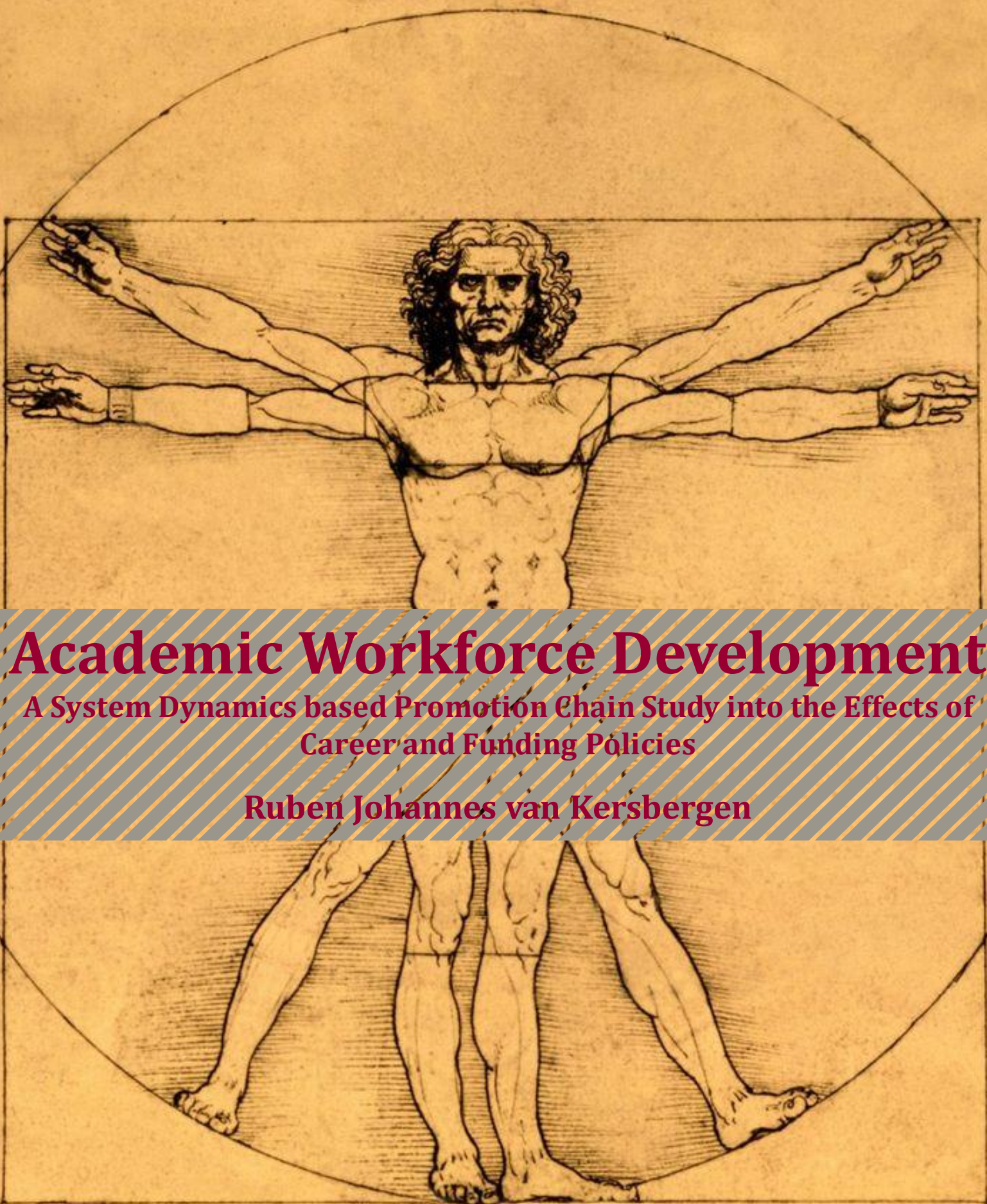




Academic Workforce Development

A System Dynamics based Promotion Chain Study into the Effects of
Career and Funding Policies

Ruben Johannes van Kersbergen

Academic Workforce Development

*A System Dynamics based Promotion Chain Study into
the Effects of Career and Funding Policies*

Delft University of Technology
Faculty Technology, Policy and Management
Master Systems Engineering, Policy Analysis and Management
SEPAM M.Sc. Thesis Project

Chairman Graduation Committee:	Prof.dr. J.A. de Bruijn
First Supervisor TU Delft:	Dr. ir. C. van Daalen
Second Supervisor TU Delft:	Dr. M.L.P. Groenleer
First Supervisor Rathenau Institute:	Dr.ir. C. Chiong Meza
Second Supervisor Rathenau Institute:	Dr. E. Horlings

Author:	R.J. van Kersbergen
Student number:	1541013
E-mail:	r.j.vankersbergen@gmail.com
Publication date:	07-12-2015

EXECUTIVE SUMMARY

A healthy science system is important for continued economic growth. In the Netherlands, the government supports the science system by implementing policies, in the hope of developing a robust academic workforce. In recent years, under the influence of these policies, the science system has changed. Noteworthy is the change from a direct institutional based support system to an indirect competitive based support system. Simultaneously, public research organisations started to rely on a temporary science workforce to deal with growing financial uncertainties. However, as these changes are manifold and complex, it is difficult for policy makers to determine the consequences it can have on the science system. Because knowledge about these impacts is essential, research is needed to understand and explore the behaviour of enacted policies over time.

This research addresses this problem in two ways. First, the science system will be analysed by identifying key concepts, the current issues and the policies that are in place. In this process, the Principal-Agent Problem is used to explain why regulation does not always have the right impact. The research focuses on how the government can regulate the workforce in an environment where perceptions differ and objectives are not aligned. Based on the notion of policy-making in complex environments, three funding regimes are identified that can induce the right incentives: direct institutional funding, indirect performance based funding and indirect performance agreements.

Second, the System Dynamics method is adopted and a model is created that explores the academic workforce development in the timeframe 1999-2029, based on the different funding regimes and policy measures. This will further increase the insights in the science system and create a tool in support of a policy-making process. The model has been applied to the case of the Netherlands and is successful in replicating the observed historical data and behaviour. Because a governmental top-down policy perspective is adopted, an uncertainty analysis will be conducted to test whether different system perspectives lead to different behaviour. The model is then used to conduct multiple policy experiments to analyse the effect of different policies and funding regimes on the workforce development and research output.

The following three conclusions are found. First, research found that a relationship exists between the increased focus for competitive funding and the increased focus on a temporary workforce. When it is uncertain if funds will be obtained, public research organisations are more likely to hire temporary research staff, who are flexible, interchangeable and inexpensive. Additionally, the focus on competitive funding could lead to productivity losses, as researchers spend more time on the acquisition of funds. Second, results found that contract policies for temporary researchers do not have the intended effect. Changing contract structures could lead to a different balance but does not decrease the uncertainties in contract accumulation and turnover. Third, because policy-making is difficult in light of the existing information asymmetries between the government and the professionals on the work floor, which means additional research is needed. Here the focus will be on the different perceptions of the science system, the integration efforts of bottom-up and top-down perspectives and the testing of uncertainties.

ACKNOWLEDGEMENTS

It is dreary Sunday night, late in autumn. I am trying to concentrate while the rest of the world seems to sleep. For the first time I notice that this is really the end. Life is a constant transition. I know. I have been told many times. But now. Now it is even more so. It is time to write the acknowledgement page, as the last writing endeavour before the close. A page that is feared by many. It is an educational reflection. Yet, it seems so personal. After all this time, writing profound academic English, it is time to write about oneself.

In the end of day writing a thesis is all about “committing oneself to a task that seems big and impossible”. And writing this thesis has been an impossible task at times. A lonely intellectual endeavour of the mind. Trying to remain sane in the chaos of it all. The all-nighters processing data. The realisation of wrong observations. The frustration with the conclusion page. Many times I felt so lost, stuck, without any prospect of completion. But at these times, there were always people to help me continue. This acknowledgement page is dedicated to these people.

I would like to start by thanking my first supervisor Dr.ir. van Daalen for her continuous support during the process. At times, writing this thesis was difficult. However, she always helped me with extensive feedback and helpful insights. I would also like to thank the other members of my graduation committee, Prof.dr. de Bruijn and Dr. Groenleer, with their help during the graduation process. From my faculty, I would also like to thank the academic counsellor Drs. Brand for her continuous support for my study over the years.

I would also like to thank the Rathenau Institute, for giving me the opportunity to conduct the research indoors. A special thanks goes to my internship supervisors, Dr.ir Chiong Meza and Dr. Horlings, for their help during my thesis work. I found working among these erudite people an intellectual bliss. My time at the institute gave me insights into the conducts of a science system research organisation. Thank you for this opportunity.

Finally, I would like to thank my family and friends for their continuous love and support. A special thanks goes to my uncle Wen for the opportunity to study in the Burgundy and Emma for the opportunity to study in Finland. Changing places really helped my intellectual endeavour and creativity. A lovable thanks also goes to Mum&Dad and my brother Daniël for their life-long support and dedication.

I know it has been a long time. Many have been patient. The long wait is finally over. Time to embark on a new path in life.

Ruben van Kersbergen

TABLE OF CONTENTS

EXECUTIVE SUMMARY	I
ACKNOWLEDGEMENTS	II
TABLE OF CONTENTS.....	III
LIST OF FIGURES	V
LIST OF TABLES	VII
LIST OF EQUATIONS	VII
LIST OF ABBREVIATIONS	VIII
1. INTRODUCTION	1
1.1 PROBLEM BACKGROUND	1
1.2 PROBLEM ARTICULATION.....	5
1.3 RESEARCH OBJECTIVE.....	7
1.4 RESEARCH SIGNIFICANCE	8
1.5 RESEARCH QUESTIONS	8
1.6 POINT OF DEPARTURE	9
1.7 THEORETICAL FRAMEWORK	9
1.8 CONCEPTUAL FRAMEWORK	10
1.9 RESEARCH DEMARCATION	11
1.10 RESEARCH STRUCTURE	12
2. ACADEMIC RESEARCH CAREERS	14
2.1 THE DEVELOPMENT OF ACADEMIC RESEARCH STAFF	14
2.2 MOBILITY OF ACADEMIC RESEARCH STAFF	16
2.3 EXPLORING THE ISSUES.....	17
2.4 NORMATIVE PERCEPTIONS	17
2.5 ORGANISATIONAL MODELS	18
2.6 SUMMARY	19
3. SCIENCE SYSTEM CONCEPTS.....	20
3.1 THE SCIENCE SYSTEM	20
3.2 ACTORS IN THE SCIENCE SYSTEM.....	20
3.3 POLICY INSTRUMENTS IN THE SCIENCE SYSTEM	23
3.4 PUBLIC RESEARCH FUNDING.....	24
3.5 EXPLORING THE ISSUES	27
3.6 RESEARCH OUTPUT.....	27
3.7 SUMMARY	28
4. SCIENCE SYSTEM COMPLEXITIES	29
4.1 POLICIES WITH IMPACT.....	29
4.2 THE PRINCIPAL-AGENT PROBLEM & CONTRACT THEORY	29
4.3 SETTING THE RIGHT INCENTIVES	30
4.4 POTENTIAL FUNDING REGIMES.....	33
4.5 SUMMARY	34

5. MODELLING METHOD	36
5.1 ACADEMIC RESEARCH LIMITATIONS	36
5.2 THE NEED FOR SIMULATION	37
5.3 DEFINING THE METHOD FOR THE SYSTEM UNDER STUDY	38
5.4 THE SYSTEM DYNAMICS MODELLING METHOD	39
5.5 SYSTEM DYNAMICS SCIENCE SYSTEM STUDIES	42
6. MODEL BUILDING	44
6.1 MODEL IMPLICATIONS.....	44
6.2 MODEL OVERVIEW AND MAIN CAUSAL RELATIONS	46
6.3 MODEL CONSTRUCTION	49
6.4 DEALING WITH UNCERTAINTY	58
6.5 SYSTEM DYNAMICS MODEL UNCERTAINTIES	59
7. MODEL TESTING	63
7.1 THE VERIFICATION AND VALIDATION TESTING CYCLE	63
7.2 CONDUCTING THE MODEL TESTS	64
7.3 CONCLUSION	72
8. SIMULATION RESULTS	73
8.1 BASE RUN SIMULATION.....	73
8.2 PRINCIPAL-AGENT THEORY IMPLICATIONS.....	78
8.3 POLICY EXPERIMENTS.....	79
8.4 UNCERTAINTY ANALYSIS.....	85
9. CONCLUSIONS.....	88
9.1 ADDRESSING THE RESEARCH QUESTIONS.....	88
9.2 DISCUSSION.....	92
BIBLIOGRAPHY	95
APPENDIX 1: WORKFORCE DEVELOPMENT	99
APPENDIX 2: RESEARCH PERFORMANCE.....	100
APPENDIX 3: MODEL IMPLEMENTATION	106
APPENDIX 4: MODEL FORMULATION.....	110
APPENDIX 5: PARAMETERS AND EXOGENOUS VARIABLES	115
APPENDIX 6: EXTREME VALUE TEST RESULTS	117
APPENDIX 7: SENSITIVITY ANALYSIS RESULTS	126
APPENDIX 8: MODEL CALIBRATION RESULTS.....	137
APPENDIX 9: BEHAVIOURAL PATTERN TESTS RESULTS	139
APPENDIX 10: UNCERTAINTY ANALYSIS	143

LIST OF FIGURES

FIGURE 1: ACADEMIC POSITIONS, WITHOUT HOOP AREA HEALTH, 1999-2014	2
FIGURE 2: ACADEMIC RESEARCH FUNDING, 1999-2014 (REALISATION), 2015-2019 (PROGNOSES) AND 2009-2019 (PROGNOSES TERTIARY FUNDING), BASED ON FAIR VALUE, EURO*1.000.000	3
FIGURE 3 THE MECHANISMS, STRATEGIES AND OUTCOMES OF THE PUBLIC FUNDING SYSTEM, ADAPTED FROM (OYO, WILLIAMS, & BARENDSEN, 2008).....	9
FIGURE 4: SYSTEM DIAGRAM, ADAPTED FROM (ENSERINK ET AL., 2010).....	10
FIGURE 5: THESIS OUTLINE	12
FIGURE 6: ACADEMIC STAFF AND POSITIONS	15
FIGURE 7: TEMPORARY STAFF AND PERMANENT STAFF	16
FIGURE 8: THE US AND THE DUTCH ORGANISATIONAL SYSTEM (VAN BALEN & VAN DEN BESSELAAR, 2007).....	18
FIGURE 9: ACADEMIC RESEARCH FUNDING, 1999-2014 (REALISATION), 2015-2019 (PROGNOSES) AND 2009-2019 (PROGNOSES TERTIARY FUNDING), BASED ON FAIR VALUE (2014), EURO*1.000.000	25
FIGURE 10: DIRECT FUNDING AND INDIRECT FUNDING BASED ON FAIR VALUE (2014), EXCLUDING MEDICAL FUNDING, RETRIEVED AND ANALYSED FROM CBS, EY-REPORT, RATHENAU	26
FIGURE 11: THE NEED FOR SIMULATION, ADAPTED FROM (BORSHCHEV & FILIPPOV, 2004).....	37
FIGURE 12: DAPTED FROM (BORSHCHEV & FILIPPOV, 2004): PROBLEM APPROACHES AND SIMULATION METHODS BASED ON THEIR ABSTRACTION AND THEIR SYSTEM STATE	38
FIGURE 13: EXAMPLE OF A FEEDBACK LOOP	40
FIGURE 14: EXAMPLE OF STOCK-FLOW STRUCTURE	41
FIGURE 15: STOCK FLOW STRUCTURE WITHIN A MODEL ENVIRONMENT	41
FIGURE 16: SYSTEM DYNAMICS OUTPUT DIAGRAM.....	42
FIGURE 17: RESEARCH WORKFORCE PIPELINE AND MODEL BOUNDARY. NOTE THAT THE FACTORS INFLUENCING THE PIPELINE (POLICIES & FUNDING MECHANISMS) ARE OMITTED FROM THIS VIEW.	47
FIGURE 18: MAIN FEEDBACK BEHAVIOUR IN ACADEMIC WORKFORCE DEVELOPMENT SYSTEM [LIMITS TO GROWTH ARCHETYPE]	47
FIGURE 19: EXTENDED FEEDBACK BEHAVIOUR IN THE ACADEMIC WORKFORCE DEVELOPMENT SYSTEM	48
FIGURE 20: SIMPLIFIED STOCK-FLOW DIAGRAM OF THE IN- AND OUTFLOW OF ACADEMIC STAFF WITHIN THE PHD PHASE	50
FIGURE 21: SIMPLIFIED STOCK-FLOW DIAGRAM OF THE IN- AND OUTFLOW OF ACADEMIC STAFF WITHIN THE OTHER ACADEMIC STAFF PHASE	51
FIGURE 22: SIMPLIFIED STOCK-FLOW DIAGRAM OF THE IN- AND OUTFLOW OF ACADEMIC STAFF WITHIN THE PERMANENT STAFF PHASES	53
FIGURE 23: SIMPLIFIED STOCK-FLOW DIAGRAM OF THE IN- AND OUTFLOW OF RESEARCH FUNDING FOR PUBLIC RESEARCH ORGANISATIONS.....	54
FIGURE 24: CAPACITY MECHANISM OF PERMANENT STAFF	55
FIGURE 25: RESEARCH PERFORMANCE AND INFLUENCE ON FUNDING.....	56
FIGURE 26: INFLUENCE COMPETITIVE FUNDS ON RESEARCH ACTIVITY	57
FIGURE 27: TESTING CYCLE ADAPTED FROM STERMAN (2000) AND BARLAS (1996)	63
FIGURE 28: INTEGRATION ERROR TEST	69
FIGURE 29: : PHASES IN SENSITIVITY ANALYSIS	70
FIGURE 30: BASE RUN SIMULATION RESULTS: (A) PHD CANDIDATES AND (B) INFLOW TO AND OUTFLOWS FROM THE PHD PHASE....	74
FIGURE 31: BASE RUN SIMULATION RESULTS: (A) TEMPORARY RESEARCH STAFF, (B) INFLOWS TO AND OUTFLOWS FROM THE TRS PHASE.....	74
FIGURE 32: BASE RUN SIMULATION RESULTS: (A) AVERAGE DURATION OF TRS PHASE (B) TURNOVER TEMPORARY RESEARCH STAFF	75
FIGURE 33: BASE RUN SIMULATION RESULTS: (A) TRS WITH SUBSCRIPTS (B) THE AGING TRS POPULATION	75
FIGURE 34: BASE RUN SIMULATION RESULTS: (A) ASSISTANT PROFESSORS, (B) ASSOCIATE PROFESSORS, (C) FULL PROFESSORS AND (C) INFLOWS TO AND OUTFLOWS FROM THE PERMANENT FACULTY POSITIONS.....	76
FIGURE 35: BASE RUN SIMULATION RESULTS: (A) DISTRIBUTION AND (B) TURNOVER OF ACADEMIC STAFF	76
FIGURE 36: BASE RUN SIMULATION RESULTS: (A) FUNDING, (B) RESEARCHER PRODUCTIVITY (C) RESEARCH PUBLICATIONS, (C) TURNOVER OF ACADEMIC STAFF (C) TOTAL RESIDENCE TIME	77
FIGURE 37: SIMULATION RESULTS COMPETITION FOCUS: (A) DECREASE IN TEMPORARY RESEARCHERS (B) THE INCREASE OF PERMANENT RESEARCHERS (C) INCREASE IN TOTAL ACADEMIC STAFF (D) INCREASE IN TURNOVER IN ACADEMIC STAFF	80
FIGURE 38: SIMULATION RESULTS COMPETITION FOCUS: (A) INSIGNIFICANT INCREASE IN RESEARCH ACTIVITY AND (B) INSIGNIFICANT INCREASE IN RESEARCH PUBLICATIONS.....	81
FIGURE 39: SIMULATION RESULTS INSTITUTIONAL FOCUS: (A) INCREASE IN TEMPORARY RESEARCHERS (B) THE DECREASE OF PERMANENT RESEARCHERS (C) DECREASE IN TOTAL ACADEMIC STAFF (D) DECREASE IN TURNOVER IN ACADEMIC STAFF	81

FIGURE 40: SIMULATION RESULTS INSTITUTIONAL FOCUS: (A) INSIGNIFICANT DECREASE IN RESEARCH ACTIVITY AND (B) INSIGNIFICANT DECREASE IN RESEARCH PUBLICATIONS	82
FIGURE 41: SIMULATION RESULTS NON-FIXED AGE: (A) DECREASE IN PERMANENT RESEARCHER HIRING (B) DECREASE IN PERMANENT RESEARCHERS LEAVING	82
FIGURE 42: SIMULATION RESULTS NON-FIXED AGE: (A) NUMBER OF PERMANENT RESEARCHERS AND (B) THE DECREASE IN TURNOVER OF ACADEMIC STAFF	83
FIGURE 43: SIMULATION RESULTS CONTRACT TERMS (A) BASE RUN TEMPORARY RESEARCH STAFF AND (B) TEMPORARY RESEARCH STAFF WITH DURATION CAP.....	83
FIGURE 44: SIMULATION RESULTS CONTRACT TERMS (A) AGING IN CONTRACT PHASES AND (B) TURNOVER OF TEMPORARY RESEARCH STAFF.....	84
FIGURE 45: SIMULATION RESULTS FINANCIAL STABILITY (A) TEMPORARY RESEARCHERS, (B) PERMANENT RESEARCHERS, (C) RESEARCH PUBLICATIONS AND (D) TURNOVER OF ACADEMIC STAFF	84
FIGURE 46: UNCERTAINTY ANALYSIS – TOTAL PERMANENT RESIDENCE TIME: (A) PERMANENT STAFF AND (B) STAFF TURNOVER.....	86
FIGURE 47: MOBILITY IN THE ACADEMIC CAREER, ADOPTED FROM (GOEDE ET AL., 2014), EXCLUDING DEMOTIONS AND SUPPORT AND MANAGEMENT STAFF	99
FIGURE 48: RELATION BETWEEN ORGANISATIONAL FACTORS AND RESEARCH PERFORMANCE, ADOPTED BY (VERBREE ET AL., 2015).....	103
FIGURE 49: DETAILED PHD MODEL SEGMENT	106
FIGURE 50: DETAILED TEMPORARY RESEARCH STAFF MODEL SEGMENT	107
FIGURE 51: DETAILED CAPACITY MECHANISM TEMPORARY RESEARCH STAFF.....	107
FIGURE 52: DETAILED ACADEMIC RESEARCH FUNDING	108
FIGURE 53: FULL MODEL OVERVIEW.....	109
FIGURE 54: EXTREME VALUE TEST - HIGH PERMANENT COSTS	118
FIGURE 55: EXTREME VALUE TEST - LOW PERMANENT COSTS	119
FIGURE 56: EXTREME VALUE TEST - HIGH TEMPORARY COSTS	120
FIGURE 57: EXTREME VALUE TEST - LOW TEMPORARY COSTS	121
FIGURE 58: EXTREME VALUE TEST – LOW PROMOTION TIME	122
FIGURE 59: EXTREME VALUE TEST – LONG PROMOTION TIME	122
FIGURE 60: EXTREME VALUE TEST – LOW TRS CONTRACT TIME	123
FIGURE 61: EXTREME VALUE TEST – HIGH TRS CONTRACT TIME	124
FIGURE 62: EXTREME VALUE TEST – LONG PROFESSORSHIP.....	125
FIGURE 63: SENSITIVITY ANALYSIS – BASIC REPRODUCTION NUMBER.....	127
FIGURE 64: SENSITIVITY ANALYSIS – CONTRACT TIME TRS	128
FIGURE 65: SENSITIVITY ANALYSIS – CONTRACT TIME TRS PHASES	128
FIGURE 66: SENSITIVITY ANALYSIS – TIME TO ADJUST THE GAP	129
FIGURE 67: SENSITIVITY ANALYSIS – TEMPORARY RESEARCH COSTS	130
FIGURE 68: SENSITIVITY ANALYSIS – PERMANENT RESEARCH COSTS	131
FIGURE 69: SENSITIVITY ANALYSIS – RESIDENCE TIME ASSISTANT	131
FIGURE 70: SENSITIVITY ANALYSIS – RESIDENCE TIME PROFESSOR	132
FIGURE 71: SENSITIVITY ANALYSIS – TOTAL RESEARCH TIME	133
FIGURE 72: SENSITIVITY ANALYSIS – MULTIVARIATE RESIDENCE TIME	134
FIGURE 73: SENSITIVITY ANALYSIS – MULTIVARIATE COST STRUCTURE	135
FIGURE 74: SENSITIVITY ANALYSIS – MULTIVARIATE PROMOTION FRACTIONS.....	136
FIGURE 75: CALIBRATION: REAL-VALUE TO FAIR VALUE (A) OLD MODEL AND (B) OLD GRAPHICAL OUTPUT.....	137
FIGURE 76: CALIBRATION: OLD FUNDING STRUCTURE	138
FIGURE 77: GRAPHICAL REPRESENTATION OF PHD AND TRS PHASES	140
FIGURE 78: GRAPHICAL REPRESENTATION OF ASSISTANT- AND ASSOCIATE PROFESSOR PHASES.....	141
FIGURE 79: GRAPHICAL REPRESENTATION OF THE PROFESSORS PHASE AND RESEARCH PUBLICATIONS.....	142
FIGURE 80: UNCERTAINTY ANALYSIS, INDIVIDUAL RESIDENCE TIME	144
FIGURE 81: UNCERTAINTY ANALYSIS, FACULTY RESIDENCE TIME	145
FIGURE 82: UNCERTAINTY ANALYSIS – PROMOTION FRACTIONS.....	146
FIGURE 83: UNCERTAINTY ANALYSIS – COMBINED INPUT UNCERTAINTIES.....	147
FIGURE 84: UNCERTAINTY ANALYSIS – PHD PROMOTION	148
FIGURE 85: UNCERTAINTY ANALYSIS – TRS PROMOTION	149
FIGURE 86: UNCERTAINTY ANALYSIS – DESIRE FOR FUNDING	150

LIST OF TABLES

TABLE 1: ACADEMIC STAFF IN 2014 IN FTE IN THE NETHERLANDS PER TYPE OF CONTRACT	14
TABLE 2: NUMBER OF ACADEMIC STAFF BETWEEN 1999 AND 2014.....	15
TABLE 3: ACTORS: THEIR TASK, THEIR PLACE IN THE SCIENCE SYSTEM AND THEIR AREA OF INTEREST (RATHENAU-INSTITUTE, 2015A), AS ADAPTED FROM (HAZEU, 1986)	22
TABLE 4: FUNDING: TYPE, FORM AND ORGANISATION	24
TABLE 5: INSTITUTIONAL FUNDING ALLOCATION SCHEME.....	27
TABLE 6: INCENTIVES FOR THE SCIENCE SYSTEM, ADOPTED FROM (VAN DALEN ET AL., 2012)	32
TABLE 7: LIMITATIONS AND OPPORTUNITIES OF DIFFERENT FUNDING REGIMES, ADOPTED FROM (VAN DALEN ET AL., 2012)	34
TABLE 8: UNCERTAINTY IN SD MODELS, ADAPTED FROM (PRUYT, 2014).....	58
TABLE 9: INCLUDED EXPERT MEETING CONCEPTS IN THE SD MODEL	66
TABLE 10: EXCLUDED EXPERT MEETING CONCEPTS IN THE SD MODEL	67
TABLE 11: BEHAVIOURAL PATTERN TEST RESULTS	72
TABLE 12: SIX SIMULATION EXPERIMENTS AND DIRECTIONS OF THEIR EFFECTS ON DIFFERENT POLICY MEASURES	79
TABLE 13: INPUT UNCERTAINTY: PROMOTION OF FACULTY MEMBERS IMPACT	86
TABLE 14: STRUCTURAL UNCERTAINTIES	87
TABLE 15: MODEL FORMULATION PART 1	110
TABLE 16: MODEL FORMULATION PART 2	111
TABLE 17: MODEL FORMULATION PART 3	112
TABLE 18: MODEL FORMULATION PART 4	113
TABLE 19: MODEL FORMULATION PART 5	114
TABLE 20: LIST OF PARAMETERS AND EXOGENOUS VARIABLES PART 1	115
TABLE 21: LIST OF PARAMETERS AND EXOGENOUS VARIABLES PART 2	116
TABLE 22: EXTREME VALUE TEST ASSUMPTIONS	117
TABLE 23: DATA REPRESENTATION FOR CALCULATION R2 AND MAPE	139
TABLE 24: UNCERTAINTY ANALYSIS, JUSTIFICATION INDIVIDUAL RESIDENCE TIME, PARTLY BASED ON EMPIRICAL OBSERVATIONS (RATHENAU-INSTITUTE, 2015A)	143
TABLE 25: UNCERTAINTY ANALYSIS, PROMOTION FRACTIONS	146

LIST OF EQUATIONS

(1) STOCK FLOW MECHANISM.....	40
(2) REPRODUCTION NUMBER	51
(3) CAPACITY MECHANISM.....	55
(4) DESIRED PUBLICATIONS	56
(5) DISCREPANCY MECHANISM.....	57
(6) R-SQUARED METRIC	71
(7) MAP E METRIC.....	71

LIST OF ABBREVIATIONS

AP:	ASSISTANT PROFESSOR
ABM:	AGENT BASED MODELLING
ACP:	ASSOCIATE PROFESSOR
AWTI:	THE ADVISORY COUNCIL FOR SCIENCE, TECHNOLOGY AND INNOVATION
BRN:	BASIC REPRODUCTION NUMBER
EMA:	EXPLORATORY MODELLING AND ANALYSIS
EZ:	MINISTRY OF ECONOMIC AFFAIRS
FL:	FEEDBACK LOOP
FR:	FUNDAMENTAL RESEARCH
FP:	FULL PROFESSOR
FTE:	FULL TIME EQUIVALENT
GDP:	GROSS NATIONAL PRODUCT
HOOP:	HIGHER EDUCATIONAL RESEARCH AREAS
HE:	HIGHER EDUCATION
HR:	HUMAN RESOURCES
HRM:	HUMAN RESOURCES MANAGEMENT
IBO:	INTERDEPARTMENTAL POLICY RESEARCH
KNAW:	THE ROYAL NETHERLANDS ACADEMY OF ARTS AND SCIENCES
KPI:	KEY PERFORMANCE INDICATOR
NWO:	THE DUTCH ORGANISATION OF SCIENTIFIC RESEARCH
OAS:	OTHER ACADEMIC STAFF
OCW:	MINISTRY OF EDUCATION, CULTURE AND SCIENCE
PHD:	DOCTOR OF PHILOSOPHY
PRF:	PUBLIC RESEARCH FUNDS
PRO:	PUBLIC RESEARCH ORGANISATION
PUI:	PARA-UNIVERSITY INSTITUTE
SA:	SENSITIVITY ANALYSIS
SD:	SYSTEM DYNAMICS
SDM:	SYSTEM DYNAMICS MODEL
TNO:	APPLIED PHYSICS RESEARCH INSTITUTE
TRS:	TEMPORARY RESEARCH STAFF
TSR:	TOP SECTOR RESEARCH
UA:	UNIVERSITY JOB CLASSIFICATION SYSTEM
VSNU:	THE ASSOCIATION OF UNIVERSITIES IN THE
WOPI:	ACADEMIC STAFF INFORMATION (WOPI)

1. INTRODUCTION

Academic research and scientific development are some of the main drivers for continued economic growth (Chiong-Meza, 2012; Rathenau-Institute, 2015a). In the Netherlands, the academic workforce is supported by the Dutch government through the ministry of Education, Culture and Science (OCW) and the ministry of Economic Affairs (EZ), with the objective to stimulate research and development (Versleijen & van der Meulen, 2007). However, over the past years the financial support for the academic workforce has been stagnating, even though the number of new students is rising (OCW, 2014). Simultaneously, policies with regard to contract and funding instruments have been enacted to support the research body in the pursuit of continued high impact research. It is unknown what the effects of the changing policies are on the development of the academic workforce. This study aims to analyse and understand the impact of funding regimes and policy measures on the workforce development at public research organisations (PROs) in the Netherlands. Based on the study result recommendations will be made.

1.1 PROBLEM BACKGROUND

Traditionally, academic research was mainly conducted autonomously within research organisations (AWT, 1999; Hazeu, 1986). The government provided direct institutional funding to institutes, with the assumption that fund would be allocated efficiently (AWT, 1999; de Weert, 2001). With the large scale liberalisation advocated during the nineties, academic institutes were expected to become more competitive, both among universities and individual researchers (Goede, Belder, & Jonge, 2014; Versleijen & van der Meulen, 2007). As governmental regulation would no longer be detailed, the emerging autonomy gave universities the opportunity to self-direct while being responsible for quality and productivity.

Today academic research is conducted in a growing international and multidisciplinary context. The necessary funds that enable researchers to work are obtained from a variety of sources, both public and private, and are increasingly international. The multitude of funding regimes makes it difficult for research institutes to manage and direct their research body while effectively allocating their means (Enders & Teichler, 1997; Huisman, Weert, & Bartelse, 2002). Trends suggest that the landscape of the academic workforce has drastically changed with an emerging focus on temporary research staff. Governmental funding also seems to stagnate over the last years due to the growing variety of external funds. The focus on temporary staff and external funding might have negative effects on the workforce and research output over time (Enders, 2007; Rathenau-Institute, 2015a).

WORKFORCE CHARACTERISTICS AND CAREER PROGRESSION

The academic workforce is primarily composed of researchers within the eight Higher Educational Research (HOOP) areas: agriculture, natural sciences, engineering, health, economics, law, humanitarian and social sciences. In recent years the Netherlands has seen a tremendous increase in the production of doctorates. Figure 1 shows that the number of degrees have doubled over the past 15 years, a remarkable trend when compared to the number of other academic positions which remained relatively stable (Rathenau-Institute, 2015a).

Most academic staff enter the academic system through a PhD program (Enders, 2007; van Arensbergen & van den Besselaar, 2012). This program provides the funding for a research leading up to a doctoral degree. In most cases this will take four years, in which the graduate has to write and defend a thesis in becoming eligible for a postdoctoral position while acquiring a distinct academic title. However most PhD candidates fail to succeed within the four years and over a quarter leaves the academic world without a doctorate (Goede et al., 2014; Huisman et al., 2002). Governmental incentives have significantly increased the PhD workforce over the last two decades. However, while over 55 per cent of the PhD workforce wants to acquire a permanent position in academia, the prospects remain relatively low (Huisman et al., 2002; OCW, 2014; van Balen & van den Besselaar, 2007). This conflicts with the career aspirations of most PhD candidates. The academic career has traditionally been the goal for most researchers entering the PhD program and it is designed as the objective within a graduate program (Van Balen, 2010).

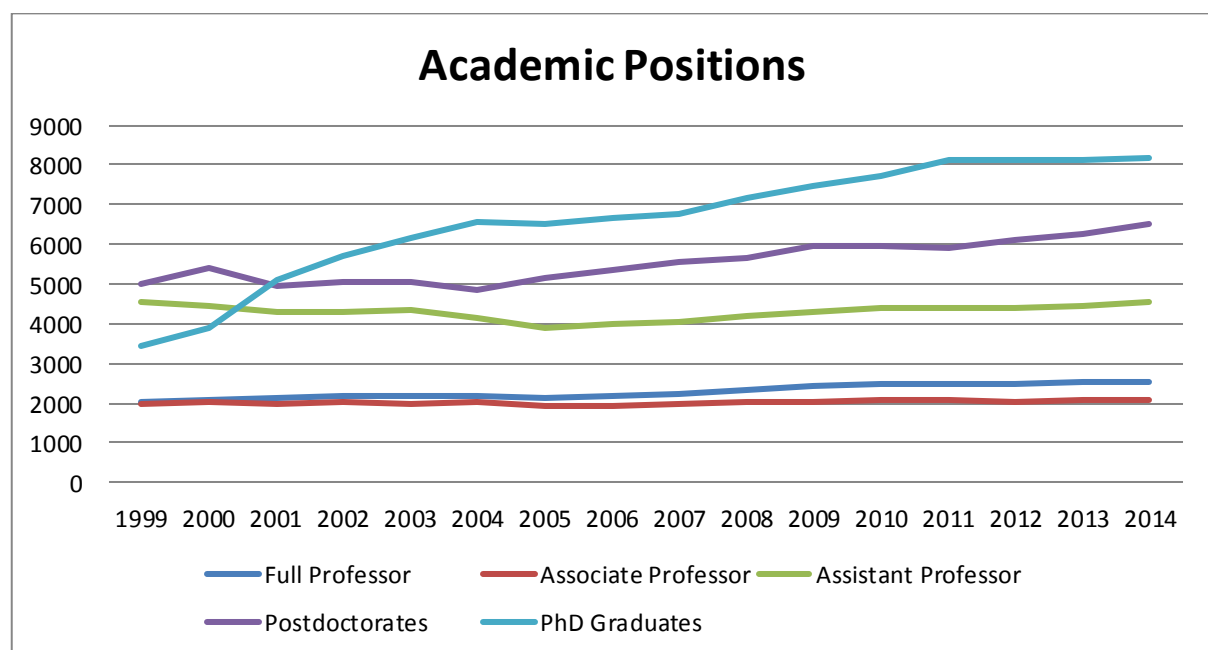


Figure 1: Academic positions, without HOOP area Health, 1999-2014

PhD graduates who follow the academic career path and are able to navigate through the process of reappointment and promotion will eventually acquire a permanent position. It is however common to first engage in a period of postdoctoral training. The postdoctoral positions do not give automatic access to a permanent position (Goede et al., 2014). It is a period of gaining research experience and not necessarily a requirement for acquiring a permanent position (van Balen and van den Besselaar 2007). As seen in Figure 1, the number of postdoctoral researchers has increased substantially over the years, while the number in permanent positions has remained relatively stable. Only thirty per cent of temporary researchers eventually acquires a permanent position, while the remaining seventy per cent leaves the academic world (Arensbergen, Hessels, & Meulen, 2013; Van Balen, 2010). To deal with this uncertainty, new funding policies were introduced, such as the Veni-Vidi-Vici Grant and the Tenure track appointment.

After a period of postdoctoral training, only a small percentage of temporary researchers acquires a permanent faculty position, either as assistant, associate or professor (Goede et al., 2014; Huisman

et al., 2002). The limited availability of faculty positions is partly based on the hierarchical and static structure of the academic career system (De-Jonge-Akademie, 2010). Since 1984, the academic career policies are based on the formation principle, that structures the in- and outflow of permanent researchers which is based on the static number of full time equivalents (FTEs). Before, policy makers thought it was too easy to attain a high position in academia. To reduce costs and manage the staffing structure the formation principle was introduced. While it has influenced the staffing structures an unwanted situation has emerged. The academic system seems to be clogged as staff often remains in one permanent position. The perspectives of young talented staff is deteriorating as there is not enough space for most of them to become a permanent member of academia.

PUBLIC RESEARCH FUNDING

Currently the Dutch government contributes 2.7 billion annually in support of researchers within public and private research organisations (IBO, 2014; OCW, 2014). Primary funding is given to universities and research institutes, international research organisation, high prioritised research and individual research programs (Versleijen & van der Meulen, 2007). The Dutch Organisation of Scientific Research (NWO) provides secondary funding with a budget of 700 million euro annually for international top sector research, emerging research areas and top talent (Rathenau-Institute, 2015a). The NWO has been created as a supporting organisation of specific societal research. Aspects that are now considered for the distribution of funding are quality competence, social relevance and macro-expediency (AWT, 1999). Tertiary funding is given by the European Union, other public parties and private organisations in support of excellent high potential researchers. Figure 2 shows the different funding types until 2019, based on fair values and their estimates. Note that tertiary funding includes funding from private organisations. This graph shows that while the total amount of public research funding has remained stable, institutional funding has decreased while competitive funding has increased, showing a focus shift.

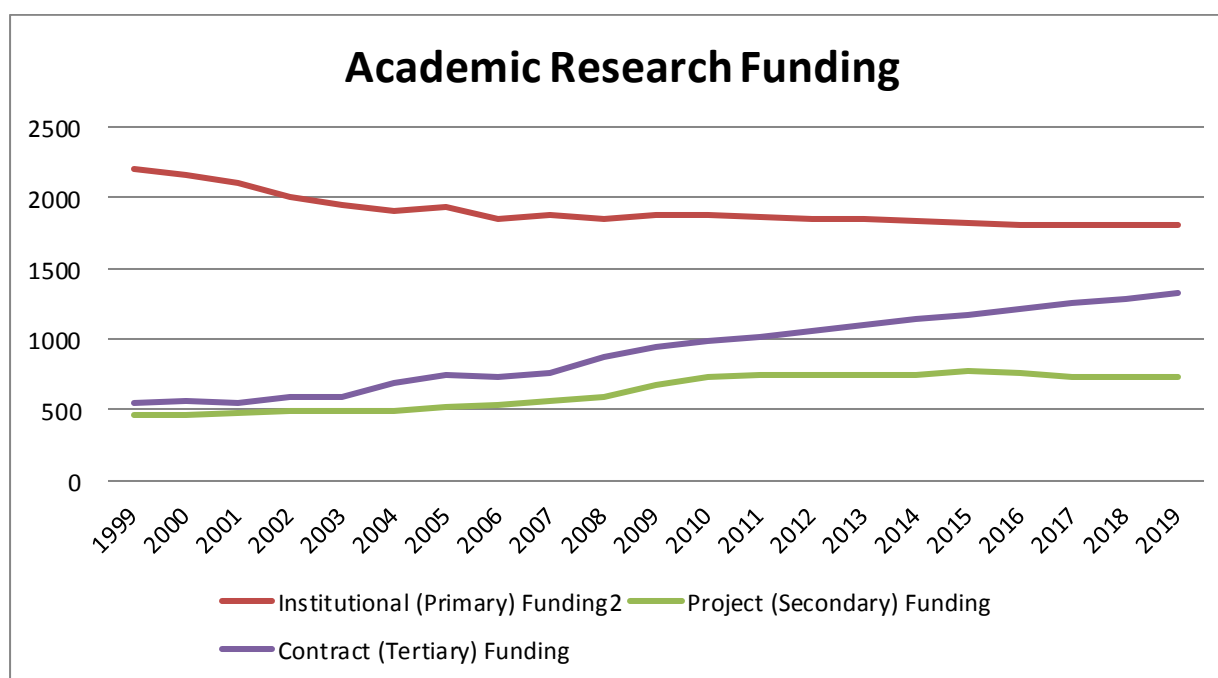


Figure 2: Academic research funding, 1999-2014 (realisation), 2015-2019 (prognoses) and 2009-2019 (prognoses tertiary funding), based on fair value, euro*1.000.000

Science in the Netherlands is divided into Fundamental Research (FR) and Top Sector Research (TSR). While fundamental research is highly autonomous the Dutch government does promote competition and cooperation among researchers. For fundamental research the budget will increase annually from 75 million euro in 2014 to 150 million in 2017 (OCW, 2014). Top sector research is specific research in which companies, universities and the government work together. NWO provides an additional 275 million euro a year for specific research that seems beneficial for economic growth. Aside from primary and secondary funding there is 1.3 billion euro available for more specific research by companies, governmental organisations, foundations, foreign funds and individuals.

