were defined as rates dependent on other variables. In addition, a number of variables were formulated as normalised, dimensionless indices to represent the relative influence of qualitative factors, such as the intensity of administrative bureaucracy, regulatory stability, and the level of elite trust.

Qualitative concepts (e.g., elite trust and bureaucratic intensity) were operationalised as dimensionless indices. When empirical proxies were available, indices were constructed via min–max normalisation; otherwise, values were elicited from domain experts and then calibrated within plausible bounds. These indices enter the model through nonlinear multiplier functions.

3.2. Formulation of dynamic hypotheses

In system dynamics, a ‘dynamic hypothesis’ is a structural explanation of why the system produces the observed reference behaviour. Dynamic hypotheses are narratives based on reinforcing and balancing feedback loops. They clarify: (i) which causal relationships and which feedback loops generate growth or decline of key variables over time; and (ii) how changes in policies or parameters can alter the future behaviour of the system.

In this study, based on an analysis of the literature, statistical evidence, and expert input, five main dynamic hypotheses were developed and are explained in detail below.

3.2.1. Dynamic Hypothesis 1: Growth of higher education and industrial elites

It is assumed that the quantitative and qualitative expansion of higher education, together with policy support, shapes the pipeline of industrial R&D talent and, through feedback effects, influences industrial R&D employment and the dynamics of industrial knowledge-based companies.

More explicitly, an increase in foundation-supported elites can strengthen industrial R&D capacity and firm formation; these effects reinforce future elite entry through capability, trust, and absorptive-capacity feedbacks.

On the other hand, strengthening elite faculty in universities improves the quality of education and research and enhances university–industry interaction, which gradually leads to an increase in both the number and quality of postgraduate graduates in industrial fields. Thus, a reinforcing feedback loop is formed. This hypothesis suggests that, in the absence of other constraints, substantial and relatively stable growth of industrial elites would be expected towards 1420; however, in practice, this trajectory faces limitations that are explained in later hypotheses.

3.2.2. Dynamic Hypothesis 2: Innovation, industrial R&D, and industrial value added

According to this hypothesis, increasing the number of elites employed in industrial R&D units enhances innovation capacity through the development of new products, improvement of production processes, and strengthening of engineering design and technology development. These improvements increase productivity and ultimately raise industrial value added. With higher industrial value added:

- Firms' financial ability to invest in industrial R&D increases.
- Industrial R&D expenditures increase.
- As a result, more R&D projects can be executed, and a larger number of elites can be recruited into R&D units.

This hypothesis posits that when favourable institutional and economic conditions prevail, the industrial production system can enter a long-term, knowledge- and innovation-based growth

 DOI: 10.22067/jstinp.2026.96998.1194

path. At the same time, the dependence of this reinforcing loop on macroeconomic conditions and policy stability makes it vulnerable to external shocks and constraints.

3.2.3. Dynamic Hypothesis 3: Development and sustainability of industrial knowledge-based companies

This hypothesis posits that an increase in industrial value added and the presence of elites in industrial R&D and firm management facilitate the formation and development of industrial knowledge-based companies. The greater the number of these companies:

- Employment opportunities for elites in knowledge-based domains increase.
- Elite employment in knowledge-based companies grows.
- The share of knowledge-based products and services in GDP and industrial exports increases.

An increased share of knowledge-based products is interpreted as a sign of the relative success of technology and innovation policies and typically encourages policymakers to strengthen financial support for elites and knowledge-based firms (for example, through higher budgets, financial facilities, tax exemptions, and similar instruments).

If this support is accompanied by an enabling institutional environment (including regulatory stability, sufficient industrial venture capital, and adequate infrastructure), this hypothesis implies a reinforcing loop that sustains the growth of industrial knowledge-based companies. Conversely, if administrative bureaucracy, regulatory instability, and financial constraints intensify, the exit and inactivation of knowledge-based companies may increase and the reinforcing loop may weaken.

3.2.4. Dynamic Hypothesis 4: Unemployment, absorption capacity, and elite migration

This hypothesis emphasises labour-market constraints: when there are insufficient suitable, high-quality R&D jobs and innovation-oriented firms, graduates and elites are pushed towards non-R&D employment or emigration, thereby weakening the elite–industry linkage.

High unemployment among elites has several important consequences:

- Reduced attractiveness of industrial and R&D career paths.
- Reduced willingness of elites to enter or remain in industrial R&D units.
- Increased propensity of industrial elites to migrate abroad.

As the migration and exit of elites from R&D units and knowledge-based companies increase, the effective stock of elites in industry declines. This, in turn, reduces innovation and decreases industrial value added. Lower value added reduces firms' ability to create new job opportunities

DOI: 10.22067/jstinp.2026.96998.1194

and expand absorption capacity, thereby intensifying unemployment and migration. Thus, expanding higher education and even increasing the number of elites without simultaneously improving absorption capacity and institutional conditions can lead to undesirable behaviours such as the accumulation of unemployment and widespread elite migration.

3.2.5. Dynamic Hypothesis 5: Trust, bureaucracy, and elite return

This hypothesis focuses on ‘soft’ institutional variables such as trust, administrative bureaucracy, and regulatory stability. It is assumed that:

- Elites’ experience of the real implementation of support policies (not merely their announcement),
- The ease or difficulty of administrative procedures for receiving support, establishing knowledge-based companies, and executing R&D projects,
- The stability of regulations and policies related to elites and knowledge-based companies,

These factors jointly shape the level of elites’ trust in the sustainability of support policies.
The higher the regulatory stability and quality of policy implementation and the lower the intensity of administrative bureaucracy, the higher the level of elite trust. Higher trust affects behaviour through two channels:

- Reduced tendency to exit the industrial pathway and reduced elite migration.
- Increased tendency of emigrant elites to return and participate in the country’s industrial production system.

An increase in returning elites and a reduction in exits raise the number of elites in universities, industrial R&D units, and knowledge-based companies. Through the previous hypotheses (innovation, value added, and company development), industrial performance improves. Improved performance reinforces perceptions of policy success and strengthens policy commitment, thereby forming a reinforcing loop among ‘elite trust’, ‘policy sustainability’, and ‘elite retention/return’.

3.3. Causal Loop Diagrams (CLDs)

In the model developed, based on the dynamic hypotheses, several major reinforcing and balancing loops were identified. The most important are:

Reinforcing loop R1 (Higher education and emerging industrial elites) captures the self-reinforcing interaction between higher-education expansion, industrial capability, and the growth of industrial R&D talent.

 DOI: 10.22067/jstinp.2026.96998.1194

Reinforcing loop R2 (Innovation, industrial R&D, and industrial value added): More elite employment in R&D → higher innovation and productivity → higher industrial value added → greater financial resources for R&D → higher R&D expenditure and project execution → further recruitment of elites into R&D.

Reinforcing loop R4 (Industrial knowledge-based companies): More knowledge-based companies → more elite jobs and more knowledge-based output → stronger perceived policy success and greater support (facilities, tax exemptions, budgets) → stronger innovation capability and entrepreneurship → more knowledge-based companies.

Balancing loop B1 (Exit of knowledge-based companies): High bureaucracy and low regulatory stability → higher exit/inactivation of companies → slower growth of knowledge-based firms and weaker absorption of elites → reduced knowledge-based output.

Reinforcing loop R6 (Return of elites): Better return policies and domestic opportunities → higher return of emigrant elites → higher domestic elite stock in R&D and firms → better innovation performance and value added → stronger trust and credibility → further return and retention.