With the increasing autonomy of universities the government is not able to regulate the research body directly. Because of governmental support, policy makers would like to incentivise research that is promising from a societal perspective. Through project and contract funding, partly distributed by the NWO, the government has an instrument to influence the behaviour of researchers. The organisation of the public research funding, however, has also become increasingly complex over the years. It is not always known how changes in funding regimes could influence the workforce development. It is therefore important to shed light on the complex relationship that exist between the workforce ecosystem and research funding, as changes within a complex environment could cause noteworthy and unintended effects.

QUALITY AND EXCELLENCE

The quality outlook of universities is to a great extent connected with the expertise of the academic workforce. With the emergence of the policy measure ‘management for excellence’, universities started to focus on talent and talent policy. Excellence is mainly concerned with scientific expertise and productivity but also with social skills and values such as motivation, perseverance and showing initiative (Arensbergen et al., 2013). Because management for excellence is becoming a key issue in higher education several programs and policy initiatives are currently implemented such as the Tenure Track programme, scholarships for excellent PhD candidates and programs for promising female scientists. However the scouting process is often carried out on an ad hoc basis without the notion of excellence (Arensbergen et al., 2013; van Balen, van Arensbergen, van der Weijden, & van den Besselaar, 2012). Programs are mainly focussed on applying for external grants and funding. This deliberate change of funding policy, from an internal institutional approach to a project oriented approach had its effects on workforce development and time management. Securing these grants has become increasingly important in the promotion process. Moreover, scouting for excellence often happens according to the formation principle. Only when there is place available, room will be made (Van Balen, 2010). Therefore universities often wait for scientists to attain a personal scholarship or application from outside before it begins to award researchers with a promotion or appointment. Coupled with the uncertainty and inflexibility of the academic career, excellent researchers are leaving academia for business or industry or move abroad (Arensbergen et al., 2013). To prevent this ‘knowledge drain’, policies for individual researchers are needed.

SCIENCE SYSTEM POLICIES

The governmental goal for the science system is the development of a competitive international research environment challenging researchers to conduct high performance research which is satisfactory from a societal perspective (OCW, 2014). In the autumn of 2014 the ministry of OCW

presented their vision on how this goal would be accomplished. Maintaining a competitive position in Europe by dealing with globalism, to share knowledge and funding by creating public-private partnerships and to deal with the increasing publication pressure. However, there are many indicators that show that these goals will not be reached. First, the Rathenau Institute expects that the total funding for research and development will decrease in the Netherlands in comparison to other countries (Arensbergen et al., 2013). In such an environment potential and excellent PhD candidates and other researchers could go or remain abroad. Second, there is an increasing demand for societal research which will change the scientific landscape as scientists are more bound to specific research objectives. Third, the Rathenau institute expects that this will lead to unexpected behaviour in the workforce development in academia. With the growing international competition researchers feel the pressure to publish while they also have to deal with time issues such as management, valorisation and funding (Goede et al., 2014).

This governmental vision on the science system intends to create policies that improve funding regimes and contractual arrangements (OCW, 2014):

- *Increasing financial stability*
Less focus on external performance indicators that define funding such as PhD-graduates and student numbers and the increased focus on long-term financial structures within research organisations.
- *Increasing workforce stability*
More career opportunities for temporary research staff by capping the number of succeeding contract to prevent temporary contract accumulation and the possibility to be promoted towards an associate position.
- *Increasing research performance*
Setting the right policy incentives with the focus on competitive research funding to induce more societal and qualitative research output and maintaining prospective professor staff.

However it is not known how these changing funding regimes and career policies will effect workforce over time. In light of unintuitive consequences that changing policies can have it is therefore necessary to study the workforce development over time. It is not possible to test these policies in a real time manner. For this purpose a model could be created that looks at the impact of proposed policies on the workforce over time (Forrester, 1992; Kwakkel & Pruyt, 2013; Sterman, 2000)

1.2 PROBLEM ARTICULATION

Dutch society wants to be among the leaders in research and education and develop a knowledge based society (De-Jonge-Akademie, 2010; OCW, 2014; van Dalen, Mehmood, & Verstraten, 2012; Versleijen & van der Meulen, 2007). Over the last years the Royal Netherlands Academy of Arts and Sciences (KNAW), the Association of Universities in the Netherlands (VSNU), the Dutch Organisation of Scientific Research (NWO) and the Ministry of Education, Culture and Science have specifically focussed on the career development in the academic world, as human capital is among the most important factors for providing quality in research and development. However, studies suggest that there are some bottlenecks in the distribution of academic staff and the academic career development that could hamper this goal (De-Jonge-Akademie, 2010; van Arensbergen & van den

Besselaar, 2012; Van Balen, 2010; van den Brink, Fruytier, & Thunnissen, 2013). One of the main problems is the inflexibility in human resource management which is based on the formation principle.

Staffing policies are based on this principle which is relatively inflexible to change. Promoting talented researchers is only possible when FTEs for the same research group are available. This has several consequences for the promotion of academic staff.

- Many postdocs aspire to become permanent member of academia. In a postdoc position, the researcher can increase its expertise, its experience and focus solely on its research task in becoming eligible for a permanent position. However, postdocs sometimes accumulate many contracts, that are accepted due to limited promotion space in permanent positions. Many of these postdocs leave university, often over the age of 35, with qualifications that are not useful outside academic organisations (De-Jonge-Akademie, 2010; Navid Ghaffarzadegan, Hawley, Larson, & Xue, 2014).
- The age distribution of permanent staff in academia is static. The average age of an associate is 42 and of a professor is 46, with low variance. The system seems to prefer age -experience over talent (Goede et al., 2014).

The formation principle creates a high degree of external movement in the lower ranks and limited external movement in the higher ranks of the academic career system. On average, only 20 per cent acquires a permanent position while 55 per cent would like to remain in the academic world (Goede et al., 2014).

The career prospects of young researchers within universities are limited. However the outflow of PhDs & postdocs is often hampered by their ill-preparation for the non-academic world, their age, and for some fields their over-qualification (pile up of qualifications). The formation principle depicts that only a certain amount of places will become available when other researchers leave. Moreover, talent selection often happens on an ad hoc basis, making potential researchers discouraged due to temporary contract accumulation. This could hamper the acquisition of qualified staff.

Most qualified staff would like to attain an independent research portfolio but are often obstructed by room in the higher ranks of the academic career. Due to many temporary contracts, future career prospects and the hierarchically build career model the universities could earn a bad reputation on the (inter)national job market (Navid Ghaffarzadegan et al., 2014).

In their vision of policy for science, the Ministry of OCW wants to increase the potential of the academic career by creating policies supporting the following goals (OCW, 2014):

- Robust inflow, flow and outflow of academic staff in academic research positions
- Well balanced distribution of academic staff over different positions
- Flexibility in structure and financing

VSNU and the Rathenau Institute support this vision as they think a well-balanced distribution of academic staff across the academic career system is the criterion for success in research and development (Rathenau-Institute, 2015a). The structure of the academic career model (organisation) and HR policies should accommodate the flow of talented researchers through the systems as it drives innovation and performance.

Many policy measures have been proposed and implemented over the years to support these goals such as the AiO scheme, the Tenure Track scheme, contractual agreements and financial incentives such as European Grants and the 'Vernieuwingsimpuls'. The Rathenau institute conducted studies both qualitatively and statistically to analyse these policies. These studies remain primarily static representations of the career system. Not much is known about the impact of these policy measures on the workforce development over time. It is essential understand the holism of the academic career system and the impacts of policies.

The structure of the academic workforce, the support it receives from government and the impact of academic research on society and the scientific and economic landscape urge improved knowledge of the academic career system. By providing an understanding of the dynamical characteristics and complexities that are underlying to the behaviour of the workforce development, policy makers could be assisted in understanding the effects of changing policy measures. This understanding is also essential to enhance the distribution of researchers and subsequently the effectiveness of public spending on research and development.

1.3 RESEARCH OBJECTIVE

In light of the unintuitive consequences that policies can bring, the purpose of this study is to examine how career and funding policies influence the development of the academic workforce over time. This study will further emphasize on how the organisational career structure and staffing factors can influence research output in academic research organisations.

The policy makers within the government perceive the science system as linear and information symmetrical. From their normative perspective on the science system they create policies that have the intended impact. However, the science system is a complex collection of partially connected sub-systems that interact and are intrinsically interwoven (Rathenau-Institute, 2015a). For such systems static or implicit mental models are inherently deficient as they do not incorporate causality and interaction (Kwakkel & Pruyt, 2013). Complex concepts such as interacting behaviour, information delays, accumulations and non-linearities have to be taken into account if policy makers want to make sense of their enacted policies. However, studying these complex linkages at various parts of the system can be a time-consuming, costly and, in some cases, practically impossible task. Due to these constraints, modelling the system and simulating the problem field is the only realistic way to test the system on policy behaviour (Borshchev & Filippov, 2004; Sterman, 2000). To model this system, different methods can be used. Based on the problem articulation a modelling method is needed that can incorporate the different concepts of the science system, its inherent complexities, its continues interaction and the impact of policy measures over time from a strategic level.

To examine the effects of policies on the workforce development in academia some research variables have to be identified. The different academic positions (PhD candidates, postdocs, assistants, associates, professors) in the science system will be studied and analysed over time. A distinction will be made between temporary and permanent positions and their influence on the research output (research publications). The flow of staff through the system will be analysed based on time and refresh rate (staff turnover, residence time in academia). Finally the study will look at the amount of time a researcher is conducting research (research productivity).

The normative perspective of the government on the workforce development is adopted for this study. First, because it adheres to the stakeholders interests and second, because the normative perception of actors differs across the organisational layers of the science system. As such, not all actors within the science system would agree that the changing balance between temporary and permanent staff and the expected changing balance in funding regimes is necessarily a problem. In a system with enough prospective candidates this is the case. However, in an environment without enough qualified staff, the acquisition and preservation of staff is intrinsically important.

1.4 RESEARCH SIGNIFICANCE

The findings of this study will redound to the benefit of society considering that scientific research and technological advancement plays an important role in economic growth and the modernisation of our welfare state. The greater demand for research that benefits society justifies the need to understand the implications of governmental policies on the workforce development and research output in academia. The model, which will be created for this study, will be used to understand the underlying behaviour of the workforce development system in the Netherlands. With this understanding comes the ability to simulate policy experiments and perceive the effects on the system over time. Furthermore, it will advance literature covering the science system in the Netherlands and model based studies covering promotion chains and workforce development in academia. For the researcher, it will help to uncover critical areas of the science system that are yet to be explored. Thus, a new perspective on the impacts of policies on the science system may be found.

1.5 RESEARCH QUESTIONS

To understand and examine the effects of policies on the academic workforce in the Netherlands the following main research question is formulated:

“How can career and funding policies affect the development of the academic workforce in the Netherlands over time?”

In order to address the main research question, sub questions have been formulated on which the thesis will be structured:

Theory

1. What are the main mechanisms in the science system that influence the development of the academic workforce in the Netherlands?

Method

2. Which method can be used to adequately analyse and understand the complexities of the academic workforce development in the Netherlands?

Analysis

3. What relationships exist between career and funding policies and the academic workforce development and research output in the Netherlands?
4. What are the effects of proposed policy measures on the workforce development and output in academia?

5. How can this study contribute to the knowledge of the academic workforce development, be used in a policy-making process and justify the need for future research?

1.6 POINT OF DEPARTURE

This study focuses on the possible causal relation between science system policies and the effect on the workforce and output of researchers (Frølich, 2006; Hicks, 2012; Srikanthan & Dalrymple, 2007; van Dalen et al., 2012). This concept is shown in Figure 3. It is expected that the positioning of public research funding influences the strategy of research organisations. Funding enables them to increase the workforce, train graduates and spend time on societal research. Based on the output and performance on the workforce, the government can decide to adjust the amount of public funding or change public funding mechanisms. While the causal relation is contested it is also supported by literature (Rathenau-Institute, 2015a). This causal feedback system represents goal seeking behaviour. Because these relations cannot be modelled with traditional methods, the System Dynamics Method, which incorporates these non-linearities and the self-driven behaviour, is adopted to simulate the effects of changing policies on the workforce development and research output over time.

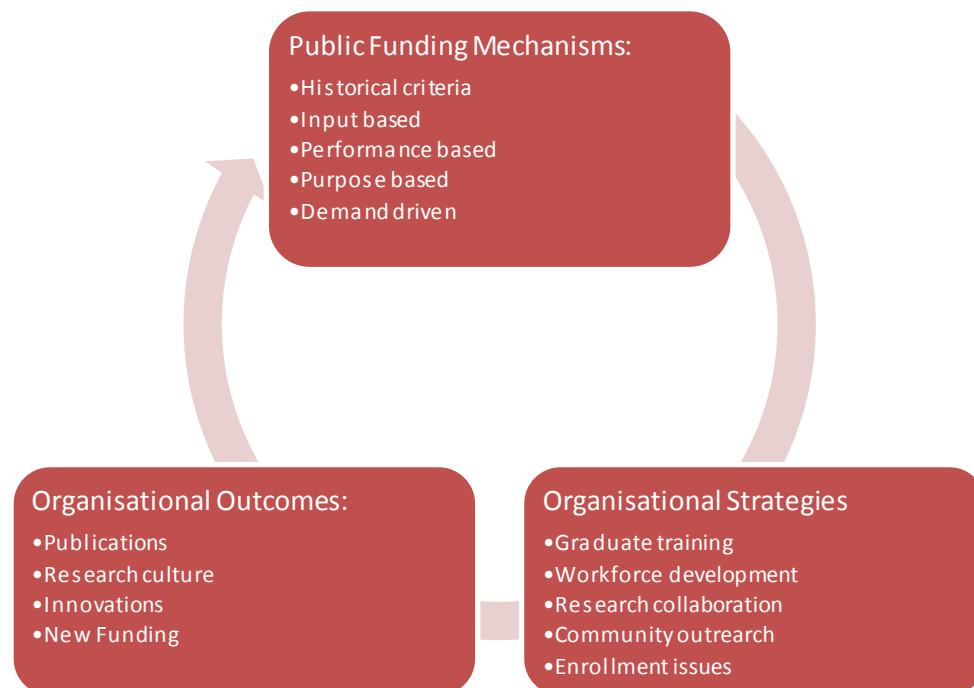


Figure 3 The mechanisms, strategies and outcomes of the Public Funding System, adapted from (Oyo, Williams, & Barendsen, 2008)

1.7 THEORETICAL FRAMEWORK

The government creates policies for the science system to incentivise the behaviour of researchers: creating research in the best interest of society. From their normative perspective on the science system, as they assume that the system is static and information symmetrical, they create policies with the desired impact. The Agent-Principal Problem is used to clarify why this is often not the case in complex social systems. In combination with notions of policy making in complex environments, several governmental incentives are proposed that could have a desired policy impact.

The System Dynamics Method, which is grounded in dynamical systems theory, deals with long-term qualitative behaviour of dynamical systems in a mathematical way, is adopted as the main tool for analysing the science system from a strategic perspective. The focus is on the behaviour of the system over time in comparison to precise forecasting. It is also grounded in complexity theory, as it is a method trying to understand the behaviour of a given system through its structure. The science system organisation is a complex network of interactions in which the system is self-driven. Therefore implicit mental models, linear or statistic models are not able to analyse these systems and validate enacted policies.

1.8 CONCEPTUAL FRAMEWORK

The conceptual overview of this thesis work is shown in Figure 4. The system diagram, which is adopted from (Enserink et al., 2010) is used to create the structure needed to address the research questions. The basic system elements are all represented: the means of the policy maker, the external factors which cannot be changed and the influences of these factors on the system and relevant criteria. The System Dynamics method is adopted to incorporate the different factors identified in the system diagram. Concepts and data retrieved from Rathenau institute, VSNU, KNAW, OCW and other online sources are combined and replicated to simulate the behaviour of the system over time.

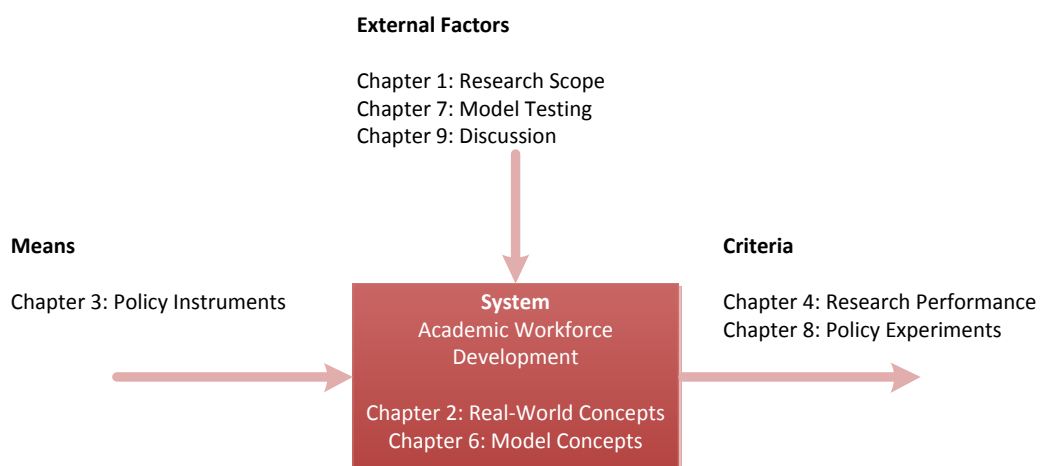


Figure 4: System Diagram, adapted from (Enserink et al., 2010)

First, the system structure, which is limited by the system demarcation, will be further analysed. Top down regulation is nearly impossible in complex and interwoven systems. For such systems, mental models do not suffice. This calls for a method that can include these concepts. System Dynamics is chosen as the modelling method. Then the conceptualisation within the virtual model environment takes place. Based on the conceptualisation and model testing, several model outcomes are presented. To increase robustness, uncertainty analysis will be performed that also looks at other system perspectives.

The knowledge gap between the desired system state and the actual situation can be defined as not knowing how career and funding policies influence the academic workforce in the Netherlands over

time. The objective is to clarify the academic workforce development and create a tool which can be used in a policy-making process. To test the model outcomes, key performance indicators are identified. The government has several means through which it can influence the system, improving the overall conditions in accordance with the stakeholder's objectives. There are also several external factors, that cannot be influenced that. These limitations have to be identified and analysed in order to see the influence on the outcomes.

1.9 RESEARCH DEMARCATION

The assumptions, limitations and system scope create the boundaries on which the study will be structured. Not all real-world concepts can be included when analysing a certain problem within a model environment. The most relevant concepts are included for the purpose of answering the research question. Section 6.1 will focus on the implications of the demarcation on the solution space of this research.

ASSUMPTIONS

To answer the research question, a model will be created that looks at the workforce development in the Netherlands from an aggregated perspective. It is assumed that amalgamation of these universities and professionals is possible when analysing the system from a strategic perspective (Rathenau-Institute, 2015a). It is further assumed that there is a causal relationship between funding, workforce development and research output as described in Section 1.6.

LIMITATIONS

In a model environment all relevant concepts and data that exist in the academic workforce development system in the Netherlands are used. It is however possible that there are some data limitations, making the model less usable. The model boundary, which will be identified in Chapter 6 will further limit the model.

SCOPE

This study focuses on the academic workforce development in the period 1999-2029 from enrolment into the PhD program until retirement, looking at different steps along the way and key decision points in academic careers. The analysis will focus on how the different variables interact, correspond to each other and give rise to complex dynamic behaviour. It will also focus on providing a tool to assess policy measures, trying to assist in a policy-making process (Arensbergen et al., 2013). Additionally, this study focuses on universities alone as they are the core of the research and development system in the Netherlands. Of course there are other relevant institutes that are part of this domain, such as other research institutes, HBOs and research companies. However, this will fall outside of the research scope. The two other obligations of researchers, valorisation and education will also fall outside of the research scope.

The size of the model is initially kept small by focussing on the concepts to ensure that results are easily communicated to policy makers. This will, however, have an impact on the usability of the model. Funding mechanisms and contract agreements will be included. The notion of excellence and research quality will fall outside the model environment.

It is expected that the results of this study are generalizable in other countries with similar funding and policy regimes. It is the responsibility of the researcher to initially compare the science system concepts before it can make any supra-national assumptions.

1.10 RESEARCH STRUCTURE

The structure of this thesis is shown in Figure 5. It is structured around four sections: the first section provides the theory needed to understand the inherent complexities within the science system. Based on these complexities a modelling method is chosen and used in the second section, as the system is too complex to analyse with implicit mental or statistical models. In the third section the system will be analysed and several policy experiments are conducted. In section four the study results will be concluded and recommendations will be made.

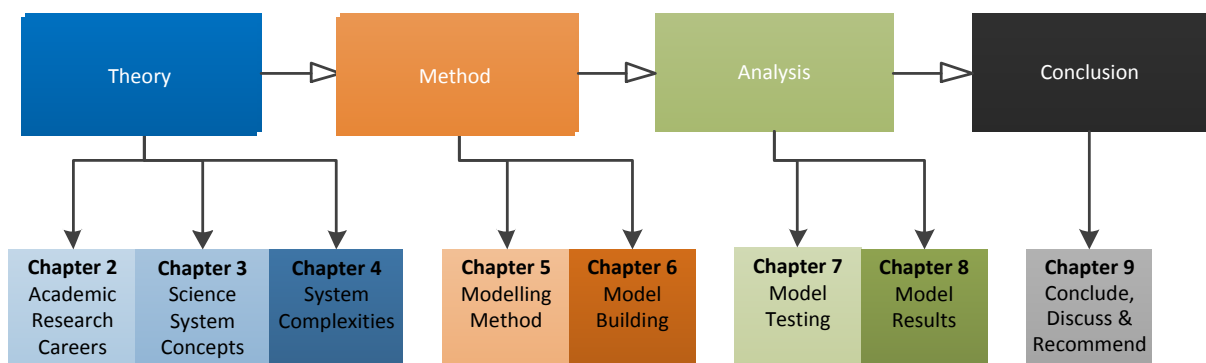


Figure 5: Thesis Outline

The full outline of this study is as follows: chapter 2 shows the workforce development in the science system. Chapter 3 shows the different concepts that are in place to explain the science system. Chapter 4 explores the inherent system complexities. Based on this theory, a model perspective is needed to analyse the given system. Chapter 5 presents the research methodology, previous research in the field and its limitations. Chapter 6, shows the conceptualisation and specification of the model. The model will be verified and validated in chapter 7. After the model design, results of the study will be shown and analysed in Chapter 8. In Chapter 9 this thesis work will be concluded by presenting the model and theory results and discussing the limitations and contributions.

PART 1:

THEORY

2. ACADEMIC RESEARCH CAREERS

The aim of this chapter is to describe the academic workforce development in the Netherlands from a historical perspective. The focus will be on the main trends in the inflow and throughput of academic staff within the formalised academic system which has gained increasing attention by policy makers over the years. Section 2.1 will describe the development of academic research staff between 1999 and 2014. The next section, 2.2, will show the mobility between different stages based on a study by (Goede et al., 2014). Section 2.3 will explore the problems of the academic research careers and possible solutions. Section 2.4 will show two organisational models from based on different science system perspectives. Section 2.5 will reflect on this chapter and provides the conclusions that are needed to analyse policies within the model environment.

2.1 THE DEVELOPMENT OF ACADEMIC RESEARCH STAFF

The University Job Classification System, UFO, keeps track of the different positions in the academic research career which is based on a collective labour agreement. Table 1 shows the different academic positions at universities with the corresponding staff numbers, as per 31 December, 2014. Five main positions can be distinguished: PhD candidate, Other Academic Staff (OAS), assistant professor, associate professor and full professor. The positions of a postdoc is not registered as a separate entity but falls within the OAS position (van Balen & van den Besselaar, 2007). Data concerning academic research staff is maintained by the VSNU and published as scientific staff information (WOPI)

	Academic Staff [fte]		
	Total	Permanent	Temporary
Professor*	2.648	2.515	132
Associate	2.224	2.157	67
Assistant	4.830	3.383	1449
OAS			
-Teacher	2.539	1219	1320
-Researcher/Postdoc	4005	-	4005
-Other	435	37	398
PhD**	8.714	-	8714
Total Academic Staff	25 394	9.309	16.085

*Does not include endowed professors

**Does not include non-university employed PhD candidates

Table 1: Academic Staff in 2014 in fte in the Netherlands per type of contract

In the Netherlands, over 30,000 individuals are employed by universities in academic positions, which equals 25,394 full time equivalents. At the bottom there are 9.000 PhD candidates and at the top over 2600 full professors. Within these ranks almost all appointments are on a permanent basis, while PhDs and postdocs often work on a temporary basis (Goede et al., 2014)

The historical data that is used for the time period under study, 1999-2014, is adopted from VSNU. The numbers found in the dataset between 1999-2004 and 2005-2015 are for a number of reasons not completely comparable. Most academic staff working in medical institutions and university faculties for medicine are not included in the 2005-2015 dataset. In total this would add up to 2,500 fte in 2004 (van Balen & van den Besselaar, 2007). Correcting this number would increase the

number of academic staff with 10 per cent in 2005. Second, some universities have adopted a PhD scholarship policy in late 1998. While this policy measure has been reversed, it is unknown how many PhD candidates on a scholarship have remained outside the WOPI-publications. Third, the employment of new staff that is paid by NWO has been transferred to universities. Fourth, the OAS function has been split up in academic staff focussing on research, education and others. Table 2 shows an academic staff overview where the HOOP area Health, which is dentistry, veterinary medicine, and medicine, is omitted from the data set for validation and comparative reasons.

Academic Staff [fte]	1999	2005	2005 relative to 1999 in %	2014	2014 Relative to 2005 in %
Professor	2013	2165	+5.0	2529	+16
Associate	1972	1909	-3.3	2097	+9.0
Assistant	4539	3909	-16	4539	+14
OAS (Research)	5024	5167	-3.5	6515	+26
PhD	3417	6521	+48	8160	+20
Total Academic Staff*	14814	10713	+14	21073	+18

*Does not include OAS staff that have an educational task

Table 2: Number of Academic Staff between 1999 and 2014

Based on the above mentioned data limitations a comparison can be made between the different stages of the academic career in the period 1999-2014 with the correction for the HOOP area Health. In 2005, the number of professors had increased with 5 per cent in comparison to 1999, the number of associates had decreased with 3.3 per cent and the number of assistants had decreased more drastically, with 16 per cent. If these numbers are not corrected with the HOOP area Health, the decrease is more stringent (van Balen & van den Besselaar, 2007). In 2014 staff sizes have increased over the whole range in comparison with 2005. Only associate professors did not grow in the same manner.

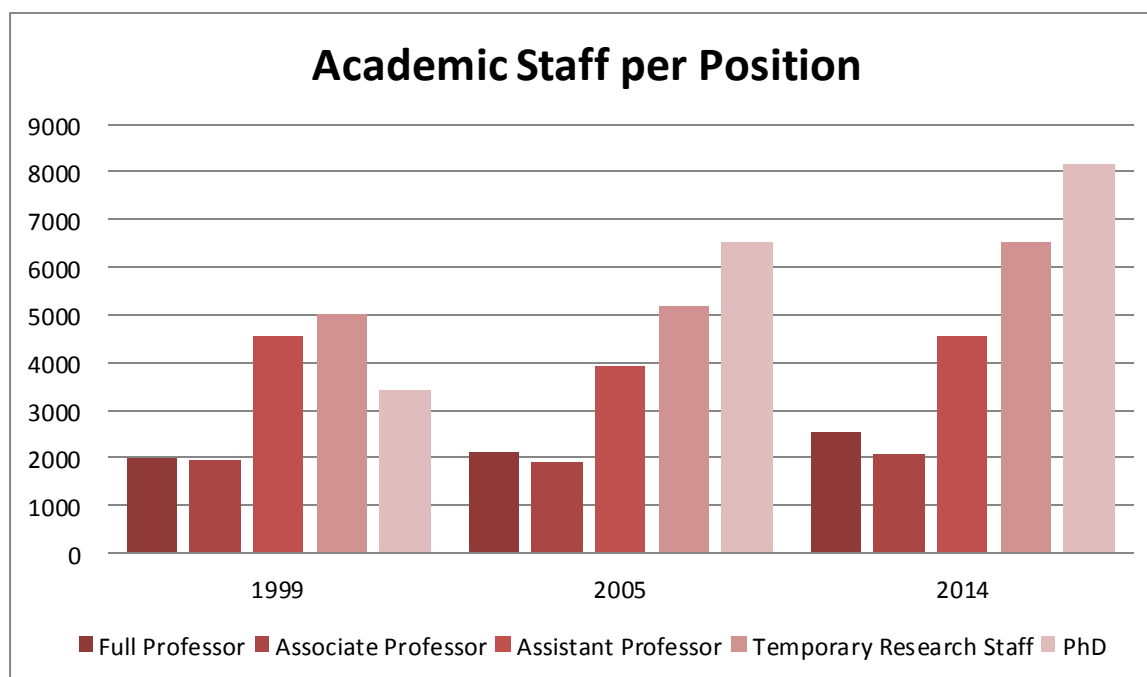


Figure 6: Academic Staff and Positions

The emphasis on contract type has also changed between 1999 and 2014, which is shown in figure 21 and 2.2. For permanent positions, there has been a gradual change over time. The number of associate professors has decreased while assistant- and full professors have grown over time. The

number of temporary research staff (TRS), which is a significant part of the OAS, and PhD candidates have increased over the years, with the sharpest increase for PhD-candidates. Part of this growth is caused by a transfer in contract structure between NWO and the universities.

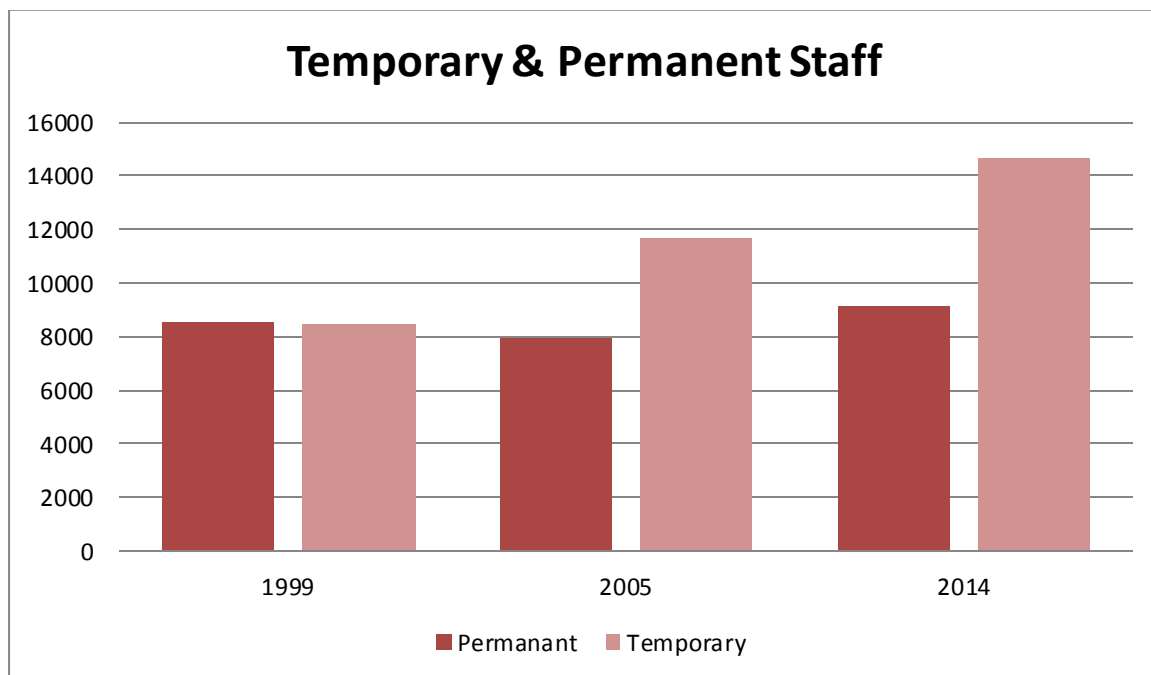


Figure 7: Temporary Staff and Permanent Staff

The proportion of temporary staff and permanent research staff also changed over the years, as seen in figure 2.2. Where in 1999 the majority of academic staff conducted research at universities on a permanent basis, this changed towards a more temporary contract based system.

2.2 MOBILITY OF ACADEMIC RESEARCH STAFF

Advancing mobility between positions is considered as one of the ways to create room for the new talented academic staff (De-Jonge-Akademie, 2010). In the Netherlands, mobility between academic positions is based on a hierarchical structure (Goede et al., 2014). Appendix 1 shows a static overview of the mobility of academic staff in the time frame 2003-2011. The mobility of academic staff seems to suggest that it is a dynamic and decisively open system with a strong selective character (Goede et al., 2014). Especially in the lower positions of the academic career there is a lot of movement. The majority of these positions find work outside of Dutch universities suggesting that there is limited space for a permanent positions in academia which corresponds with figure 2.2. One of the reasons for this the growing emphasis on temporary staff is the interest for PhD candidates by policy makers and academic institutions. A knowledge economy is not only in need for a professional workforce but also of specific knowledge coming from PhD-graduates.

Academic research positions all have a specific role in the promotion chain. The postdoc position, which falls within the OAS category based on the UFO-classification, is the link between the PhD-program and a more independent research position at the university. Within the OAS category a distinction is made between staff focussing on education, research or secondary tasks. OAS contract are becoming increasingly shorter: as of 2010 every year one third of all OAS staff changes position

(Goede et al., 2014). The largest part of this outflow, which are mostly foreign researchers, and PhD graduates, finds work outside academia. The OAS position is the main gateway to more permanent faculty positions. However, only a small percentage successfully navigates the hurdles of the academic world and acquires a permanent position (De-Jonge-Akademie, 2010; van Balen et al., 2012). The next stage in the academic career is the one of the independent researcher; the assistant professor. After the assistant professor the associate is the next stage in the academic career, which is also the most closed, only a small percentage moves every year (Goede et al., 2014). The function of the professor is the highest rank in the academic career ladder and the face of the research section.

2.3 EXPLORING THE ISSUES

Funding, which is analysed in more detail in chapter 3, has a major impact on the promotion of academic staff (De-Jonge-Akademie, 2010; Goede et al., 2014; Hoffius & Surachno, 2006). In the perception of many, institutional funding, which is the normative funding regime is deteriorating in comparison to national and international competitive funding (Van Steen, 2012). In 2014, almost all PhD-candidates were financed by the funds obtained through competition (Rathenau-Institute, 2015a). The decrease of institutional funding will lead to fewer permanent positions in academia and the deterioration of the infrastructure (van Balen & van den Besselaar, 2007). The infrastructure, however, cannot be managed by competitive project funding, which focusses on staff instead of infrastructure. To maintain the workforce, the acquisition of external funds becomes increasingly important. Because this will naturally lead to more financial uncertainty in research organisations, there will be an emphasis on temporary staff. While this could be socially acceptable for some, it is detrimental for stable research careers. However, institutional funding is also dependent on a wide variety of indicators as analysed in chapter 3. Because these indicators change on a frequent basis it is increasingly difficult for individual research organisations to solely rely on lump sum funding (van Dalen et al., 2012).

2.4 NORMATIVE PERCEPTIONS

The academic promotion system in the Netherlands and the influence of funding seem to be the most significant bottlenecks for researchers following the academic career path. PhD candidates who acquire a position work in service of the university during their research. Because there is no significant understanding of the limited development potential in academia, and the research institutions do not actively support the non-academic career potential during a PhD training, the image arises that it is a tenured position for life (Van Balen, 2010; van Balen et al., 2012). Together with the increasing uncertainty in obtaining research funds, research organisations will increasingly rely on temporary staff to fill their vacancies. Talented individuals could find it undesirable to choose for an academic career in the Netherlands as the career path is highly uncertain.

From the perspective of the individual researcher this is highly undesirable. The researcher is uncertain about his/her future career prospects, chooses to stay in academia by accepting many temporary positions in the hope of acquiring a much desired faculty positions, but leaves after some years due to the inaccessible career system (Larson, Ghaffarzadegan, & Xue, 2013). With a limited availability of talented researchers this seems undesirable. However, in a system where there is an abundance of talented staff perceptions could be different. From the perspective of a professor this could be a desirable situation: there is a large pool of potential and qualified researchers where the

professor could scout for promising new staff. The policy maker wants to create policies that induce societal research, without interfering with contractual agreements. As such, the normative perception of the workforce development is not homogeneous across all actors within the organisational layers as seen in the area of interest in Table 3 (Rathenau-Institute, 2015a). From an aggregated system perspective, with enough supply of talented staff, a highly adaptive system is desired. This is a system where the demand is quickly satisfied by the supply. From a detailed system perspective, also the interests of the individual researcher should be considered.

This study perceives the focus on temporary research staff and competitive funding regimes as undesirable from a long-term perspective. The science system should accommodate the most talented researchers from different backgrounds and disciplines. There should be enough space for such a researcher to independently set out his/her own research portfolio, unconstrained by the lack of funding or organisational bottlenecks. In an environment where the researchers feel the confidence to do fundamental research, which is not always beneficial in the short-term, new paradigms could emerge.

2.5 ORGANISATIONAL MODELS

Some faculties have incorporated the so called tenure track appointments to recruit highly qualified research staff. There are two types of tenure track appointments in the Netherlands. One is the normative type, where assistants get the opportunity to grow towards a full professorship appointment at the faculty. The new tenure track is to attract and recruit highly qualified staff. One of the most important parts of the new tenure track are the non-hierarchical characteristics: the tenure trackers can have their own independent research portfolio, which has its resemblances to the US academic staff system.



Figure 8: The US and the Dutch organisational system (van Balen & van den Besselaar, 2007)

The aim of the Dutch hierarchical system is to have a layered structure of academic staff, in which assistant and associates work according to the leadership and programme of the professor. The research group is seen as a relevant unit, which is part of a greater research field of the institute which origin can be found in the Dutch culture of collectively (van Balen & van den Besselaar, 2007). The implication is that the Dutch academic system does not allow all staff to become a full professor. The image of the organisational structure can be compared with a hat as seen in Figure 8. In comparison, the US system aims for tenured staff with many professors, which corresponds to a vase. The two systems are based on different thoughts. The US system focusses on the mobilisation of individual talent, while the Dutch system focusses on the mobilisation of research groups. The choice for one of the two models is of essential importance for the future of the Dutch academic system.

2.6 SUMMARY

The performance of the science system is mainly determined by researchers within the system and their research performance. The organisations that educate, recruit, select and regulate the research careers are of critical importance to this performance. Based on the analysis of literature and the available data the issues have been mapped, which focuses on the inflow throughput and outflow of academic staff in the Netherlands. The results show that the academic career system is decisively open and dynamic in temporary positions and closed and static in permanent positions. While large numbers of temporary and permanent members of academia find their way through the academic career, only a small percentage acquires a permanent position in academia. It is expected that the duality will increase as the number of temporary appointments is increasing in comparison to the permanent appointments, making it increasingly unlikely for young researchers to acquire a tenured faculty position. Also the number of associate professors is decreasing in comparison to the number of assistants and full professors which suggests that the importance of the three function is changing. The normative perception on these changes, and the underlying problems that could emerge, are not shared by all the actors within the science domain. It is therefore imperative to understand what the differences of perceptions are, how that translates to policies and how these policies affect the workforce development in academia. The next chapter will elaborate on the different actors within the science system, the instruments the policy maker adopts to regulate the science system and the influences of these instruments on the workforce and output in academia.

3. SCIENCE SYSTEM CONCEPTS

The aim of this chapter is to introduce the key concepts that are needed to understand the science system in the Netherlands. The focus will be on the actors that play a role in different institutional layers, the instruments they use to regulate and steer the science system such as funding and policy measures and the outcomes of the science system such as the development of knowledge and the academic workforce (Dalderup, 2000; Verbree, Horlings, Groenewegen, Van der Weijden, & van den Besselaar, 2015; Versleijen & van der Meulen, 2007). Section 3.1 will elaborate on the key science system concepts. Section 3.2 will focus on the actors in the different institutional layers and their perspectives on the science system. Then, in section 3.3, the instruments that actors can use to influence the science system will be shown, with a special section, 3.4, dedicated to public research funding as a policy instrument. Then, in section 3.6 the focus will be on system outputs, such as knowledge and workforce development.

3.1 THE SCIENCE SYSTEM

Research and development will have a continued impact on our society, as it influences the way people think, act and live. Many individuals who create knowledge do so in universities, public research organisations (PSO) or large industrial companies. Research is, however, not necessarily society driven as there are many factors that influence performance of researchers, such as the reputation of the institutes, the acquisition of external funds or even personal interests (van Dalen et al., 2012). The government wants to set the right incentives to enable researchers to conduct research in the best interest of society. Therefore, the government has to adopt policy instruments that structure the public science system and regulate individual researchers.

The governmental goal with the science system is the development of a competitive international research environment that challenges researchers in conducting high performance research that is satisfactory from a societal perspective (OCW, 2014). This goal is achieved by the right distribution of funds, incentives and directives, what makes science policy, condition based policy. (Dijk, Frankfort, Horn, & Vos, 1993; Hicks, 2012). However, the government and the advisory boards that distribute these funds are not able to judge and evaluate the research that they support. It is therefore imperative to create policies that have the right impact on the workforce.

The definition of research is an original investigation undertaken in order to contribute to knowledge and understanding (OCW, 2014). The research can however come in a wide range of output: public disseminations, presentations, performances or exhibitions. Because research can both be quantifiable and non-quantifiable it is difficult for the policy maker to direct the workforce.

3.2 ACTORS IN THE SCIENCE SYSTEM

This paragraph gives an overview of the relevant actors in the science system in the Netherlands. The focus will be on the different actors within the organisational layers, their perception on the science system corresponding to the perceived problem and the means that are available to them. This section follows the 4-layer framework as created by (Dijk et al., 1993) and (Hazeu, 1986):

- The Operational Layer
- The Financial Layer
- The Advisory Layer
- The Policy Layer

THE OPERATIONAL LAYER

In the Netherlands, there are around 100,000 individuals that conduct research, on which, on average 50 per cent works at universities or research institutes and the other half in industry. The Netherlands has 14 research universities, that educate around 250.000 students with the emphasises on conducting academic research (Goede et al., 2014). Another task of the university is valorisation or aiding in society needs. These three tasks: academic- education, research and valorisation are defined by law, but the accent has changed over the years. While researchers want to increase the amount of time conducting research, society demands more focus on education as the number of students has been increasing tremendously over the years (Chiong-Meza, 2012). Apart from universities there is a wide range of university affiliated- and independent research institutes. Para-university institutes (PUI) conduct research on specific fields, but have strong ties with one or more universities. The present PUI's are part of the NWO- or KNAW-organisation and conduct fundamental research. Not-for-profit organizations conduct fundamental research without a profit objective but are financially separate from universities and PUI's.

THE FINANCIAL LAYER

There are many organisations that contribute financially to the science system in the Netherlands. First there are the governmental departments that divide the institution funding. Then there are organisations such as NWO and the European Union that contribute to competitive oriented project funding. The main contributors to public research funding, both the institutional part and the project part via NWO, is the ministry of Education, Culture and Science. It also owns an additional budget for the promotion of strategic research programs (Dijk et al., 1993). The ministry of Economic Affairs supports more technological oriented research and the university of Wageningen. Other ministries only marginally support science system in the Netherlands.

NWO is the largest secondary funding allocating organisation in the science system. It has the task to incentivise the quality of research and to promote new developing fields. The main instrument is to provide the right incentives through funding (van Dalen et al., 2012). The amount of funding is supplied by the ministry of OCW, and then passed down to underlying foundations and institutions. It however does not supply funding for infrastructure at universities; only for staff costs (Dijk et al., 1993). Project funding, which is the second funding stream, is relatively small in comparison with other countries. Section 3.4 will focus on funding as a policy instrument in more detail.

THE ADVISORY LAYER

Policy makers want to make sense of their created policies. However, organisations within the science system consists of highly autonomous researchers who demand control of their work. Mintzberg classifies universities as professional organisation where decision making is decentralised. Because the professional organisational structure is lacking control mechanisms policy makers find it increasingly difficult to direct and regulate the workforce with policies. As top down regulation and

centralised decision making does not work policy advisors with specific knowledge about the science system are needed (de Boer et al., 2015; Mintzberg, 2006; van Dalen et al., 2012).

The KNAW is the oldest advisory board in the Netherlands. Its task is to advise the government in science related fields, improve the cooperation of national and international researchers and promote specific research. The Advisory Council for Science, Technology and Innovation (AWTI) is another generic advisory board that helps the government in making decision regarding the science system. Apart from these main institutions there are many other small institutions, both general and specific that help the government in decision and policy-making.

THE POLICY LAYER

The governmental officials, who are responsible for the science system in the Netherlands, take decisions that are submitted to the Second Chamber. The preparation of the decisions making is delegated to the ministry of OCW and the advisory board AWTI. Their task is to prepare the decision making process in the following fields: science policy and scientific research, technology policy and innovation policy (Dijk et al., 1993).

ACTOR ENVIRONMENT

This section has addressed the variation and high-profile actors within the science system. Table 3 shows an overview of the actors, their tasks and their area of interest. It is important to see that the normative perception of the relevant actors who perceive the science system are not all aligned. Therefore, a policy measure could not be beneficial to all.

Moreover, it is important to note that this perception of the actors within the system is only of limited representation. As the science system is growing, many policies and organisations change to adhere to changing conditions. It also just shows the main players within the policy environment. There are many more institutions that are not included. This paragraph is here to show the variation of actors within the field, which emulates the difficulty to change certain conditions within the system.

<i>Level</i>	<i>Task</i>	<i>Actor</i>	<i>Area of Interest</i>
1	Defined tasks	PhD & OAS	Fundamental Research, Good Career Prospects
2	Situational Response	Professors	Research Output & Performance
3	Systematic tasks	Research Group	Reputation, Flexible Workforce
4	Comprehensive set of tasks within a certain field	Faculty & Institute	Reputation
5	Broad array of tasks	Research Organisation (University, VSNU, TNO)	Reputation, Good Education
6	Strategy Development	Advisory Board (KNAW, AWT)	Societal Research (Good Education)
7	Articulation of norms and values of society & policy development	Government & Parliament	Societal Research, Good Career Prospect, Good Education

Table 3: Actors: their task, their place in the science system and their area of interest (Rathenau-Institute, 2015a), as adapted from (Hazeu, 1986)

3.3 POLICY INSTRUMENTS IN THE SCIENCE SYSTEM

The identification of problems, such as knowledge gaps or the unbalanced use of research staff and funding, and formulating the possible solution space is not sufficient to deal with problems in complex professional organisations (Dijk et al., 1993; Thissen & Walker, 2013). The use of policy instruments, that look at the underlying problems of the system, are needed to reach a desired system state. This paragraph gives an overview of the relevant instruments needed to incentivise behaviour within the science system.

Traditionally, governing the science system happened according to regulation and legislation. Today these instruments are still used, however, top down coordination no longer reaches its desired effect (Auranen & Nieminen, 2010; Benner & Sandström, 2000). This emerges with the increasing complexity of our modern environment, in which an actor, in this case the researcher, is exposed to many policy incentives. In an open, consensus driven society, subtle diplomatic cohesion is needed to change the status quo (Dijk et al., 1993). In a policy arena with many actors in a variety of organisations, its policy targets and instruments that are in place decide for the outcome of the implementation process. The government can use three instruments to play a role science policies (Dijk et al., 1993; Rathenau-Institute, 2015b):

- Financing
- Regulation & Legislation
- Consultation & Persuasion

Almost all researchers working within universities or institutes are dependent on third party funding. The government provides research organisations with direct structural funding, which is used to maintain the research infrastructure. Additionally, the government provides direct funding for specific research run by research organisations and provides indirect funding via intermediary organisations like NWO and the Netherlands Enterprise Agency.

One of the most important factors in which the government regulates the science system is the remuneration and position of academic staff that work in service of the government. A number of research organisations have direct links with the government, such as the KNAW, AWTI, NWO and TNO, who have statutory duties under governmental legislation that define their duties, responsibilities and activities. Science policies are in that sense human resources policies (van den Brink et al., 2013). Universities are more independent and have no direct ties with the government. Creating policies that incentivise their behaviour is therefore difficult, even more so in a system where the operational layer is highly autonomous, independent in the exploration of research fields and subject to a high degree of tacit knowledge.

Administrative consultations within the science systems is to establish a relationship between the government and research organisations which is based on dialogue and consultations. This happens between various organisational layers: between the ministers and the advisory boards, between administrators and civil servants and directly to organisational units. Consultation between the relevant actors provides for the opportunities to make agreements, discuss problems or raise important issues. Administrative persuasion provides a tool to propagate a thought or policy

objective in such a way that the target audience adopts this thought (Pavitt, 1987). The policy vision on science, one of the main uses of persuasion, gives an overview of the actual situations from a societal context which is often the start of the policy-making process. Another way to persuade actors within the system is to set number of performance requirements: compare governmental spending based on the GDP with other countries or setting the right input and output quotas on research. However, while there can be a certain research output threshold that government want to attain on a yearly basis, it is not always easy to define these indicators. Qualitative indicators, such as the amount of funding, workforce, and the number of publications are easy to make. Harder to define is the quality of the used means.

Due to changing societal conditions and opinions, the role and purpose of science system policies are often changing, that a policy instrument could become redundant and will lose its purpose. Therefore it is important to see whether the goals of the policies and policy instruments lead to the desired behaviour and system objectives set out by the government. This thesis tries to link the different pieces of instruments together; to explore and understand the influence of policy measures, with the special emphasis on funding, on the development of the system and its output.

3.4 PUBLIC RESEARCH FUNDING

One main factor in the organisation of the science system is the size, form and organisation of research funding (Benner & Sandström, 2000; van Dalen et al., 2012; Versleijen & van der Meulen, 2007). Because individual researchers and public research organisations base their behaviour in research activities on the availability of funds, it is essential to know and understand the impact of funding on the academic workforce. Four types of public funding allocation regimes can be distinguished in the Netherlands as seen in Table 4. Chapter 4 will further focus on setting the right incentives with public research funding

<i>Level</i>	<i>Type</i>	<i>Form</i>	<i>Organisation</i>
1	Institutional	Lump-Sum based on criteria	Direct [ex-ante]
2	Project	Competition	Indirect [ex-ante]
3	Contract	Competition [including private]	Indirect [ex-post]
4	Medical	Lump-Sum based on criteria	Indirect [ex-ante]

Table 4: Funding: type, form and organisation

Direct governmental funding, which is the traditional form of funding, is determined based on certain organisational indicators and supplied in lump-sum form. Indirect governmental funding, of which project funding is allocated through NWO and contract funding is allocated through public or private organisations such as the EU. The fourth type of funding is allocated through intermediary organisations to the HOOP area health. Most funding regimes work on an ex-ante basis why others work on an ex-post basis. These four funding schemes are the backbone of the research funding in the Netherlands.

DEVELOPMENT OF PUBLIC RESEARCH FUNDING

In the Netherlands, around 3.5 billion euro is spent on academic research funding in 2015, which is 0.74 per cent of the Dutch GDP (VSNU, 2015). Institutional funding has increased over the years to accommodate and support the increasing student body at universities and academic workforce, from

767 million in 1975 to 2,583 million in 2014 (nominal values), which is an increase of 330 per cent. Indirect funding has also changed substantially, from 73 million in 1975 to 1,300 million in 2014 (nominal values), mainly due to European projects and industrial contract research, which is an increase of 1,800 per cent.

Figure 9 shows the academic research budget in fair values between 1999 and 2019. Note that the numbers of 2019 are expected and partly estimated (IBO, 2014; Rathenau-Institute, 2015a). All funding levels seem to grow over time, apart from the institutional funding that declines. Figure 10 compares direct funding and indirect funding. The focus has changed from a primarily direct funding based regime, in which only 31 per cent in 1999 is indirect, to a more mixed regime, in which 51 per cent is indirect in 2014. This could have several implications, that will be discussed in section 3.5.

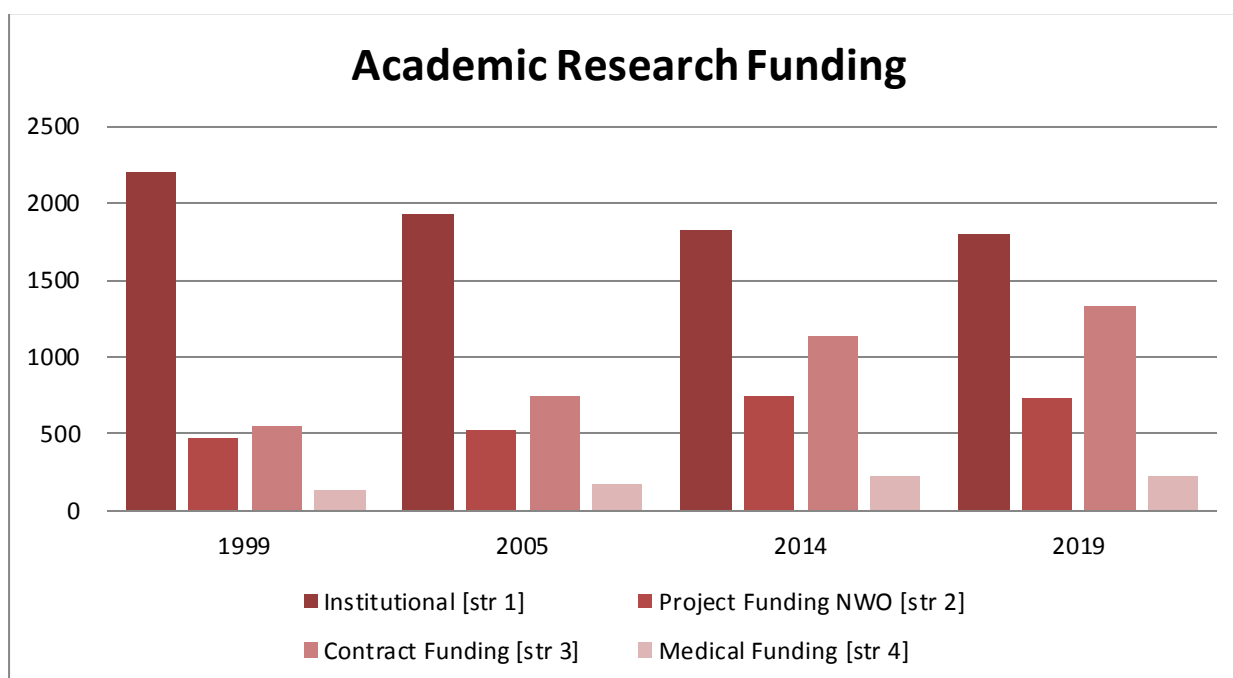


Figure 9: Academic research funding, 1999-2014 (realisation), 2015-2019 (prognoses) and 2009-2019 (prognoses tertiary funding), based on fair value (2014), euro*1.000.000

PUBLIC FUNDING ORGANISATIONS

The ministry OCW and EZ are the main contributors to research and development in the Netherlands: roughly 90% of the total public research funding. The largest part of this amount, 4,975 million in 2011, is spent on the research component of higher education (van Dalen et al., 2012). Roughly 75% of all research funds go to universities and medical research centres. Then 20% of the budget goes to intermediary organisations such as NWO and KNAW. NWO receives the majority, which is further allocated to institutions and indirect funding to projects and contract agreements (van Dalen et al., 2012). The remaining 5% goes to smaller research institutes. There are three main intermediary organisations that have the role of allocating public research funding to universities and institutes. These are the NWO, KNAW and the NL Agency. These agencies will be described below:

NWO is the national research council, consisting of various organisational units such as science divisions, foundations, institutes and taskforces. With its budget of 755 million euro in 2011 it

allocates subsidies to the best scientific talent and best research proposals in the Netherlands (van Dalen et al., 2012). Part of this budget is also spend on the NWO research institutes, management and overhead. Most funding NWO receives is from the Ministry of Education, Culture and Science. In 2011, 22% of the total public research funding went to NWO.

The duty of KNAW is to “serve as a learned society representing the full spectrum of scientific and scholarly declines, to act as a management body for national research institutes and to advise the Dutch government on matters related to scientific pursuit”(van Dalen et al., 2012). Apart from advising the government on science policies, the KNAW also has a number of own institutes who carry out societal research.

The Netherlands Agency is a division of the Ministry of Economic Affairs that carries out policy and subsidy programs for business initiatives, which also includes the Dutch patent offices. These programs have a focus on innovation, entrepreneurship and sustainability.

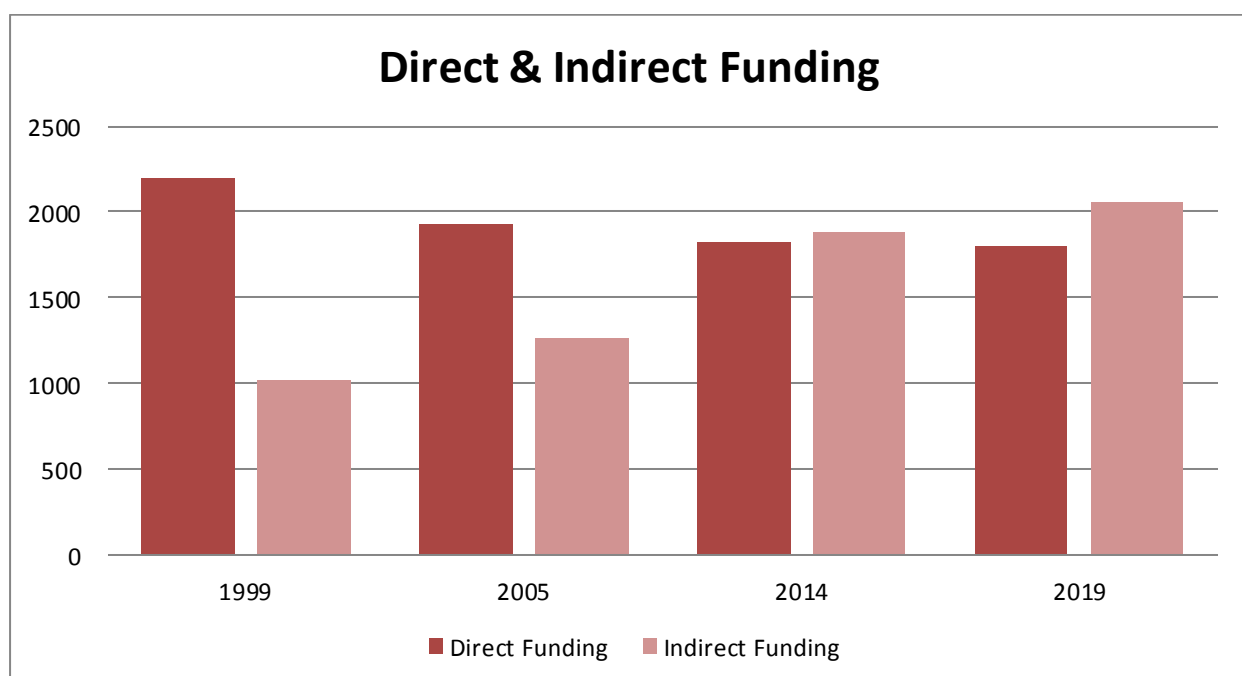


Figure 10: Direct Funding and Indirect Funding based on fair value (2014), excluding medical funding, retrieved and analysed from CBS, EY-Report, Rathenau

DIRECT FUNDING ALLOCATION SCHEME

Universities receive direct institutional funding from the ministry of OCW and EZ. The funding consists of education and research part. While there is a division between education and research, universities can freely choose how to allocate their funds internally. Thus, the funding is not earmarked for research and education but the funds are based on specific research and education parameters. Table 5 shows an overview of the funding parameters, and dimensions, of the education, research and medical centres part of the institutional funding:

Education [41 %]

- Number of students and degrees [35 %]
- Education provision [35%]

Research [44 %]

- Number of Diplomas [15 %]
- Number of PhD dissertations [20 %]
- Research Schools [5 %]
- Research provision [60%]

Academic Medical Centres [15 %]

Table 5: Institutional Funding Allocation Scheme

3.5 EXPLORING THE ISSUES

While the total governmental support of scientific research (fair values, 2014) is relatively stable since 1999, as shown in figure 2, research organisations experience financial difficulties. This has a number of reasons. First there was the focus shift from institutional funding to project funding in 2008, to benefit the new policy measure ‘Vernieuwingsimpuls’. Second, the total size of institutional funding has decreased in comparison to project funding, under influence of the growing internationalisation of research and an increase in private funding initiatives (IBO, 2014). Third, many research organisations use institutional funding to complement their second and third stream research, the so called matching principle. Due to increasing student number, and funding levels did not commensurate, the relative research budget has decreased, between 200 and 2013 from 64 per cent to 52 per cent (IBO, 2014). Moreover, funding within the second and third stream are often focused on short term projects. With the increase in competitive funding, there is only limited room for projects that are uncertain for their results in the long run. Also it depreciates the infrastructure. Research organisations desire more financial stability, which is important for the continuity of long term risky research, but also the maintain a healthy workforce.

While the focus shift to more competitive oriented funding is regarded at something positives, it has some drawbacks. Researchers are increasingly occupied with the application for research funds, what has its impact on their research time. Research has indicated it is around 6 per cent of the time in 2014.

3.6 RESEARCH OUTPUT

It is often difficulty to determine the productivity of researchers and the impact of research. However, measuring the effectiveness is important for academic institutions but also for the government. Governments spend a considerable amount of budget on funding the academic workforce. There are many methods to assess productivity and impact, the H-index is used to examine the researchers publications, or the citations or collaborations index is used, however none of these measures also grasp the qualitative aspect or unmeasured aspects of research.

3.7 SUMMARY

Academic professionals conduct research in the executive layer of the science system. They want to have the position to freely and independently do fundamental research that is meaningful from a scientific perspective. However, these professionals work in an environment that is dependent on support from the government. The government would like the science system to conduct research that is meaningful for society as a whole. Therefore an objective gap between the policy maker and the academic professional could emerge. The government tries to influence the behaviour of academic professionals by creating policy instruments that set the right incentives. One of the main policy instruments the government uses to support and influence the behaviour of research organisations is academic research funding. However, due to the inherent complexity of the science system there is information asymmetry between the different institutional layers and there are conflicting interests among the actors, it is increasingly difficult to design policies that have the desired impact. The next chapter will elaborate on the difficulty in designing policies that set the right incentives with the focus on how funding as a policy instrument influences research output.

4. SCIENCE SYSTEM COMPLEXITIES

The aim of this chapter is to show the inherent complexities in developing policies for the science system. The focus will be on how funding, as a policy instrument, affects the science system and how policies will not always have the desired impact. The theory on the Principal-Agent problem is used to show this complexity and to come to three different funding strategies policy makers can adopt to manage the science system (Bolton & Dewatripont, 2005; Laffont & Martimort, 2009). Section 4.1 gives an overview on the relationship between academic research funding and research output. Section 4.2 will elaborate on the difficulties in creating policies in the science system. Section 4.3 shows the incentives needed to influence the science system and Section 4.4 defines the possible funding regimes that have impact. Section 4.5 will reflect on these notions and provides the conclusions needed to analyse policies within the model environment.

4.1 POLICIES WITH IMPACT

The government wants to create policies that influence the science system in such a way that it leads to desired behaviour. As described in Section 2.4 and 3.2, the government does not always have the same objectives as the researchers working in the operational layers. Funding is a policy instrument that can influence the science system with the intended purposes. Over the last years, the positioning of funding as a policy instrument has gained increasing attention, with the focus on how research funding affect the research output of research institutions. Aghion et al (2010) tested the hypothesis whether research organisations are more productive when they are more autonomous and face more competition in the acquisition for funds. This study shows a strong correlation. It also stresses that European universities could benefit from enhancing their competition fund acquisition. Auranen and Nieminen (2010) did a similar comparative study and found that countries with more competitive funding environments were better in attaining high publication output but were not able to increase efficiency. Daraio et al. (2011) also did not find a clear defined pattern between funding and research output.

One of the reasons no clear pattern is found is the partial conflicting interests between the actors involved. Additionally, there is a high degree of information asymmetry between policy maker and professional on the work floor. This tension can be described with the Principal-Agent problem, that describes policy-making as a relatively difficult exercise in a complex environment. In this chapter this complexity is explained, with the focus on how to create policies that have impact on the science system in which funding is used as an example. The notions found in this chapter will be used within the model. Three types of public research funding regimes are distinguished, with the focus on public research organisations, by using complexity theory and the theory of incentives: principal-agent problem (Bolton & Dewatripont, 2005; Laffont & Martimort, 2009).

4.2 THE PRINCIPAL-AGENT PROBLEM & CONTRACT THEORY

Principal-Agent theory is used to describe the effects of funding regimes on the performance of public research organisations (PRO). Answers can be used to postulate hypotheses on how funding regimes and performance indicators of PRO's interact and how it could be incorporated within a model environment. Societies spend significant amount of their public expenditures for research and

development, in the Netherlands equal to 0.74 per cent of the gross national product (Rathenau-Institute, 2015a). For this investment the government expects something in return. This could be the production of knowledge that is useful for society, inducing the production of knowledge in prospective research fields or developing research skills of students at universities (van Dalen et al., 2012). However, while government can have specific expectations, they have limited knowledge on how to conduct research and how to explore and develop promising research field. Because research institutions do this on a daily basis, they are much better in understanding the research field. The situation in which the policy maker [the principal] wants to induce specific behaviour of researchers [the agents] that leads to a desired situation, while the objectives of both parties are not completely aligned and the information distribution is limited, can be called the principal-agent problem (Laffont & Martimort, 2009).

The theory on the principal-agent problem can be described with an example in the physician-patient relationship (Fernández-Carro, 2007). The principal, which is the patient, is not able to monitor the conducts of the agent, which is the physician. The relationship between the conducts of the physician and the positive outcomes of the treatment are not necessarily aligned, yet it is assumed that there is some connection. However, the fee the physician charges for his conducts is in no way related to the outcome. In many ways the objectives of the principal and the agent are not aligned. Contract theory then asks the question how the Principal can set the right incentives that the agent will act in best interest of the Principal. The best contract will then depend on the difference in objectives among the Principal and the agent, the uncertainty between input and output and the degree in which the output can be monitored (Fernández-Carro, 2007; van Dalen et al., 2012)..

4.3 SETTING THE RIGHT INCENTIVES

The government wants to set the right incentives to enable the agents [researchers] to conduct research in the best interest of the Principal [government]. Contract theory is used to analyse the best contract between the two parties that induces the right behaviour of the Principal in the presence of information asymmetry (Bolton & Dewatripont, 2005). Three different asymmetries can be identified within the funding of science system: the gap between objectives of the Principal and the agent, the uncertainties in the research process and the ambiguity of output indicators (Fernández-Carro, 2007; van Dalen et al., 2012). Then three different contract incentive schemes will be identified: high-powered incentive contract, low-powered incentive contract and no-powered incentive contracts (Fernández-Carro, 2007; van Dalen et al., 2012).

THE GAP BETWEEN OBJECTIVES

The government has several goals to achieve in supporting public research organisations. Policies for science should enable the production knowledge, let society benefit from it and teach research skills to students (OCW, 2014). The government also wants to promote that research is relevant for society. However, the multitude of objective can challenge the relationship between the Principal and the agents. First, the government and research institute can perceive the objectives differently, which could lead to different research, as the government has national objectives in mind while research institutes can have more specific objectives in mind as described in Section 2.4 and 3.2. Secondly, the government is not the only institution that supplies incentives to research organisations. There are more funding partners that could have the influence in how the research

institutes explore their research objectives. Thirdly, research institutes, in contrary to the government, intrinsically cares about reputation in the hope of attracting prospective students, staff and funds (van Dalen et al., 2012). As these concerns also play a crucial role how research institutes define their objectives, it is not always easy to align the objectives and work towards a common goal.

PROCESS UNCERTAINTY

Conducting research with the aim of developing new concept and ideas is not always successful. It could happen that a promising research project leads to limited or no results, while it could also happen that a minor project could lead, sometimes by chance, to a paradigm change in science. In a situation that results are expected and a researcher is goal driven, fraudulent research can be conducted which is, in no means, useful for society as a whole and the research institute. Secondly, the government can have a different perception of research results. While the researcher would disregard a study as not 'publication worthy' it could have its influence on society.

AMBIGUITY OF OUTPUT INDICATORS

Bibliometric outcomes of research such as publications and citation counts are well defined and quantifiable. However it is not the all-encompassing instrument to determine knowledge production. There are more indicators, that are harder to determine in quantitative terms, that influence knowledge production such as producing relevant research for society. As such, the government can expect certain research output by steering with funds, but will neglect research that is more likely to be immeasurable. While funding is a steering mechanisms to incentivise research performance, many other organisational factors can be determined that influence research performance, which can be found in Appendix 2.

SUMMARY

Policy makers intrinsically expect they have full control when it comes to regulating the science system (Rathenau-Institute, 2015a). From their linear and normative perspective, they create policies that should have the intended impact. However, these asymmetries make it increasingly difficult to manage and direct the science system as a whole. Therefore a new perspective on the use and implementation of policy instruments is needed to deal with these asymmetries. Additionally, policy makers should understand that detailed regulation is not possible as the science system is subject to a multitude of actors, external incentives and factors that create an environment where actors could behave irrationally. In such an environment linear decision making and top-down regulation is not the right approach. Based on these asymmetries, three incentive schemes, which are adapted from (van Dalen et al., 2012) and shown in Table 6, will be introduces that can mitigate the issues with detailed regulation.

HIGH-POWERED INCENTIVE CONTRACT

In this incentive scheme the government steers PRO's with funding that is based on research output and knowledge production. As this is not a quantifiable indicator, there can be a fixed amount of funds per publication or for every citation. With this scheme, the government would stipulate the production of as many units of knowledge until the marginal reward for the paper is larger than the production cost (van Dalen et al., 2012). This would be a promising incentive scheme, if is a causal relationship between the efforts of researchers and the research results. However, there is not always a positive relationship between the efforts of the researcher and the production of new

knowledge. In many cases, the emergence of new technologies or promising innovations happen by chance. The government, that acts as the principal, is however not able to monitor the quality of the produced knowledge effectively. Therefore, this incentive scheme can just be used when there is a close cooperation between the government and the researcher.

LOW-POWERED INCENTIVE CONTRACT

In this incentive scheme the government does not control the output but sets the research agenda by funding specific research. This incentive scheme could be promising as research results are hard to monitor and do not always lead to the expected results. Two low-powered incentive schemes can be distinguished: one where the goals of the government and the institution are perfectly aligned, in which the incentive leads to the right behaviour, and the one where goals are not aligned and different studies will be conducted. As the government does not regulate the research output, it can waste resources with unsuccessful research and different perception of objectives.

NO-POWERED INCENTIVE CONTRACT

In this incentive scheme the government does not control the output nor does it set a research agenda. A study by Holmström (1999) on institutional incentives shows that, even in the absence of an incentive structure, the agent can still perform in the best interest of the Principal. If motivational and reputational concerns drive the performance of institutes, and the objectives are aligned with the government, monetary incentives might not be necessary (Holmström, 1999). With this scheme, research institutions will allocate their funds to their best means and conduct research both in the interest of the institute and society.

SUMMARY

Different information asymmetries between the governmental policy-makers and the PRO's call for different contractual agreements. Table 6 shows the different contract incentive schemes the government can adopt to manage the science system and steer for productivity. When there is a large gap between objectives and the process and output can be understood and monitored, the government can adopt a high-powered incentive scheme. When there is a small gap between objectives and the process and output cannot be monitored, it is better to let the PRO work independently and no incentive scheme is necessary. However, in many cases the uncertainty of the three information asymmetries are not definable. Additionally, not all combinations of information asymmetries fit within this scheme. Then, no optimal incentive structure can be chosen. However, if an incentive structure can be chosen based on the available information, a number of funding regimes can be identified.

Contract Incentive Scheme	Objective Gap between Principal & Agent	Process Uncertainty	Degree in which Output can be Monitored
High-Powered Incentive	Big	Low	High (partly)
Low-Powered Incentive	Average	High	Low
No Incentive	Small	High	Low

Table 6: Incentives for the science system, adopted from (van Dalen et al., 2012)

4.4 POTENTIAL FUNDING REGIMES

Based on incentives schemes that are identified in the previous section, potential contracts can be formulated that set the relationship between PRO's and the government. A distinction can be made between performance-based funding, performance agreements or lump sum funding. Performance-based agreements are associated with a system that funds for actual performance, so after the actual performance has taken place (ex-post), performance agreements are associated with future performance, so before the actual performance has taken place (ex-ante) and lump sum funding agreements are associated with a system that funds without ex-ante or ex-post performance requirements.

- *Ex-post funding*: Based on the high-powered incentive scheme, this funding contract entails the outsourcing of control from the government to the PRO's. They determine the research agenda, while the government monitors the output and efforts of researchers. Funds will be awarded based on the output of researchers and is not fixed beforehand. This can mean that the government has to adjust their performance expectations to the amount of funds it is willing to spend on research. However, because the performance requirements are set beforehand, this funding regime can cause perverse effects where physical requirements are met but quality is discarded. As an analogy; in the medical research field it is required beforehand to publish at least 2 articles before the PhD program is completed (Rathenau-Institute, 2015a). Consequentially, researchers publish as many papers as possible, often they split studies and disregard quality to attain a high publication count.
- *Ex-ante funding*: Based on the low-powered incentive scheme, this funding contract entails the regulation by the government, or associated research institute such as NWO, to define the research topics and the researchers conducting that research. The choice for researchers can be predefined or allocated under open competition. Funding does not necessarily lead to high productivity or research output. However, because the reputation of the research organisation is at stake, individual researchers will use their professionalism to create high impact research. The size of the research organisation is dependent on the allocation of funds. This could lead to an unwanted situations where research organisations who were, in an earlier stage, successful in applying for ex-ante funding, become bigger and more skilled in the application process, therefore securing more funds. As such, organisations who already have a history in securing funds are more likely to secure more; which is a success to the successful archetype and a market failure (Sterman, 2000)
- *Fixed funding*: Based on no-powered incentive scheme, this funding contract entails that the government sets a fixed yearly budget and allocates it to PRO's to conduct research. The government, that does not monitor the process or expect certain results, allocates the funds that the organisations can use efficiently. If the objectives of the organisation and the government are aligned this will eventually lead to the expected results. However, as previous chapters explained, PRO's often have different objectives in mind making research not always in the best interest of society.

SUMMARY

Most countries use one, or a combination, of these funding regimes to support their science system. The ex-ante funding regime can be compared with project funding, the ex-post funding regime can be compared with contract funding and the fixed funding regime can be compared with institutional funding. While in most countries there is one dominant form of funding, the Netherlands has it emphasis on more funding forms (Versleijen & van der Meulen, 2007). Table 7 shows the main characteristics of the different types of funding regimes across the four dimensions. Based on the different types of research project, a contract scheme can be chosen. It is however important to note that not all dimension combinations are shown. As such, it is difficult to choose a funding scheme in light of ambiguous information asymmetries, science system complexities and variety of research projects.

Contract Incentive Scheme	Outcome Control?	Budget Control?	Research Control?	Subject Control?
Ex-Post funding [High-Powered Incentive]	Yes	No (yes – with goal adjusting delay)	No	No (yes – with additional funds to promising fields)
Ex-Ante funding [Low-Powered Incentive]	No	No	Yes	Yes
Fixed Funding [No Incentive]	No	Yes	No	No

Table 7: Limitations and opportunities of different funding regimes, adopted from (van Dalen et al., 2012)

4.5 SUMMARY

The information asymmetries between the policy-makers and the professionals conducting research make it difficult to set the right incentive. From the governmental perspective, research should be focused on creating knowledge for society, while researchers would be also focused on reputation and career perspectives. Based on these asymmetries three funding contract regimes have been identified, in the hope of inducing behaviour among researchers. However, it is not known how these funding regimes interact with the workforce and performance of researchers within the science system. Because the science system is inherently complex, mental models do not suffice in understanding the mechanisms that work. To test these regimes and the earlier identified policy measures, a model environment is needed. Chapter 5 describes the need for simulation more extensively, and chooses SD as the method of preference.

PART 2:

METHOD

5. MODELLING METHOD

In this chapter the choice for the modelling method will be further explained. Based on the identified knowledge gaps, the limitations of previous research and the notion of decision making in complex environments, a modelling method is chosen with the aim of understanding the system and inherent system complexities while providing a tool for decision making. Previous chapters have clarified the difficulty of analysing the complex environment in which the science system is situated. System Dynamics (SD) is a method to understand and analyse inherently complex non-linear systems (Forrester, 1994; Sterman, 2001). Here the main concepts of the system dynamics (SD) framework will be shown. It will further explained why this multifunctional method is the prime tool for adequately addressing the main research problem. Section 5.1 shows previous studies within the science system assessment field. The limitations of these studies will be clarified, which is the basis for a different research perspective. Section 5.2 explains the need for a simulation study to adequately address the research problem. Then, in section 5.3, different modelling methods are summarised and SD is adopted as the chosen method. Section 5.4 will explain the SD method in further detail. Based on the chosen method, other science system related SD studies will be shown in section 5.5. This study partly builds on previous studies conducted in the science system where SD was used as the method for analysis.

5.1 ACADEMIC RESEARCH LIMITATIONS

The science system has changed substantially over the years. Many policy instruments have been enacted to deal with the ever changing system. In the Netherlands, the Rathenau Institute, assesses the science system and studies the effects of a the changing system and the impact of policies. Over the years many studies have been published (Arensbergen et al., 2013; Van Balen, 2010; van Balen et al., 2012; van Balen & van den Besselaar, 2007; Versleijen & van der Meulen, 2007). Other organisations in the Netherlands, both public and private have also studied this field extensively (De Jonge-Akademie, 2010; de Boer et al., 2015; van Dalen et al., 2012). The main focus of these studies were either qualitative, with the use of interviews or surveys, or quantitative, correlation based with the use of comparative or statistical methods. However, these studies analyse the system from a static perspective. Moreover, it perceives the behaviour of actors, and their interaction, both on governmental and institutional scale as static and unchangeable over time. This, however, does not suffice when the system under study is a complex collection of partially connected sub-system that interacts and changes over time.

In general, policy makers perceive problems as series of cascading events, which could lead to event oriented problem solving (Kwakkel & Pruyt, 2013). However in social systems the policy maker does not only influence the system but is also embedded in the system. In the science system, the policy makers within the government that use policy instruments to drive research behaviour, perceive the system linearly and information symmetrical. From their normative perspective on the science system they create policies with impact. However, in inherently complex, interwoven and adaptive systems, detailed regulation is nearly impossible (Rathenau-Institute, 2015a). As such, policy makers could enact polices with specific positive expectations, but create policies that lead to adverse effects and counterintuitive behaviour.

The policy makers want to understand how enacted policies behave in the science system. However, due to inherent system complexities, simple implicit mental models do not suffice. In this situation modelling and simulation can be used to test certain policies within a virtual setting without actually testing them in real life.

5.2 THE NEED FOR SIMULATION

Statistical or Implicit mental models are inherently deficient when analysing complex systems as they do not incorporate causality and interaction (Pruyt, 2010; Sterman, 2001). Complex systems are multi-layer systems where all layers and agent within the layers interact with each other in multiple ways (Porter, 2004). Concepts such as interacting behaviour, time delays, accumulations and non-linearities all have to be taken into account if policy makers want to make sense of their enacted policies. However, studying these complex linkages at various parts of the system can be a time-consuming, costly and, in some cases, practically impossible task. Due to these constraints, modelling the system and simulating the problem field is the only realistic way to test the system on policy behaviour. Figure 11 shows these constraints: reality cannot be analysed practically, therefore the perceived system is deduced to its key characteristics in a model environment. Based on a virtual environment, the model can be used for policy experiments. Now the model can be used by the policy maker to understand the real-world system and the impact of enacted policies.

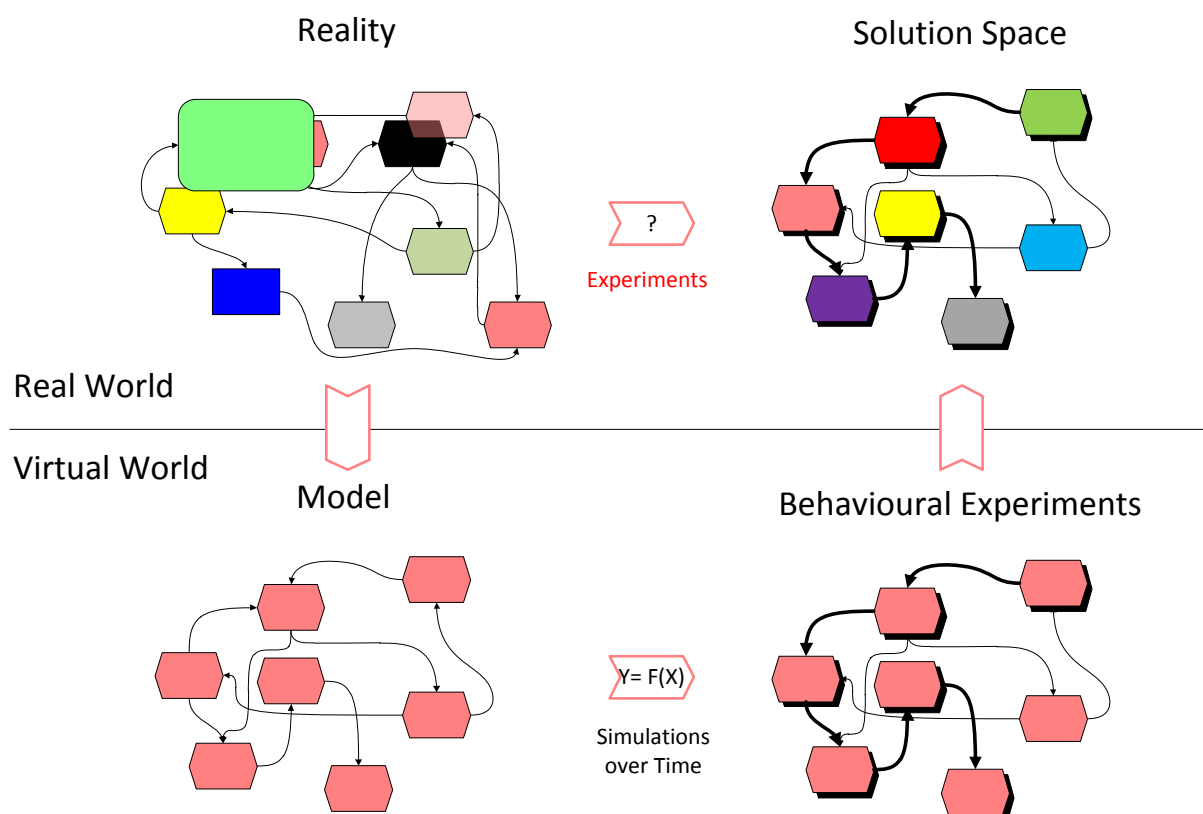


Figure 11: The need for Simulation, adapted from (Borshchev & Filippov, 2004)

Building an explicit model could change the way the system under study is conceived. Not because models are inherently correct and provide accurate predictions; none of them do; but because it creates a conceptual environment that structures the mental process while providing a tool on which the modeller and others can replicate the data and use it for system forecasting. Another advantage

of modelling is the possibility to conduct sensitivity analysis. A wide range of parameters can be tested over a vast range of scenarios to identify important uncertainties, regions of robustness and thresholds (Sterman, 2001). Revealing these trade-offs, sensitivities and uncertainties can substantiate the dialogue about the system under study.

A modelling method is needed to incorporate the problem field, that overcomes the limitations of previous educational research, unconstrained by demand for analytic tractability, based on realistic assumption about human behaviour and grounded in the field of policy analysis and decision making.

5.3 DEFINING THE METHOD FOR THE SYSTEM UNDER STUDY

There are many problems that can be efficiently addressed by creating simulation models. However, there are many modelling methods that serve different goals and different problems. Based on the chosen system scope, the problem demarcation and the system characteristics a modelling method can be chosen.

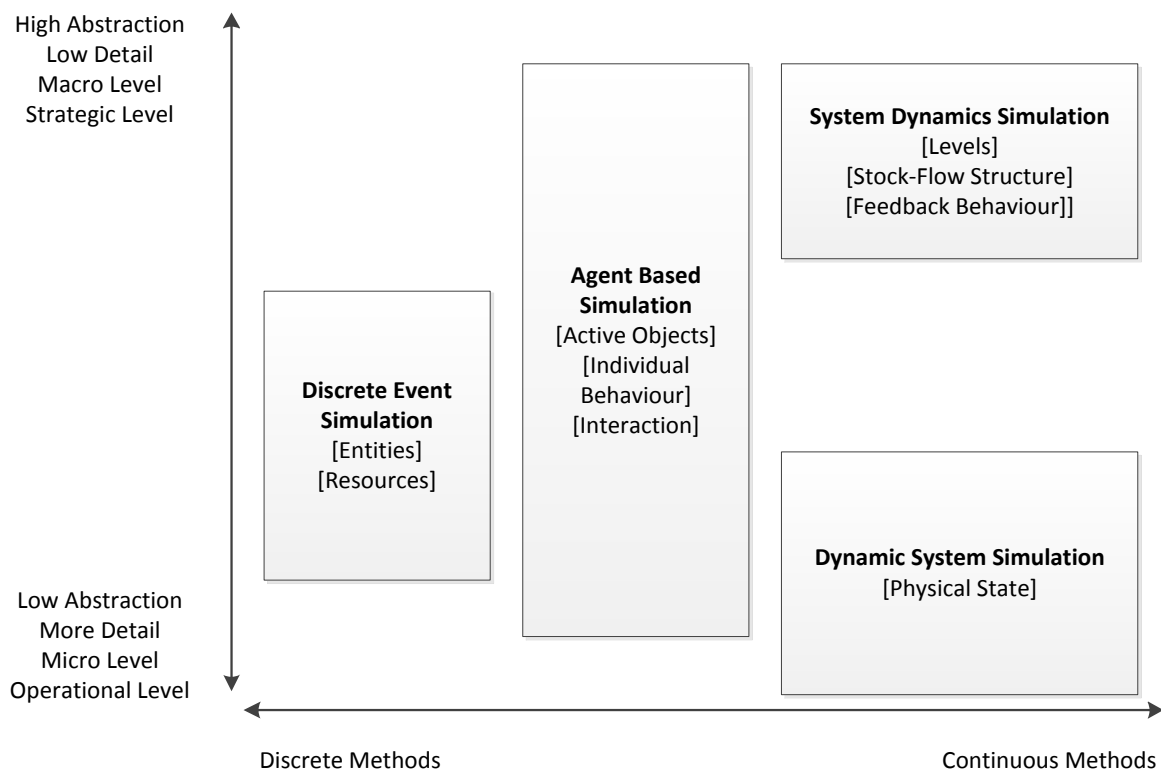


Figure 12: dapted from (Borshchev & Filippov, 2004): Problem approaches and simulation methods based on their abstraction and their system state

Typically, problems are arranged based on their level of abstraction and their event (discrete) or time (continuous) based characteristics as shown in Figure 12 (Borshchev & Filippov, 2004). At the low abstraction level, physical simulation models are used to integrate exact concepts. Less detailed system, such as factory floor models, are more abstract as they integrate average physical trajectories and timings. Business process and network models are even more abstract as they perceive the system from a macro level, that studies aggregated processes instead of individual change. The highest level of abstraction often deals with global trends and aggregated values. Based on the perception of the system one can choose for a discrete method, where the state of the

system changes discretely (one entity at a time), or for a continuous method, where the state of the system changes continuously (fraction of the entity per time step). In a discrete simulation models, system constructs are identified in terms of events leading to a certain situation, in which the simulation is advanced from time event to time event based on the model requirements and the perception of the model environment. In a continuous simulation model, system constructs are identified as a set of equations that change over time, which can be a fraction of the studied event or entity.