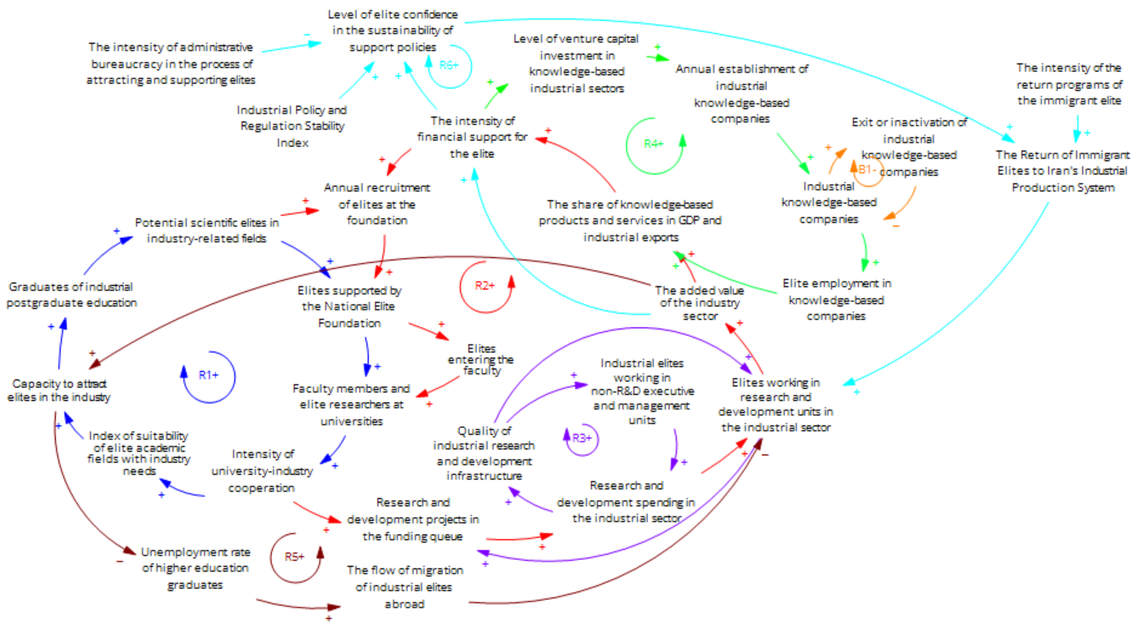

Figure 2. CLD of the industrial elite system of Iran.

3.4. Stock and Flow Diagrams (SFDs)

Based on the above loops, stock and flow diagrams were designed for the main subsystems of the model and are shown in Figure 3. Key stocks in the model include:

- Elites supported by the National Elite Foundation;

- Elites employed in industrial R&D units;
- Industrial elites employed in executive and managerial units;
- Industrial knowledge-based companies;
- Emigrant elites related to industry.

Related flows include the annual entry of elites into R&D, the exit of elites from R&D, the transfer of elites to industrial management, retirement or exit from management, the migration of industrial elites, the return of emigrant elites, the annual establishment of knowledge-based companies, and the exit/inactivation of companies.

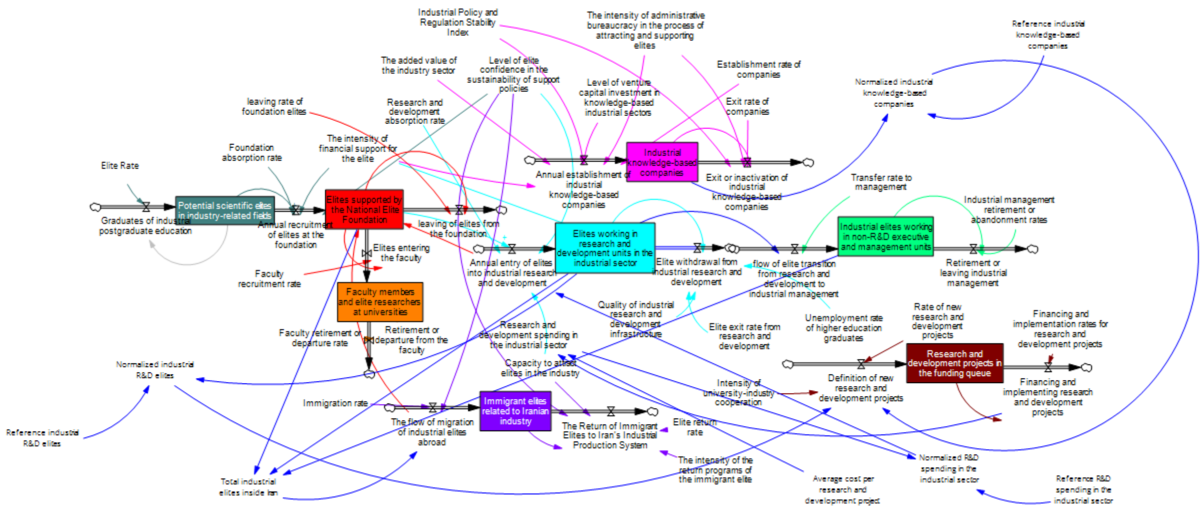

Figure 3. SFD of attracting and leveraging industrial elites in Iran's industrial production system.

3.5. Model formulation (simulation equations)

In this section, the stock and flow structure is briefly and representatively translated into implementable equations in Vensim (Table1).

Table 1. Complete list of model variables and equations as implemented in the model

Variable Name	Type	Unit	Equation / Definition
Research and development projects in the funding queue data	Data (lookup)	project	([(1391,0)-(1400,185565)],(1391,83727), (1392,84678), (1393,96589), (1394,108500), (1395,114881), (1396,122482), (1397,131405), (1398,125097), (1399,140928), (1400,185565))
Elites working in research and development units in the industrial sector data	Data (lookup)	person	([(1391,0)-(1400,283139)],(1391,137312), (1392,144893), (1393,152474), (1394,202562), (1395,210143), (1396,225658), (1397,247597), (1398,254796), (1399,280663), (1400,283139))
Annual entry of elites into industrial research and development	Flow	person/Yea r	Capacity to attract elites in the industry *Elites supported by the National Elite Foundation*Level of elite confidence in the sustainability of support policies *Research and

Variable Name	Type	Unit	Equation / Definition
			development absorption rate*Research and development spending in the industrial sector
Elite withdrawal from industrial research and development	Flow	person/Year	Elite exit rate from research and development *Elites working in research and development units in the industrial sector *Quality of industrial research and development infrastructure*Unemployment rate of higher education graduates *The intensity of financial support for the elite
Research and development spending in the industrial sector	Parameter (constant)	Dmnl	Baseline value: 64.2605; dimensionless spending index; rescaled from official industrial R&D expenditure statistics for 2012–2021 and calibrated; used as a multiplier to preserve dimensional consistency.
Unemployment rate of higher education graduates	Parameter (constant)	Dmnl	Baseline value: 0.01; fraction (equals 1%); unemployment pressure for the targeted graduate/elite group; can be implemented as a time-series lookup when annual data are available.
"Industrial knowledge-based companies (data)"	Data (lookup)	Firm	([(1391,0)-(1400,4307)],(1391,0), (1392,0), (1393,1200), (1394,2200), (1395,2400), (1396,2400), (1397,2400), (1398,2600), (1399,3000), (1400,4307))
leaving of elites from the foundation	Flow	person/Year	leaving rate of foundation elites*Elites supported by the National Elite Foundation
Elites supported by the National Elite Foundation	Stock	person	INTEG(Annual recruitment of elites at the foundation -Annual entry of elites into industrial research and development-Elites entering the faculty -leaving of elites from the foundation-The flow of migration of industrial elites abroad, 54026.6)
Definition of new research and development projects	Flow	project/Year	Rate of new research and development projects *"Normalised industrial R&D elites" *"Normalised industrial knowledge-based companies"*"Intensity of university-industry cooperation"
"Normalised industrial knowledge-based companies"	Auxiliary	Dmnl	"Industrial knowledge-based companies" /"Reference industrial knowledge-based companies"
"Normalised industrial R&D elites"	Auxiliary	Dmnl	Elites working in research and development units in the industrial sector /"Reference industrial R&D elites"
The flow of migration of industrial elites abroad	Flow	person/Year	Immigration rate*Total industrial elites inside Iran *(1-Level of elite confidence in the sustainability of support policies)
Elites working in research and development units in the industrial sector	Stock	person	INTEG(Annual entry of elites into industrial research and development -Elite withdrawal from industrial research and development, 137312)
flow of elite transition from research and development to industrial management	Flow	person/Year	Elites working in research and development units in the industrial sector *Transfer rate to management
"Reference industrial R&D elites"	Parameter (constant)	person	137312

Variable Name	Type	Unit	Equation / Definition
"Industrial knowledge-based companies"	Stock	Firm	INTEG("Annual establishment of industrial knowledge-based companies" -"Exit or inactivation of industrial knowledge-based companies", 0)
"Reference industrial knowledge-based companies"	Parameter (constant)	Firm	4307
Total industrial elites inside Iran	Auxiliary	person	Elites supported by the National Elite Foundation +Elites working in research and development units in the industrial sector+"Industrial elites working in non-R&D executive and management units"
Level of elite confidence in the sustainability of support policies	Parameter (constant)	Dmnl	0.97
"Level of venture capital investment in knowledge-based industrial sectors"	Parameter (constant)	Dmnl	2.20925
Capacity to attract elites in the industry	Parameter (constant)	Dmnl	0.862877
The intensity of financial support for the elite	Parameter (constant)	Dmnl	1.4
Quality of industrial research and development infrastructure	Parameter (constant)	Dmnl	0.1
"Annual establishment of industrial knowledge-based companies"	Flow	Firm/ Year	Establishment rate of companies *Industrial Policy and Regulation Stability Index *"Level of venture capital investment in knowledge-based industrial sectors"*The added value of the industry sector *Industrial Policy and Regulation Stability Index *The intensity of administrative bureaucracy in the process of attracting and supporting elites *The intensity of financial support for the elite
Elites entering the faculty	Flow	person/Year	Elites supported by the National Elite Foundation*Faculty recruitment rate
Elite exit rate from research and development	Parameter (constant)	1/Year	0.123747
leaving rate of foundation elites	Parameter (constant)	1/Year	0.02
Elite return rate	Parameter (constant)	1/Year	0.001
Establishment rate of companies	Parameter (constant)	Firm/ Year	100
"Exit or inactivation of industrial knowledge-based companies"	Flow	Firm/ Year	Exit rate of companies *"Industrial knowledge-based companies"*The intensity of administrative bureaucracy in the process of attracting and supporting elites *Industrial Policy and Regulation Stability Index
Exit rate of companies	Parameter (constant)	1/Year	0.0469627
Faculty members and elite researchers at universities	Stock	person	INTEG(Elites entering the faculty - Retirement or departure from the faculty, 100)

Variable Name	Type	Unit	Equation / Definition
Retirement or leaving industrial management	Flow	person/Year	"Industrial elites working in non-R&D executive and management units" *Industrial management retirement or abandonment rates
Faculty retirement or departure rate	Parameter (constant)	1/Year	0.5
Financing and implementation rates for research and development projects	Parameter (constant)	1/Year	Baseline value: 0.00218956 1/year; first-order throughput rate (fraction of funding-queue projects financed and implemented per year); estimated via calibration to reproduce the historical funding-queue behaviour.
Financing and implementing research and development projects	Flow	project/Year	Financing and implementation rates for research and development projects *Research and development projects in the funding queue
The intensity of the return programmes of the immigrant elite	Parameter (constant)	Dmnl	0.01
Immigrant elites related to Iranian industry	Stock	person	INTEG(The flow of migration of industrial elites abroad - The Return of Immigrant Elites to Iran's Industrial Production System, 60000)
Immigration rate	Parameter (constant)	1/Year	0.176571
"Industrial elites working in non-R&D executive and management units"	Stock	person	INTEG(flow of elite transition from research and development to industrial management -Retirement or leaving industrial management, 100)
Industrial management retirement or abandonment rates	Parameter (constant)	1/Year	0.2
Industrial Policy and Regulation Stability Index	Parameter (constant)	Dmnl	1.1902
"Intensity of university-industry cooperation"	Parameter (constant)	Dmnl	1
Rate of new research and development projects	Parameter (constant)	project/Year	Baseline value: 15808.8 project/year; national-level annual rate of new industrial R&D project definition; consistent with the observed project-series scale and calibrated within plausible bounds.
Research and development absorption rate	Parameter (constant)	1/Year	0.0121775
Research and development projects in the funding queue	Stock	project	INTEG(Definition of new research and development projects -Financing and implementing research and development projects, 83827)
The intensity of administrative bureaucracy in the process of attracting and supporting elites	Parameter (constant)	Dmnl	1.24362
Retirement or departure from the faculty	Flow	person/Year	Faculty retirement or departure rate*Faculty members and elite researchers at universities

Variable Name	Type	Unit	Equation / Definition
The added value of the industry sector	Parameter (INITIAL)	Dmnl	INITIAL(1)
The Return of Immigrant Elites to Iran's Industrial Production System	Flow	person/Year	Elite return rate *Capacity to attract elites in the industry*Immigrant elites related to Iranian industry *Level of elite confidence in the sustainability of support policies*The intensity of the return programmes of the immigrant elite
Transfer rate to management	Parameter (constant)	1/Year	0.032862
Faculty recruitment rate	Parameter (constant)	1/Year	0.02
Foundation absorption rate	Parameter (constant)	1/Year	0.95
Elite Rate	Parameter (constant)	1/Year	4.05632
"Potential scientific elites in industry-related fields data"	Auxiliary/Parameter	person	([(1391,0)-(1400,6350)],(1391,4193), (1392,3430), (1393,4408), (1394,5240), (1395,6350), (1396,5920), (1397,5500), (1398,5060), (1399,4640), (1400,4200))
"Potential scientific elites in industry-related fields"	Stock	person	INTEG(Graduates of industrial postgraduate education - Annual recruitment of elites at the foundation, 3956.14)
Annual recruitment of elites at the foundation	Flow	person/Year	Level of elite confidence in the sustainability of support policies * The intensity of financial support for the elite* "Potential scientific elites in industry-related fields"* Foundation absorption rate
Graduates of industrial postgraduate education	Flow	person/Year	WITH LOOKUP(Time, ([(1391,0)-(1400,9100)],(1391,4646.39),(1392,5403.04),(1393,6518.76),(1394,7870.12),(1395,7762.13),(1396 ,7217.39),(1397,6655.55),(1398,6107.91),(1399,5546.06),(1400,5418.42)))

Note to Table 1: Several institutional and policy drivers are implemented as dimensionless indices (Dmnl) after rescaling official national statistics to comparable magnitudes. Baseline values reported here correspond to the calibrated model used for the historical validation window (2012–2021). Parameters are interpreted as fractions (0–1), first-order rates (1/year), or aggregate flows (units/year) as indicated in the Unit column.

4. Results

4.1. Model testing and validation

4.1.1. Boundary adequacy and dimensional consistency

In the first step of structural validation, the boundary adequacy test asks: which variables must be included to explain the selected reference behaviours and which variables can reasonably remain outside the model boundary. According to Sterman's guidelines, the boundary should neither be so narrow that important structural drivers are excluded nor so broad that the model becomes unnecessarily complex and difficult to calibrate. In this study, boundary adequacy was assessed by examining whether the key feedback structures and drivers required for explaining the reference behaviours were included within the model.

Concretely, the model boundary includes: higher education and postgraduate graduates in industrial fields; the elite identification and absorption mechanism of the National Elite Foundation; elite employment in industrial R&D; establishment and exit of industrial knowledge-based companies; industrial value added; unemployment and absorption capacity; migration and return of elites; and institutional variables such as bureaucracy, regulatory stability, and elite trust. Variables such as international oil prices or broad political events were treated as exogenous shocks and were not modelled endogenously, because the focus of this paper is the endogenous elite–innovation–industry feedback structure.