The main approaches in simulation modelling are Dynamic System Simulation, System Dynamics Simulation, Discrete Event Simulation and Agent Based Simulation. Figure 12 shows the different approaches based on their abstraction level and model orientation. The Dynamic System methods are often at the bottom of the chart and typically integrate specific and detailed concepts to perceive the time varying behaviour of the system under study. The System Dynamics method is often used for more aggregated, less detailed systems that try to understand the behaviour of interacting concepts over time from a more strategic perspective. The discrete event methods are often used to model the operation of a system as a discrete set of events that occur over time. Agent based methods are often used to understand the individual and collective behaviour of agents within a multi actor system over time.

This study tries to understand and analyse the effects of policy measures on the development of the academic workforce in the Netherlands. Chapter 2, 3 and 4 show the inherent complexities of the science system in the Netherlands. Simple mental models are intrinsically flawed when dealing with these complex systems. Statistical methods, which are based on correlations, only perceive the impact of given policies on specific intervals. Qualitative based methods could not show the development of academic staff over time. Therefore a model environment has to be chosen, as the real-world science system is too difficult to comprehend with mental models and real-world experiments are constrained by time, costs and practicality. The focus will be on aggregated processes: the development of academic staff in the science system and the effect on research performance over time. This calls for an abstract modelling method that does not look at detail but perceives the system from a strategic level. The focus will be on continuous system state as the workforce is considered in full time equivalents, that change over time, to get the optimal results from a system perceived from an abstract level.

System dynamics is an adequate modelling method to tackle the research question as it could incorporate the different concepts of the science system, its inherent complexities, its continuous interaction and the impact of policy measures over time from a strategic level.

5.4 THE SYSTEM DYNAMICS MODELLING METHOD

System Dynamics is a method for analysing dynamic systems to support policy analysis and decision making. The main difference, compared to other model environments, is the emphasis on dynamic interacting processes where complexity comes from within the system. A SD model is created to provide insights into the behaviour of the system through its structure (Forrester, 1994). While SD has been a well-used method for system analysis it is rather new in exploring the workforce

development in the science system (Navid Ghaffarzadegan et al., 2014). Chapter 5.5 shows previous science system SD studies.

Creating a model is equivalent to reality deduction: not all real-world concepts can be conceived, interpreted, explained in mathematical terms or included in the model. Because this will inherently lead to uncertainties in the model, SD models cannot be used for accurate forecasting and prediction but rather as models that explore the behaviour of the perceived system over time (Forrester, 1992, 1994; Sterman, 2000).

SD models are comprised of stock-flow structures and feedback loops. Feedback loops represent causal relations between two variables, where one variable influences the other. An example can be found in Figure 13. The population increases when there is a constant birth rate, leading to more births over time, which is a reinforcing feedback loop. However the population also declines due to deaths. This behaviour, that stabilises the population over time, is a balancing feedback loop. Feedback loops are an important concept in SD models, as multiple feedback loops, both positive (reinforcing) and negative (balancing), can cause dynamic complexity, or unexpected behaviour, over time.

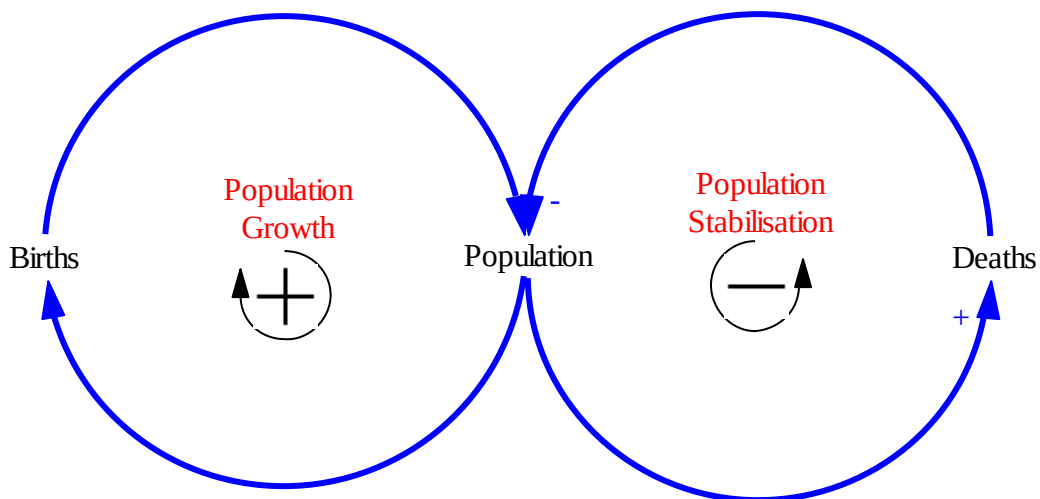


Figure 13: Example of a Feedback Loop

Another important concepts within SD models is the stock-flow structure. Stocks represent bathtub variables that increase or decrease by flows over time as shown in Figure 14. To use the same example: the population of a society, without any immigration and emigration, increases with births and decreases with deaths. The mathematical representation of a stock is shown in equation 1. It is a first order integral equation where t_0 is the initial time and t is the time of the model.

$$Stock = Initial\ level + \int_{t_0}^t (Flow\ 1 - Flow\ 2) dt \quad (1) \text{ Stock Flow Mechanism}$$

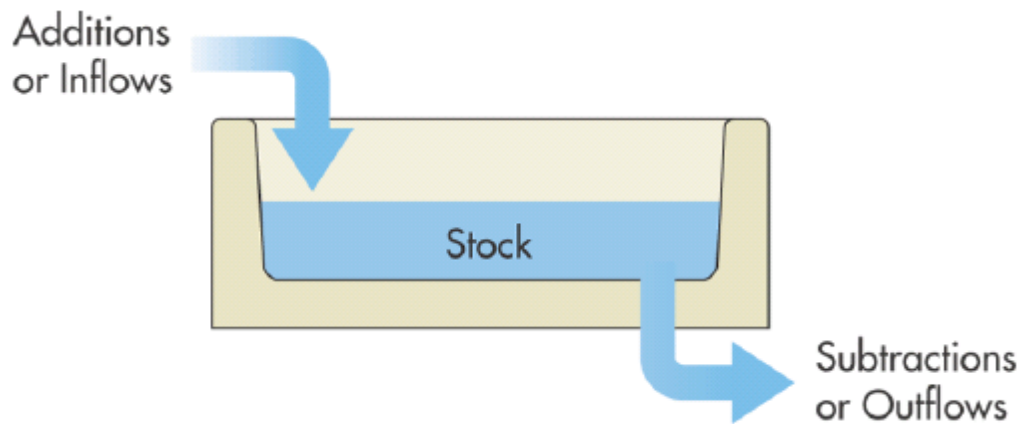


Figure 14: Example of Stock-Flow Structure

Figure 15 shows the stock-flow structure in the model environment. Auxiliary variables can influence the stock by changing the in- or outflow rate, which is based on a value per time unit. Constants, which remain the same during the run of the model, can also influence certain parts of the model. The figure shows a reinforcing and balancing feedback loop which means that the population either grows exponentially or stabilises depending on the dominant feedback behaviour. In a model with multiple feedback loops, or interacting mechanisms, it is hard to anticipate system behaviour.

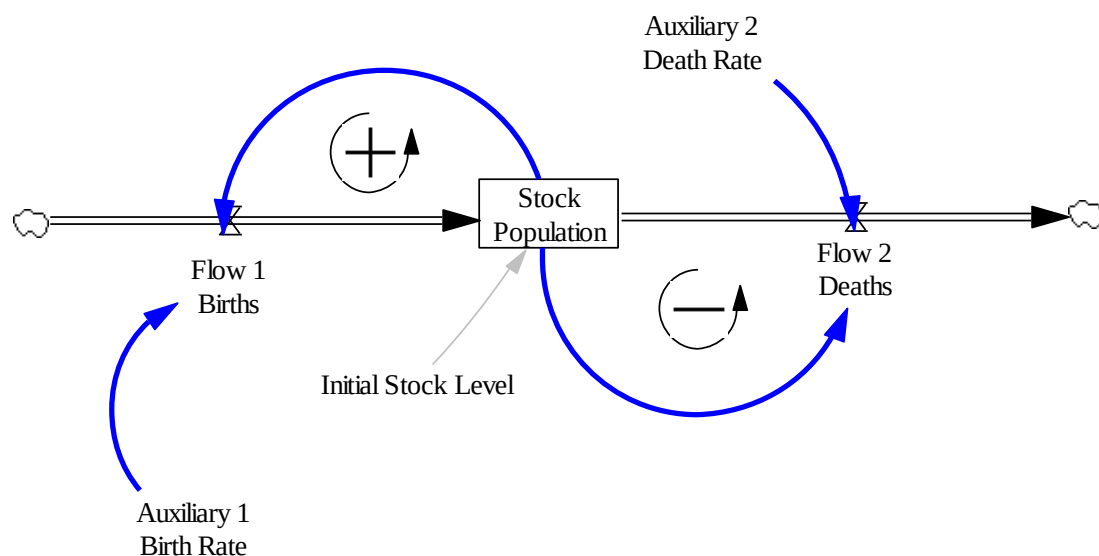


Figure 15: Stock flow Structure within a model environment

By connecting the stock-flow structures with feedback loops, an appropriate system description can be reached. These interacting stock-flow mechanisms are then analysed as a whole, and not in isolation, to perceive an interacting system over time. These interactions are crucial when analysing the science system, since a policy, that influences the science system for a certain period, can change the policy perception or influence the system in unexpected and unwanted ways.

SD model output is generated by computing all the integral equations used based on a numerical integration method. In the modelling program Vensim, which is used for this study, Euler and Range-Kutta methods can be used. It can be represented in a graph of the variable of interest over time as seen in Figure 16.

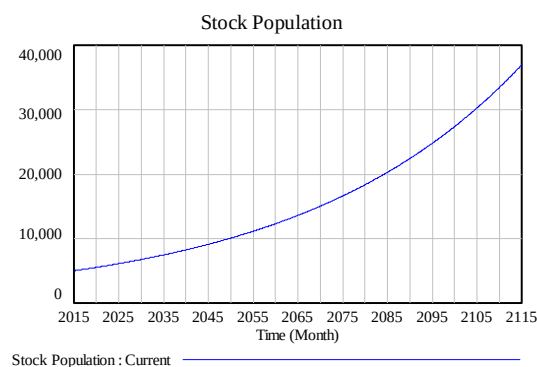


Figure 16: System dynamics output diagram

5.5 SYSTEM DYNAMICS SCIENCE SYSTEM STUDIES

The amount of research into educational and science system policies with the use of System Dynamics is limited. Kennedy has published several articles about managerial issues at higher education (HE) organisations. The first paper describes the efforts to develop a model that “assesses the complex set of variables concerned with managing quality in higher education” (Kennedy & Clare, 1999). Being a pilot study many non-real world concepts were used within the model making the validation difficult. However, a first foundation was created that links concepts (funding, research output, staff performance) within HE organisations in a model. A follow-up study by Kennedy describes the issues in human resource management processes in higher education institutes (Kennedy & Clare, 1999). Various structures have been proposed to link and assess the impact of resources on the quality of research. Relative importance between the concepts and the inclusion of actor behaviour was not included. Since then, two studies have been published by the same author that review the past studies on educational policy issues and includes topics such as: corporate governance, planning, resources and budgeting, human resource management, quality and enrolment (Kennedy, 2000, 2011). While most studies acknowledge the complex interaction in higher education institutes, only few use methods such as SD that incorporates system characteristics (Oyo, Williams, & Barendsen, 2008). A study of Try measures the relationship between resources and outcomes using hierarchical linear modelling (Try & Grøgaard, 2003). However this study sacrifices non-linear dependencies. A study by Vinnik and Scholl also use a linear approach to explore the relation between educational capacity and resource management. They, however, did not include the concept of quality.

In his book *Business Dynamics* Sterman develops a model of academic promotion within universities based on different stages of the academic career (Sterman, 2000). His research is based on the promotion and exit rate of scientific staff at the Massachusetts Institute of Technology between 1930 and 1993, in a modelling example how aging chains within organisations can be used to describe the distribution of persons within a hierarchical system. Oyo seems to be the first one to extend that model by including funding, quality and policy aspects (Oyo et al., 2008). His initial assumption about

the direct link between educational activities, its strategic directions and the produced quality form one of the main assumptions for this thesis work. However, this study focusses on educational literature and concepts in a developing world country with the emphasis of funds acquisition.

In a study by Larson and Gomez an aggregated dynamic model was created to analyse the recruitment process within universities based on a non-fixed retirement age (Larson & Gomez Diaz, 2012). In a follow up research Gomez describes the transition between young researchers and established researchers (Gomez Diaz, 2012). A study by Ghaffarzadegan shows the workforce distribution among national and international postdocs for biomedical research in the US (Ghaffarzadegan, Hawley, & Desai, 2014) The model suggests that mostly international researchers benefit from funding. Researchers that might go return home after finishing their employment could lead to a brain drain. Another model from the same author researched the notion of underemployment in industry due to the increase of PhD graduates and the resulting diploma depreciation (N Ghaffarzadegan, Xue, & Larson, 2014).

Overall, none of these studies have specifically focussed on the influence of career and financial policies on the workforce development within public research organisations in the Netherlands. More importantly, none have dealt with the notion of uncertainty within the constructed models. This thesis addresses that gap and focuses on the workforce development.

6. MODEL BUILDING

[inputs – outputs – environment]

The system SD model is the backbone of this research and therefore the prime tool for analysis. It also serves as a descriptive tool for system analysts who want to examine the behaviour of academic staff in the workforce development system. The complete model is an effort to include the different stages of the academic career, the effects of funding and career policies and the influences on the research output. The aim of this chapter is to describe the structure of the workforce development system within the system dynamics model environment. The focus will be on how the system is conceptualised in the model and how specific concepts interact and drive system behaviour. Section 6.1 will describe the model implications which were found in the theory chapters. As the model is only a limited representation of the real-world system, some assumptions have to be made (Forrester, 1997; Sterman, 2000). Section 6.2 will give a general overview of the feedback behaviour and scope of the model. Then in section 6.3 all segments of the model will be shown and explained. Section 6.4 will present the uncertainties within the model environment. Then in section 6.5 model specifics will be detailed.

6.1 MODEL IMPLICATIONS

The science system theory on academic workforce development, analysed in chapter 3, 4 and 5 show an image of a complex and interwoven system. Based on interviews with system experts from the Rathenau Institute the most important concepts were taken into account (Rathenau-Institute, 2015a). However, not all real-world concepts can be incorporated in the model, simply because the real-world system is too complex to comprehend and there are always more correlations and causalities between system concepts than are conceivable (Sterman, 2001). Appendix 2 gives, for instance, an insight into the many factors that determine research performance in academia. To deal with this, the real-world system will be reduced by making several assumptions that are shown below. It is, however, valuable to know what this reality reduction can have on the validity of the model results. First the model implications found in the theory will be shown. Then the limitations of reducing real-world concepts into a model environment, and the impact on the validity of the results, will be discussed.

IMPLICATIONS FOR WORKFORCE DEVELOPMENT [CHAPTER 2]

The different career positions will be integrated within the SD model, with the focus on reproducing the structure of the academic promotion chain and the behaviour of researchers within this chain. The structure will resemble the workforce development figure found in Appendix 1.

- The model will focus on full time equivalents, and not individual researchers. This is a choice based on WOPI-data availability, the use of the continuous modelling method SD and the accuracy of fte's, which would compute the best results for the intended purposes. Focusing on people would not render the best results as the multiple part-time functions are not equally distributed over the academic positions.
- Most temporary appointments are PhD-candidates and OAS, while most permanent appointments are assistant-, associate- or full professors (Goede et al., 2014). It is therefore

assumed that these appointments are strictly separated. Focusing on all these differences would make the model unnecessarily large and unmanageable. Additionally, the focus of this study is to perceive the effects of an increasing temporary workforce as compared with the permanent workforce. While there are also temporary appointments in the permanent phases, it is assumed that they do not deal with same uncertainties as the temporary staff phases and will eventually secure a permanent positions (Enders & Teichler, 1997).

- As is found in literature, there is always a higher demand for academic positions than place (Van Balen, 2010; van Balen et al., 2012). Therefore the job market outside the Dutch universities is always substantially large to satisfy the call for applications making the model supply driven. Thus, Promotion is based on a capacity mechanism and not on a talent requirement, which entails that room in the system becomes available if either enough funding is obtained or academic staff leaves the promotion chain (Van Balen, 2010). If the demand for positions would be smaller than the supply, the non-academic job market would also be included in the model.
- The flow of academic staff follows a linear approach, from PhD-candidate to full professor. Only the OAS position can be avoided by PhD-graduates that evade this position and become assistant professor. In the real-world system, academic staff can evade several positions or be demoted. However, these numbers are negligible and therefore not included in the model (Goede et al., 2014).
- Graduates that become PhD-candidates are hired by the promotion staff, which are the full professors, when enough funding is available. While this is not a real-world concepts, an average number of promotions per year, this will be used within the model to endogenously (from within the model) drive the hiring behaviour of the system. This could lead to changes in the model outcomes as it is not known if the promotion number has remained stable over the years. During the model calibration test and the uncertainty analysis it was found that a capacity allocation mechanism interacting with this reproduction number, which is used and described in this chapter, computes better results than the a sole focus on a stable number. The number is maintained in this chapter to explain the hiring process at universities and to express another perspective on the system.

IMPLICATIONS FOR FUNDING [CHAPTER 3]

The different funding regimes, and the change in total research funding, will be integrated within the system dynamics model, with the focus on understanding the effects on the workforce development.

- PhD candidates are almost completely remunerated with project funding (VSNU, 2015). Therefore the model uses the competitive project funds for the acquisition of PhD staff.
- The amount of funding for educational purposes is mainly based on number and degrees of students registered at the universities. For the model, exogenous growth projections are used to simulate the growth of funding over time. The amount of funding for research purposes is based on a number of factors. Importantly is the number of PhD promotions that increases the funding over time. In the nineties, with the agreement on this policy change, the PhD positions increased dramatically (Goede et al., 2014).
- There is some uncertainty among system experts how the funding of the science develops over time (Rathenau-Institute, 2015a). One view on the development of funding expects growth to happen according to political change and solely based on a funding allocation

scheme (Versleijen & van der Meulen, 2007). Another view links expected research output to the amount of funding as explained in Section 1.6. This thesis adopts the second view where growth in funding is related to research output (Oyo et al., 2008).

IMPLICATIONS FOR PERFORMANCE [CHAPTER 4]

The influence of funding and career policies on the research performance will be integrated in the SD model, with the focus on quantifiable criteria such as research publications. Because research output also comes in different non-quantifiable forms, and there are more additional factors that influence performance as shown in Appendix 2, the outcomes of this model will pose several limitations on the usefulness of this part of the model results. First, with the focus on quantifiable output indicators the image could arise that this is the preferred output, which could lead to wrong incentives. Second, policy makers could assume that they directly steer performance in research organisations. However, chapter 4 describes that in, inherently complex, interwoven systems detailed regulation is nearly impossible. Moreover, the science system works as a professional organisations with a large degree of autonomy, in such a situation top down steering by policy makers does not always lead to the best results. The inclusion of performance is to get insights into the possible change on both the workforce development and changes in the funding structure.

- The model uses data on productivity published by the Rathenau Institute and the VSNU (Chiong-Meza, 2012; VSNU, 2015). This will pose for some limitations as productivity is not equally distributed over the different positions and senior staff is often more occupied with networking and managing than conducting research (van Arensbergen & van den Besselaar, 2012; van Balen & van den Besselaar, 2007).
- Influencing factors as found by in literature and shown in Appendix 2: the ideal age for full professors to be research group leader, the proportionality of junior staff (PhD & OAS) in comparison to senior staff, the diversification of funding and the preference of academic staff over staff from outside the Dutch universities. Many changes in the policy instruments for science is also detrimental for research. This assumes that researchers fare well in a stable and uncomplicated academic environment. Of course these findings represent performance in research groups. It is however assumed that the link between group performance and performance of the total academic workforce can be made. It is important to note that this study, as shown in Appendix 2, only found correlations, and no causations, between these factors (Fernández-Carro, 2007; van Dalen et al., 2012).

6.2 MODEL OVERVIEW AND MAIN CAUSAL RELATIONS

Figure 17 represents the different stages of the academic career in the Netherlands. This structure is followed in the model. Individuals enter as they are admitted to a PhD degree programme and move towards a permanent faculty position directly or through a postdoctoral period. Applicants from outside academia are also admitted to all positions in the promotion chain. Through this paths, a considerable proportion of researchers drops out, graduate and find work outside academia. The focus on this research is the influence of funding and career policies on in- throughput- and outflow of the academic workforce over time and the implications for research performance.

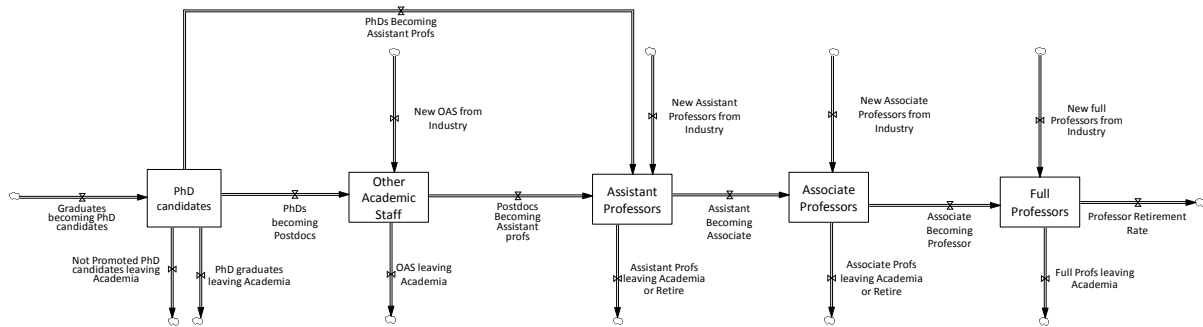


Figure 17: Research Workforce Pipeline and model Boundary. Note that the factors influencing the pipeline (policies & funding mechanisms) are omitted from this view.

MAIN FEEDBACK BEHAVIOUR

Figure 18 describes the main feedback situation in the academic workforce development system. Growth in academic staff is produced by a reinforcing feedback loop: professors promoting their junior staff or hiring from outside research organisations as seen in loop 1. However this growth is limited by the total amount of governmental support of the science system as seen in balancing feedback loop 2. The funding mechanisms, and their positioning, are determined by policy makers and therefore outside the organisational control. Additionally, there are some delays in the system such as the choice and time to hire and the influence of changing the amount of funding or funding regimes. This behaviour can be seen as the limits to growth archetype (Navid Ghaffarzadegan et al., 2014; Sterman, 2001). The causal relationship diagram can be read as reinforcing growth in academic staff, loop 1, limited by the amount of capacity which is based on the amount of funding, loop 2.

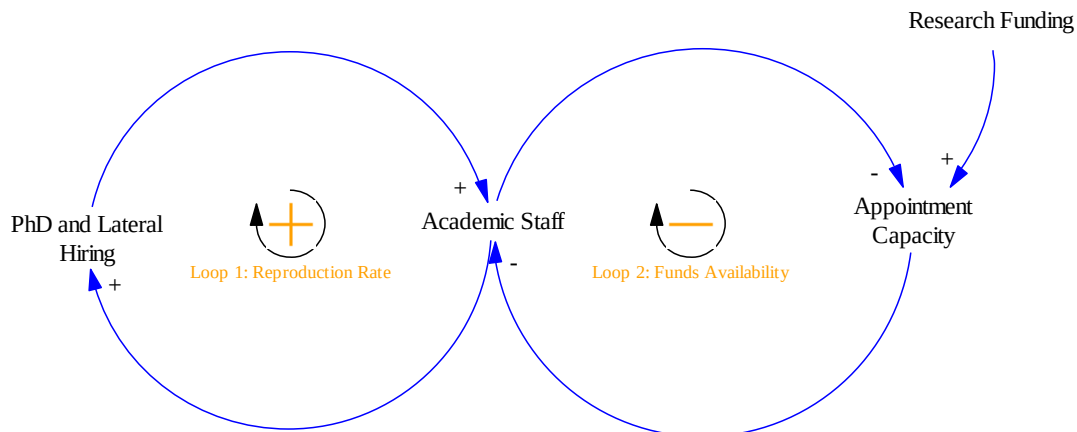


Figure 18: Main Feedback Behaviour in Academic Workforce Development System [Limits to Growth Archetype]

EXTENDED FEEDBACK BEHAVIOUR

Figure 19 shows the extended causal loop model for academic researchers in the Netherlands. There are six major feedback loops in this system.

- Feedback loop 1 represents, in combination with loop 2, a limits to growth archetype. Full professors have the opportunity to promote or hire external, non-permanent, members of academia. It is known that reproduction rate in academia is very high, leading to unprecedented growth if there is no system limitation (Navid Ghaffarzadegan et al., 2014). In

a steady state system this would lead to system saturation; there is no room to absorb new academic staff. This loop therefore grows until the system reaches its peak, after is halted by external limits of the system: the availability of funds and the capacity to hire which is loop 2.

- Feedback loop 3 represents a basic goals-seeking loop: fostering research and scientific discoveries are main motives for the governmental to support the science system with funding. The government, especially the ministry of Education, Culture and Science and the ministry of Economic Affairs, therefore respond to the call for scientific progress, when there is significant political pressure, by investing in research (Gomez Diaz, 2012; Oyo et al., 2008). If the research budget increases, universities can hire additional staff and expand their overall amount of research activity. If the amount of research output is satisfactory, no additional funds are needed. However if the amount of research output is unsatisfactory, a discrepancy between the desired research output and the actual research output arises that incentivise the need for additional funds. As the discrepancy falls, the desire for increasing the governmental budget decreases which, overtime, stabilises the goal seeking behaviour.

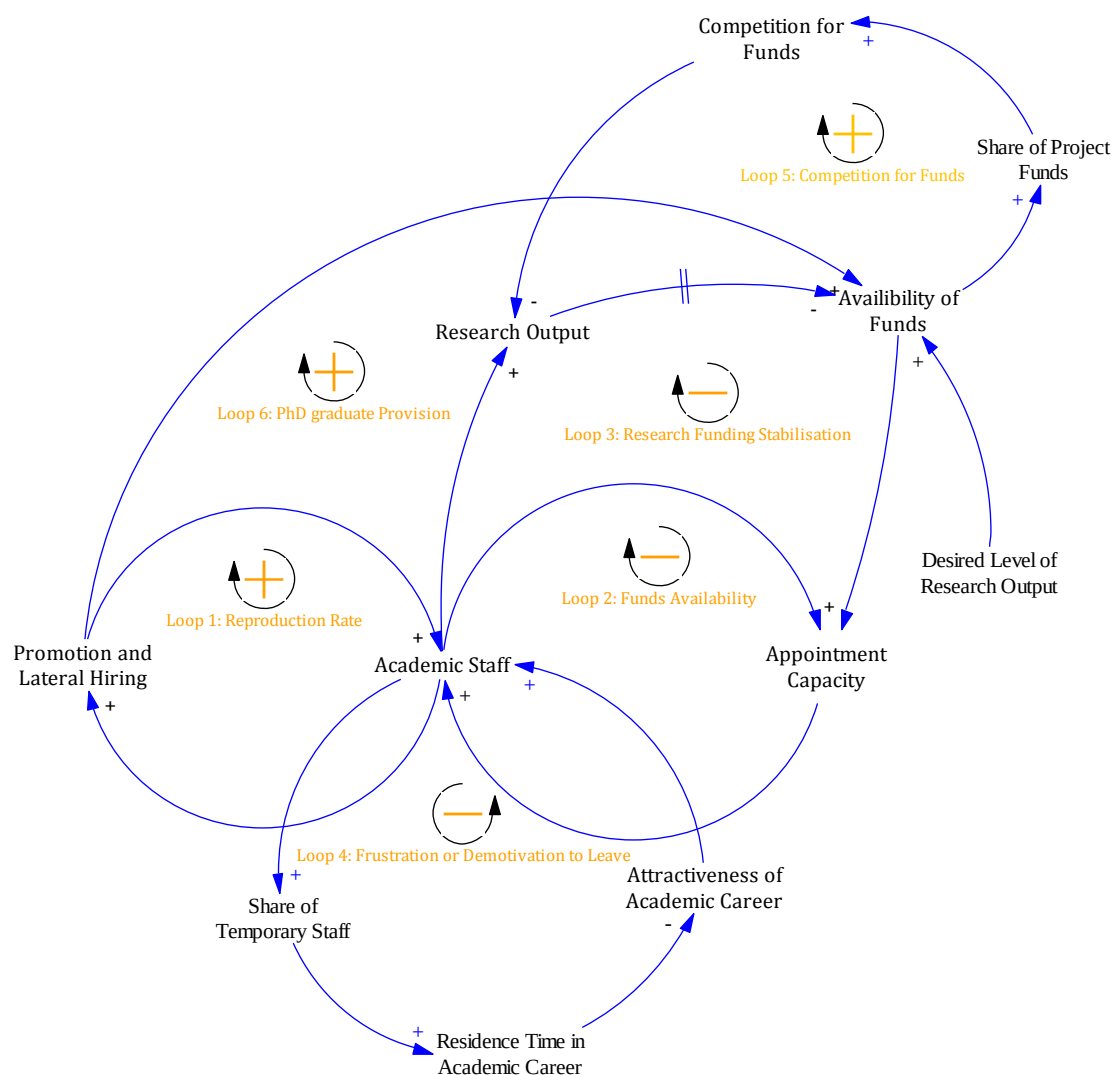


Figure 19: Extended Feedback Behaviour in the Academic Workforce Development System

- Feedback loop 4 represents the workforce development of temporary research staff and the attractiveness of the academic career. It is the psychological, legal or economic pressure

after residing for some time in this positions to leave for an application outside academia (Ghaffarzadegan et al., 2014). Temporary researchers cannot stay in academia forever, as these jobs are low paid and don't provide long term stability. When the residence time of researchers in this position increases they are more likely to face pressure to leave.

- Feedback loop 5 represents the increased competition between researchers to acquire funds. If there are more grants available, competition among researchers to acquire these funds will increase. Researchers will increase their application time to produce more quality, to secure these grants. However, more applications for the same grant leads to more time spent by researchers on writing funding applications. As such, researchers find themselves busy with writing proposals while they refrain from their core activity: research.
- Feedback loop 6 represents a reinforcing growth in funding based on the funding allocation mechanism and the number of new PhD staff. When additional PhD candidate is hired, public research organisations get an additional amount of funds. This growth is halted by the total amount of funding that is available for researchers. This was one of the main mechanisms why researchers started to hire additional amounts of PhD staff from 1994 onwards (van Dalen et al., 2012).

6.3 MODEL CONSTRUCTION

In this section the different model segments will be identified and explored, with the focus on how structure drives the behaviour of the system. The following structure per segment will be followed:

- The development of the stock
- The inflow characteristics
- The outflow characteristics
- Important concepts

PHD CANDIDATES

The population of researchers within the science system increases by the openings created by the promotion staff, which in the Netherlands are the full professors or chairs and corresponds to feedback loop 1, and based on the availability of funds for this group. Professors are often responsible for the strategy and objectives of the research group. As they deem fit, funds are exploited for new research opportunities and, as such, new potential researchers are promoted within the research group. In the model, graduates who become PhD candidates are hired by full professors based on the number of promotions professors are willing to make on a yearly basis and the availability of funds what corresponds with feedback loop 2 and is constructed around a capacity mechanism described below.

Upon successful completion of their PhD, graduates will be confronted whether they want to stay in academia. PhD candidates who continue in academia do so often at their own organisation, however a small proportion moves to other universities. There is also a significant proportion of PhD candidates who do not successfully finish their studies and moves to industry. Graduated PhDs often prefer to acquire a permanent position at their faculty, rather than becoming part of the temporary workforce in academia with the possibility of temporary contract accumulation. However as candidates are often expected to publish several papers in leading journals only a small proportion will get the opportunity to acquire a permanent position right away. However many researchers who

think they have better future opportunities accept low paid academic jobs and stay in academia for a prolonged period (Larson et al., 2013). In the model, the PhD candidates either become promoted, based on capacity availability and a promotion fraction, or leave academia, either upon successful completion of a degree or beforehand. The PhD model segment can be found in Figure 20.

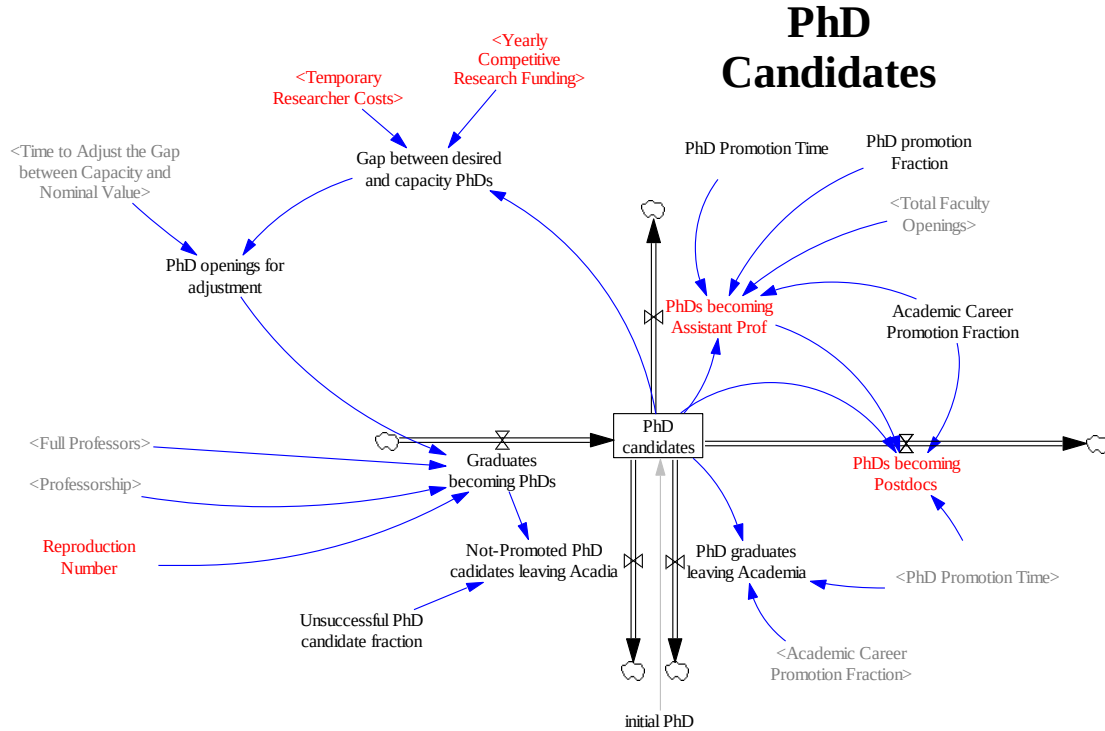


Figure 20: Simplified Stock-Flow Diagram of the in- and outflow of Academic Staff within the PhD Phase

The Basic Reproduction Number (BRN), defined as R_0 , is the average number of PhD candidates that the promotion staff will graduate over the course of their academic career (Larson et al., 2013). To determine this number longitudinal PhD inflow data from the Rathenau Institute is used. Then R_0 can be calibrated over time. While it is an ideal approach to use a model that can simulate these factors endogenously the model boundary is set around the inflow of PhDs in purpose of our stakeholders interests. The main role of the PhD inflow is that it matches and replicates the real data over time. As such the basic reproductive number becomes the object of interest.

When the capacity of academic staff is stable, the entry rate of researchers into academia must equal the exit rate. When $R_0 = 1.0$, each professor will graduate one new PhD that can replace him or her. In a system where a professors tends to graduate more than 1.0 PhD candidates over their active career this stability is affected. If R_0 is bigger than 1.0, PhD graduates would not be able to stay in academia as there is not enough capacity for the faculty positions. However, 50 per cent of PhD graduates want to stay in academia (Goede et al., 2014). For them it is a rational choice to stay in academia in the hope of acquiring a permanent which is, in some sense, beneficial for universities, as they are a low paid and highly trained workforce. Equation 2 describes R_0 , which is based on the average capacity growth rate, μ , C_f is the capacity of faculty staff and δ is the fraction willing to become a permanent member of academia.

$$R_0 = \frac{\mu C_f}{\delta} \quad (2) \text{ Reproduction number}$$

OTHER ACADEMIC STAFF

For TRS positions, the growth of new other academic staff is determined by the openings available due to the exit rate and limited by the capacity. The capacity mechanism, which interact with the funding regimes and the workforce development will be explained in the corresponding sub-section. The number of applicants is a function of the number of PhD graduates who obtained their degree in the Netherlands, as well as the applicants from outside academia. These are often international applicants or researchers who spend some time in business or industry before coming back to academia. It is reasonable to assume that professors tend to prefer PhD graduates over applicants from outside academia. Furthermore, it is reasonable to assume that PhD graduates tend to prefer to acquire a permanent appointments rather than a temporary OAS position. In this case they will skip this step in the promotion chain.

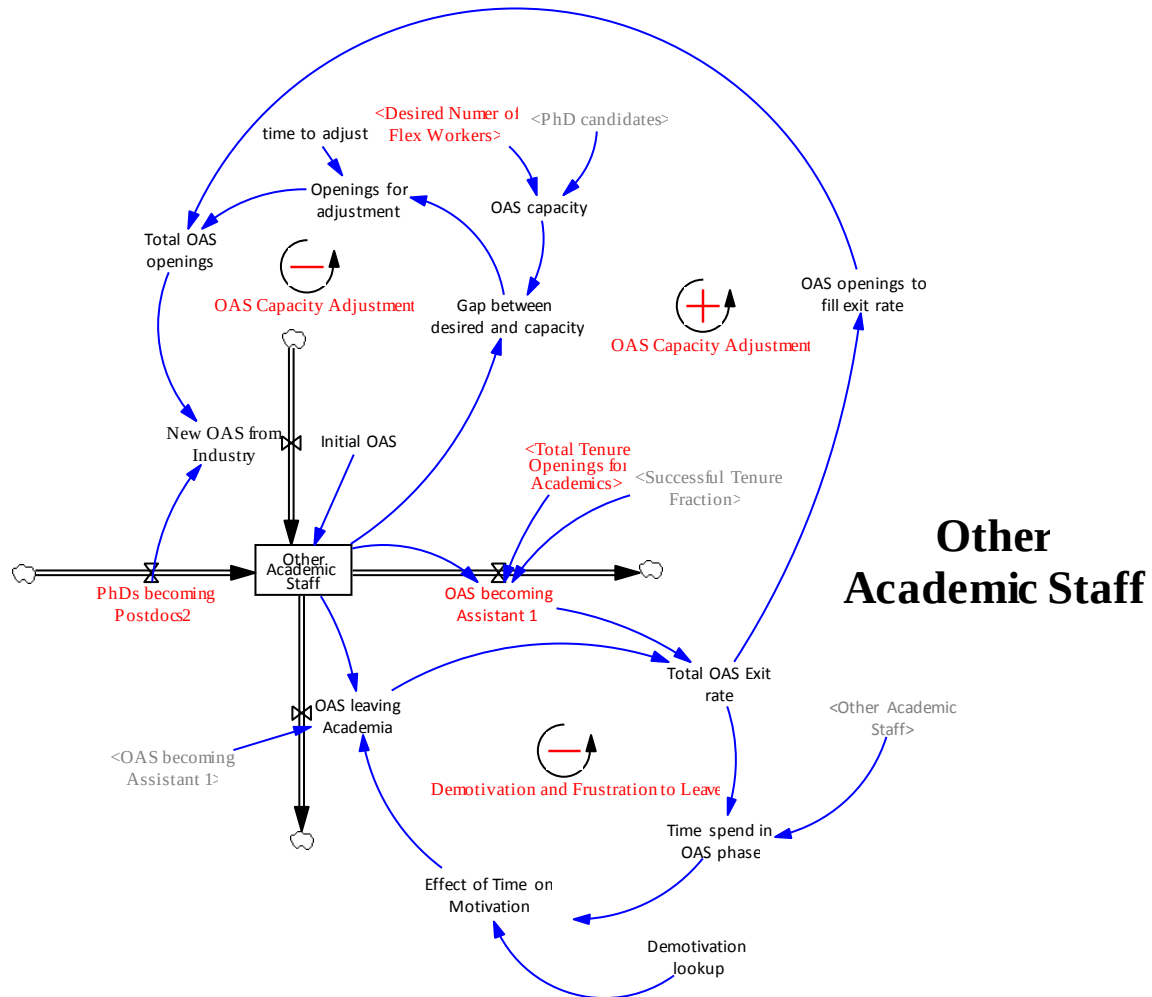


Figure 21: Simplified Stock-Flow Diagram of the in- and outflow of Academic Staff within the Other Academic Staff Phase

For becoming Assistant Professor the same formulation method is followed. In this case, however, also new PhD graduates compete for permanent faculty positions. These are two groups with a

different level of competitiveness. While staying longer in academia increases ones curriculum vitae, by producing more papers and gaining more knowledge it will also lead to more uncertainty in promotion opportunity making it more likely for researchers to leave for industry (Ghaffarzadegan et al., 2014; Hur, Ghaffarzadegan, & Hawley, 2015).

A study by van Balen (2010) emphasizes that the performance of researchers is not directly related to the likelihood of promotion. It was mainly coincidence as being there at the right time with vacancies, the successful acquisition of external funds or the number of published papers. As it is assumed that there is enough demand for academic positions, corresponding to section 6.1, the growth of assistant professors is based on coincidence, and it is expected that with demand the

The growth of Assistant Professors is therefore determined based on a coincidence factor and not a quality factor as assumed in section 6.1. The OAS model segment can be found in Figure 21. The table function of demotivation time effects on OAS and Quality is by the authors' assumption (and maybe in a later stage model calibration). It is furthermore assumed that the proportion of OAS that plan a temporary stay in academia is negligible.

In the model, researchers could go through 3 distinct phases to represent the temporary contract accumulation and the effect of coincidence, demotivation and quality on the promotion flow of these phases. The three phases represent the three 2 year temporary contract the researcher goes through hoping to acquire a permanent faculty position. The maximum duration of OAS is six years in the Netherlands. However the third phase is slightly different, representing the final stage of temporary development at universities also the ones that use loopholes to remain within the academic world. As such average time spent in the OAS phase increases over time, coupled with the coincidence of landing a permanent position could make effect of demotivation bigger.

PROFESSORS

There are three distinct stages that researchers go through when acquiring a permanent position in academia, assistant-, associate- and full professor, that represent their full growth in academia. Some researchers do not follow the promotion chain in a linear fashion, as they get promoted towards a higher position or get demoted. However, from a systems perspective these numbers are negligible (Goede et al., 2014). When a permanent position is granted, most professors have the rare luxury of job security. As such, prospective young researchers want to navigate the hurdles of being a temporary researcher to acquire a much desired faculty position. (Fruijtier, 2007; Larson & Gomez Diaz, 2012). Over the last 15 years the number of permanent positions have remained stable around 8000 with an decreased focus on associate professors and an increased focus on temporary staff (VSNU, 2015).

There are three types of permanent faculty members that can be hired: PhD graduates that did not become postdocs, OAS that are promoted and lateral hires from outside academia in a later stage of their career. For assistant professors, the inflow of new staff is based on these three types. The number of hires is based on the availability of capacity with a preference for non-lateral hires. The capacity mechanism, which interacts with the funding regimes and the workforce development will be explained in the corresponding sub-section. For the other two permanent positions, the assistant-

and full professors, hires are based on promotion of academic staff and lateral hiring. Permanent staff leaves the promotion chain when they decide to work in industry or business or when they retire.

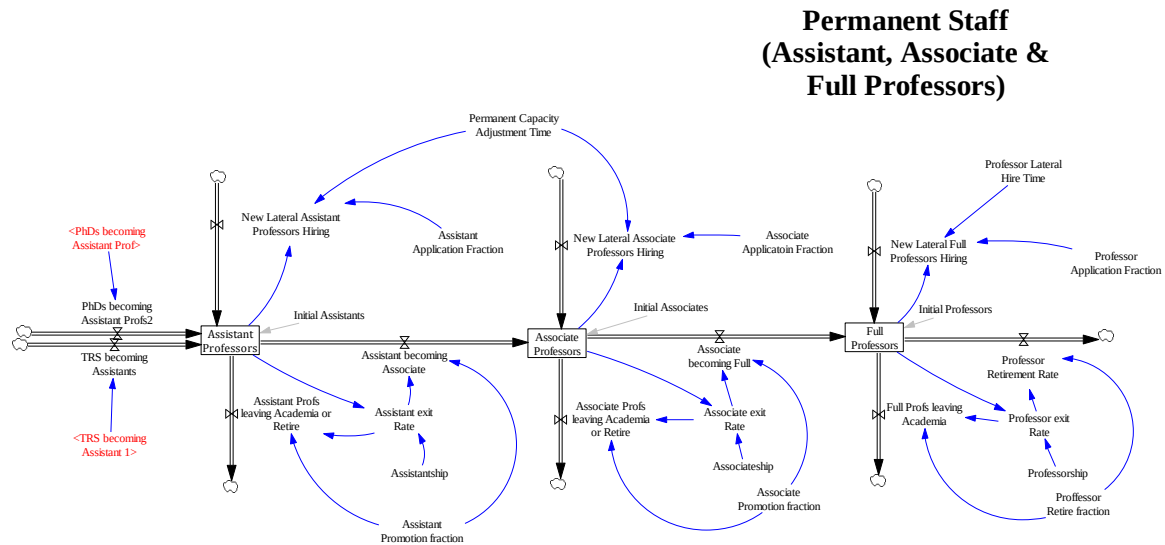


Figure 22: Simplified Stock-Flow Diagram of the in- and outflow of Academic Staff within the permanent staff phases

In correspondence with literature, the faculty positions have been modelled in a static and linear fashion (De-Jonge-Akademie, 2010; Goede et al., 2014). Promotion in these stages happen according to an average residence time. After a certain residence time, researchers become promoted, retire or leave academia behind. This decision is based on a number of promotion fractions, that are retrieved from the Rathenau database. The lateral hire fractions are also retrieved and used to model the external inflow. The residence times, hire and promotion fractions are relatively stable over time (Goede et al., 2014; Rathenau-Institute, 2015a). However, changing the residence times and promotion fractions could have a substantial effect on the model outcomes. It is therefore vital to see how the model reacts to uncertainty margins in these factors in a later stage of this study. Additionally, due to these fractions, the model is now temporary staff driven: the number of temporary staff inflow decides to a large extent the number of lateral hires. This could have an effect on the inflow volatility of the assistant professor phase. However, from a systems perspective, the career phases are deeply interwoven and therefore corresponding with literature.

RESEARCH FUNDING

One a yearly basis, public and private funding is allocated to research organisations to support the workforce and infrastructure. There are three forms of funding with a different effect on the workforce and the research performance. Over the last 15 years the amount of institutional funding, in fair values, has decreased from 2,200 in 1999 to 1,800 million euro in 2014 while competitive funding has increased from 1,000 to 1,900 million euro.

The inflow of funding is dependent on the governmental support on the science system. Additionally, private organisations invest in research conducted in public research organisations. The institutional funding increases based on the factor and allocation scheme as described in Section 3.4. The

competitive funding increases based on the spending by NWO and the projected support of third party organisations and the European Union.

The outflow of funding is dependent on the average stipends in academia. Because fair values are used for funding, no inflation correction is needed. As the focus is on research funding, the costs for investments and machinery will not be included. However in recent years these costs are included in certain projects and institutional funding (Versleijen & van der Meulen, 2007).

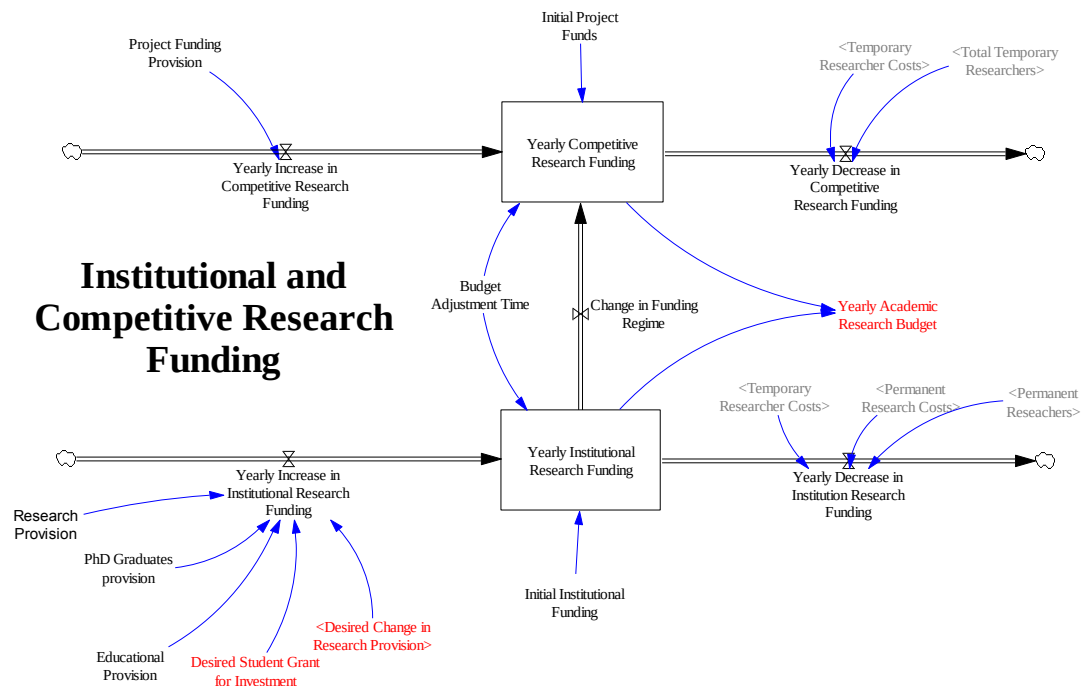


Figure 23: Simplified Stock-Flow Diagram of the in- and outflow of Research Funding for public research organisations

CAPACITY MECHANISM

The relationship between funding and workforce development is an ambiguous one. While funding supports the workforce in academia, it does not compute a one-on-one causal connection. The number of funding sources are numerous and difficult to determine and the number of disbursements are equally difficult to define. Additionally, the governmental intended purposes with the support can often be different from the actual, as the government cannot directly set the disbursement requirements (Versleijen & van der Meulen, 2007). It is therefore imperative to understand that the capacity mechanism only makes sense from a systems perspective, with the focus on behaviour over time, and not detailed forecasting.

Permanent Research Staff Capacity Adjustment

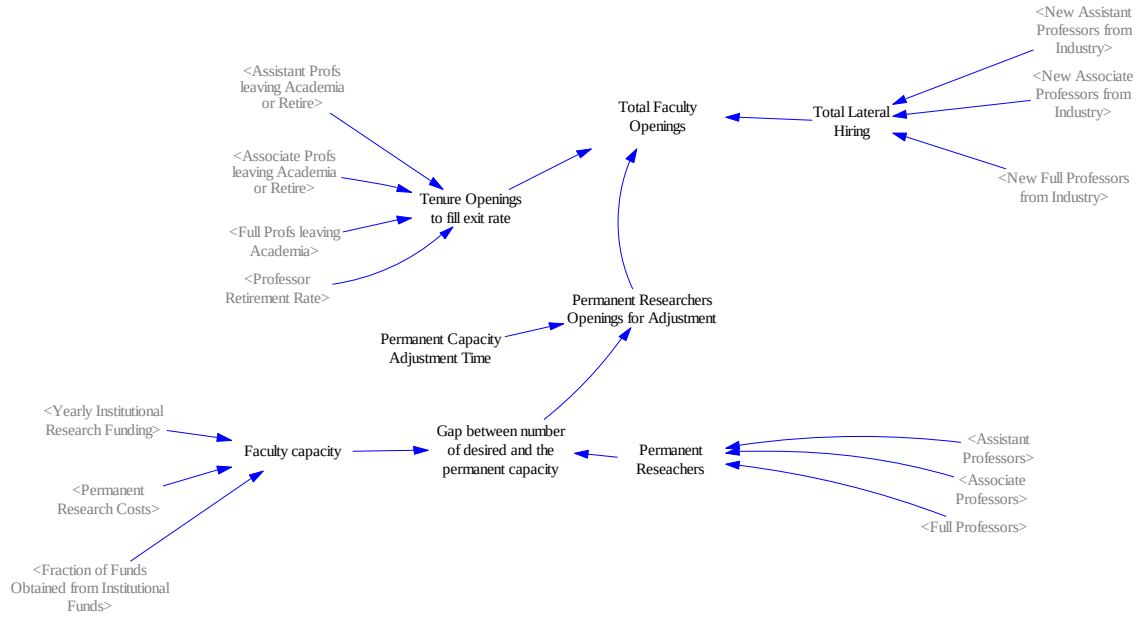


Figure 24: Capacity Mechanism of permanent staff

In the model, funds are exploited to support the workforce. An example of this mechanism, specific for the determination of the permanent workforce, can be found in Figure 24. The amount of yearly funding, divided by the average researcher costs, determines the capacity of staff, C_f . The discrepancy between the staff capacity and the number of present staff can be accommodated with new workforce openings. Based on the total amount of openings, minus the professors leaving the promotion chain and the number of lateral hires, the variable ‘total faculty openings’ is created which determines the openings for PhDs and OAS. Formula 3 describes this mechanism, in which f is total hiring for faculty positions, α is the fraction of funding exploited for stipends, f_e is the total amount of funding, c_e is the total cost of a researcher, s is the number of academic staff, t is the capacity adjustment time and s_0 is the academic staff outflow. Note that these variables change over time.

$$f = \max\left(\left(\frac{\alpha \frac{f_e}{c_e} - s}{t}\right) - s_0, 0\right) \quad (3) \text{ Capacity mechanism}$$

RESEARCH PERFORMANCE

One of the main assumptions in this study is that funding influences the development of the workforce, the workforce produces research and that the demand for research drives the call for additional research funds as described in Section 1.6 and shown in Figure 3. This Feedback loop 3 shown in Figure 19, representing goals-seeking behaviour is contested but supported by literature (Frølich, 2006; Hicks, 2012; Oyo et al., 2008; Srikanthan & Dalrymple, 2007; van Dalen et al., 2012).

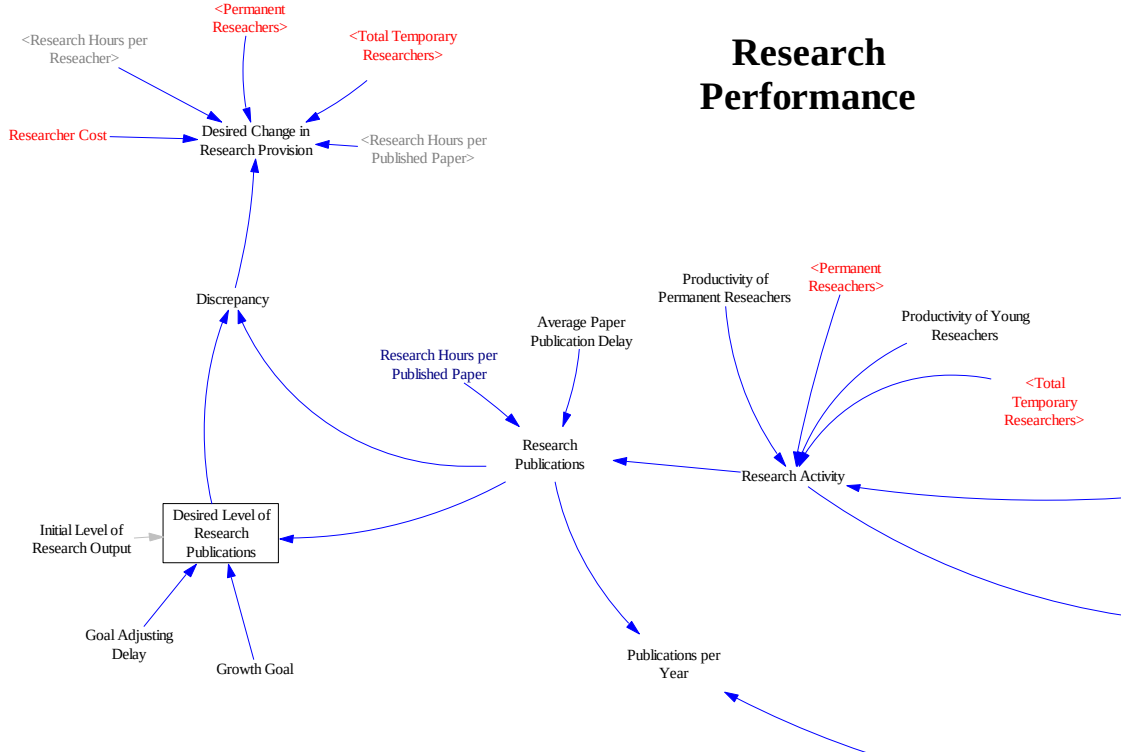


Figure 25: Research Performance and Influence on Funding

In the model, the workforce produces scientific output by conducting research based on their productivity. The research activity defines the number of publications individual researchers make on a yearly basis. It is important to note that in an increasing international and interdisciplinary environment researchers find themselves conducting research within research groups (van der Weijden, Verbree, Braam, & van den Besselaar, 2009). The variable ‘research hours per published paper’ is therefore used as an average and calibrated to fit the observed historical data. Additionally, researchers also produce valuable qualitative research output what is omitted from this study based on model limitations.

Because it is the governmental aim to become the frontrunner when it comes to research and development and building a knowledge based society, the government will further increase their support of the workforce if this objective is not met (OCW, 2014). In the model, this is the discrepancy between the desired level of research output and the actual research output. If this discrepancy grows, the government has the incentive to increase their support of the workforce. Formula 4 describes the desired research output, p_d , which is based on linear growth based on a static growth fraction g_f and delayed by the goal adjustment time t_a . It is calibrated over time and correspond to the historical data between 1999 and 2010.

$$p_d = \left(\frac{38,000 + 0.025g_f}{t_a} \right) \quad (4) \text{ Desired publications}$$

The discrepancy mechanism, in which d is the discrepancy between desired and actual research output, p_d describes the desired output and p_a describes the actual research output is shown in formula 5. Based on this discrepancy there is a call for additional funds.

$$d = \max (p_d - p_a, 0) \quad (5) \text{ Discrepancy Mechanism}$$

COMPETITION FOR FUNDS

The government want to drive the behaviour of researchers in public research institutions by setting the right incentives. Competitive funding, both the ex-ante and ex-poste, can be used to induce research behaviour. When the government increases the available competitive funds, competition among researchers will increase as more researchers will apply for certain funds. As competition increases, the researcher will increasingly work on their grant proposals. This will eventually diminish the time researchers spend on their research.

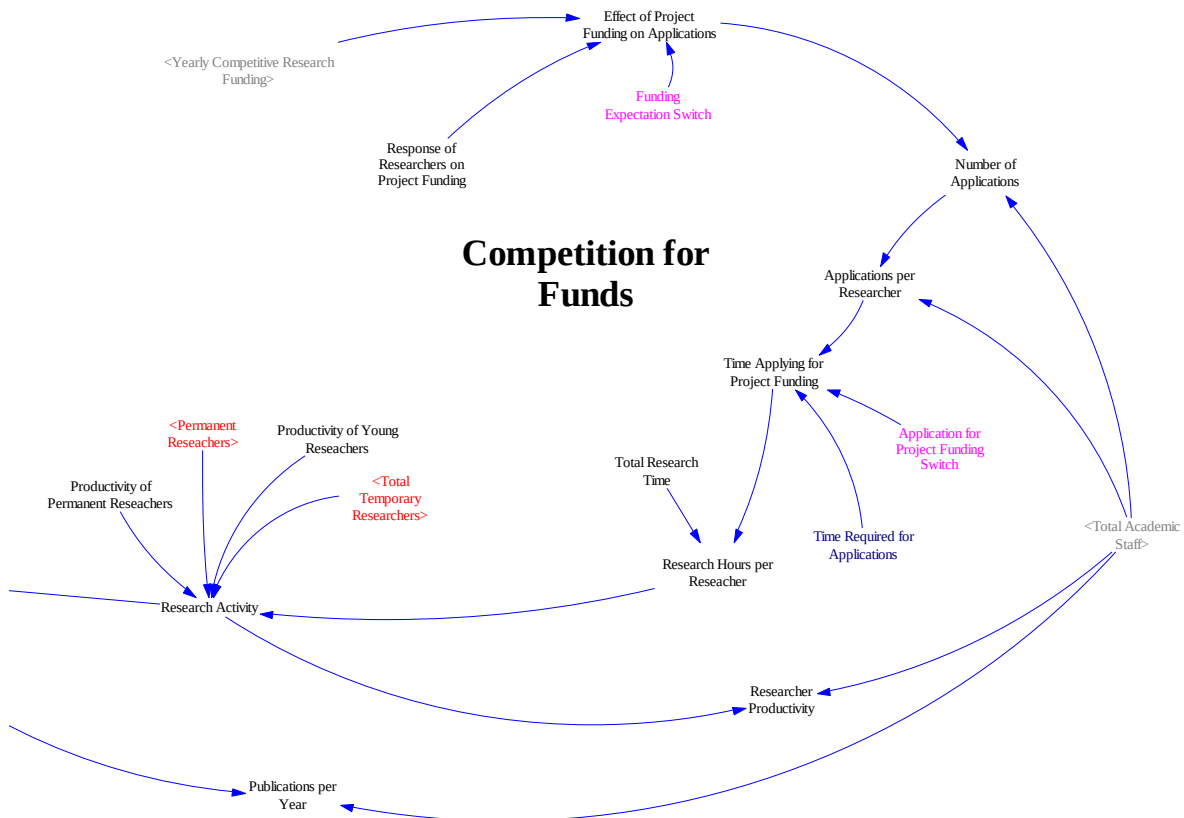


Figure 26: Influence competitive funds on research activity

In the model, the number of applications for funding will increase when the total amount of competitive funding increases. This is not a real-world variable but is used to model the increase of grant proposals and calibrated to fit the data. The total number of applications will increase the applications per researchers, thus increasing the time of applying for competitive funds. The amount of time applying for competitive funds will decrease the time conducting research.

Applications from industry or business are regarded as exogenous variables and are retrieved from the Rathenau Institute Database. While it is an ideal approach to have a model that can simulate these factors endogenously the model boundary depicts that the market creation of potential applications from industry are outside of the scope.

6.4 DEALING WITH UNCERTAINTY

Studying a real-world system requires the identification of uncertainties. Uncertainty can generically be defined as the absence of information about the past, present and future of a given system (Van Asselt & Rotmans, 2002; Walker, Marchau, & Swanson, 2010). From a policy perspective, uncertainty is the gap between the available knowledge and the knowledge that is needed to create the best policies (Walker et al., 2010). These uncertainties are also primarily normative, since they are coloured by the perceptions of the actors involved in the policy-making process. Uncertainties can be found in all aspect of the policy-making process. Because a model is created that analysis the given issue, the primary focus will be on the identification of uncertainties within the model environment.

To analyse a certain problem within a model environment, reality needs to be deduced as explained in section 5.2. Many exogenous parameters and variables should describe the real-world system. However, these structures will never completely resemble the real-world environment. Therefore, the uncertainties in these factors should be analysed. Additionally, uncertainties are also omnipresent in the real-world system. Due to information asymmetry and normative perceptions the conceptualisation of the given problem can differ among actors. Because models are inherently incomplete, incorrect and intuition alone is not always sufficient to understand the underlying uncertainties, simulation is needed (Kwakkel & Pruyt, 2013; Pruyt, 2014).

Angle	Uncertainty			
Location:	Input	Structural	Methodological	Output
Reason:	Lack of data	Conflicting perceptions and values	Scope	Variability
Level:	Marginal	Shallow	Medium	Deep
Approach:	Process	Sensitivity Analysis	Multi-Methods	Uncertainty Analysis

Table 8: Uncertainty in SD models, adapted from (Pruyt, 2014)

The uncertainties within the SDM environment can be perceived from four different angles as shown in Table 8: the location of the uncertainty within the model, the reason of the uncertainty, the level of expected impact and the method for dealing with these uncertainties:

- **Location:** Input uncertainties are related to model quantities such as parameters, exogenous data and initial states. They often emerge from the appropriateness and quality of the data that is used to describe the system (Walker et al., 2010). Structural uncertainties are related to the model structure and the functional relationship between variables. These uncertainty are important, as SD is about the structural characteristics that drive the behaviour of a given system (Forrester, 1994). These uncertainties are often epistemological in nature, as the model should adequately describe the system to understand and dissolve the given issues (Walker et al., 2010). Methodological uncertainties are related to the method that is used to address the issues, both externally, in which SD might not be the best method to adequately understand and dissolve the issues and internally, that the method for implementing a certain concept is not possible or univocally agreed upon. Output uncertainties are related to

the robustness of the model; whether the model can adequately describe the system behaviour.

- **Reason:** There could be a general lack in available data or the data that is available varies for different sources that quantification of important parameters is difficult. This could make the model outcomes less valuable. The normative perception of the system and the issues underneath could also be conflicting. As such, the modeller is not able to create a system conceptualisation that incorporates all values and perspectives of the different actors involved. The chosen scope could also make it uncertain whether model outcomes are generalizable or extrapolated to other situations (Walker et al., 2010).
- **Level:** There are many uncertainties within the SD model. However not all uncertainties have to be dealt with. Some uncertainties are negligible for the model outcomes, while others are deeply uncertain and therefore action is needed. Within this study the most important uncertainties that are identified are characterised as medium. Deep uncertainty, which could be analysed with the combination of multiple methods such as the use of SD in combination with the exploratory modelling and analysis (EMA) framework, is purposively left outside this study for scoping reasons.
- **Approach:** If the identified uncertainty could have a significant impact on the model results, uncertainty analysis is needed. Some input uncertainties are traditionally dealt with in the SD environment by the process of model formulation and sensitivity analysis (SA), which will be conducted in section 7.2 (Pruyt, 2014). However, SA only perceives behavioural changes when model parameters are slightly changed. Sudden changes and surprises that are outside the model environment are not dealt with (Walker et al., 2010). Therefore it could be useful to test some uncertain input variables on realistic deviations. This will be done with the uncertainty analysis (UA) which will be conducted in section 8.4. Structural and methodological uncertainties are less developed and tested within the SDM environment. A multi-method approach to deal with these uncertainties can be included to increase overall validity of the model outcomes (Kwakkel & Pruyt, 2013; Pruyt, 2007). This will be described in the discussion, section 9.2, and is purposively left outside this study for scoping reasons. Some structural uncertainties will be dealt with by UA. Output uncertainties are traditionally dealt with in SD by behavioural interpretation of the model results.

Policy makers want to make sense of their enacted policies. However uncertainties are omnipresent in real-world systems. Additionally, models are often incomplete, incorrect and based on a limited understanding of reality. It is therefore vital to understand the uncertainties within the model to create policies that are robust. The next section will identify the key uncertainties within the SDM environment.

6.5 SYSTEM DYNAMICS MODEL UNCERTAINTIES

In this section the main uncertainties of this study will be identified. The focus is on uncertainties within the SDM environment. The uncertainty typology is used as described in Table 8. The external methodological uncertainty: the use of SD as the proper tool to analyse the given issue is discussed in section 5.3 and will be concluded in the discussion, section 9.2. Based on the theory chapters, the focus on the top-down perspective and through interviews at the Rathenau Institute two types of uncertainties have been chosen for this study: input uncertainties and structural uncertainties. First

the input uncertainties will be discussed, then the structural uncertainties will be identified with the focus on a bottom-up perspective.

PROMOTION OF FACULTY MEMBERS [INPUT – PERCEPTIONS AND VALUES/VARIABILITY – MEDIUM]

The static characteristics of the faculty segment of the promotion chain, which is assumed in section 5.1 and explained in section 2.5, is modelled with the use of stable input. However, while the choice of these fractions are based on these assumptions, and quantified and calibrated with the use of WOPI data, it is unlikely that they are completely stable over time. Additionally, trends in literature suggest that the proportionality between the faculty functions are changing. Based on this information the input fractions could be changed with realistic deviations and expectations to perceive the behavioural changes over time, which is described in section 8.4.

PHD HIRING [STRUCTURAL – PERCEPTIONS AND VALUES/SCOPE – MEDIUM]

The focus on capacity mechanisms for the promotion of academic staff disregards choice. However, apart from funding, it is often choice that initiates a hiring process. The model is now constructed around the capacity mechanisms, that decides for the amount of room in the academic career system. This will pose limitations, as the real-world behaviour is not always directly related to funding. Based on different model perceptions a bottom-up approach is chosen to analyse this uncertainty.

The reproduction rate, which is described on page 50, could also decide for the number of PhD hiring in academia. While this makes the model more demographically based, which, in essence, is a promotion chain, it will also lead to other limitations. The reproduction rate is not a real-world concept and therefore limited information is available. Additionally, the reproduction rate could change over time based on a number of factors. Therefore quantification might be difficult. The behaviour of staff within the chain can only be modelled rationally and behavioural noise and sudden changes are disregarded. Moreover, the reproduction rate is limitedly generalisable over all fields as for instance, doctorates in engineering will be less interested in pursuing an academic career.

The way in which the PhD hiring process takes place at PRO's can be perceived as an uncertainty that is primarily based on different perceptions and values of the system structure. Because the scope is around the promotion chain, and external market side competition structures are not included, the uncertainty can also be based on the scoping of the issue. Section 8.4 describes the behavioural changes when the capacity mechanism of PhDs is substituted with a BRN. Note, that the intention of this structural change is not to reproduce the exact or optimal value for the workforce development, which depends on a number of factors, but to create a number that could endogenously describe the workforce development based on demographical factors. Additionally, it could test whether the structural changes would compute different model behaviour.

PROMOTION OF TRS [STRUCTURAL - PERCEPTIONS AND VALUES/SCOPE – MEDIUM]

The focus on capacity mechanisms for the promotion of academic staff disregards quality. However quality also decide whether a staff member is promoted. Temporary researchers who pursue an academic career are now often faced with multiple-accumulating temporary contracts before they acquire a permanent position. In these temporary contracts, researchers improve their knowledge and increase their research output. Because there is much uncertainty whether these staff members

eventually obtain a permanent position, the tendency to leave academia is high. The model is now constructed around the capacity mechanism, that decides for the amount of room in the academic career system. The capacity mechanism for TRS is based on chance rather than quality which follows from a study by Van Balen (Van Balen, 2010). This study did not find a significant relationship between quality of staff and the chance of being promoted. It primarily being there at the time there was room in the system. However, the validity of this study is contested. As such, this assumption could pose certain limitations, as the real-world behaviour is not always directly related to chance but also to the individual quality of the applicants.

The residence time of TRS, which is described in Section 6.3, could also decide for the hiring choice. This will make the model more knowledge based, which, in essence should be the foundations of the hiring process. However it will also lead to other limitations. Defining quality is difficult if one analyses research endeavours. Apart from the number of quantifiable and non-quantifiable research output, residence time does not necessarily entail quality. If we accept that residence time within academia equals the quality of the given researcher, accepting multiple-accumulating contracts is the preferred option. However, this thesis addresses the limited room in the permanent faculty stage of the academic career and perceives contract accumulation in this phase as unwanted as researchers would become demotivated and leave academia.

The way in which the faculty hiring process takes place at PRO's can be perceived as an uncertainty that is primarily based on different perceptions and values of the system structure. Because quality is not considered it can also find its uncertainty in the scoping of the problem area. Section 8.4 describes the behavioural changes when the choice for faculty members is substituted to a residence time based mechanism.

RESEARCH FUNDING & PUBLICATIONS [STRUCTURAL – PERCEPTIONS AND VALUES – MEDIUM]

The system based increase of the desired research funding, which is assumed in section 5.1 and explained in section 1.6 which is based on a desired publication count is contested. The different actors within the system do not agree on how this concept should be integrated within the model environment. The model is now constructed around the increase in funding based on a desired research output with regards to publications. External factors such as economic and political change are not included. This will pose limitations, as the real-world behaviour of this system is not always expected and sudden changes could occur. Additionally, the focus is not on the quantifiable research output, which is not the only factor that defines quality.

The desired increase in funding, which is described in Section 6.3, can also be discarded, which makes the model exogenous variable based with less feedback loops that create the dynamic behaviour over time. However, when this concept is omitted it is harder to determine the change in funding levels in the near future. The way in which the funding levels increase in PRO's can be perceived as an uncertainty that is based on different perceptions and values on the system structure. Section 8.4 describes the behavioural changes when the Research funding increase is not endogenously driven but exogenously based on growth expectations.

PART 3:

ANALYSES

7. MODEL TESTING

The aim of this chapter is to build trust in the model that is used to describe and analyse a real-world system. This chapter is however not intended to show that the model is correct or not. Sterman (2000) and Barlas (1996) note that all models are inherently wrong, as they try to capture reality in a simplified manner. This chapter will mainly be constructed around several test to show the usefulness of the model, and whether it fits the intended stakeholder uses. Section 7.1 will present a design cycle on which the model testing is structured. The next section, 7.2, will show the implementation process of these tests. Based on these tests, section 7.3 will reflection on the results and will include concluding remarks about the usefulness of the model.

7.1 THE VERIFICATION AND VALIDATION TESTING CYCLE

The process of model verification analyses whether the model implementation represents the conceptual description. Here, flaws in the implementation process can be removed. The process of model validation analyses if the model corresponds with the real-world system. It should also correspond with the model purposes of the stakeholder. These tests do not prove that the model is correct, it merely shows whether the model is of sufficient level for the intended use (Barlas, 1996; Sterman, 2000).

Sterman (2000) and Barlas (1996) suggest a wide range of verification and validation tests that can be both qualitative and quantitative in nature. These tests all focus on different aspects of the model, therefore a combination is needed. Figure 27 shows the testing cycle design that is used to analyse the model.

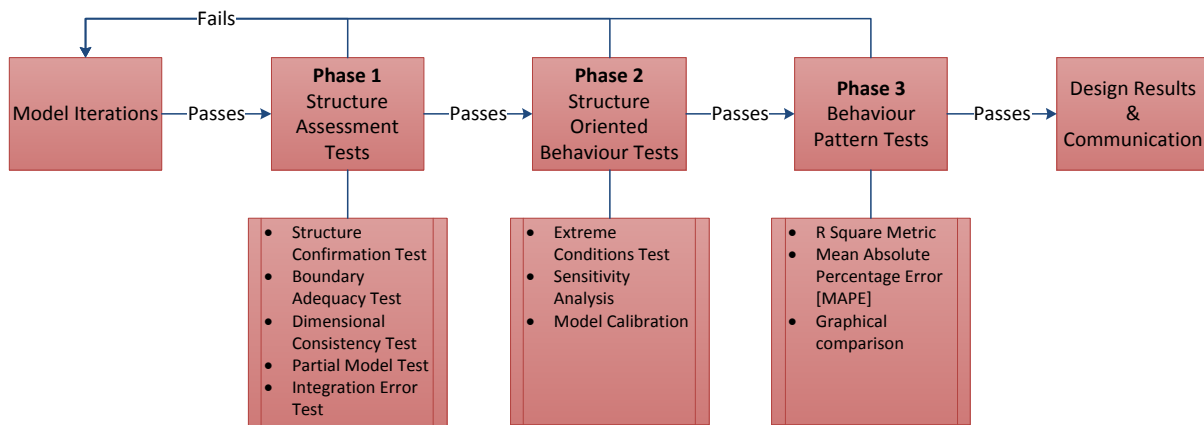


Figure 27: Testing cycle adapted from Sterman (2000) and Barlas (1996)

The model testing cycle starts with the structure assessment tests. They look at whether the structure of the model corresponds with the literature and the perceived real-world system. Based on two interviews with experts from the Rathenau Institute these tests have been conducted. The first test in this phase is the structure confirmation test which looks if the level of aggregation is appropriate and whether it is consistent with the given system knowledge. The second test in this phase is the boundary adequacy test that shows whether the model includes the necessary concepts and feedback structures corresponding with the real-world system. The third test in this phase is the

dimensional consistency test that analyses whether the equations and units are consistently used and whether they have real-world counterparts. The fourth test in this phase is the partial model testing which perceives the behaviour of independent parts of the model. When these structure assessment tests are successfully completed the next phase can commence.

The model testing cycle continues with the structure oriented behaviour tests. They look at how the model behaves under different circumstances. The first test in this phase is the extreme condition test that analyses the validity of the used equations by comparing the results under extreme conditions with logical expectations of the real-world system. The second test in this phase is the sensitivity analyses that looks for parameters that are sensitive to change. When the structure oriented behaviour tests are successfully completed the next phase can commence.

The third step in the verification and validation process is to see whether model behaviour fits the past behaviour of the real-world system. For this purpose the R Squared and Mean Absolute Percentage Error metrics are used. Based on the differences, a graphical representation will be shown, which concludes the historical validation. To measure the effect of these tests on the model, the following Key Performance Indicators (KPIs) are used:

<i>Key Performance Indicator</i>	<i>Unit</i>
<i>Temporary Research Staff</i>	<i>Staff</i>
<i>Permanent Research Staff</i>	<i>Staff</i>
<i>Ratio of Temporary to Permanent Staff</i>	<i>Dmnl</i>
<i>Staff Turnover</i>	<i>Dmnl</i>
<i>Research Output</i>	<i>Publications/Year</i>

The next section will follow the structure of the testing cycle as defined above. Because not all of these tests are quantitative, therefore not having a direct influence on the numerical outputs of the model, not all tests will show the KPIs.

7.2 CONDUCTING THE MODEL TESTS

In this section the different verification and validation tests will be conducted. When certain tests fail to meet the desired quality the model will be restructured and improved following an iterative cycle.

STRUCTURE CONFIRMATION TEST

The purpose of the structure confirmation test is to verify whether the structure of the model is consistent with the descriptive knowledge of the system. The test also looks at the level of aggregation, the consistencies between sub-models, whether it adheres to basic system rules and whether stakeholder decisions can adequately effect system behaviour (Barlas, 1996; Sterman, 2000).

The verification of the structural confirmation was tested separately by two experts of the Rathenau Institute. At these meetings the model structure was discussed, including the important feedback structures and aggregation level. The model primarily looks at the promotion of academic staff within academic institutions based on institutional and project funding. The experts have noted that the influence of funding will only lead to a limited representation of the academic workforce

development. However, they agree that the structure that is implemented in the model is designed according to the stakeholders interests and is of sufficient depth for the intended purposes. As such detailed market side competition, quality considerations and prospective academic staff are omitted from the model. After incorporating the valuable concepts that were discussed during these meetings, which are described in detail in Table 9, and the verification of the restructured model it can be concluded that the model structures is consistent with the descriptive knowledge of the system.

BOUNDARY ADEQUACY TEST

The purpose of the boundary adequacy test is to verify if the model represents the real-world system sufficiently and whether the model is of appropriate use for the stakeholder (Barlas, 1996; Sterman, 2000). It also checks which important feedback should be included endogenously to better represent the real-world system. The verification of the boundary adequacy was tested separately by two experts of the Rathenau Institute. Based on system knowledge and the comparison with earlier publications and workforce development studies, important concepts were discussed. Some concepts found in literature, such as the American academic workforce structure, were not included as they did not have a academic counterpart in the Netherlands. Due to data limitations not all of these could be included in the model. Table 9 shows the included concepts discussed during the expert meeting. Other, more generic, system concepts have been adapted from literature and verified during these meetings. Table 10 shows the concepts that were excluded based on data limitations.

In Model	Concept	Implementation
+/-	Professor Promotion Rate	In the model the PhD candidate inflow is modelled as the number of PhD promotions professors make during their academic career. If the reproduction of academic staff is higher than the outflow of academic staff in permanent positions the system will be unbalanced; more desired positions than actual positions. As such the system will become saturated. Note that this concepts is used in the UA and compared with the used capacity adjustment structure.
+	Contract Accumulation	The accumulation of temporary contracts in the temporary research staff phase. In the model the contract accumulation is modelled with subscripts of three contract phases of 2 years showing increased contract accumulations, as temporary staff growths while there is not enough room in the permanent researcher phases.
+	OAS Demotivation	The psychological, legal or economic pressure of postdocs to leave the temporary research staff phase. In the model the temporary research staff phases demotivation factor is modelled as a linear look-up function over time to represent this behaviour.
+	Capacity Matching	With the formulation of matching mechanisms, the proportion of openings for temporary and permanent

		functions are created. In the model the openings for the different functions are limited by the change in capacity based on sufficient funds and external and internal movement.
+/-	Effect of research output on Institutional Funding	The relationship between the research output (published papers) of universities and the amount of institutional funding for research. In the model exogenous funding data is used to drive the increase in institutional funding for science. A switch factor (1,0) is included that could drive the increase of research funding based on research output.
+/-	Formation principle – queuing for permanent positions	Temporary academic staff are queuing for permanent professor positions at universities. Arrivals to this queue are often young, temporary staff. Departures from the queue are the ones that do not pass a promotion or acquire a tenure position, become demotivated, gain contract accumulation or retire. However there are also less-often used ways to leave the queue. The queuing for permanent positions is only partly adopted within the model. Queuing represents discrete events while system dynamics provides a dynamic simulation.
+	Fund Matching	Universities find it increasingly difficult to sustain their staff for the attracted project funds. They often need more funds to pay stipends to their staff. Therefore institutional funding is used in support of the projects.

Table 9: Included expert meeting concepts in the SD model

In Model	Concept	Implementation
-	Postdoctoral Learning	As the duration of postdoctoral training increases, researchers could benefit and increase their achievements by writing more papers, gain experience in teaching and extend their network. As such they become more likely to find permanent academic positions. The concept of postdoctoral learning is not implemented in the model as the definition of staff quality is too ambiguous and outside the model scope.
-	Benefits of Temporary Academic Staff	For many postdocs who want to acquire a permanent position in academia the rational decision is to acquire a temporary position to gain more experience. This could increase their chances of acquiring a permanent position. Universities benefit from the hiring of low paid, highly trained staff. Postdocs help professors handle more research projects which further increases new temporary staff. The concept of benefits is not implemented in the model as it is outside of the model scope.
-	Underemployment	As more academic staff work on temporary contracts, as

		there is a higher demand for places in permanent positions than availability, PhD graduates turn to opportunities outside academia. Because more PhD graduates look for work in the non-academic job market, companies will require higher diploma standards. As such, it becomes almost necessary to acquire a PhD for certain work that does not require it.. The concept of underemployment is not implemented in the model as the outside job market it outside of the model scope.
-	Fund Competition	As project funding increases more research groups will try to acquire funding. However, while there are more competitors for the available funds some researchers will tend to stop competing as it time consuming. The concept effect on fund competition is not included in the model.

Table 10: excluded expert meeting concepts in the SD model

The model has all the important concepts and feedback situations incorporated in the model while excluding some concepts that are too ambiguous or outside the model scope. While this poses certain limitations, such as the main dependency of institutional and project funds, the model that is created is useful for the purpose of the stakeholder.

DIMENSIONAL CONSISTENCY TEST

The purpose the dimensional consistency test is to verify if units of the model are used in a consistent and correct manner and whether equations correspond with real-world concepts (Sterman, 2000). System Dynamics models consist of algebraic and differential equations. These parameters and functions can be expressed in terms of units they are measured in. For instance PhDs becoming Postdocs is measured in staff per year and Young Researcher Cost is measured as euro per staff per year. The different units used to describe the equations must be used in a consistent manner. Otherwise these functions refer to different concepts than the equations used. The parameters that have no real world meaning are modelled 'dimensionless'. These units are acceptable if they represent a percentage. The parameters of which no unit can be defined are also dimensionless and are justified below. Appendix 4 shows the model formulations of the different variables. Appendix 5 show the exogenous values and parameters.

- The effect of time on motivation
This variable can be understood as a percentage of the temporary staff, with a value ranging between 0 and 1, that become demotivated due to their appointment as temporary staff and the likeliness of attaining a permanent position. The longer they reside in this stock the more demotivated they become. This look up variable is dimensionless as it would add an unwanted dimensions.
- The effect of project funding on competition
This variables can be understood as a percentage of the total research staff, with a value ranging between 0 and 1, that will become active in applying for external funds due to the increase in competitive project funding. This look up variable is dimensionless as it would add an unwanted dimensions.

During implementation of the model the integrated dimension check within the modelling software Vensim Professional was used to check dimensional consistency. After the correcting the wrong units, only minor inconsistencies were found.

PARTIAL MODEL TEST

The purpose of the partial model test is to verify whether different components of the model can run simulations independently. This also calls for a more iterative development of the model as parts of the model can already be improved during development. Partial testing is preferable to whole model testing for the purpose of selecting and estimating pieces of the structure. Partial model testing is useful as a step in the process of model development and testing to maximize structural and behaviour validity (Sterman, 2000).

During the development of the model, components were built and adjusted independently of the full model. The different components were simulated in order to see whether the model simulated the expected results. When the model would render errors or unexpected behaviour the model was improved. For partial model testing the following parts of the model were analysed and run separately and integrated fully within the model:

- PhD Candidates
- Temporary Research Staff
- Permanent Research Staff
- Research Activity and Competition
- Academic Research Funding

INTEGRATION ERROR TEST

The purpose of the integration error test is to verify whether the chosen integration method and time step do not influence the model in a negative way. Different computational methods can lead to small value differences. As these values are the starting point of other values it can have a substantive effect on the model output.

The unit of time that is used to determine the change in academic staff is year. The smallest time step, should be chosen in relation to the response time of variables such as delays, is 1/32 of a year to render sufficient accurate results as shown in Figure 28. The integration method used within the model is the fourth order Runge Kutta with auto adjusted time steps. This integration method is chosen as the model does not include any discrete equations.