Dimensional consistency was checked using the Units Check tool in Vensim to ensure that all equations are dimensionally coherent. Appropriate units were defined (e.g., persons for stock variables, persons/year for flow variables, and dimensionless indices for normalised constructs). Where inconsistencies were detected, equations and parameters were corrected until the software confirmed dimensional consistency (Units are OK), as shown in Figure 4.

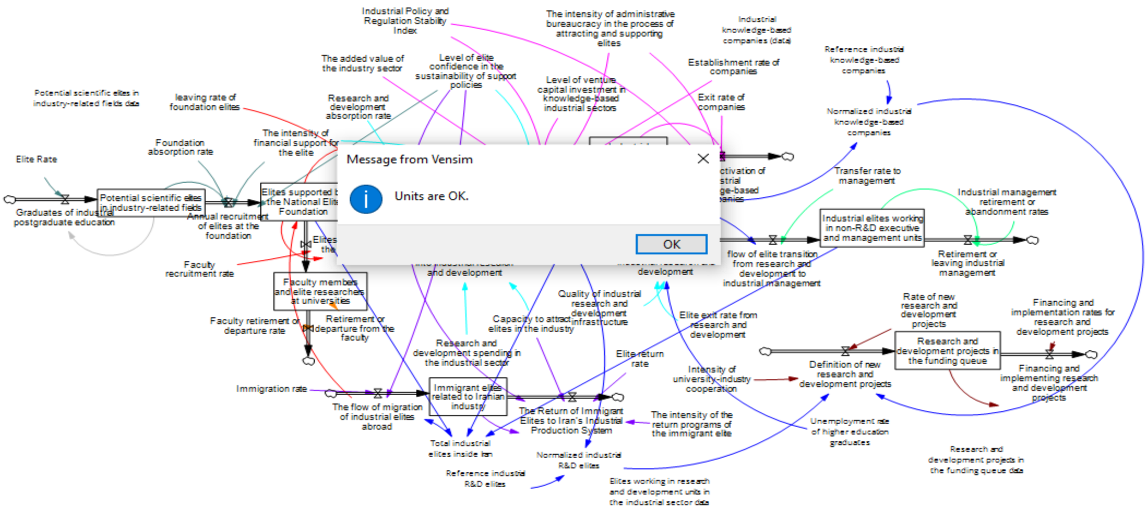

Figure 4. Dimensional-consistency test (Units Check) in Vensim: Units are OK.

4.1.2. Parameter verification

Parameter verification, following Sterman's validation checklist, examines whether each equation and each parameter value is conceptually meaningful and consistent with the modelled real-world relationships. For instance, a formulation that would increase elite trust when regulatory stability decreases would be conceptually inconsistent and should be revised. In this model, equations were specified to reflect the intended causal logic (e.g., migration increases with unemployment and decreases with trust; return increases with trust and domestic opportunities; and company exits increase with bureaucracy and instability).

After specifying the full set of equations and parameter values in Vensim, the Model Check command was executed. The output reported ‘Model is OK’ for the whole model, indicating that no equation errors were detected. Figure 5 shows the Model Check output window.

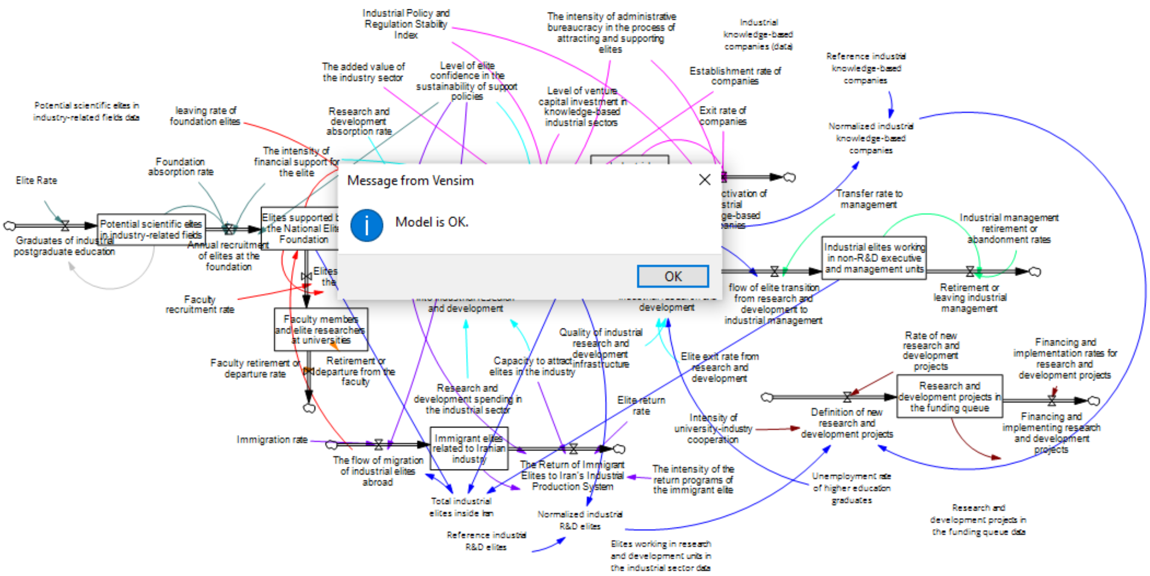

Figure 5. Model Check in Vensim: Model is OK.

4.1.3. Historical behaviour reproduction

For behavioural validation, model outputs over the historical period 2012–2021 (1391–1400) were compared with observed data for three key variables:

1) The number of industrial knowledge-based companies (Figure 6).

2) The number of industrial R&D projects awaiting financing (Figure 7).

3) The number of elites employed in industrial R&D units (Figure 8).

Interpretation of residual diagnostics: In panel (b), the residual series r(t) is defined as r(t)=Obs(t)-Sim(t) for each year. The horizontal line at r(t)=0 is a zero-reference line indicating exact agreement between observation and simulation. Positive residuals indicate underestimation by the model (Obs>Sim), whereas negative residuals indicate overestimation

(Obs<Sim). Panel (c) reports the autocorrelation function (ACF) of r(t) to assess whether any systematic temporal structure remains in the residuals.