The test checks whether the results of the model significantly differ when a different time step and/or integration method is used. For the test a decreased time step and the Euler method were compared to the nominal model output. The visual inspection, shown in Figure 28, shows an insignificant difference between the runs. The numerical results, as present in Figure 28, shows the PhD candidate population 10 years into the simulation. It shows consistent results for all the runs, which indicates there are not large integration errors.

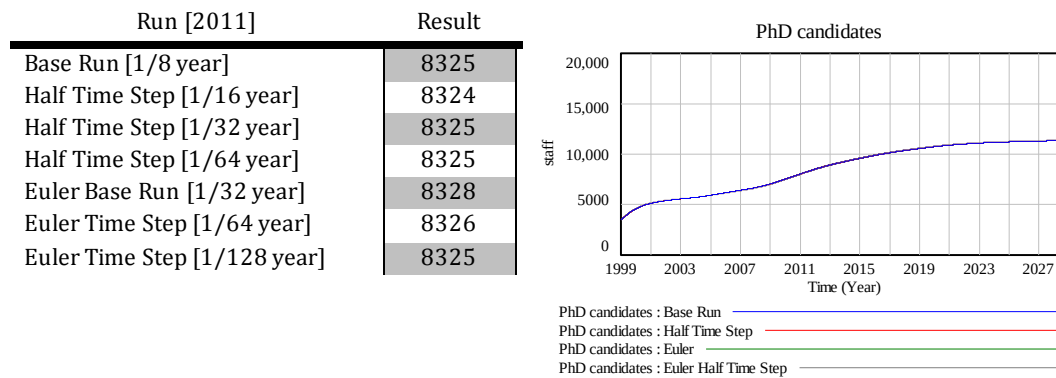


Figure 28: integration error test

EXTREME CONDITION TEST

The purpose of the extreme condition test is to see whether the behaviour of the model can be expected under extreme conditions. With this knowledge, it is easier to reason what policy measures are needed if such a situation would occur. For this purpose, model parameters are changed to extreme values to perceive the system behaviour under stress. The parameters that were tested under extreme conditions are listed below. The results accompanied with the detailed behavioural analysis can be found in Appendix 6.

- The costs of permanent staff under extreme conditions
- The costs of temporary staff under extreme conditions
- The promotion time of PhD candidates under extreme conditions
- The contract time of temporary research staff under extreme conditions
- The residence time of professors under extreme conditions
- The number of research hours under extreme conditions

The results of the extreme condition test show expected model behaviour. However, the observed results also highlight the effects of some uncertain parameters such as the research costs. Because the model is constructed around the promotion chain and funding instruments, parameter changes in researcher costing could have substantial impact on the model outcomes. While this test found that special attention is needed to understand the influence of this parameter on the model, it concludes that the extreme value test was successful.

SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to test the impact of small parameter changes on different parts of the model. The results can then be used to describe or understand the behaviour of the system, the uncertainty space that can be used for the creation of policy alternatives and to see potential errors in the model. The model can be numerically and behaviourally sensitive to changes. The numerical sensitivity is the numerical impact of parameter changes. The behavioural sensitivity looks at the behavioural changes in graphical output when parameters are changed. With this test parameters could be observed that are able to reinforce or reverse the impact of a given policy. To test the sensitivity of the model the important exogenous parameters are changed by 10 per cent with random uniform distributions. Both the univariate, one parameter at a time, and the multivariate analysis, combining parameter changes, will be conducted. The sensitivity cycle, as shown in Figure 29, is followed to perform the tests.

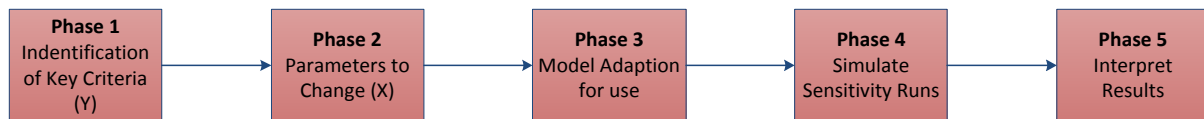


Figure 29: : Phases in Sensitivity Analysis

In phase 1 the key criteria, on which the model will be tested, have to be identified. These are the key performance indicators and relevant secondary variables. The main components of the this model are the promotion chain, the funding for science and the research activity of researchers. In phase 2 the parameters that will be changed during the sensitivity analysis have to be determined. Based on system analysis and expert interviews 14 parameters have been selected due to their uncertainty, because they can be influenced by actors in the system or because they represent a component within the system that has these properties. These variables can be found in Appendix 5. In phase 3 the system dynamics model is adapted to facilitate the sensitivity analysis. The internal Vensim mechanisms is used to conduct these experiments. In Phase 4 the model both the univariate and the multivariate analysis are conducted. Then, in Phase 5 the results are interpreted. The detailed results can be found in Appendix 7.

The results of the univariate sensitivity analysis show that the model is relatively robust against parameter changes, making it only numerically sensitive to most of the alterations made. The parameter changes that have more impact are analysed in the Appendix. The main results show that the Basic Reproduction Number and the Professors Costs have a significant numerical sensitivity, which can raise questions regarding model validity of these integrated concepts. Changes of 10 per cent in these numbers have an immediate effect on population changes. While this does not need to be considered as a flaw in the model, it is important to notice this impact. The results of the multivariate sensitivity analysis show that, even with a combination of parameter changes, only numerical sensitivity takes place. However it is important to keep in mind that for policy testing, the alteration of numerous exogenous variables, has a bigger numerical impact on the model.

MODEL CALIBRATION

The purpose of model calibration is to create a match between the observed and simulated model behaviour. The background theory of the science system has been formulated in previous chapters. It provides the information needed to create the system structure and incorporate decision policies that generate the observed behaviour. The model is the conveyor of the theory, creating the relation between the structure, captured in equations, parameters and model concepts, and the behaviour, captured in simulation output. However, for any given system there could be more than one interpretation of the structure to compute the observed behaviour. Therefore, model calibration can also be used to test whether the theory links the structure to the observed behaviour of the system (Oliva, 2003). The detailed results can be found in Appendix 8.

The model calibration test was performed and the results were compared to the observed historical data. Several model adjustments were made to compute robust model behaviour: (1) the substitution of the researcher costs, corrected by inflation, with a funding scheme that is fair-value based, (2) the substitution of a stock-flow funding structure to a single variable based funding structure and (3) the parameter correction of promotions within the permanent phase. The results show promising

behaviour, but the representation of the observed behaviour remains limited. Additionally, the calibration test computes different behaviour when parameters are changed within the uncertainty range. This suggests that the incorporated concepts, variables and parameters do not completely describe the system under study and other interpretations, both methodological and structural, could also describe the system.

BEHAVIOURAL PATTERN TEST

The purpose of the behaviour pattern tests is to make a comparison between the historical data and the model results. To serve this purpose, the R square and Mean Absolute Percentage Error (MAPE) metrics are used. The R squared metric, which is also called the coefficient of determination, is a statistical measure of how close the historical data is to the model data. The coefficient of determination ranges between 0 to 1, in which 1 is the best fit in comparison with the historical data. The definition is shown below, in which A_t is the actual historical value, F_t is the forecast model value and A_m is the mean of the actual historical values (Cameron & Windmeijer, 1997).

$$R^2 = 1 - \frac{\sum_{t=1}^n (A_t - F_t)^2}{\sum_{t=1}^n (A_t - A_m)^2} \quad (6) \text{ R-squared metric}$$

MAPE is also a statistical measures that determines the average error between the forecast model value and the historical value. It expressed the accuracy as a percentage, as is defined by the formula below. Here A_t is the actual historical value and F_t is the forecast model value (Cameron & Windmeijer, 1997).

$$M = \frac{1}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right| \quad (7) \text{ MAPE Metric}$$

While the MAPE metric is used to show the percentage of error between the data, R squared is used to see the fit in terms of patterns. The use of both of the metrics will finally give a better understanding whether the model is fit for purpose. The metrics are used for five different key performance indicators, which comprises the whole promotion chain. The historical data, that have been found, range from 1999-2014 and is adopted from VSNU WOPI-publications. The numbers found in the dataset between 1999-2004 and 2005-2015 are for numerous reasons not completely comparable and are dealt with and explained in Chapter 2. Table 11 shows the result of the tests. The yearly numbers and the graphical comparison of the data can be found in Appendix 9.

Based on the described data limitations a comparison can be made between the different stages of the academic career in the period 1999-2014. The historical data shows that the model is only able to limitedly replicate the historical data. Also the graphical comparison, as shown in Appendix, does reproduce the same type of behaviour as the historical data. As such, it can be assumed that the model does have some comparison with the real-world system.

	R Square	Mean Absolute Percentage Error	Comments
PhD Candidates	0.97	1.0%	The results show that the capacity mechanisms structure is able to replicate the historical observed behaviour of this phase. Both the R square and MAPE metric compute excellent results.
Temporary Research Staff	0.49	30%	The reason for having a low R square value for this variable is due to the modellers choice of making this phase directly linked to the funding and not based choice mechanisms. It therefore follows the volatile behaviour of the capacity adjustment.
Assistant Professors	0	99%	The reason this phase has a very low R square value is due to the direct influence by TRS phase and the volatile nature of the historical data which the model does not replicate. While it does not follow the exact numerical output, comparative model behaviour is observed.
Associate Professors	0.37	39%	For associate professors this number is low as it does not fit the observed behaviour. This is caused by the position in the chain with other phases that do not exactly follow the observed behaviour.
Full Professors	0.74	14%	For full professors the r square and MAPE metric are relatively good. In the graphical comparison the same behavioural patterns are followed.
Research Publications	0.65	19%	For research publications a similar pattern to the historical observed behaviour is found.

Table 11: Behavioural Pattern Test Results

7.3 CONCLUSION

Based on the verification and validation tests it can be concluded that the model is only of limit use for the intended purpose. With all the necessary structures and concepts in place, and the model behaves well under stress and parameter changes, there are too many differences in comparison with the historical values. This suggests that there are additional structures that need to be included to make this model more useable. This could be promotion considerations and a more precise mechanism to describe the influence of funding. While the data does not replicate the historical data accurately it does show the same patterns of behaviour. In some cases this behaviour was initiated before or after the historical data initiated change. This could suggest another mechanism that is not included. However, as behavioural patterns are observed, the model is usable to test policies under different conditions.

8. SIMULATION RESULTS

The development of a mathematical model for system analysis is a process that improves the knowledge of the underlying system. An additional use of the model is the possibility to simulate a number of policy scenarios and examine the model responses to such changes. The aim of this chapter is to present the results of the modelling process and explore a number of (counterfactual) policy measures that will answer ‘what if’ questions, that have been raised during expert meetings and system analysis. Section 8.1 will explain the behaviour of model under the ‘business as usual’ scenario with the existing policy measures in place up until 2029. Section 0 will then be dedicated to the exploration of policy experiments. Section 8.4 will then extend the model beyond the 2019 range by performing a scenario analysis. The parameter uncertainties that have been identified are then used to test the policy experiments until 2029. For showing the simulation results the following KPIs are used:

<i>Key Performance Indicator</i>	<i>Unit</i>
<i>Temporary Research Staff</i>	<i>Staff</i>
<i>Permanent Research Staff</i>	<i>Staff</i>
<i>Ratio of Temporary to Permanent Staff</i>	<i>Dmnl</i>
<i>Staff Turnover</i>	<i>Dmnl</i>
<i>Research Output</i>	<i>Publications/Year</i>

8.1 BASE RUN SIMULATION

Appendix 7 shows the simulation results and compares them with the historical trends from the data. As the model is quite successful in replicating the observed behaviour of the system, this section will be dedicated to the explanation of observed trends in the base run simulation. The graphical representation of the model KPIs and other relevant variables will be shown and explanation of the behaviour will be made.

PHD CANDIDATES

Figure 30 (a) and (b) show the simulation results of the number of PhD candidates and the inflow to- and outflows from the PhD phase: PhD Hiring, PhD leaving Academia and PhD promoting. The figure shows the rapid growth of PhD candidates until 2015, followed by a stagnation towards 2029. For the initial rapid growth towards 2015 two driving forces can be distinguished: the introduction of the PhD provision and the reinforcing behaviour of the promotion committee. The PhD provision, a fixed sum based on the number of graduated PhD candidates, became an additional incentive to hire in the nineties. After all universities started to adopt this measure, this measure lost some of its potential, hence the stagnation of PhD candidates as of 2005. A second reason for the growth is the number of PhD candidates professors are willing to promote during their active careers. Growth as of 2020 is based on the forecast “stable governmental research funding support” as defined in the specification phase. Another thing to observe is that the rate of PhD candidates leaving academia is larger than combined promotion rate. Only 30 per cent acquires an additional position in academia. Furthermore, the number of PhDs that find a faculty position is relatively low, but the number of PhDs who choose to exit the promotion chain to work outside academia is increasing.

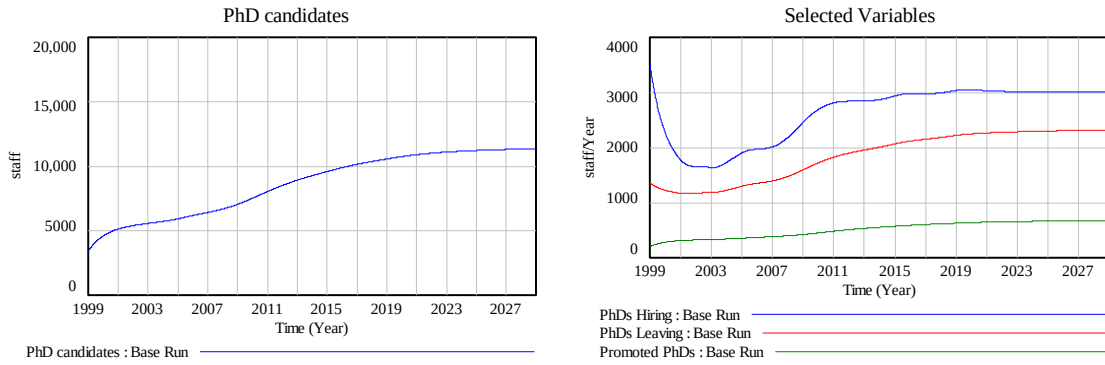


Figure 30: Base Run Simulation Results: (a) PhD candidates and (b) Inflow to and outflows from the PhD phase

TEMPORARY RESEARCH STAFF

Figure 31 (a) shows the simulation results of the number temporary research staff. The figure shows an initial decline followed by rapid growth towards 2015, after which the growth is stagnating towards 2029. The initial decline, which is consistent with the observed historical data, is caused by the transition in staff data as described in Section 2.1. The rapid growth towards 2015 is caused by the increasing focus of temporary staff in academia. This focus change is caused by the increasing dependency on private and competitive research funding. As researcher institutions are less likely to acquire these funds, they are more likely to hire temporary staff over permanent staff. The growth stagnation, is caused by the expected stagnation in public research funds and uncertainty about the private research funds. Figure 31 (b) shows the inflow to- and outflows from the TRS phase: TRS Hiring, TRS leaving Academia and TRS promoting. Note that the temporary research staff that leaves academia is increasing over time while TRS that are promoted are decreasing. This shows the decreased likelihood of acquiring a permanent faculty position which is caused by the focus on temporary staff.

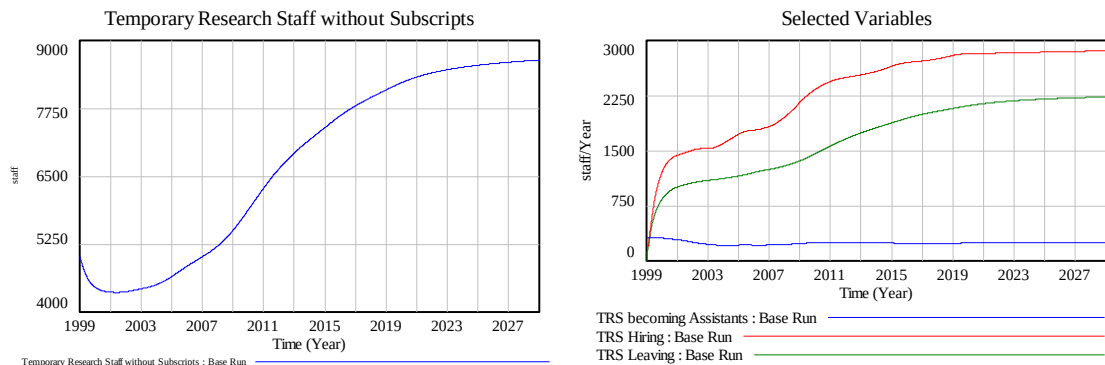


Figure 31: Base Run Simulation Results: (a) Temporary Research Staff, (b) Inflows to and outflows from the TRS phase

Figure 32 (a) and (b) show the simulation results of the average residence time and the turnover of temporary research Staff. As the likeliness of acquiring a faculty position is decreasing over time researchers accept new temporary contract and remain in this phase longer. They either remain, become successful in acquiring a faculty positions, or become demotivated and leave academia behind. As the average residence time increases more researchers will find work outside academia which can be seen in Figure 32 (b). While this can lead to temporary contract accumulation and uncertainty, it leads to a lower staff turnover which can be good for the overall expertise of the workforce.

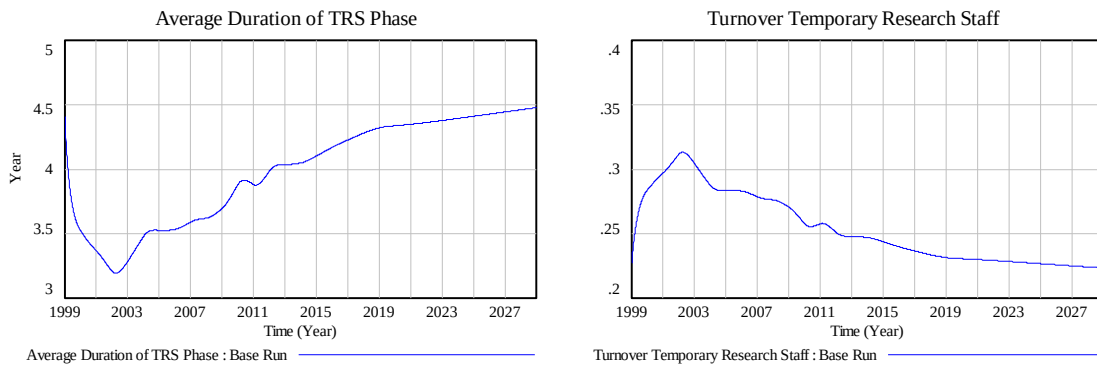


Figure 32: Base Run Simulation Results: (a) average duration of TRS phase (b) turnover temporary research staff

As described in Section 6.3, the TRS segment is constructed around three contract phases which staff members can follow in the hope of acquiring a permanent position. Subscripts are used within the SD model to drive this behaviour, with the expectation to explore the behaviour under different contract terms as proposed by the policy makers (OCW, 2014). Figure 33 (a) shows the TRS over the different phases. Most TRS remain in the first phase for one contract term and are either promoted or decide to leave academia, which is consistent with the data in the TRS position (Goede et al., 2014). Figure 33 (b) shows the transition between the three phases by the aging variable. Note that the amount of researchers moving towards the second phase are significantly larger than the ones moving towards the third phase.

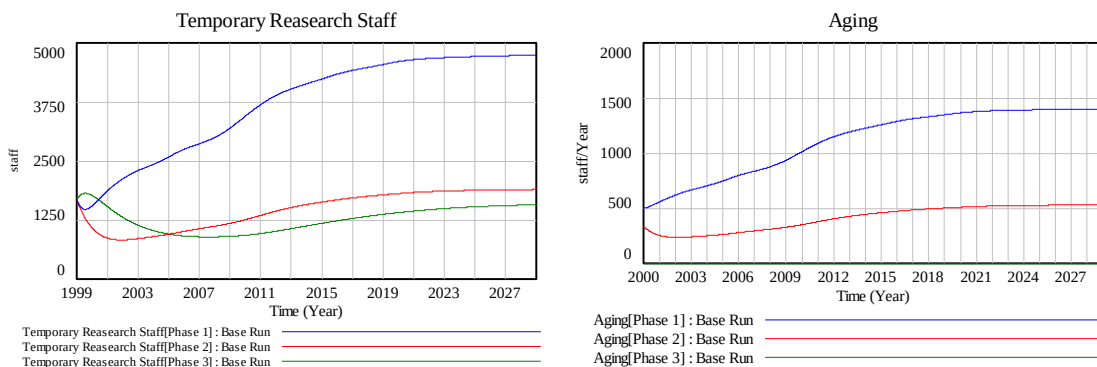


Figure 33: Base Run Simulation Results: (a) TRS with subscripts (b) the aging TRS population

PERMANENT RESEARCH STAFF

Figure 34 (a), (b) and (c) show the simulation results of the permanent research staff in the assistant, associate, and full professor phases. The number of assistant professors decreases substantially in the first years, due to the emphasis of attracting temporary staff instead of permanent staff, which represents the behaviour of the historical data, and the decrease in institutional funding and stabilises from 2010 based on institutional funding. Also the number of associate professors decreases over time until 2019 after which it stabilises under the influence of the stabilising institutional funding. The professor phase grows over time after which it stabilises from 2015 onwards. The professor phase seems to be unaffected by the decline and stabilisation of institutional research funds. This has two reasons. First, the permanent research staff phases are rather statically organised and modelled in correspondence with the actual situation (De-Jonge-Akademie, 2010). The flow over these phases is dependent on a number of fractions and residence times that are constant over time. Second, the researchers within these phases work under permanent contracts making it unlikely for them to move involuntarily. Thus the researchers already working in these phases can

stay until they retire. Because the overall residence time is on average 25 years, and the total running time of the model is 30 years, professors are initially barely effected by the change in funding. Figure 34 (d) shows the inflows to and outflows from the permanent researcher phases. One of the things to observe is the relatively stable outflow over time and the more volatile inflow of permanent staff with goal seeking behaviour. This shows that the model reacts quickly to capacity adjustments, but overshoots several time until it reaches stability. This could suggest that a long-term human resource strategy is needed when dealing with changing funding regimes.

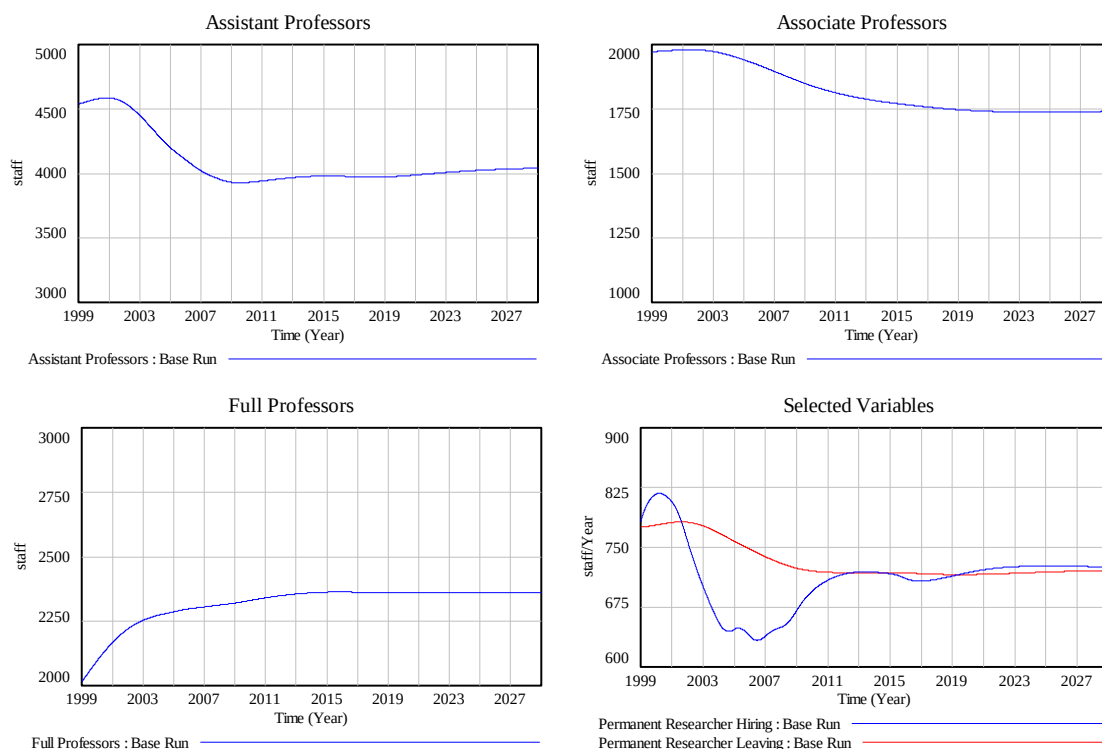


Figure 34: Base Run Simulation Results: (a) Assistant Professors, (b) Associate Professors, (c) Full Professors and (d) Inflows to and outflows from the permanent faculty positions

STAFF SIZE AND TURNOVER

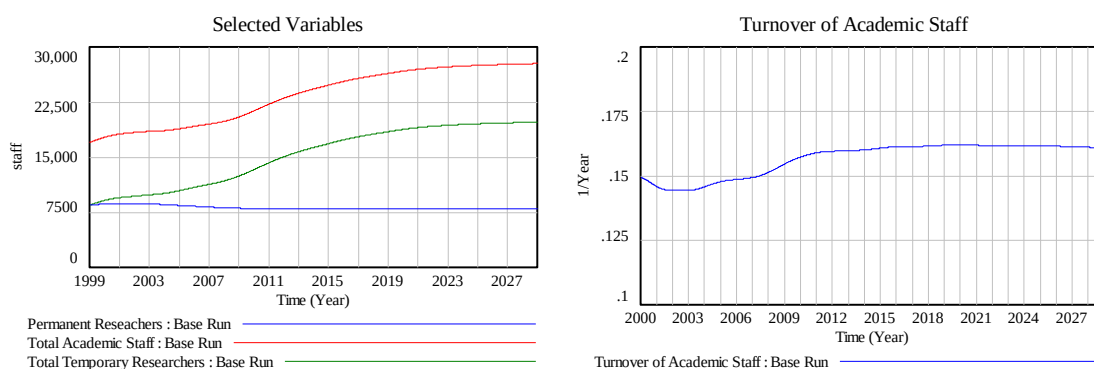


Figure 35: Base Run Simulation Results: (a) distribution and (b) turnover of academic staff

Figure 35 (a) shows the increase of academic staff and the distribution between temporary and permanent staff over time. It shows the increased focus on temporary staff, which increases significantly over time, in comparison to permanent staff, which is relatively stable. Figure 35 (b) shows the turnover of academic staff, which is a representation how often the total research body is renewed, that increases over time suggesting that staff leave academia at an increasing rate. This is

caused by the increasing residence time of temporary positions that want to acquire a permanent position, but wait and leave due to capacity issues.

RESEARCH FUNDING & ACTIVITY

Figure 36 (a) shows the expected growth of institutional, project and total funding for public research organisations towards 2029. Numbers are based on fair values and extrapolated over time. Appendix 8 describes the process of transferring nominal to fair values and the extrapolation process. The total amount of the yearly academic research budget is increasing under the influence of private funding. Note that from 2016 it is expected that more funds are obtained from secondary and tertiary sources than from direct sources. Figure 36 (b) shows the number of dedicated research hours per researchers. One of the first expected observations is the decrease in productivity caused by the increased competition for funds. As more research groups want to acquire additional funds, less time is dedicated to their core research activities. Figure 36(c) shows the amount of research publications that increases significantly over the years under the influence of the increasing temporary workforce, that conducts research for less costs. The stagnation towards 2029 is caused by the stagnation of expected private research funds. Figure 36 (d) shows the average residence time for a researcher that follows the whole promotion chain, which is relative stable over time. This seems to suggest that the current policy and funding system does not influence the residence time but the turnover of academic staff.

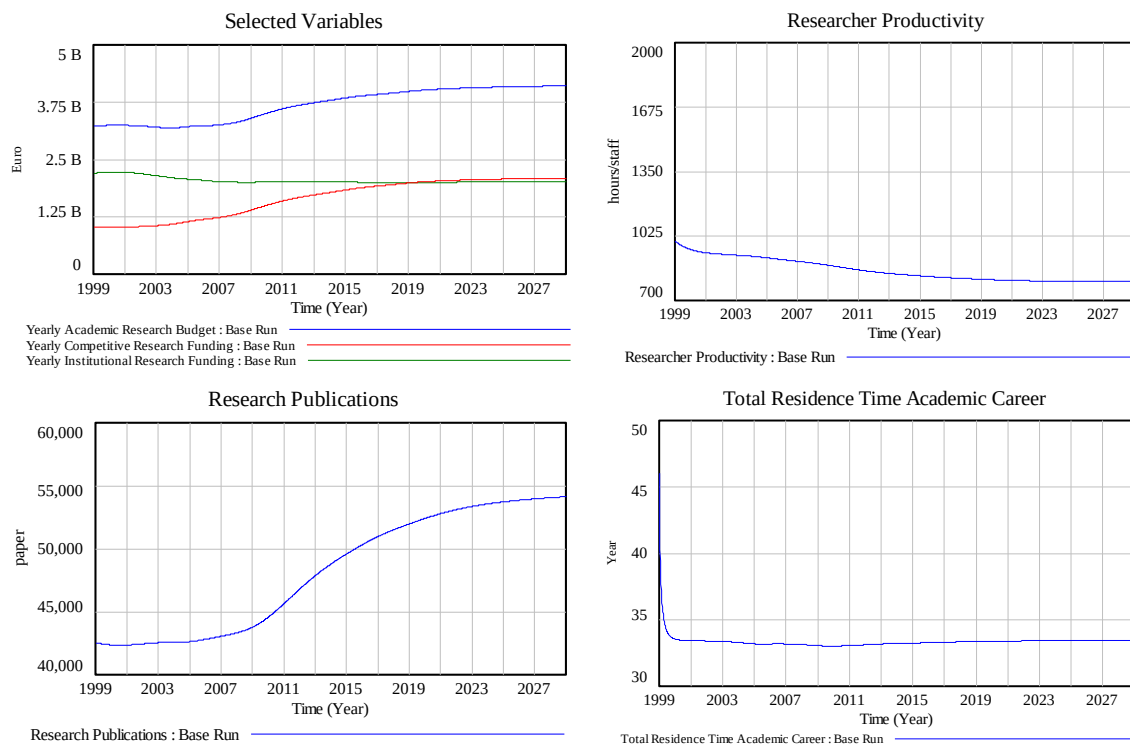


Figure 36: Base Run Simulation Results: (a) Funding, (b) Researcher Productivity (c) Research Publications, (c) Turnover of Academic Staff (c) Total Residence Time

8.2 PRINCIPAL-AGENT THEORY IMPLICATIONS

After the model is created, and the base run simulation is analysed, policy experiments can be conducted to perceive the behaviour of different policies on the workforce development. However, with the introduction of the principal-agent problem in section 4.2, that analyses the relation between the government and the science system, some model observations have to be made.

Science policies are created to balance the interests of the principal [government] and the set of agents [researchers]. Researchers tend to desire autonomy within the lowest organisational layer and the government has often subscribed this idea. This works, when one assumes that the expertise and knowledge of researchers is related to the needs of society. However, as analysis have indicated in section 4.3, this is often not the case. The purpose of creating science system policies is to stabilise this on-going agent-principle problem. Because the perception among actors can change, the government constantly adapts its policy structure, in the hope to increase its socio-economic returns. Additionally, national research councils have mediated the gap between the principal and the agents, by presenting the political and policy interest in the academic world and promote the academic interests in the policy world. To a certain extent, this will bridge the gap between the conflicting interests and align the perceptions of the academic, policy and societal world. However, the principal agent problem also creates limitations on the validity of the model results.

Because not all real-world concepts and all perceptions of these concepts can be included in the model, reality needs to be deduce. The SD model is now created around the governmental perception of the science system, which is justified in section 2.4, as the SD methodology can only equip one model representation. The structures, which are included in the model environment, are primarily top down. The principal expects to be able to structurally enforce regulation on the science system. However, due to information asymmetries and knowledge gaps, policies can be created that do not have the desired impact. Therefore, the policy experiments, conducted in the next section, could prove ineffective. This is partly mediated by performing the uncertainty analysis, conducted in section 8.4. There, multiple uncertainties will be explored and tested upon the model environment and conflicting perceptions and values on the model structure can be tested and compared to see if it computes different behaviour.

These uncertainties can further be mitigated by creating a multi-method approach, which combines the top-down and bottom-up perception of the science system. Exploratory Modelling and Analysis (EMA) can be used to analyse the deep uncertainty about the perception of the system within the SD framework. Agent-Based Modelling (ABM) can be used to describe the bottom-up perceptions and the behaviour of individual researchers within the system. These methods are intentionally left outside the study scope. Reflections and discussions on these promising methods can be found in section 9.2.

Not all policy and model uncertainties can be prevented. Therefore it is important to define the usefulness of the model. The model focusses on the perception of the policy-maker and does not incorporate all perception in the model. First, the model can be used for strategy development by perceiving the global behaviour of policy measures. Second, the model can be used to see where policy interventions could create counterintuitive or wrong behaviour. Third, the model can be used

to see how the different organisational layers and concepts interact. With this knowledge, additional understanding of the science system is created.

8.3 POLICY EXPERIMENTS

This section will be dedicated to the exploration of a number of policy scenarios that will answer ‘what if’ questions. The main focus is on the implementation or absence of policies regarding career opportunities and career funding. Since the model consist of many policy parameters, this analysis will limit itself to changes in parameters that decision-makers within the government can actually make. First the model is used to examine the effects of three hypothetical policies: (1) the increased focus on competitive funding; (2) the increased focus on institutional funding and (3) the implications of a non-fixed retirement age. Then model is used to examine the effects of two governmental proposed policies: (4) the effect of capping the duration of the TRS phase at 4.5 years; (5) and the effect of changing the financial stability from 1 to 3 years. These policy measures are listed in in Table 12. The + and - signs refer to the variable going up or down and does not necessarily suggest any connotation as this is depends on the perception of the actors involved. The operationalization of the simulation experiments can be found in Appendix 7. Every policy alternative will be introduced before the simulation results are presented. The policy experiments will be initiated from 2015 onwards

Simulation Experiments	Policy measures				
	Temporary Staff	Permanent Staff	Ratio of Temporary to Permanent	Staff Turnover	Research Output
(1): Focus on competitive funding	+	--	+	+	+
(2): Focus on institutional funding	--	+	-	-	0
(3): Non-Fixed retirement age	0	0	0	-	0
(4): Capping duration of TRS-phase at 4.5 years	+	0	+	++	+
(5): Longer financial Stability	-	-	0	0	-

Table 12: Six simulation experiments and directions of their effects on different policy measures

The simulation runs are shown in the figures belonging to that policy experiment. The base run, indicated in red, represents a situation with no policy changes. The blue line represents the impact of the policy change over time. As such, different variables can be compared.

THE FOCUS ON COMPETITIVE FUNDING

Traditionally the science system in the Netherlands was focused on institutional funding. Nowadays the different funding regimes are distributed over the science system and no form is dominant. Other academic funding systems, such as the one existing in the US, work primarily with competitive research funding. There, the amount of funding is predetermined and allocated based on research proposals. If the focus of the Dutch government would be in favour of this regime, it could have a substantial impact on the workforce development and research output.

In the model the distribution between institutional and competitive funding is changed from 2015 onward with an expected shift of 500 million euro toward competitive funding. A smooth function is used to simulate the gradual shift in funding over time. The operationalization of this simulation experiment can be found in Appendix 7.

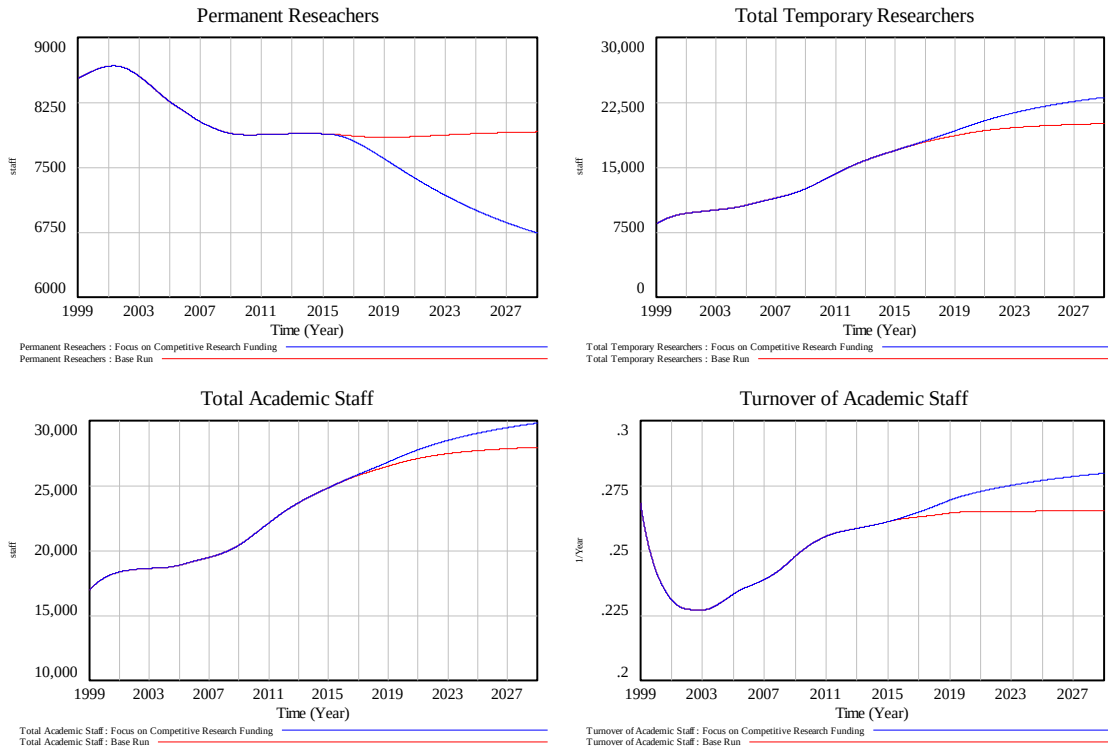


Figure 37: Simulation Results Competition Focus: (a) decrease in temporary researchers (b) the increase of permanent researchers (c) increase in total academic staff (d) increase in turnover in academic staff

Figure 37 shows the simulation outcomes for this policy experiment. The results are counter intuitive and contrary to initial expectations. It was expected that more competitive funding leads to an increased focus on temporary staff. Because stipends are lower in temporary staff positions, the total amount of academic staff is increasing. Because temporary staff often works on temporary positions the turnover of staff, the fraction that is renewed on a yearly basis, is increasing consequentially. However while this was expected, the increase in staff does not necessarily lead to more research activity of the workforce as shown in Figure 38, which has two reasons. First, temporary research staff is expected to be less efficient in producing research due to inexperience and other obligations (van Drooge & de Jong, 2008). Second, the increase of competitive funds has consequences for the research productivity (Gomez Diaz, 2012). As there are more project funds available, more researchers will compete with each other to acquire these funds. This will lead to a decrease in productivity of researchers as more time is consumed for writing project proposals.

The results suggest that having a more competitive funding structure does not necessarily lead to more productivity. However, the model is not suitable for testing the quality of the newly produced work.

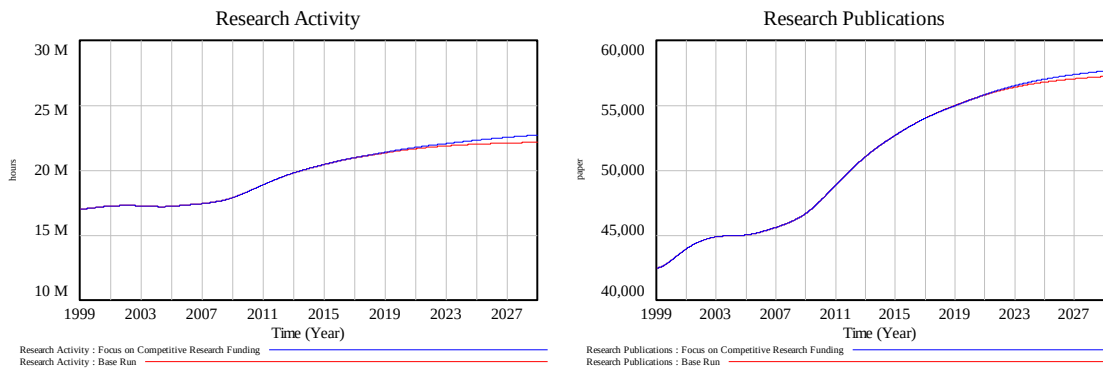


Figure 38: Simulation Results Competition Focus: (a) insignificant increase in research activity and (b) insignificant increase in research publications

THE FOCUS ON INSTITUTIONAL FUNDING

Traditionally the science system in the Netherlands was focused on institutional funding. Under the increasing pressure of conducting research to benefit society, the government adopted competitive funding regimes. If the government would restructure the system and focus on the institutional funding it could have a substantive impact on the workforce development and research output.

In the model the distribution between institutional and competitive funding is changed from 2015 onward with an expected shift of 500 million euro toward institutional funding. A smooth function is used to simulate the gradual shift in funding over time. The operationalization of this simulation experiment can be found in Appendix 7

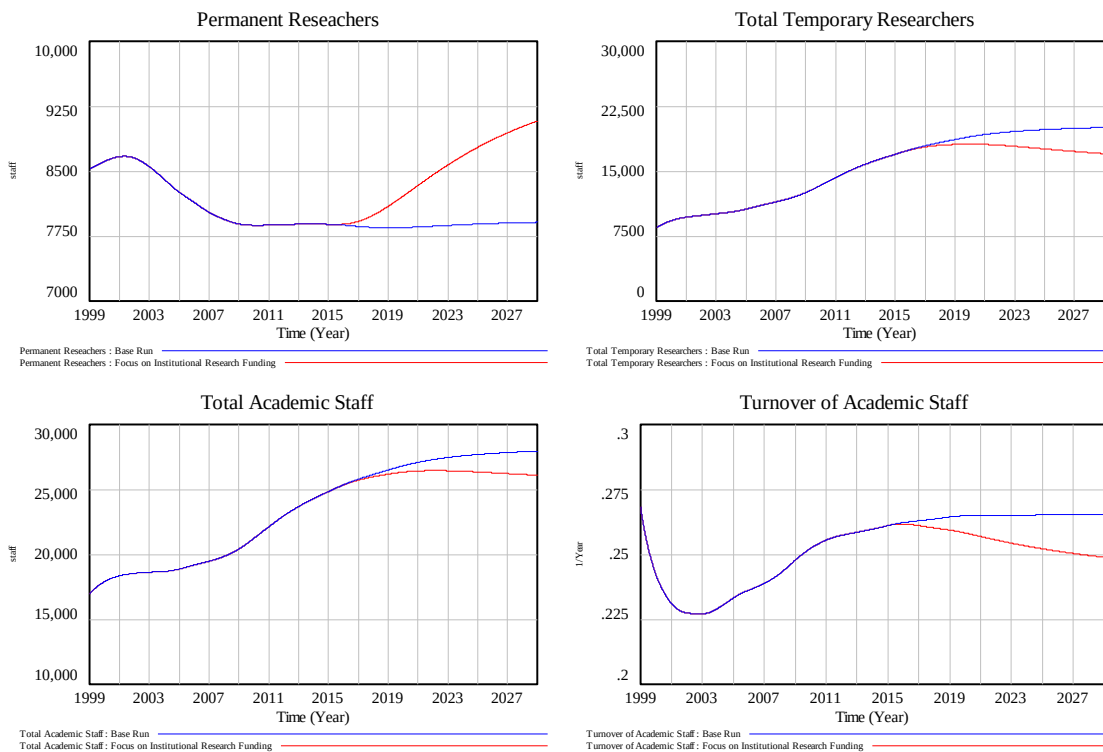


Figure 39: Simulation Results Institutional Focus: (a) increase in temporary researchers (b) the decrease of permanent researchers (c) decrease in total academic staff (d) decrease in turnover in academic staff

Figure 39 shows the simulation outcomes for this policy experiment. Mainly permanent researchers benefit from an institutional based funding regime. The turnover of academic staff also increases overtime which suggest that institutional funding makes the workforce more static, especially in the permanent phases. In terms of productivity as shown in Figure 40, the workforce produces almost the same amount of research output. This suggest that in a stable environment, where researchers do not need to worry about acquiring funds, they can work harder and more efficient. However, the model is not able to show detail on the research quality and whether the research has impact on society.

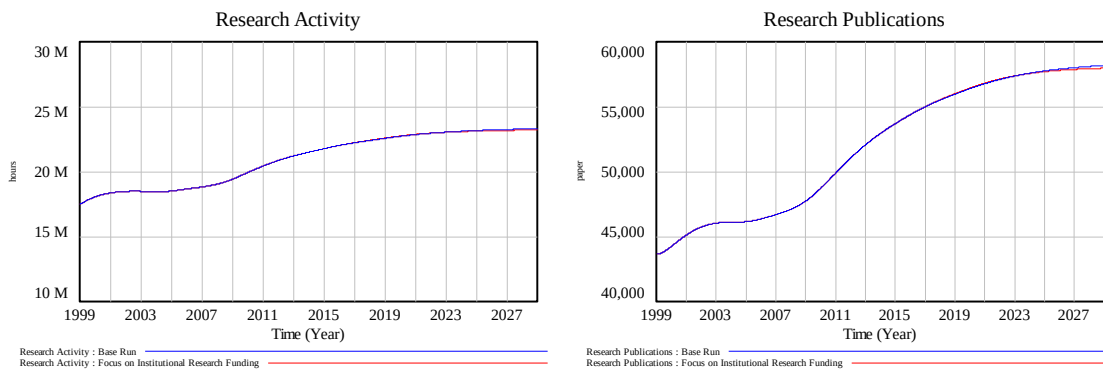


Figure 40: Simulation Results Institutional Focus: (a) insignificant decrease in research activity and (b) insignificant decrease in research publications

NON-FIXED RETIREMENT AGE

Many permanent faculty member at universities enjoy the rare job benefit of having a contract for life (Larson & Gomez Diaz, 2012). If temporary researchers successfully navigate the hurdles of reappointment and promotion, and become a permanent researcher they enjoy job security until the retire. The only way to leave academia is voluntarily or to retire at the age of 65. However, in many countries the mandatory retirement age has been prohibited all together. The philosophy behind this is that individuals should not be judged for their age but for their skills and knowledge. However in research institutions, where permanent researchers enjoy a permanent appointment for life this can have some consequences. In the model the retirement age of professors is changed from 65 to 75 in 2010 and smoothed over a period of 10 years. Figure 41 and 42 shows the simulation results.

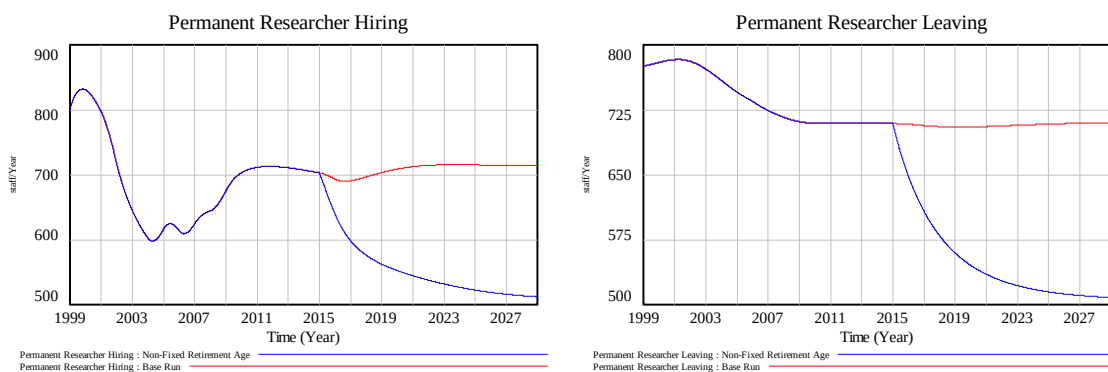


Figure 41: Simulation Results Non-Fixed Age: (a) decrease in permanent researcher hiring (b) decrease in permanent researchers leaving

The results show that the number of permanent researcher hiring starts declining in 2010 from around 1500 until reaching a new equilibrium around 900. The hiring behaviour reflect the faculty exit rate, which is also decreasing over time. The number of years that researchers stay in a

permanent position increases from 24 in 2010 until finding a new equilibrium around 34, a decade after the policy change is initiated. And most importantly, the number of permanent researchers starts to increase once the policy is initiated and then starts to decrease gradually until it returns to the target permanent capacity.

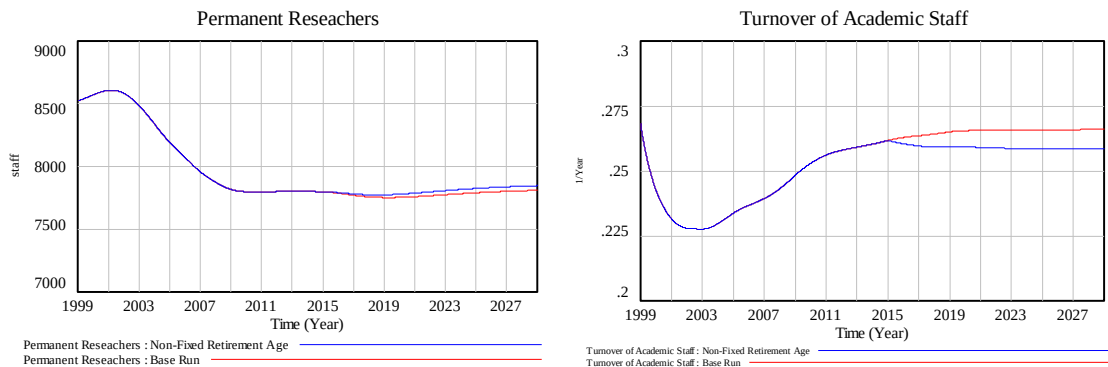


Figure 42: Simulation Results Non-Fixed Age: (a) number of permanent researchers and (b) the decrease in turnover of academic staff

Due to the elimination of the mandatory retirement age, in 2029 an additional 200 positions a year become unavailable for temporary researchers or other individuals outside academia. Percentage wise this is a decrease of nearly one third of the total of 700 a year.

CONTRACT TIME AND TERMS

With the emergence of temporary project funds, there has been an increase in temporary research staff at universities. Professors often apply for these project funds through a process of competition. Their stipends are often paid, so the project funds are used to acquired additional staff to aid in the project work. However, with the increase of funding perverse behaviour emerged (Ghaffarzadegan et al., 2014). As project funds are often only used for a short duration it was often more interesting to hire temporary staff on short contracts. This has increased the turnover of temporary research staff. The government want to reduce this behaviour by allowing only little contract accumulations; from six year on 3 temporary contracts to 4.5 years on 2 temporary project. In the model the contract term is analysed and adjusted.

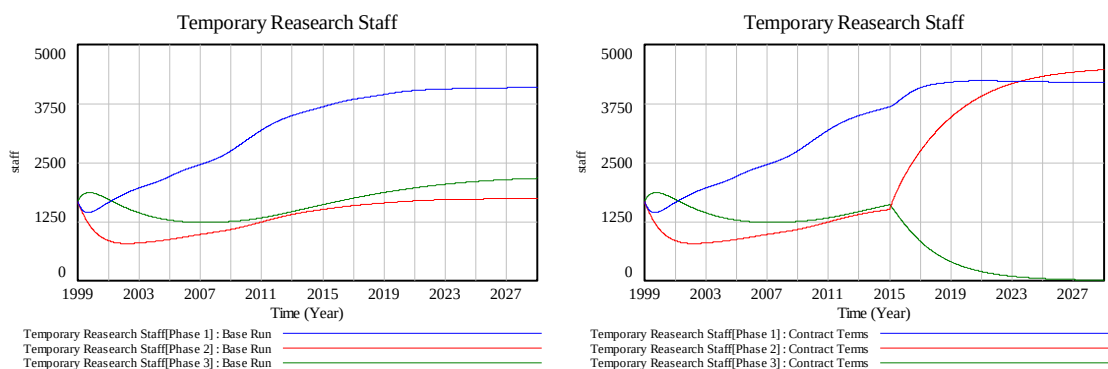


Figure 43: Simulation Results Contract Terms (a) base run temporary research staff and (b) temporary research staff with duration cap

The results, as shown in Figure 43, show that a decrease in contract time leads to a different ordering of research staff over the different contracts. The base run shows three different contract terms of 2 years. With the decrease of the contract terms to two and the maximum amount of residence time

to 4.5 only the ordering with the TRS phase changes. The number that will just have one contract will decrease. However the number of research staff in the second contract will increase substantially. Overall, the total number of temporary research staff will not increase dramatically. However, the turnover increases substantially as shown in Figure 44.

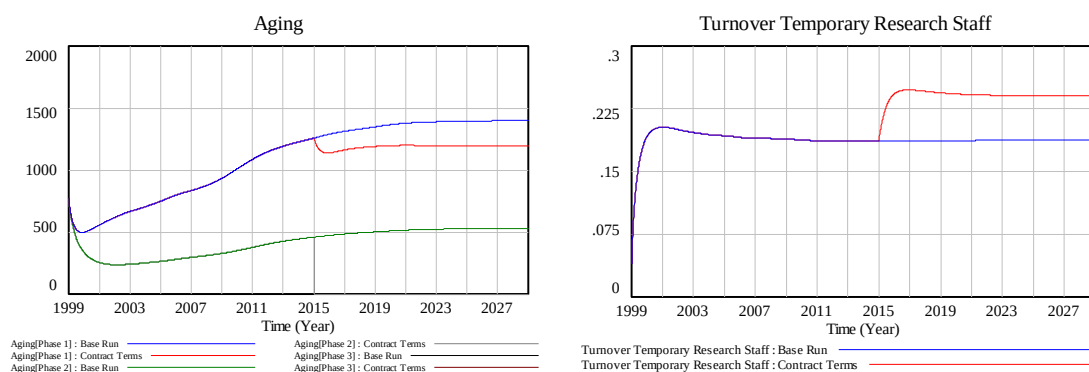


Figure 44: Simulation Results Contract Terms (a) aging in contract phases and (b) turnover of temporary research staff

The results suggest that the change in contract terms does not decrease the number of temporary research staff in Academia, more the contrary. With the decrease in contract terms the in- and outflow of temporary staff will further increase. Not only does the system become unbalanced, it also leads to an additional flow of newcomers that are often less qualified as contracts of qualified staff cannot be renewed.

LONGER FINANCIAL STABILITY

The government wants to increase the financial stability of public research organisations by allowing them to balance their funds over three consecutive years. This will enable them to mitigate possible funding deficits in some years by using funding surplus of other years.

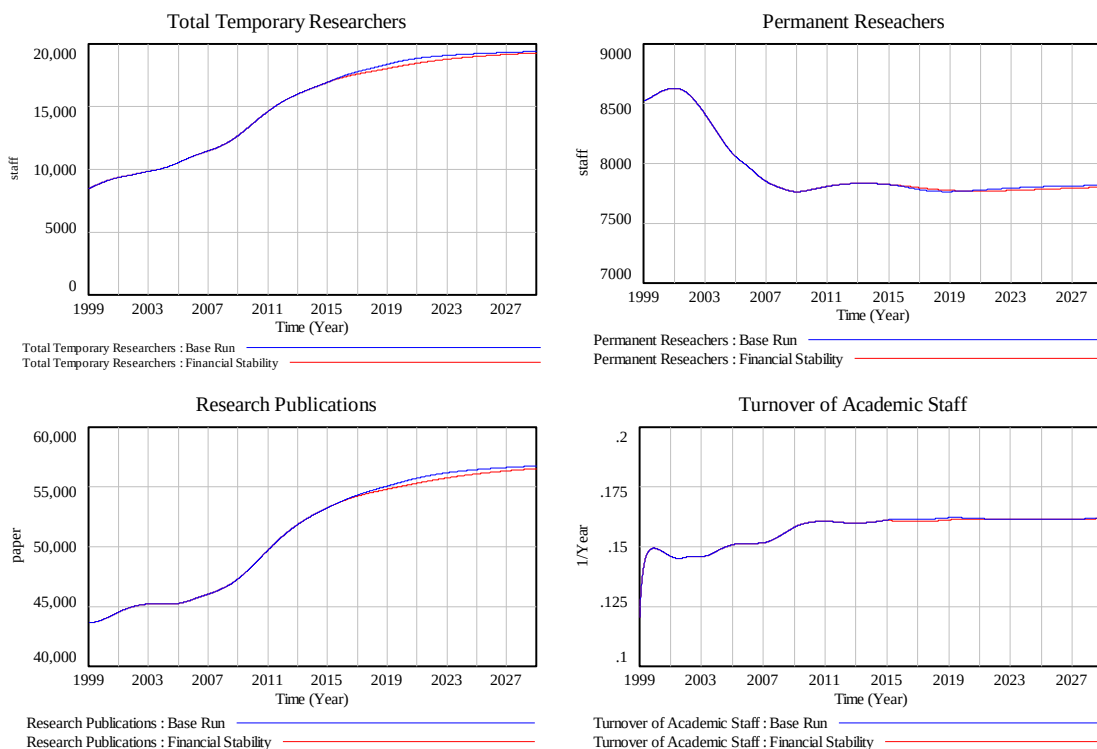


Figure 45: Simulation Results Financial Stability (a) Temporary Researchers, (b) permanent researchers, (c) Research Publications and (d) Turnover of Academic Staff

In the model this policy is implemented by using a smooth function for 3 years for all funding types. The results of this test can be found in Figure 45. The results only show significant behaviour in the 2019-2029 timeframe. This suggests that from 2019, when the amount of funding obtained becomes uncertain, organisations are more likely to hire additional permanent staff members than temporary staff members. This is expected, as financial security gives universities the incentive to hire additional permanent staff.

8.4 UNCERTAINTY ANALYSIS

Here, the uncertainties that were identified in section 6.5, will be analysed with the use the Monte-Carlo method which can be used to model a realistic uncertainty range within the SD model. The focus is on the uncertainty that have impact on the system and policy outcomes that were identified during analysis of the system and interviews at the Rathenau Institute. The detailed results of the uncertainty analysis can be found in Appendix 7.

INPUT UNCERTAINTY: PROMOTION OF FACULTY MEMBERS

The permanent researchers segment of model is constructed around the static perception of the permanent faculty staff. The inflow, promotion and outflow of staff is based on fractions and time units that remain stable throughout the model run. Here, the parameters are simulated over a realistic range of variables to perceive the impact of these input uncertainties.

First, the focus is on the average residence time these positions. The average numbers are computed by using the WOPI numbers found within VSNU database as shown in Appendix 4. Two sources are combined to obtain a realistic uncertainty range on which the model will be tested: (1) the individual residence time of the different permanent positions and (2) the total residence time of the permanent research career (Goede et al., 2014; Larson & Gomez Diaz, 2012). The UA results for the individual residence time, based on a multivariate analysis, show relatively large uncertainty in the individual stages but marginal uncertainty in the total permanent staff variable. This suggests that the uncertainty affects the distribution of staff over the phases but does not create additional room as the turnover in this UA does not show more uncertainty than in the SA. However this time the margins were larger, the normal distribution was used and the uncertainty range was realistic. The UA results for the total average residence time show expected uncertainty margins: the uncertainty in staff is marginal, however there is substantial uncertainty in staff turnover suggesting that the residence time is turnover based and not staff number based. This means that when the residence time changes the in- and outflow of staff increases but the total amount of room does not. Because it is the distribution that changes and only realistic uncertainty margins were found in literature about the total residence time, uncertainty for the total residence time will be used for the combined UA in a later stage. Figure 46 shows the important graphical outcomes of this UA.

Second, the focus is on the different factions that decide for the promotion in this model segment. These fractions are computed by using the WOPI number is the VSNU database as shown in Appendix 4. Here a random multivariate uniform distribution is chosen with a percentage rage, as limited data is available to obtain a realistic uncertainty range. These uncertain fractions show to be limitedly sensitive to changes as seen in Appendix 7. The distribution seems to shift, however the

turnover is less affected by the fractions. This suggest that these fractions, while being uncertain, prove to exert limited behavioural change in the observed variables.

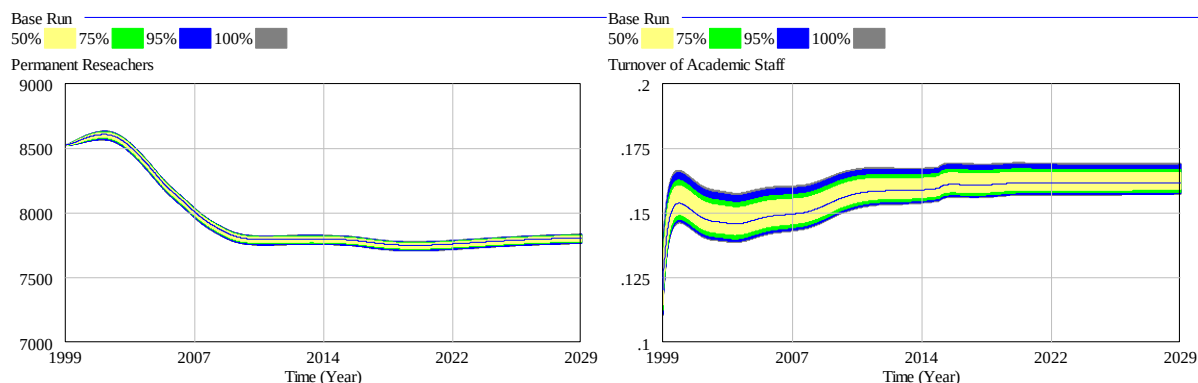


Figure 46: Uncertainty Analysis – total permanent residence time: (a) Permanent staff and (b) Staff turnover

Finally the combination of these uncertainties will be tested on the SDM environment. Generically, the combined US for the promotion of faculty members show the same results: large uncertainty in individual stages, average uncertainty in staff turnover and relatively little uncertainty in the total amount of staff and insignificant uncertainty in research output as shown in Table 13. Here ++ is medium-, + is shallow- and 0 is marginal uncertainty.

Input Uncertainty Experiments	Uncertainty Impact				
	Individual Permanent Staff	Total Permanent Staff	Ratio of Temporary to Permanent	Staff Turnover	Research Output
(1): Individual Residence Time	++	+	0	++	0
(2): Combined Residence Time	+	0	0	++	0
(3): Promotion Fractions	++	+	0	+	0
(4): Combined Experiment	++	+	0	++	0

Table 13: Input Uncertainty: Promotion of Faculty Members Impact

The general conclusion of this UA is that changes in input margins primarily affect the distribution and promotion of permanent staff members which seems to be consistent with the promotion in the academic system. However, changing uncertainty margins does not affect the ratio temporary to permanent researchers, nor does it affect the research output. The academic career changes in length [residence time], changing the staff turnover, making it more or less likely to attain a permanent position. This seems to suggest that this uncertainty will not compute different conclusions when included in the policy experiment section.

STRUCTURAL UNCERTAINTIES

There are many views on how reality should be conceived and incorporated within the created model. Here the structural uncertainties will be analysed by comparing the nominal model states to

the model states when the structure is altered. The focus, as described in section 6.5, will be on PhD promotion, TRS promotion and research funding and publications. Generic results can be found in Table 14 where ++ is a medium-, + is a shallow- and 0 is a marginal uncertainty.

First, the capacity mechanism will be substituted with a reproduction rate, as shown in section 6.3, to create a model segment that reacts to behaviour change. The BRN fraction is calibrated and quantified to 10 [dmnl] to fit the observed historical data. The BRN computes different behaviour in all stocks. However this is expected with a static exogenous parameter in comparison with a dynamic variable. The ratio of temporary to permanent staff and the research output only limitedly alters by this structural change, which suggests that both approaches will compute equal behaviour over time. Additionally, the turnover of academic staff seems to be more stable with a reproduction rate. With the BRN calibrated, it computes equal behaviour to the historical observed behaviour of the PhD stock. However in other stocks it leads to historical inaccurate behaviour. Therefore, while both mechanisms do not lead to significant different behaviour, the capacity mechanism show the best behaviour of all the stocks when compared with the historical data.

Structural Uncertainty Experiments	Uncertainty Impact			
	Numerical	Behavioural	Model Impact	Policy Impact
(1): PhD Promotion	++	++	+	0
(2): TRS Promotion	+	0	+	+
(3): Research Funding & Publications	+	+	0	+

Table 14: Structural Uncertainties

Second, the residence time of TRS as a chance mechanism is substituted with a quality indicator to become a permanent faculty member. Results show that only the TRS is affected by this structural change. Again, only the distribution between the contract phases is changed by this changing the structure. Specifically, because a longer residence time equals quality, more researchers tend to stay longer in this phase making the total residence time more uncertain.

Third, the increase in funding that is now endogenous to the system based on the desired number of publications is substituted with an exogenous variable that creates growth projections over time. Results show that from 2020 onwards additional funding is needed to satisfy the call for research output. This suggests that either other exogenous funding growth predictions are needed or the model should include economic and political parameters that endogenously describe the possible increase in PRF.

9. CONCLUSIONS

The purpose of this study was to design a model that could describe and explain the academic workforce development in the Netherlands over time and create a tool that could be used in a policy-making process. By answering five sub-questions the main research question will be answered. Based on the study findings, recommendations will be made. In Section 9.1 the research questions will be answered. Section 9.2 further describes and discusses the contributions, limitations and recommendations of this thesis work.

9.1 ADDRESSING THE RESEARCH QUESTIONS

The aim of this study was to address the main research question:

“How can career and funding policies affect the development of the academic workforce in the Netherlands over time?”

To answer this research question the Dutch academic career system was analysed and a System Dynamics model was made. The following five questions have been answered to provide a conclusion to the main research question.

THEORY

1. What are the main mechanisms in the science system that influence the development of the academic workforce in the Netherlands?

The academic workforce development system consists of five consecutive positions in which a young researcher matures and becomes professor. The promotion and development of academic staff is influenced by multiple mechanisms, both financial and contractual, and by actors such as policy-makers, advisory bodies, HR departments and individual researchers. In this environment, perceived as an on-going Principal-Agent game, the government wants to influence the workforce development and output of the science system. In the best interest of the stakeholder and with the understanding of different normative perceptions that exist, a top-down governmental policy approach is chosen as the point of departure for this study.

The main policy instrument that influences the development of the academic workforce is public research funding. Traditionally, these funds were allocated to public research organisations without an incentive scheme. The government could not exercise control over the research area, the research approach and the research outcomes. This could create research that was not beneficial to society. In light of the information asymmetries between policy-makers on top and professionals on the work floor, the government introduced competitive funding regimes: performance agreements [ex-ante] and performance based funding [ex-post], trying to increase research quality while incentivising research behaviour. Additionally, the government introduced contractual and financial agreements to stabilise financial and career uncertainties of public research organisations and individual researchers.

However, it is not known how the policy changes affect the workforce development and research output over time. Because the science system is too complex to analyse with the use of implicit mental models, a new method perspective is needed that could adequately analyse the relation between the introduced policy instruments and the effects on the workforce.

METHOD

2. Which method can be used to adequately analyse and understand the complexities of the academic workforce development in the Netherlands?

The science system has changed substantially over the years. Many policy instruments have been enacted to deal with the changing environment. To assess the impact of these changes, many studies have been published. The main focus of these studies was either qualitative, with the use of interviews or surveys, or quantitative, correlation based using comparative or statistical methods. However, these studies analyse the system from a static perspective. Moreover, it perceives the behaviour of actors, and their interaction, both in governmental and operational layers as static and unchangeable over time. This does not suffice when the system under study is a complex collection of partially connected sub-systems that interact and changes over time.

Concepts such as time delays, accumulations and non-linearities all have to be taken into account if policy makers want to make sense of their enacted policies. Studying these complex linkages at various parts of the system can be a time-consuming, costly and, in some cases, practically impossible task. Due to these constraints, modelling the system and simulating the problem field is the only realistic way to test the system on policy behaviour.

To understand and analyse the effects of policy measures on the development of the total academic workforce in the Netherlands an aggregated system perspective has to be adopted. This calls for an abstract modelling method that does not look at detail but perceives the system from a strategic level. System Dynamics is an adequate modelling method to tackle the research question as it can incorporate the different concepts of the science system, its inherent complexities, its continuous interaction and the impact of policy measures over time from a strategic level.

ANALYSIS

3. What is the relation between career and funding policies and the academic workforce development and research output in the Netherlands?

The exact relation between funding and academic workforce development is near-impossible to make. However, from the chosen aggregated system perspective realistic expectations can be made. Generally, public research funds are directly allocated to public research, organisations based on historical indicators, without an incentive scheme and indirectly through The Dutch Organisation of Scientific Research based on project proposals. Additionally, private research funds are allocated based on performance agreements. Most of these funds can be used discretionarily. In some cases the public research organisations

use this funds for different purposes. Then the intended purpose of the government is not reached. In the presence of information asymmetries between the policymaker and the public research organisations, it is difficult to set policy incentives that induce the right behaviour. It is expected that public research funds are exploited to cover the costs of researchers and public research infrastructure. This expectation is in line with the top-down policy perspective that is adopted for this study. Based on the availability of research funds, funds are distributed over the different positions. However, it is uncertain whether this perspective leads to the right real-world behaviour. To address these uncertainties, a bottom-up perspective was explored in the uncertainty analysis. Based on system analysis and interviews at the Rathenau Institute, the most important structural uncertainties were chosen. For these uncertainties only marginal differences in system behaviour were observed. This suggests that a top-down perspective of funding allocation could be one of the ways to describe the relation between funding and the workforce development in academia.

The exact relation between funding and research output is more difficult to make. It is assumed that from an aggregated system perspective general expectations are possible. As public research funds influence the development of the workforce, it influences the research output of the workforce. However, both direct and indirect governmental funding do not control the research output. Only performance agreements provide the right incentive for specific research output. Research output is an ambiguous term as both quantifiable and non-quantifiable output indicators can be created. Therefore, the research output structure of the model is not for forecasting but to gain understanding of the complex nature of this linkage and to show inherent deficiencies such as reduced performance if more competitive funding structures are adopted.

The relation between career policies and academic workforce development is based on agreements between the government and public research organisations. The government responds with policy making when behaviour is observed at human resources departments which is not aligned with governmental objectives. From the adopted top-down policy perspective this could have a desired effect. However, on the work floor agreements can be bypassed. To deal with the growing temporary workforce and accumulation of temporary contracts the government proposed to cap the amount of time a temporary researcher could be appointed. However, some public research organisations bypassed this policy by letting temporary staff be appointed elsewhere for a short duration until a reappointment was possible. This shows that a top-down perspective can still lead to perverse behaviour on the work floor.

4. What are the effects of proposed policy measures on the workforce development and output in academia?

The simulation results suggest that a link exists between the increased focus for competitive funding and the increased focus on a temporary workforce. When it is uncertain if funds will be obtained, public research organisations are more likely to hire temporary research staff, who are flexible, interchangeable and inexpensive. The focus on competitive funding could

lead to productivity losses, as more researchers spend more time on the acquisition of funds. Because a quality concept was not included in the SD model, the effects of competition on the quality of the research could not be analysed.

To prevent the contract accumulation of temporary research staff, the government proposed to limit the amount of temporary contracts a researcher could obtain. However, the simulation results suggest that it does not lead to the desired effect: the decrease in career uncertainty due to contract accumulation and the decrease of academic staff turnover. Capping the contract terms leads to a reinforced turnover of temporary research staff: a higher in- and outflow of staff. This suggests that vacancies are more likely to be filled by less qualified staff, as it becomes impossible to retain staff or let them promote towards a faculty position. Additionally, it could lead to perverse behaviour as researchers will temporarily change position to become eligible for a temporary position again.

As the Dutch population is aging, and researchers have to continue working for a longer period, it is vital to understand the dynamics if the mandatory-retirement age of 65 is changed. When this age cap is extended, the number of years professors remain in the academic world increases, which has its effect on the temporary research staff. The number of professors starts to increase when this cap is lifted and then starts to decline back to its target size. Due to the elimination of the retirement age, one third of the total yearly positions may become unavailable for temporary researchers or other individuals outside academia.

5. How can this study contribute to the knowledge of the academic workforce development and be used in a policy-making process?

The purpose of this study was to contribute to the knowledge about policy-making in the science system and the effects on the workforce. Through analyses it was found that the science system has gone through several changes in recent years. Traditionally, the science system was primarily supported by the government based on direct institutional funding. Also, most researchers acquired a permanent position. In recent years, the focus has shifted towards a temporary workforce and a more competitive funding structure. Studying the interrelations between funding and the workforce development some important concepts were found. First, the science system is a highly complex dynamic system with many interrelating features. By building a System Dynamics model these interrelations were analysed and the linkage between subsystems was made. The focus was on the relations between funding and policies on one hand and the workforce development and research output at the other hand. Second, with the use of the Principal-Agent problem it was found that policy-making in these complex environments is near-impossible. However, the policy-makers want to make sense of their policies and incentivise the behaviour of researchers. It is therefore important that policy makers set the right incentive for research to be conducted. Policy makers have a normative and static perception of the science system when it comes to policy making. They therefore create policies that should have the intended purpose. Therefore it is important to understand that these policies are created from a

normalised static and top-down perspective on the science system. The researchers in the operational layers are often thinking otherwise.

For policy makers it is therefore important to understand that policy-making happens in an arena where the environment is constantly changing, top-down enacted policies could not have the intended effects on the work floor and many factors influence research behaviour. In this environment, policy-makers should understand the dynamics and complexities at work and should not perceive the science system as static over time. Creating policies is an iterative process of adjusting and readjusting over time until the higher level of performance is obtained.

9.2 DISCUSSION

After concluding this research, it is crucial to reflect on the contributions to science, the research process and research method. Based on these reflections, recommendations for future research are made.

CONTRIBUTIONS TO SCIENCE

This study offers three main contributions to science. First, this study adds to literature covering academic workforce development. Previous studies have mainly addressed the issues in a qualitative way (Arensbergen et al., 2013; Van Balen, 2010; van Balen et al., 2012; van Drooge & de Jong, 2008). This study tries to connect this connect the information gathered from this studies (Goede et al., 2014), by creating a model that looks at the influence of governmental policies and funding (Versleijen & van der Meulen, 2007) on the workforce development and performance of academic staff (van Dalen et al., 2012; Verbree et al., 2015). Not much is known about the influence and impact of policy changes on the workforce development over time. Based on several feedback mechanisms, this system is constructed within the System Dynamics framework, including hiring and promotion rules that affect the flow of researchers in the academic positions. Second, this study adds to literature covering workforce development models. Building on other models (Navid Ghaffarzadegan et al., 2014; N Ghaffarzadegan et al., 2014; Hur et al., 2015; Larson et al., 2013; Larson & Gomez Diaz, 2012; Oyo et al., 2008; Sterman, 2000) this paper offers a focus on the impact of funding on the academic workforce and output in the Dutch academicsystem. Third, the model can now be used to understand the underlying academic development system in the Netherlands and studies the behaviour over time. With this understanding comes the ability to simulate policy experiments and to show the effect on the workforce development.

REFLECTIONS ON THE PROCESS

It is difficult to develop a generic model of the complex science system. Its functions and structures differ among public research organisations. Governmental regulations differ across universities. Furthermore, each research organisation reacts differently to governmental policies and creates different research and research output. These complexities and the choice for a systems perspective was the main obstacle in the development of the model. This problem lies in the decision of building a generic model of all public research organisations and not specifically for one university. Additionally, the choice for System Dynamics limits the choice for perspectives and valuable outcomes. These decisions posed problems regarding the construction of the model, the input of data and the incorporation of decisions mechanisms. The knowledge about the internal mechanisms

at public research organisations was limited, making it difficult to capture the decisions of the human resources departments and funding allocation management. The knowledge about the bottom-up approach could have been acquired from experts working in public research organisations which would improve the validity and importance of the study outcomes. These insights could also mitigate the uncertainties that remain with the chosen approach. For the purpose of the problem owner an System Dynamics model was developed representing the public research organisations in the Netherlands. During the process the researcher focused on the model development with the chosen perspective rather than developing many models that would incorporate the different perspectives of the science system.

LIMITATIONS OF THE RESEARCH METHOD

The chosen methodology is a promising way to capture the dynamics of the science system, but also, as all modelling studies, faces its own limitations. The boundary of the model is set around the promotion of academic staff with the focus on how different variables within that system interact. It does not include the upstream effect of students at earlier phases in the university. However the education preparation for an academic career seems to play a crucial role in the academic workforce development (Hur et al., 2015). It also does not include the entire market side competition for potential academic staff, and the notion of quality and excellence. The expertise and quality of researcher does however have a significant influence on the choice for promotion.

There are also other feedback systems to consider that could improve the overall validity of the system but could make the model unnecessarily complicated. For example, the inflow of lateral hires could be influenced by their academic qualifications. This is why the inflow is now modelled with inflow fractions to define the distribution between academic and lateral hires. The quality per group of hires can change due to economic change, educational change or the quality of international staff. Adding more detail to the characteristics of the academic staff such as age, gender, academic background or extending the model with intra-national difference between universities would enhance the model but would make it unnecessarily detailed. The scope is therefore chosen from the stakeholders perspective and serves that purpose.

RECOMMENDATIONS FOR FUTURE RESEARCH

While relevant conclusions can be drawn from this modelling study, there might be other methodologies that could equally describe this system in a consistent manner while drawing robust conclusions. A top-down strategic perspective is chosen to analyse the system. In a follow-up study the model could be extended, a bottom-up perspective could be integrated within other model approaches and uncertainties could be mitigated. Including the Agent Based Methodology could enhance knowledge of actions and interactions of researchers and other actors within the system. Additionally, the Exploratory Modelling and Analysis methodology could be adopted to analyse the uncertainties in a more comprehensive way. In light of these uncertainties, robust decisions could be made. Traditional System Dynamics modelling could be used to extend the model beyond the chosen boundaries to increase overall robustness of the model results. More analysis is also needed into the perceptions of certain system characteristics, such as the desirability of temporary research staff and competitive funding regimes. Further research is therefore needed to create a more comprehensive image of the workforce development in academia and the factors influencing it.

The conclusions drawn from this study justify the need for additional research. First, there are many model and theoretical uncertainties within this study that remain. Further research into system analysis should be conducted. The model uncertainties could be further dealt with by adopting a multi-method approach. Second, there is a need to deal with system perspectives. Opposed to the top-down policy perspective adopted in this study, a bottom-up approach could compute different behaviour. The multi-method approach, where a top down method like System Dynamics is combined with a bottom-up method like Agent Based Modelling could render more robust results. Finally, there is a need to deal with system perceptions. Multiple perceptions on the system, whether behaviour is wanted or unwanted could create obstructions in the policy-making process. Simulating different actors, within the different organisational layers of the science system, exercising behaviour and different decisions would provide significant outcomes that is not possible to capture with this research. For this multi-perspective system a multi-method approach could be used.

BIBLIOGRAPHY

- Arensbergen, P. v., Hessels, L., & Meulen, B. (2013). Talent centraal. Ontwikkeling en selectie van wetenschappers in Nederland.
- Auranen, O., & Nieminen, M. (2010). University research funding and publication performance — An international comparison. *Research Policy*, 39(6), 822-834. doi: <http://dx.doi.org/10.1016/j.respol.2010.03.003>
- AWT. (1999). Hoofdlijnen Wetenschapsbeleid. *Adviesraad voor het Wetenschaps en Technologiebeleid*.
- Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*, 12(3), 183-210.
- Benner, M., & Sandström, U. (2000). Institutionalizing the triple helix: research funding and norms in the academic system. *Research Policy*, 29(2), 291-301. doi: [http://dx.doi.org/10.1016/S0048-7333\(99\)00067-0](http://dx.doi.org/10.1016/S0048-7333(99)00067-0)
- Bolton, P., & Dewatripont, M. (2005). *Contract theory*: MIT press.
- Borshchev, A., & Filippov, A. (2004). *From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools*. Paper presented at the Proceedings of the 22nd international conference of the system dynamics society.
- Cameron, A. C., & Windmeijer, F. A. (1997). An R-squared measure of goodness of fit for some common nonlinear regression models. *Journal of Econometrics*, 77(2), 329-342.
- Cherchye, L., & Abeele, P. V. (2005). On research efficiency: A micro-analysis of Dutch university research in Economics and Business Management. *Research Policy*, 34(4), 495-516.
- Chiong-Meza, C. (2012). Feiten en Cijfers - De Nederlandse Unversiteiten *Rathenau Instituut*. Ne Haag.
- Dalderup, L. (2000). Wetenschapsvoorlichting en wetenschapsbeleid in Nederland 1950-2000. *Gewina/TGGNWT*, 23(3), 165-192.
- De-Jonge-Akademie. (2010). Rendement van Talent - Aanbevelingen voor Motiverend en Stimulerend Loopbaanbeleid. In E. Bouma (Ed.). Amsterdam: De Jonge Akademie.
- de Boer, H., Jongbloed, B., Benneworth, P., Cremonini, L., Kolster, R., Kottmann, A., . . . Vossensteyn, H. (2015). Performance-based funding and performance agreements in fourteen higher education systems. *Center for Higher Education Policy Studies*.
- de Weert, E. (2001). Pressures and prospects facing the academic profession in the Netherlands. *Higher Education*, 41(1-2), 77-101. doi: 10.1023/A:1026762712005
- Dietz, J. S., & Bozeman, B. (2005). Academic careers, patents, and productivity: industry experience as scientific and technical human capital. *Research Policy*, 34(3), 349-367.
- Dijk, A., Frankfort, J., Horn, T., & Vos, K. (1993). *Wetenschaps-en technologiebeleid in Nederland*: DSWO Press, Rijksuniversiteit Leiden.
- Enders, J. (2007). The Academic Profession. In J. F. Forest & P. Altbach (Eds.), *International Handbook of Higher Education* (Vol. 18, pp. 5-21): Springer Netherlands.
- Enders, J., & Teichler, U. (1997). A victim of their own success? Employment and working conditions of academic staff in comparative perspective. *Higher Education*, 34(3), 347-372. doi: 10.1023/A:1003023923056
- Enserink, B., Hermans, L., Kwakkel, J., Thissen, W., Koppenjan, J., & Bots, P. (2010). *Policy analysis of multi-actor systems*: Lemma The Hague.
- Falk-Krzesinski, H. J., Contractor, N., Fiore, S. M., Hall, K. L., Kane, C., Keyton, J., . . . Trochim, W. (2011). Mapping a research agenda for the science of team science. *Research Evaluation*, 20(2), 145-158.
- Fernández-Carro, R. (2007). A principal-agent model of public research with a retrospective payoff rule. *Science and Public Policy*, 34(5), 317-328.
- Forrester, J. W. (1992). Policies, decisions and information sources for modeling. *European Journal of Operational Research*, 59(1), 42-63. doi: [http://dx.doi.org/10.1016/0377-2217\(92\)90006-U](http://dx.doi.org/10.1016/0377-2217(92)90006-U)

- Forrester, J. W. (1994). System dynamics, systems thinking, and soft OR. *System Dynamics Review*, 10(2-3), 245-256. doi: 10.1002/sdr.4260100211
- Forrester, J. W. (1997). Industrial dynamics. *Journal of the Operational Research Society*, 48(10), 1037-1041.
- Frølich, N. a. K., A. (2006). *Strategic management of higher education institutions: performance funding and research output. Paper presented at he Conference on Indicators on Science, Technology and Innovation, Special session on Indicators for strategic management of higher education institutions*, . Paper presented at the Conference on Indicators on Science, Technology and Innovation, Lugano, switzerland
- Fruijtier, B. (2007). Tenure track een goed instrument voor talentmanagement? *Inventarisatie van de risico's en kansen van 'tenure track' voor de werving, binding en loopbaanbegeleiding van wetenschappelijk talent op de Nederlandse universiteiten*. Radboud Universiteit Nijmegen en Vereniging van Nederlandse Universiteiten (VSNU).
- Ghaffarzagdegan, Hawley, & Desai. (2014). Research Workforce Diversity: The Case of Balancing National versus International Postdocs in US Biomedical Research. *Systems Research and Behavioral Science*, 31(2), 301-315.
- Ghaffarzagdegan, N., Hawley, J., Larson, R., & Xue, Y. (2014). A Note on PhD Population Growth in Biomedical Sciences. *Systems Research and Behavioral Science*.
- Ghaffarzagdegan, N., Xue, Y., & Larson, R. (2014). Hiring College Graduates to Flip Hamburgers: An Endogenous Theory of Professionalization: MITESD Working Paper Series.
- Goede, M., Belder, R., & Jonge, J. (2014). Academische carrières en loopbaanbeleid/Academic careers in the Netherlands.
- Gomez Diaz, M. (2012). *Unintended effects of changes in NIH appropriations: Challenges for biomedical research workforce development*. Massachusetts Institute of Technology.
- Hazeu, C. A. (1986). De organisatie van het onderzoeksbestel; beleidsvoering en besluitvorming in een gelaagd systeem. *Beleid & Maatschappij* 4.
- Hicks, D. (2012). Performance-based university research funding systems. *Research Policy*, 41(2), 251-261. doi: <http://dx.doi.org/10.1016/j.respol.2011.09.007>
- Hoffius, R., & Surachno, S. (2006). Tussen wens en werkelijkheid: carrièreperspectieven van jonge onderzoekers. Eindrapport: Leiden: Research voor Beleid.
- Holmström, B. (1999). Managerial incentive problems: A dynamic perspective. *The Review of Economic Studies*, 66(1), 169-182.
- Huisman, J., Weert, E. d., & Bartelse, J. (2002). Academic Careers from a European Perspective: The Declining Desirability of the Faculty Position. *The Journal of Higher Education*, 73(1), 141-160. doi: 10.2307/1558451
- Hur, H., Ghaffarzagdegan, N., & Hawley, J. (2015). Effects of Government Spending on Research Workforce Development: Evidence from Biomedical Postdoctoral Researchers.
- IBO. (2014). *IBO Wetenschappelijk onderzoek*. The Hague: Inspectie der Rijksfinanciën/Bureau strategische analyse.
- Johnes, J., & Johnes, G. (1995). Research funding and performance in UK university departments of economics: a frontier analysis. *Economics of Education Review*, 14(3), 301-314.
- Kennedy, M. (2000). *Towards a taxonomy of system dynamics models of higher education*. Paper presented at the Proceedings of the 18th International Conference of the System Dynamics Society (2000) 6-10 August 2000 Bergen, Norway.
- Kennedy, M. (2011). *A review of system dynamics models of educational policy issues*. Paper presented at the Proceedings of 24th International Conference of System Dynamics Society, Washington DC, USA.
- Kennedy, M., & Clare, C. (1999). *Some issues in building system dynamics model for improving the resource management process in higher education*. Paper presented at the Proceedings of the 17th international system dynamics conference, Wellington, New Zealand.