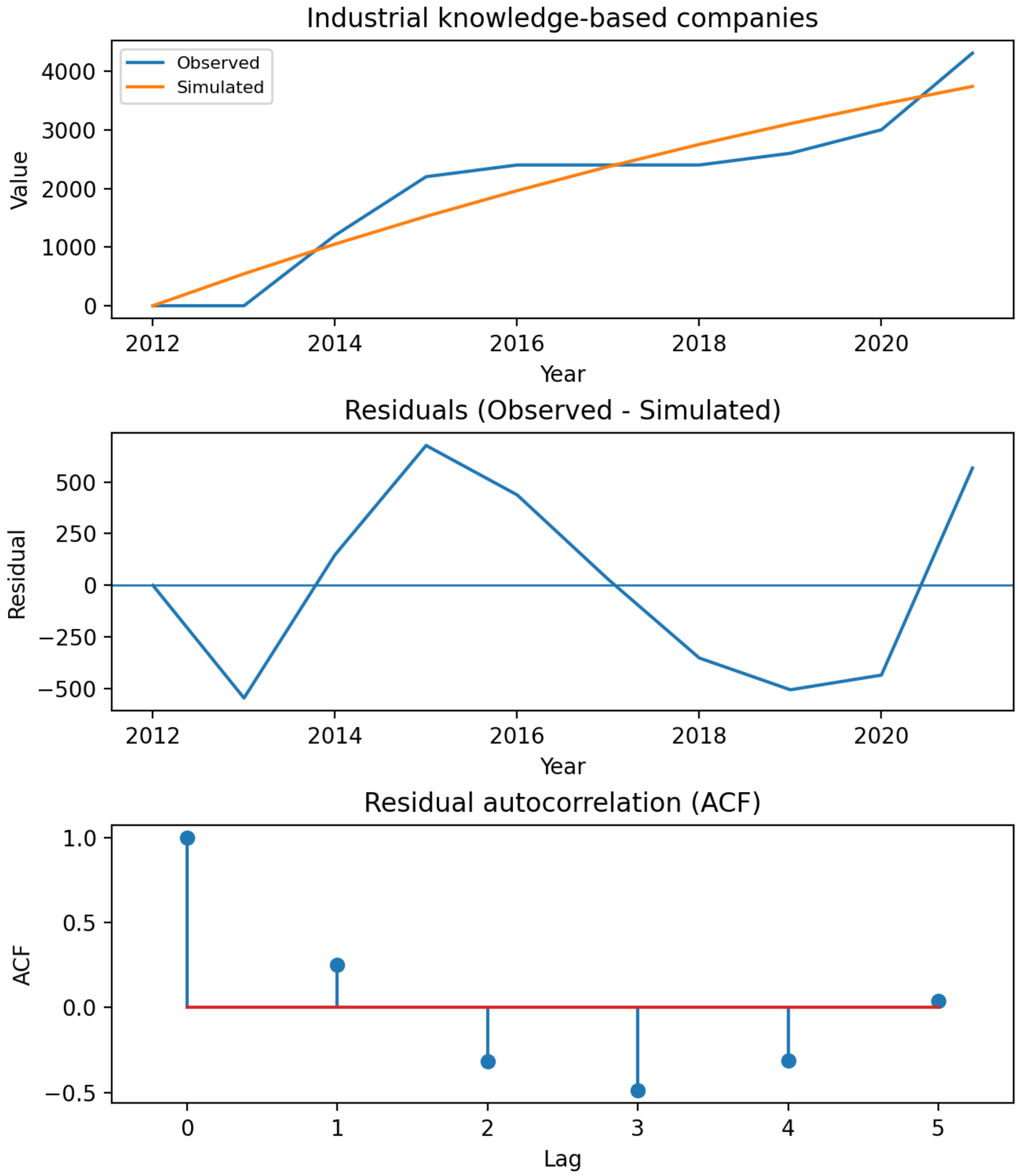

Figure 6. Historical reproduction and residual diagnostics for industrial knowledge-based companies: (a) simulation vs observation, (b) residuals (Obs–Sim), and (c) residual autocorrelation function (ACF).

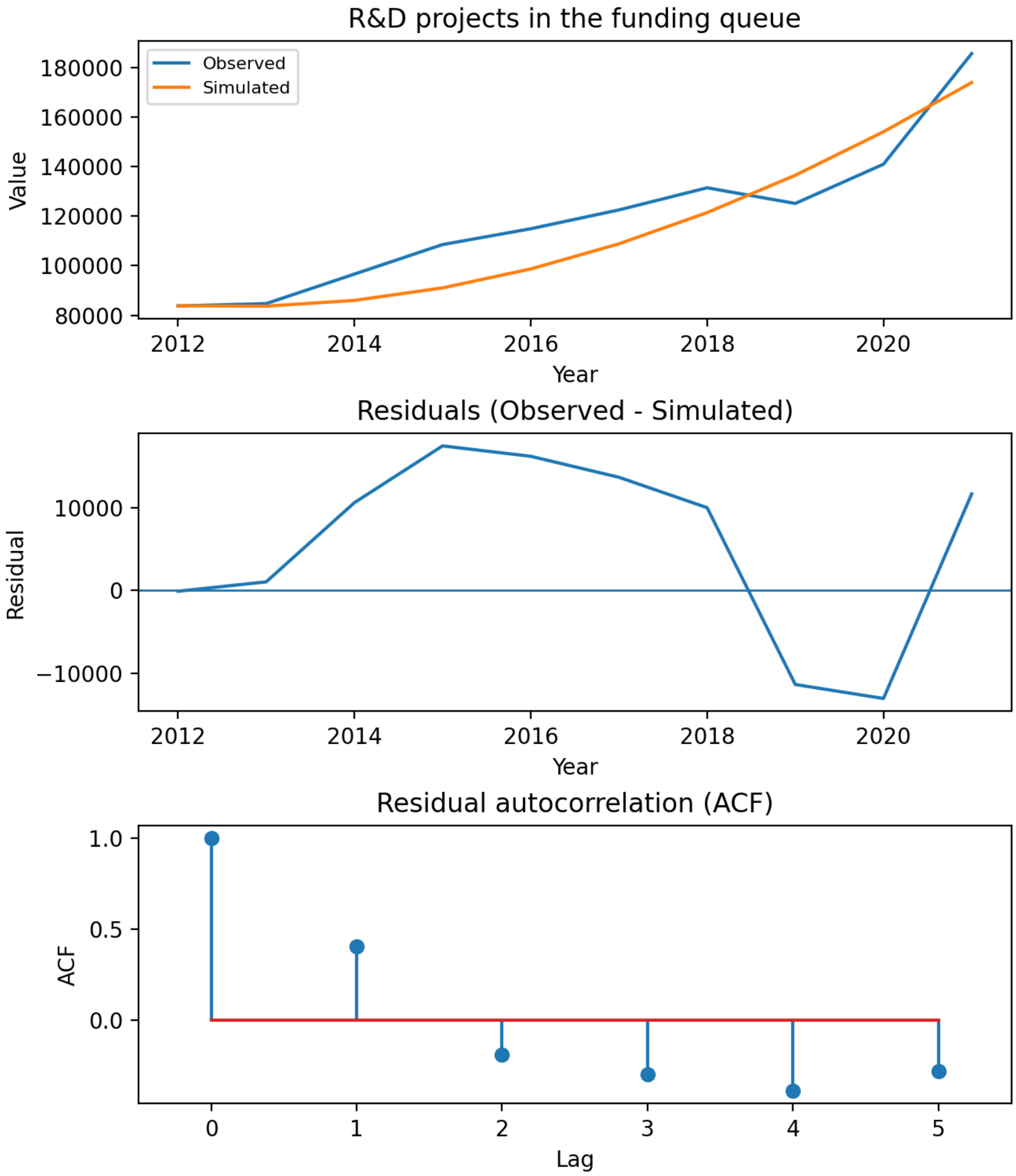

Figure 7. Historical reproduction and residual diagnostics for R&D projects awaiting financing: (a) simulation vs observation, (b) residuals (Obs–Sim), and (c) residual autocorrelation function (ACF).

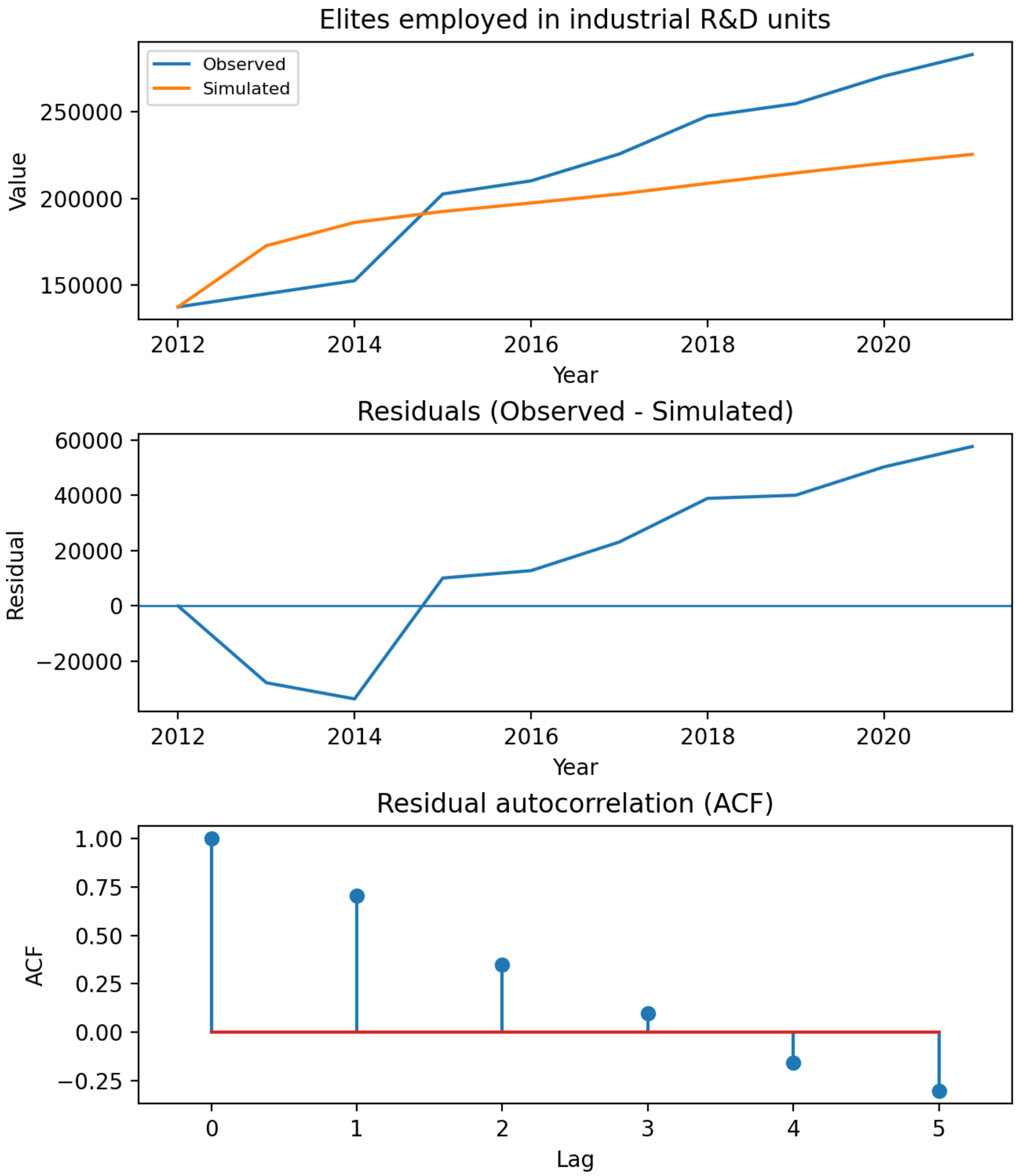

Figure 8. Historical reproduction and residual diagnostics for elites employed in industrial R&D units: (a) simulation vs observation, (b) residuals (Obs–Sim), and (c) residual autocorrelation function (ACF).

The results show that the designed model is able to reproduce the overall trends and the main turning points of these variables with acceptable accuracy. Although minor deviations exist for some years, the differences remain within acceptable bounds given data limitations and exogenous shocks; importantly, the model's simulated behaviour is consistent with the observed reference modes.

4.1.4. Quantitative fit indices and out-of-sample validation

In addition to the historical reproduction shown in Figures 6–8, the model's ability to reproduce history was assessed using quantitative fit indices (R^2 as squared correlation, RMSE, and MAPE) and residual diagnostics. Residual time-series plots and the residual autocorrelation function (ACF) are included in Figures 6–8, and the lag-1 residual autocorrelation coefficient is reported in Table 2.

To reduce the risk of overfitting, calibration and validation were separated using a split-sample (holdout) strategy: uncertain parameters were calibrated on the first part of the historical window (2012–2018), and the model was then simulated for the remaining years (2019–2021) without further parameter adjustment. The resulting out-of-sample fit indices are reported alongside the calibration fit.

Table 2. Quantitative fit statistics for the main reference-mode variables

Variable	**Calibration R^2 (squared corr., 2012–2018)**	**Calibration RMSE**	**Calibration MAPE (%)**	**Test R^2 (squared corr., 2019–2021)**	**Test RMSE**	**Test MAPE (%)**	**Residual ACF(1) (2012–2021)**
Industrial knowledge-based companies	0.859	312.4	15.4	0.902	504.8	15.7	0.281
Elites employed in industrial R&D units	0.722	20904.5	11.2	0.998	49878.7	18.2	0.816
R&D projects awaiting financing	0.883	9877.2	8.8	0.947	12065.4	8.2	0.421

Note: R^2 is reported as the squared correlation between observed and simulated series. Residual ACF(1) is the lag-1 autocorrelation coefficient of the residual series (Obs-Sim) over 2012–2021.

While the model reproduces the historical trends of the main reference-mode variables with acceptable accuracy, residual diagnostics suggest that some temporal structure remains, particularly for "Elites employed in industrial R&D units" (residual ACF(1) = 0.816). Given the annual frequency of the available time series and the likelihood of unmodelled exogenous shocks and policy discontinuities over 2012–2021, a degree of residual autocorrelation is not unexpected in a policy-oriented system dynamics model. Importantly, residuals remain bounded and do not indicate instability or implausible dynamics, and the complementary scale-sensitive measures (RMSE and MAPE) remain within acceptable ranges for the intended explanatory and policy-laboratory use of the model.

It should also be noted that the holdout period includes only three annual observations (2019–2021). Therefore, correlation-based indices such as R^2 (reported here as squared correlation) can be sensitive in short samples and should be interpreted with caution. For this reason, RMSE and MAPE are reported alongside R^2 to provide complementary evidence of out-of-sample performance.

4.1.5. Extreme-condition tests

Extreme-condition testing emphasised in classic system dynamics texts such as Forrester (1961) and Sterman (2000) examines whether the model behaves logically under very large or very small values of selected parameters and variables. A valid model should not produce implausible outcomes such as negative populations, unjustified unbounded explosions, or severe, unrealistic oscillations.

In the first scenario, it is assumed that the intensity of financial support for elites and the level of industrial venture capital are set near their maximum normalised values. Under this assumption, stronger support and venture capital are expected to lead to a significant increase in the establishment and growth of industrial knowledge-based companies. Figure 9 presents the results: compared to the baseline, the number of industrial knowledge-based companies grows more rapidly and reaches a higher level by the end of the horizon, while the model remains stable and interpretable.

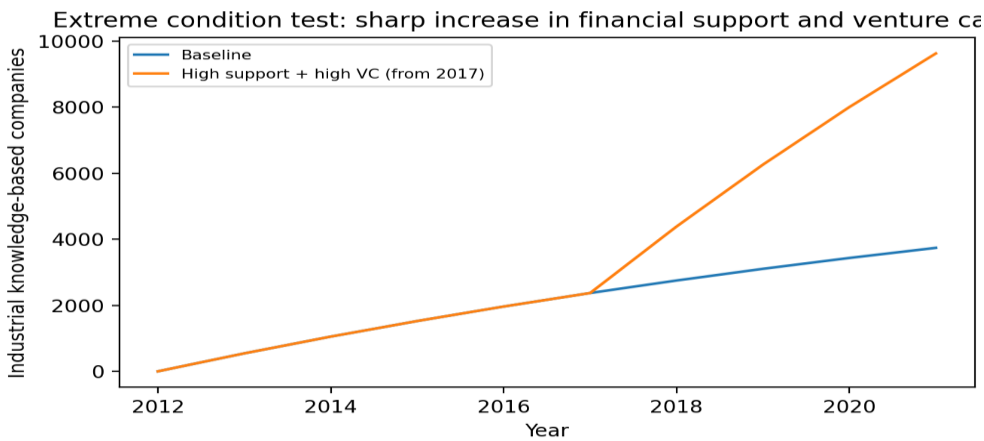

Figure 9. Extreme condition test under maximum financial support

DOI: 10.22067/jstinp.2026.96998.1194

In the second scenario, with a sharp increase in administrative bureaucracy and a sharp decrease in regulatory stability, it is expected that elite trust will decline and that exits/inactivation of knowledge-based companies will increase. Figure 10 confirms this expected behaviour. Additional extreme scenarios were also examined; in all cases, results were consistent with theoretical logic, and no unrealistic behaviours were observed.

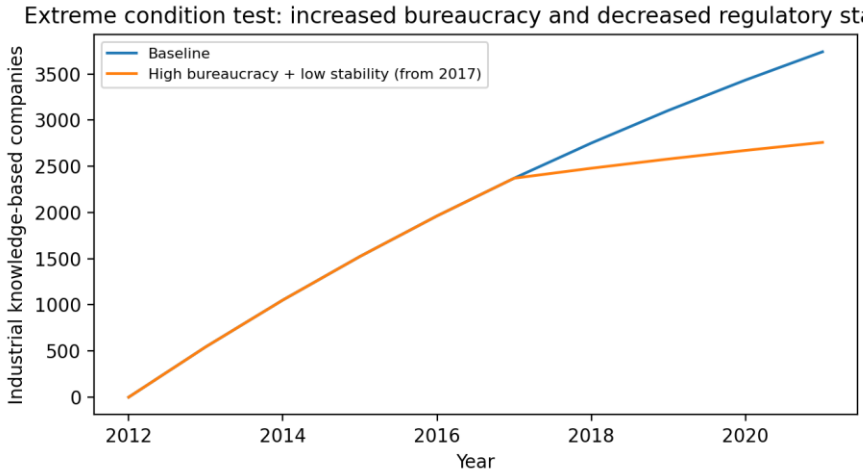

Figure 10. Extreme condition test under severe institutional barriers

4.1.6. Sensitivity analysis

Sensitivity analysis assesses the robustness of model behaviour under parameter uncertainty. We report a multi-parameter (Monte Carlo) sensitivity analysis to account for simultaneous uncertainty across uncertain rates and institutional multipliers.

In the Monte Carlo sensitivity analysis, key uncertain parameters were perturbed simultaneously within pre-specified plausible bounds around their calibrated baseline values (see the parameter table), and the model was simulated repeatedly. To ensure that the uncertainty envelopes reflect the model's plausible behavioural domain, runs that produced non-physical behaviour (e.g., negative stock values) or numerically unstable trajectories were excluded from aggregation. Accordingly, the reported 5th–95th percentile bands should be interpreted as conditional on the stated uncertainty bounds and the plausibility-screening criteria, rather than as unconditional prediction intervals. A total of 203 runs were accepted and used to construct uncertainty bands (5th–95th percentiles) for the main reference behaviours. Figures 11–12 report the resulting uncertainty envelopes.

 DOI: 10.22067/jstinp.2026.96998.1194

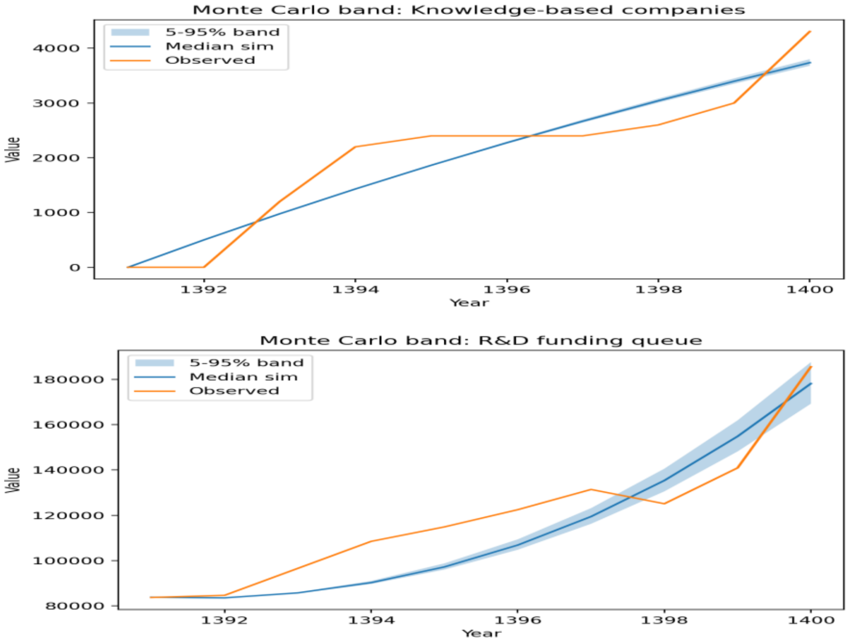

Figure 11. Monte Carlo uncertainty bands for firms and R&D queue

Overall, the Monte Carlo results indicate that the qualitative patterns of the key outputs are robust under simultaneous parameter uncertainty. Across accepted runs, the mean squared correlation (R^2) over 2012–2021 remained high for industrial knowledge-based companies (mean 0.877; 5–95%: 0.876–0.877) and the R&D funding queue (mean 0.808; 5–95%: 0.788–0.818), while elites employed in industrial R&D units showed moderate variability (mean 0.684; 5–95%: 0.604–0.770).

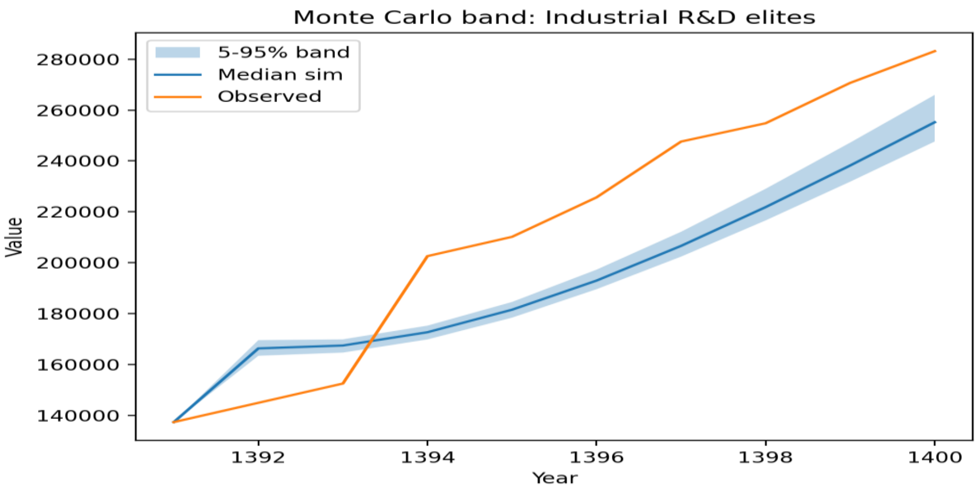

Figure 12. Monte Carlo uncertainty bands for employed R&D elites

4.2. Policy experiment set-up (brief)

After validation, the model is used as a policy laboratory by adjusting a small set of policy levers that map directly to the main feedback structures (e.g., intensity of financial support for elites, administrative bureaucracy, industrial policy and regulation stability, venture capital investment in knowledge-based industrial sectors, migration pressure, and the intensity of return programmes). Policy packages are formulated as coherent scenarios and simulated to the horizon year 1420 (2041) to compare trade-offs across outcomes such as elite retention, industrial R&D employment, and the growth of industrial knowledge-based companies. Detailed scenario design and results are reported in the author's doctoral dissertation and a companion policy-scenarios manuscript; the present paper focuses on model design and validation.

Overall, the purpose of the sensitivity analysis is not point forecasting but rather to demonstrate that the model's qualitative patterns and policy-relevant conclusions remain robust under simultaneous parameter uncertainty, which is the standard expectation for system dynamics models used as policy laboratories.

5. Discussion and Conclusion

This paper presented and validated the system dynamics model developed for Iran's industrial elite system. By covering the subsystems of industrial higher education, elite identification and support mechanisms, industrial R&D, industrial knowledge-based companies, and elite migration and return, the model provides a feedback-based explanation for the observed behaviours of the industrial elite system.

Structural and behavioural validation tests showed that the model has acceptable validity and can be used as a policy laboratory. Accordingly, future studies can apply policy scenarios such as strengthening industrial absorption capacity, increasing industrial R&D expenditure, improving return programmes for emigrant elites, reducing administrative bureaucracy, increasing regulatory stability, and improving elites' trust in the sustainability of support policies, and then examine the effects of these policies up to the horizon year 1420.

In subsequent research, the model should be calibrated for specific priority industries such as automotive, oil and gas, ICT, and pharmaceuticals, and differences in behaviour across industries should be analysed. In addition, combining system dynamics with other approaches such as agent-based modelling can enable the simultaneous analysis of micro-level elite decisions (staying, emigrating, returning, entrepreneurship) alongside macro-level feedback dynamics.

Overall, the model developed provides policymakers with a scientific and analytical infrastructure to move beyond short-term, fragmented decisions and to evaluate, in advance, the long-term and feedback-rich impacts of elite and industrial policies, thereby reducing unintended consequences.

5.1. Policy implications and managerial insights

To make the model actionable as a decision-support tool, policy experiments can be formulated as coherent packages of interventions that target the main leverage points identified in the feedback structure. Following the dissertation-based scenario design, four policy scenarios can be evaluated over a long-term horizon (e.g., up to 2041/1420): (1) continuation of current conditions (baseline), (2) reducing the intensity of industrial-elite migration, (3) strengthening financial and institutional support for industrial R&D, and (4) a combined scenario that simultaneously reduces migration and strengthens industrial R&D support. The simulation logic suggests that increasing industrial R&D support yields the largest increase in elites employed in industrial R&D units and the domestic stock of industrial elites, while the combined scenario preserves most of these gains and provides the strongest reduction in the stock of emigrant industrial elites, indicating that coordinated policy mixes outperform isolated actions.

5.1.1. Recommended policy levers suggested by the model

- Increase the absorption capacity of industry for elite talent by expanding well-funded R&D positions and creating clear innovation career paths in firms.
- Stabilise and make credible multi-year industrial R&D funding and incentive schemes to reduce policy uncertainty and strengthen elite trust.
- Reduce administrative and regulatory barriers that delay project execution, hiring, and firm creation, thereby shortening harmful time delays in the system.
- Strengthen university–industry interfaces (joint labs, industrial PhD tracks, shared infrastructure) to convert postgraduate training into industrial problem solving.
- Target support towards industrial knowledge-based companies and scale-up mechanisms (finance, procurement, market access) so that elite-driven innovation translates into output and value added.
- Complement ‘return’ programmes with diaspora networking and remote collaboration channels to move from one-off repatriation to sustainable elite circulation.

- Use scenario-based monitoring (stocks and flows) rather than single-point indicators (e.g., number of graduates) to evaluate policy success over time.

A follow-up paper derived from the author's doctoral dissertation presents the policy packages in full, together with their corresponding scenario diagrams.

5.1.2. Managerial insights for industrial organisations

- Treat elite retention as a system problem: competitive pay matters, but so do meaningful R&D problems, autonomy, learning opportunities, and fair promotion mechanisms.
- Build an internal 'innovation guideline' (idea selection → prototyping → scaling) so that elite knowledge is converted into measurable industrial results.
- Invest in cross-functional teamwork and systems-thinking routines to reduce coordination failures between R&D, production, and commercialisation.
- Allocate protected time and resources for R&D staff to publish, patent, and collaborate with universities; this increases professional identity and reduces migration pressure.• Institutionalise knowledge management so that elite-driven learning is retained inside the firm even when turnover occurs.

6. Limitations and Future Research

This model is subject to four main limitations already reflected in the validation results. First, calibration relies on annual, national-level data for 2012–2021, and the holdout period contains only three observations. Second, residual autocorrelation remains comparatively high for elites employed in industrial R&D units, indicating that some temporal structure and exogenous policy shocks are not fully represented. Third, broad external drivers, such as international commodity-price shocks and major political events, are treated as exogenous rather than modelled endogenously. Fourth, the present model is aggregate and does not represent behavioural heterogeneity across industries or individual elites. Future research should therefore extend the time series, calibrate the model for priority industries, incorporate explicit exogenous-shock scenarios, and combine system dynamics with agent-based modelling to examine micro-level decisions alongside macro-level feedbacks.

7. Data and Model Availability

Independent verification and reproducibility of system dynamics results require access to the full set of equations, parameter values, and empirical inputs. To support transparency, this manuscript reports (i) a complete list of model variables and equations (Table 1), and (ii) the historical reference-mode time series used for calibration/validation (Table 3).

Table 3. Historical time-series data used for reference behaviours (2012–2021 / 1391–1400).

Solar Hijri year	Gregorian year	Industrial knowledge-based companies	Elites employed in industrial R&D units	R&D projects in workshops with R&D activities
1391	2012	0	137312	83827
1392	2013	0	144893	84678
1393	2014	1200	152474	96589
1394	2015	2200	202562	108500
1395	2016	2400	210143	114881
1396	2017	2400	225658	122482
1397	2018	2400	247597	131405
1398	2019	2600	254796	125097
1399	2020	3000	280663	140928
1400	2021	4307	283139	185565

Source: Compiled from official statistics used in the study (e.g., Statistical Center of Iran and related national reports). These series are the reference modes for the historical behaviour reproduction tests reported in Figures 6–8.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

References

Amsden, A. H., DiCaprio, A. and Robinson, J. A. eds., 2012. *The role of elites in economic development*. Oxford: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199659036.001.0001.

Barlas, Y., 1996. Formal aspects of model validity and validation in system dynamics, *System Dynamics Review*, *12*(3), pp. 183–210. https://doi.org/10.1002/(SICI)1099-1727(199623)12:3<183::AID-SDR103>3.0.CO;2-4.

Forrester, J. W., 1961. *Industrial dynamics*. Cambridge, MA: MIT Press.

Freeman, C., 1987. *Technology policy and economic performance: Lessons from Japan*. London: Pinter.

Lundvall, B.-Å., 1992. *National systems of innovation: Towards a theory of innovation and interactive learning*. London: Pinter.

Mills, C. W., 1956. *The power elite*. Oxford: Oxford University Press.

Moghimi, M. and Memarzadeh Tehran, G., 2021. Higher education processes and elite selection and the issue of migration: Exploring the elite crisis and the role of higher education in Iran, *Educational Policy Quarterly*, *13*(4), pp. 23–41. [In Persian].

Moghimi, S. M., 2018. 'Investigating the impact of talent management in employing and attracting elites and its effects on reducing elite migration in Iran', *Business Management (Innovative Business Management)*, 10(39). [In Persian].

Naqi Pourfar, A., 2013. 'Explaining an Islamic meritocracy model to address meritocracy challenges in Iran's public organisations', *Journal of Public Administration*, 5(3), pp. 53–80. [In Persian].

Nelson, R. R., 1993. *National innovation systems: A comparative analysis*. New York: Oxford University Press.

Pareto, V., 1968. *The rise and fall of elites: An application of theoretical sociology*. Bedminster Press.

Safaie, N., Chakmehchi Khiavi, F. and Shahsavar, M. S., 2023. 'Examining the emigration of elites from Iran: A system dynamics approach', *Journal of Systems Thinking in Practice*, 2(4), pp. 17–32. https://doi.org/10.22067/jstinp.2023.85830.1083.

Shahabadi, A., Salehi, M. and Hosseinidoust, S. E., 2020. 'The impact of competitiveness on brain drain: GMM panel approach', *Journal of the Knowledge Economy*, 11, pp. 558–573. https://doi.org/10.1007/s13132-018-0556-7.

Statistical Center of Iran, 2022. *Industrial workshops with R&D activities: Annual statistics (2012–2021)*. Tehran: Statistical Center of Iran.

Sterman, J. D., 2000. *Business dynamics: Systems thinking and modeling for a complex world*. New York, NY: McGraw-Hill.