- Kwakkel, J. H., & Pruyt, E. (2013). Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. *Technological Forecasting and Social Change*, 80(3), 419-431. doi: <http://dx.doi.org/10.1016/j.techfore.2012.10.005>
- Laffont, J.-J., & Martimort, D. (2009). *The theory of incentives: the principal-agent model*: Princeton university press.
- Larson, R. C., Ghaffarzadegan, N., & Xue, Y. (2013). Too Many PhD Graduates or Too Few Academic Job Openings: The Basic Reproductive Number R_0 in Academia. *Systems Research and Behavioral Science*.
- Larson, R. C., & Gomez Diaz, M. (2012). Nonfixed retirement age for university professors: modeling its effects on new faculty hires. *Service science*, 4(1), 69-78.
- Louis, K. S., Holdsworth, J. M., Anderson, M. S., & Campbell, E. G. (2007). Becoming a scientist: The effects of work-group size and organizational climate. *The Journal of Higher Education*, 78(3), 311-336.
- Merton, R. K. (1988). The Matthew effect in science, II: Cumulative advantage and the symbolism of intellectual property. *Isis*, 606-623.
- Mintzberg, H. (2006). *Organisatiestructuren*: Pearson Education.
- OCW, M. v. (2014). Wetenschapsvisie 2025 - Keuzes voor de toekomst [Press release]
- Oliva, R. (2003). Model calibration as a testing strategy for system dynamics models. *European Journal of Operational Research*, 151(3), 552-568.
- Oyo, B., Williams, D., & Barendsen, E. (2008). *A system dynamics tool for higher education funding and quality policy analysis*. Paper presented at the Proceedings of the 24th International Conference of the System Dynamics Society.
- Packalen, M., & Bhattacharya, J. (2015). Age and the Trying Out of New Ideas: National Bureau of Economic Research.
- Pavitt, K. (1987). The objectives of technology policy. *Science and Public Policy*, 14(4), 182-188.
- Pelz, D. C., & Andrews, F. M. (1966). SCIENTISTS IN ORGANIZATIONS: PRODUCTIVE CLIMATES FOR RESEARCH AND DEVELOPMENT.
- Porter, A. L. (2004). Technology futures analysis: Toward integration of the field and new methods. *Technological Forecasting and Social Change*, 71(3), 287-303. doi: <http://dx.doi.org/10.1016/j.techfore.2003.11.004>
- Preffer, J., & Salancik, G. (1978). The external control of organizations: A resource dependence perspective. *The external control of organizations: a resource dependence perspective*.
- Pruyt, E. (2007). *Dealing with uncertainties? combining system dynamics with multiple criteria decision analysis or with exploratory modelling*. Paper presented at the Proceedings of the 25th International Conference of the System Dynamics Society.
- Pruyt, E. (2010). *Using small models for big issues: Exploratory System Dynamics Modelling and Analysis for insightful crisis management*. Paper presented at the 18th International Conference of the System Dynamics Society.
- Pruyt, E. (2014). *System Dynamics and Uncertainty, Working Paper*. Paper presented at the System Dynamics Conference, Delft, Netherlands.
- Rathenau-Institute. (2015a). Data Mining, Interviews and Meetings.
- Rathenau-Institute. (2015b). Policy instruments. Retrieved 01-09, 2015, from <http://www.rathenau.nl/en/web-specials/the-dutch-science-system/policy-and-advice/science-policy/policy-instruments.html>
- Smith, C. G. (1971). Scientific performance and the composition of research teams. *Administrative Science Quarterly*, 486-496.
- Srikanthan, G., & Dalrymple, J. F. (2007). A conceptual overview of a holistic model for quality in higher education. *International Journal of Educational Management*, 21(3), 173-193.
- Sterman, J. D. (2000). *Business dynamics: systems thinking and modeling for a complex world* (Vol. 19): Irwin/McGraw-Hill Boston.
- Sterman, J. D. (2001). System dynamics modeling. *California management review*, 43(4), 8-25.

- Stvilia, B., Hinnant, C. C., Schindler, K., Worrall, A., Burnett, G., Burnett, K., . . . Marty, P. F. (2011). Composition of scientific teams and publication productivity at a national science lab. *Journal of the American Society for Information Science and Technology*, 62(2), 270-283.
- Thissen, W. A., & Walker, W. E. (2013). *Public Policy Analysis*: Springer.
- Try, S., & Grøgaard, J. B. (2003). Measuring the relationship between resources and outcomes in higher education in Norway.
- van Arensbergen, P., & van den Besselaar, P. (2012). The Selection of Scientific Talent in the Allocation of Research Grants1. *Higher Education Policy*, 25(3), 381-405.
- Van Asselt, M. B., & Rotmans, J. (2002). Uncertainty in integrated assessment modelling. *Climatic Change*, 54(1-2), 75-105.
- Van Balen, B. (2010). Op het juiste moment op de juiste plaats. *Waarom wetenschappelijk talent een wetenschappelijke carrière volgt*. Den Haag, Rathenau Instituut.
- van Balen, B., van Arensbergen, P., van der Weijden, I., & van den Besselaar, P. (2012). Determinants of success in academic careers. *Higher Education Policy*, 25(3), 313-334.
- van Balen, B., & van den Besselaar, P. (2007). Universitaire onderzoeksloopbanen. *Een verkenning van problemen en oplossingen*.
- van Dalen, R., Mehmood, S., & Verstraten, P. (2012). Public funding of science.
- van den Brink, M., Fruytier, B., & Thunnissen, M. (2013). Talent management in academia: performance systems and HRM policies. *Human Resource Management Journal*, 23(2), 180-195.
- van der Weijden, I., Verbree, M., Braam, R., & van den Besselaar, P. (2009). Management en prestaties van onderzoeksgroepen. *Rathenau Instituut. Ne Haag*.
- van Drooge, L., & de Jong, S. (2008). Feiten & Cijfers: 20 jaar onderzoeksevaluatie.
- Van Steen, J. (2012). Feiten en cijfers: Overzicht Totale Onderzoek Financiering (TOF) 2010-2016. *Feiten en Cijfers*, 5.
- Verbree, M., Horlings, E., Groenewegen, P., Van der Weijden, I., & van den Besselaar, P. (2015). Organizational factors influencing scholarly performance: a multivariate study of biomedical research groups. *Scientometrics*, 102(1), 25-49.
- Verbree, M., Van der Weijden, I., & Van den Besselaar, P. (2012). Academic leadership of high-performing research groups. *Creativity and Leadership in Science, Technology, and Innovation*.
- Versleijen, A., & van der Meulen, B. (2007). Dertig jaar publieke onderzoeksfinanciering in Nederland 1975-2005. *Den Haag, Rathenau Instituut*.
- VSNU. (2015). Feiten en Cijfers. Retrieved 01-09, 2015, from http://vsnu.nl/nl_NL/feiten-en-cijfers.html
- Walker, W. E., Marchau, V. A., & Swanson, D. (2010). Addressing deep uncertainty using adaptive policies: Introduction to section 2. *Technological Forecasting and Social Change*, 77(6), 917-923.

APPENDIX 1: WORKFORCE DEVELOPMENT

This Appendix shows an overview of the most significant mobility in the academic career system in the Netherlands. Figure 47 shows an info graphic created by (Goede et al., 2014) and covers the average yearly mobility in number of people in time frame 2003-2011. Because it is a simplified representation of the VSNU data, not all in- and outflow of academic staff is included. While this is a static average perception of the workforce development in academia it gives insight into the important mobility for the chosen system scope and perspective.

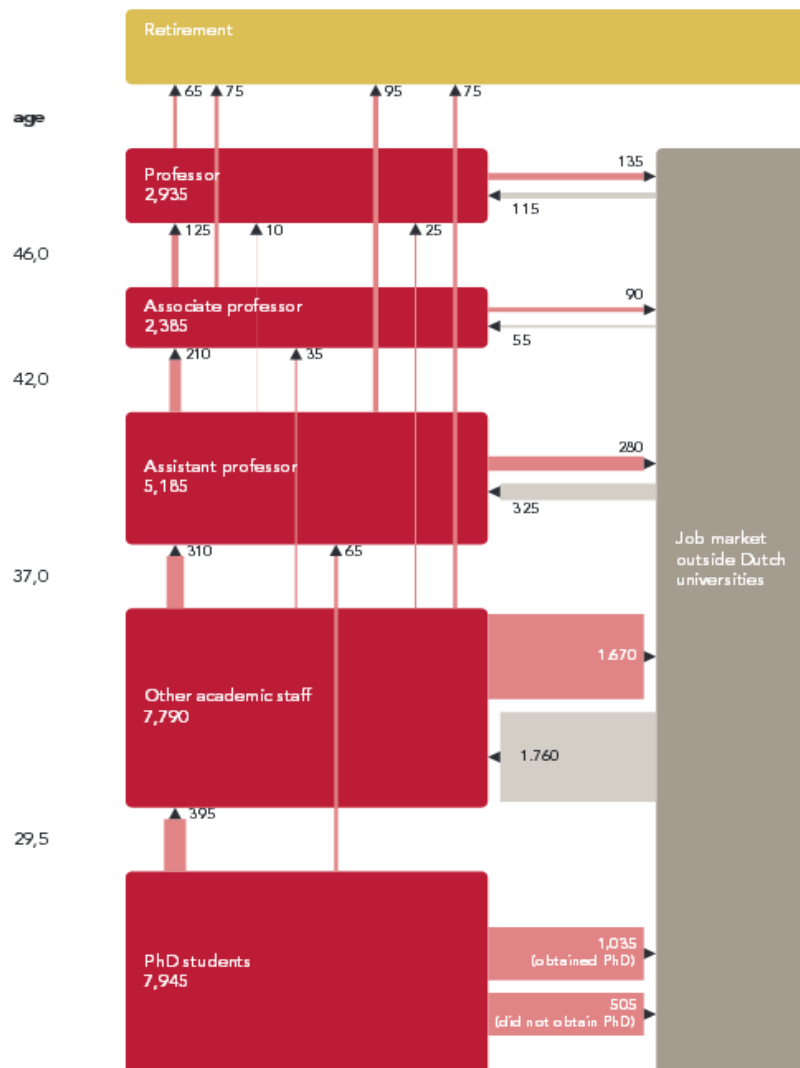


Figure 47: Mobility in the Academic Career, adopted from (Goede et al., 2014), excluding demotions and support and management staff

The figure shows the movement between the different positions. The academic job market seems to be most dynamic on the temporary staff levels, and exerts a strong selective character (Goede et al., 2014). Each year, many researchers move job or position. Conversely, there is a large inflow of academics from outside academia. While this shows the mobility of staff from a generic perspective, it is only a limited representation of reality as a limited time frame and averages are used. Therefore it does not show temporary or sudden changes to staff in- and outflow. A more comprehensive image is needed to make sense of the workforce development over time.

APPENDIX 2: RESEARCH PERFORMANCE

Public research organisations, research groups and research individuals are often compared on their performance. This is not completely valid as the research environment could change, research output cannot be compared and research goals do not entail the maximisation of output. However, it can be valuable to see which organisational factors influence research performance. In this Appendix the different key variables that determine research performance in organisations will be identified. The focus will be on factors that are useful for this study such as workforce composition, the acquisition of funds and the age and experience of group leaders. Three main studies are combined that form the basis of this review (Stvilia et al., 2011; van der Weijden et al., 2009; Verbree et al., 2015). The findings of the empirical studies provide a broad overview of the organisational determinants that are key to success in research organisations and could be used in support of a policy-making process.

INTRODUCTION

Traditionally, academic research was mainly conducted individually. With the increasing complexity and interdisciplinary of research problems, research became largely embedded in research groups. The manner in which teams are composed play an important role in how the project team functions. It is also necessary to create an environment in which research groups meet individual and collective goals (Pelz & Andrews, 1966). There are many organisational determinants that are successful in research organisations. Pelz and Andrews (1966) investigated key determinants, highlighting communication, motivation and group size as important variables that influence research performance. Others have looked at leadership and group dynamics and the influence on research performance (Louis, Holdsworth, Anderson, & Campbell, 2007; Verbree et al., 2015).

However, before analysing these studies, the definition of research performance has to be identified. Research output in literature has a multidimensional nature: publications, education, reports, technical contributions are one of the many examples. Research quality also has a multidimensional nature as it could be expressed in terms of productivity, impact and creativity. As such, the perception of quality and performance varies per field. Research performance within the main discussed article by Verbree et al (2015) is broken down into four district components. As it is a study on group performance individual and group performance factors are distinguished. Publication and Citation counts are based on research groups, while productivity is measures as the number of publications per researchers and quality as the number of citations per publication. Data of research performance is collected from three databases: PubMed, the Web of Knowledge and the Dutch Research Database over a period of 3 years.

Research is also embedded in an environment with heterogeneous demands (Verbree, Van der Weijden, & Van den Besselaar, 2012). Not only does research become more interdisciplinary, funding is often supplied from a variety of sources making academic institutions less autonomous and more focussed on acquiring funds and satisfying demand (Versleijen & van der Meulen, 2007).

The determinants for success; the relationship between the organisational factors and research performance are defined in four categories:

- Resource Strategy

- Processes in Research Organisations
- Environmental Conditions
- Personal Characteristics of Researchers

All the components in these categories interrelate and simultaneously determine research performance. While some of these components are self-driven by group leaders or chairs within research organisations some components are external. As such, effectiveness in research organisations is not merely determined by researchers within but also by the environment in which they operate. Because of funding and policy dependency, autonomous organisations such as universities become resource dependent (Preffer & Salancik, 1978), which could have an impact on how they align their strategy.

DETERMINANTS FOR SUCCESS

Resource strategy

The acquisition of staff and funding are two key resources that research groups need to attain to conduct research and realise research output (Johnes & Johnes, 1995). As the lack of funds is detrimental for research, researchers increasingly acquire funds from a variety of external and internal sources (Versleijen & van der Meulen, 2007). As funding sources have different expectations from the work, research groups feel an increasingly lack in research autonomy.

The availability of sufficient funding also limits the capacity of human capital. Larger groups do provide more research output. However there is a limit to group size as it could have diminishing marginal returns to labour (Louis et al., 2007). And then, smaller groups are easier to management, as the span of control on the group leader is smaller. Given the advantage of big and small group size alike, studies suggest that research groups need critical mass, but above a certain threshold productivity declines. This threshold of course depends on study fields and internal structure of the different organisations (Stvilia et al., 2011).

The optimal size also depends on the groups' environment. In larger heterogeneous groups it is easier to organise a variety of activities next to the core research such as fund acquisition. These groups have the advantage over smaller groups as their size and diversity reduces their dependence on critical resources. However smaller groups could create more societal output as they are often more specialised on one research goal (van der Weijden et al., 2009). Depending on the context of each research environment, groups tend to adjust their activities through management leadership and networking (Verbree et al., 2015).

The influence of workforce composition on research performance has only limitedly been investigated. For this thesis three studies will be compared that analysed workforce compositions in relation to research performance while perceiving different key determinants for research performance.

Processes in Research Organisations

In terms of *group management*, organisations have a lot to gain in terms of performance. First, they can enhance performance by offering rewards for excellent individual or collective research

outcomes (Louis et al., 2007). Secondly, organisations can stimulate communication between researchers in order to enhance group dynamics and stimulate intellectual thought (Pelz & Andrews, 1966). As research becomes increasingly group work oriented, communication is essential in creating output that is thorough and intellectually satisfying for society and science. Moreover, communication is also useful in creating support from other parts of the organisation and management layers. Quality control is a third tool which a research coordinator could use to enhance quality of the created work. This is related to the balance of coordination and professional autonomy (Pelz & Andrews, 1966). Traditionally, the suggestion was that researchers needed full autonomy to define and pursue individual research goals and be maximally creative (Smith, 1971). As the degree of autonomy is now bounded to the research agenda which adheres to funders and collective research goals, quality control is an important factor.

Within research groups, *leadership* in group coordinators is needed to maintain expertise throughout the project cycle. High performance is not just dependent on the excellent research qualities, but also on being a good leader and manager of the group (van der Weijden et al., 2009). Group motivation is also important for performance. A group leader should be strongly committed and involved in the research of the group, which is beneficial for performance (Dietz & Bozeman, 2005).

In terms of *network management*, both internal and external relationships of research group have to be managed. Internally, mainly to share knowledge and externally to gain access to knowledge, information, funding and experience. Interaction with other researchers provides the intellectual exchange that is essential for the creation of knowledge and the development of creative new ideas (Verbree et al., 2015).

Personal Characteristics

Personal characteristics could also have a determining effect on workforce performance. Research output could change when researchers get older as they become more responsible for non-related activities such as human resources and fund acquisition. However, aging could also have a diminishing effect on creativity (Packalen & Bhattacharya, 2015).

Environmental Conditions

The research environment, in which research groups are embedded, could have a significant effect on the research performance of the group. Researchers fare well in environments that remain relatively stable over time. For some research groups, research is not their main activity. They could, for instance, be occupied with education, training, producing new goods or services or participate in public debate. As such, not all groups yield the same output, and it is therefore hard to compare different fields. Performance standards of different groups have an additional effect on performance. As such, performance can only be evaluated in the appropriate environmental context. With all these exogenous variables influencing the system it is hard to make general assumptions on research performance (Pelz & Andrews, 1966).

THE RELATIONSHIP BETWEEN ORGANISATIONAL DETERMINANTS AND RESEARCH PERFORMANCE

Figure 48 represents the four main components that influence research performance in academic organisations. The two components in the middle are the resource and process variables that are both influenced by environmental conditions. The main interest is the influence of human capital and

the acquisition of funds on research performance. The feedback between changing personal characteristics and resource strategy are also omitted. Environmental conditions also have a direct influence on research performance, although they are partly mediated by resource strategy and process (Verbree et al., 2015).

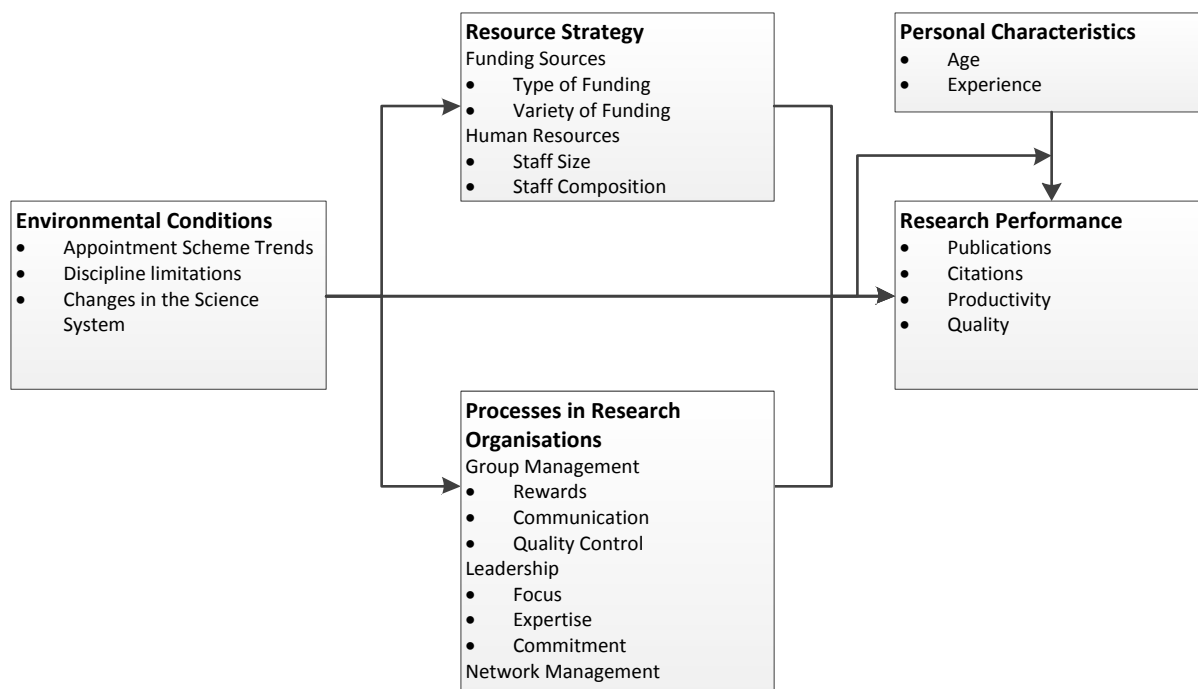


Figure 48: Relation between organisational factors and research performance, adopted by (Verbree et al., 2015)

FINDINGS OF PREVIOUS STUDIES ON RESOURCE STRATEGY & PERSONAL CHARACTERISTICS

The combination of three multivariate studies were combined to come to these findings on resource strategy and personal characteristics of researcher leaders that could be useful in the model environment or/and in support of the policy development stage of this study.

The composition and size of research groups has a considerable impact on research performance (Stvilia et al., 2011; van der Weijden et al., 2009; Verbree et al., 2015). Increasing the number of PhD candidates within research groups leads to more productivity, more output and more citations. However, while increasing group size leads to more publications and citations within groups it could have a negative effect on the individual performance. This suggests group size limitations, in which the marginal return in productivity diminishes with the increase in group size. A high percentage of senior staff does correlate negatively with performance and output (Verbree et al., 2015). This is in correspondence with an older study stating the same (Smith, 1971). Teams consisting of members with a heterogeneous institutional background were overall more productive than their homogeneous counterparts. It is likely that less hierarchical groups, with a heterogeneous PhD and Postdoc background and a more homogeneous senior staff background, perform better (Stvilia et al., 2011; Verbree et al., 2015). For the biomedical field the ideal group size is 18, consisting of 8 PhD candidates, 4 supporting staff member (OAS) and 6 seniors staff members (van der Weijden et al., 2009).

Acquiring funds from a variety of sources leads to higher citation counts as one's work is shared among institutions (Verbree et al., 2015). However, this correlation could work both ways. When more research is shared, the visibility of the research group increases in the scientific community increasing acquisition of more funds. As such, research groups that have already acquired funds in an earlier stage are more likely to acquire more. Moreover, research groups with a large funding portfolio may be bigger and therefore may have a more diverse research output becoming more visible in scientific communities. Groups that are dependent on a smaller source for funding may not venture into a new research domain as they have less flexibility. Reputation then leads to more and more diverse funding which again leads to more reputation, a reinforcing feedback situation (Merton, 1988). Because direct funding has decreased, from 42 to 32 %, while project funding has increased from 52 to 64 %, changes in funding mechanisms constrain research output (Versleijen & van der Meulen, 2007). With this, research groups become more dependent on external sources and less independent in creating their own research scope.

The relation between age of research group leaders and performance is shaped as an inverted U-curve and has a maximum when the researcher is in his or her forties (Pelz & Andrews, 1966). They will also become responsible for non-research related activities such as human resources. As this often leads to more members to the research group, such as PhD candidates. Many years of experience of researchers within groups could add to the knowledge and values, strengthening leadership and improving overall performance.

Changing one's institution or position could be detrimental for the researcher as it takes, on average, 3 to 6 years to adjust to a new environment (Cherchye & Abee, 2005). Also, researchers that had some experience outside the academic work often perform less in terms of productivity than their academic counterpart (Dietz & Bozeman, 2005). The science system can also change over time.

STUDY LIMITATIONS

Many studies have looked at organisational determinants that influence research performance (Falk-Krzesinski et al., 2011; Pelz & Andrews, 1966; Stvilia et al., 2011; van der Weijden et al., 2009; Verbree et al., 2015). However, these studies have mainly investigated how researchers perform within research groups. The study by Verbree et al. (2015), for instance, was mainly conducted based on surveys among group leaders within the biomedical research field. It also regards performance in terms of numerical output (publications, citations, productivity and quality) and does not include factors such as societal impact and factors related to valorisation. Furthermore, it solely looks at the biomedical workforce in the Netherlands. Other studies had the same limitations as they looked at a specific workforce.

IMPLICATIONS FOR THE MODEL

The empirical findings of the organisational determinants that influence research performance within groups is just of limited use within the model. It is more a supportive Appendix that can help with the scope and design of the policy experiment section. However, some information is useful. For instance, the ideal age for senior staff to be research group leader, the proportionality of junior staff (PhD & OAS) in comparison to senior staff, the diversification of funding and the preference of academic staff over staff from outside the Dutch universities. Many changes in the policy instrument

for science is also detrimental for research. This assumes that researchers fares well in a stable and uncomplicated academic environment. Of course these findings represent performance in research groups. It is however assumed that the link between group performance and performance of the total academic workforce can be made.

CONCLUSIONS

In this Appendix important organisational determinants that influence research performance have been identified. Some determinants can be used within the model environment, while others can be used in support of a policy-making process. Group compositions has an impact on research performance. Group composition is also important in attaining funding from a variety of sources. Groups with relatively many PhD perform better in that regard. The study suggests that a flat group structure, with less hierarchical operational patterns, is beneficial for performance. In terms of funding, diversity has a positive correlation to citations counts. With this diversity a larger research portfolio can be created leading to even more citations.

APPENDIX 3: MODEL IMPLEMENTATION

This Appendix shows the model implementation process. All the different model segments will be shown in detail. Note that model segments that were shown in detail in Section 6.3 are not included in this Appendix.

PHD-CANDIDATES

Figure 49 shows the PhD segment of the model. Inflow of academic staff happens according to capacity mechanism of PhD staff and is calibrated over time to fit the historical data. The capacity is determined based on the number of funds available to hire PhD staff. Based on data it is assumed that most PhD staff are hired on secondary and tertiary research funds (VSNU, 2015). After the residence time within the stock, the outflow is based on fractions that are relatively stable over time (Goede et al., 2014).

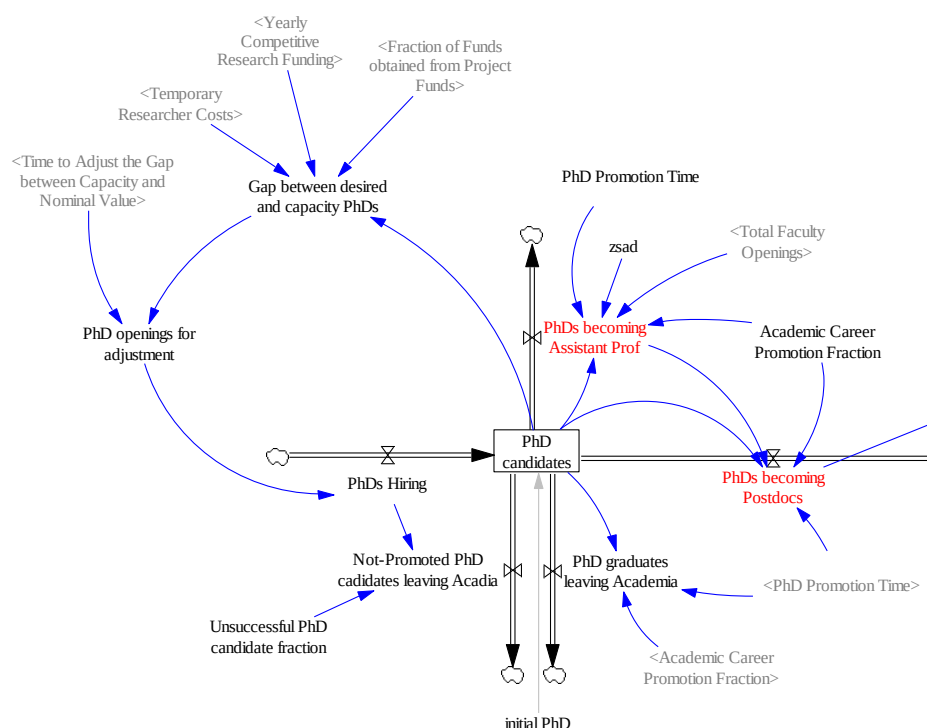


Figure 49: Detailed PhD model Segment

TEMPORARY RESEARCH STAFF

Figure 50 shows the temporary research staff segment of the model. Inflow of academic staff happens according to capacity mechanisms for TRS. In the stock researchers will either go through one, two or three contract phases to describe the contract accumulation in the TRS phase. The subscripts, which are included in the model, are positioned within the TRS stock and TRS outflows. The outflow variable 'aging' is used to model the transition between the contract phases. The outflow of TRS to positions outside academia is modelled as a feedback loop. When researchers reside longer in this stock, they get demotivated and drop out. TRS becoming assistants are based on the capacity mechanism for tenured staff. When place becomes available TRS can acquire a position in the faculty staff.

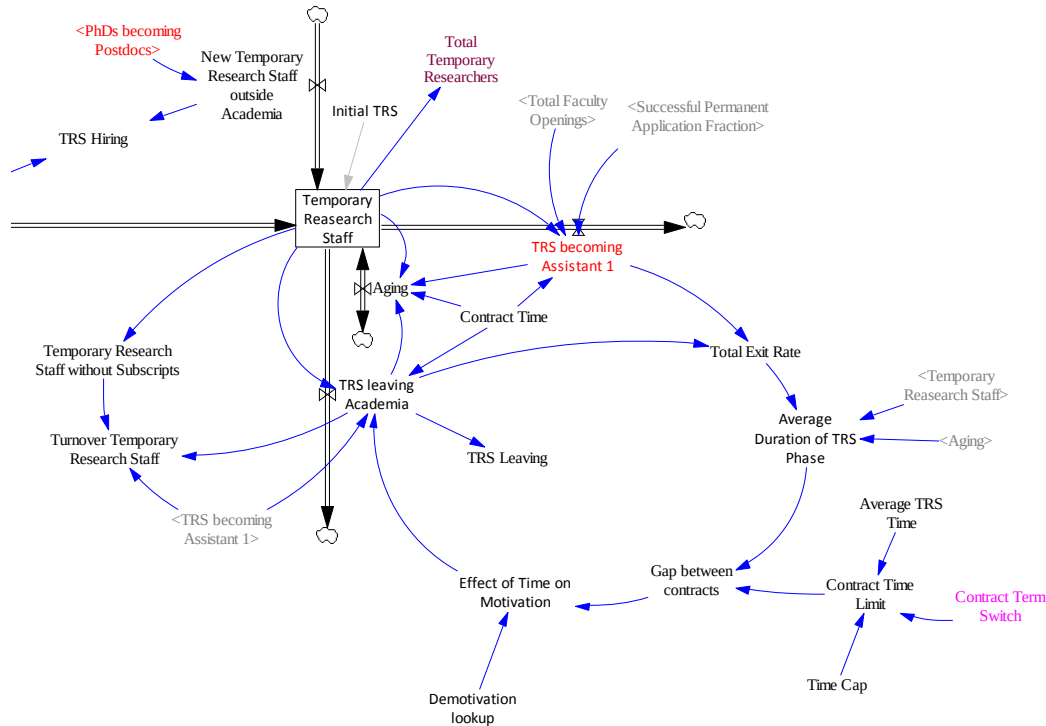


Figure 50: Detailed Temporary Research Staff model Segment

CAPACITY MECHANISM TEMPORARY RESEARCH STAFF

Figure 51 shows the capacity mechanism for temporary research staff. This capacity mechanism is comparable to the one of the permanent staff as explained in Section 6.3. Here, however, the both institutional and project funds are used to cover the stipends of this staff.

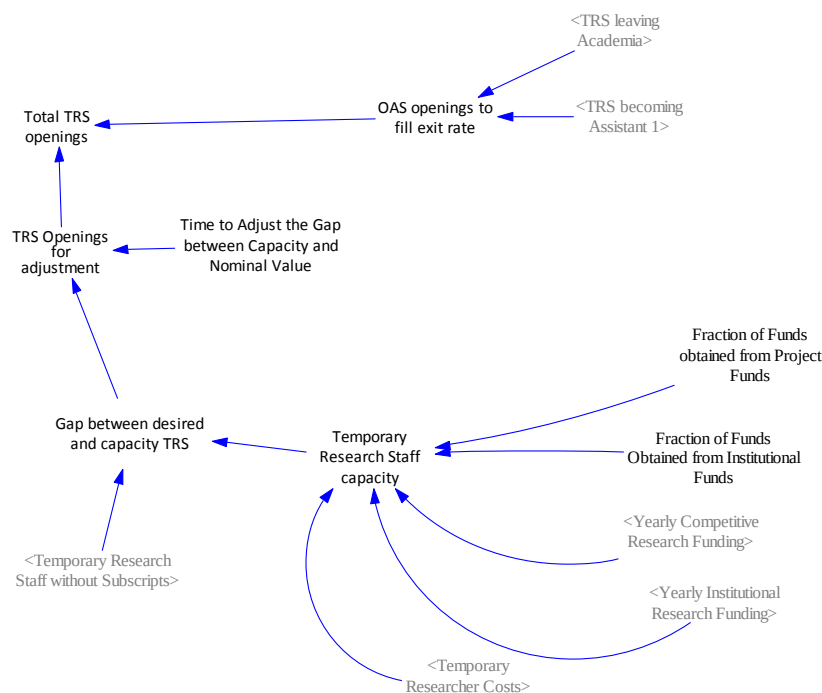


Figure 51: Detailed capacity mechanism Temporary Research Staff

ACADEMIC RESEARCH FUNDING

Figure 52 shows a detailed overview of the academic research funding. The yearly institution research funding increases based on the expected research provision, the number of PhD graduates, the number of total students and the desire to increase the research funding. These factors are supported by literature and extensively described in Section 3.4 and 6.2. The yearly competitive research funding is based on a project, secondary funding, part and a contract, tertiary funding, part. The flow between the two stocks represents possible changes in research funding orientation.

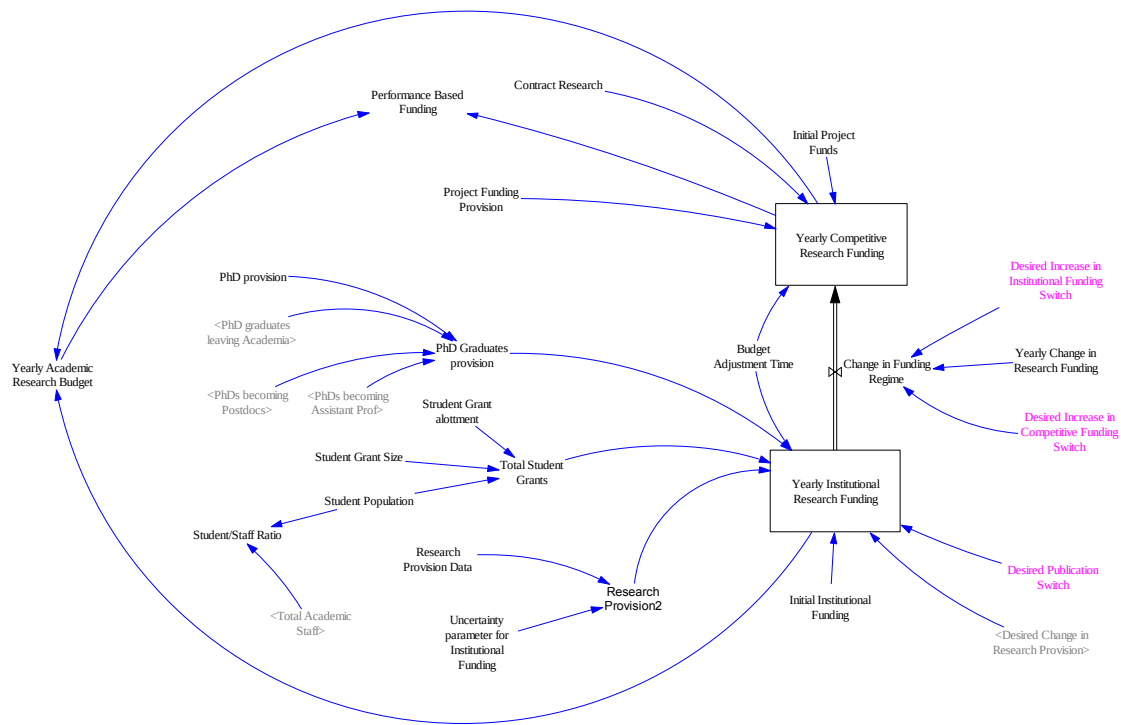


Figure 52: Detailed Academic Research Funding

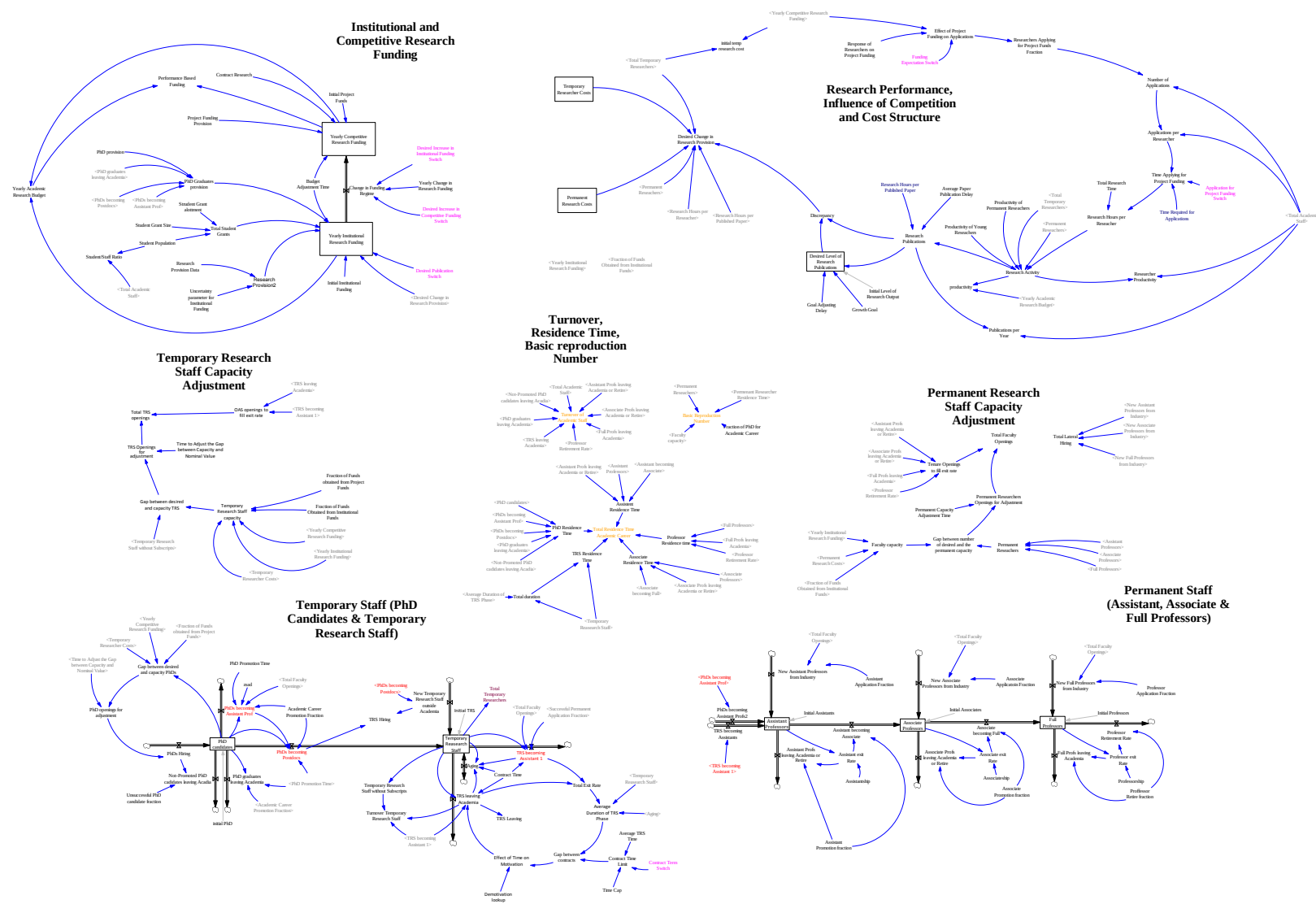


Figure 53: Full Model Overview

APPENDIX 4: MODEL FORMULATION

Notation	Formulation	Unit
Aging[Phase 1]	Temporary Research Staff[Phase 1]/ Contract Time - TRS becoming Assistant 1[Phase 1] - TRS leaving Academia[Phase 1]	Staff/Year
Aging[Phase 2]	Temporary Research Staff[Phase 2]/ Contract Time - TRS becoming Assistant 1[Phase 2] - TRS leaving Academia[Phase 2]	Staff/Year
Applications per Researcher	Number of Applications/Total Academic Staff	Application/Staff
Assistant becoming Associate	Assistant Promotion fraction*Assistant exit Rate	Staff/Year
Assistant exit Rate	Assistant Professors/Assistantship	Staff/Year
Assistant Professors	New Assistant Professors from Industry+ PhDs becoming Assistant Profs2+TRS becoming Assistants-Assistant becoming Associate-Assistant Profs leaving Academia or Retire, Initial Assistants	Staff
Assistant Profs leaving Academia or Retire	Assistant exit Rate*(1-Assistant Promotion fraction)	Staff/Year
Assistant Residence Time	Assistant Professors/(Assistant becoming Associate+ Assistant Profs leaving Academia or Retire)	Year
Associate becoming Full	Associate exit Rate*Associate Promotion fraction	Staff/Year
Associate exit Rate	Associate Professors/Associateship	Staff/Year
Associate Professors	Assistant becoming Associate +New Associate Professors from Industry-Associate becoming Full-Associate Profs leaving Academia or Retire , Initial Associates	Staff
Associate Profs leaving Academia or Retire	Associate exit Rate*(1-Associate Promotion fraction)	Staff/Year
Associate Residence Time	Associate Professors/(Associate becoming Full+ Associate Profs leaving Academia or Retire)	Year
Average Duration of TRS Phase[Phase 1]	Temporary Research Staff[Phase 1]/Total Exit Rate[Phase 1]	Year
Average Duration of TRS Phase[Phase 2]	Temporary Research Staff[Phase 1]/(Aging[Phase 1]+Total Exit Rate[Phase 1])+Temporary Research Staff[Phase 2]/Total Exit Rate[Phase 2]	Year
Average Duration of TRS Phase[Phase 3]	Temporary Research Staff[Phase 1]/(Aging[Phase 1]+Total Exit Rate[Phase 1])+Temporary Research Staff[Phase 2]/(Aging[Phase 2]+Total Exit Rate[Phase 2])+Temporary Research Staff[Phase 3]/Total Exit Rate[Phase 3]	Year
Basic Reproduction Number	(1+MAX(Faculty capacity/Permanent Researchers/100,0)*Permanent Researcher Residence Time)/Fraction of PhD for Academic Career	Dmnl

Table 15: Model Formulation part 1

Notation	Formulation	Unit
Desired Change in Research Provision	Discrepancy*Research Hours per Published Paper/Research Hours per Researcher*(((1-Permanent Researchers/Total Temporary Researchers	Euro
Discrepancy	MAX(Desired Level of Research Publications-Research Publications,0)	Paper
Effect of Project Funding on Applications	SMOOTH((Response of Researchers on Project Funding(Yearly Competitive Research Funding), 1, 0) *Funding Expectation Switch	1
Effect of Time on Motivation[TRS Phases]	SMOOTH((Demotivation lookup(Gap between contracts[TRS Phases]), 1, 0)	Dmnl
Faculty capacity	(Yearly Institutional Research Funding*(1-Fraction of Funds Obtained from Institutional Funds))/Permanent Research Costs	Staff
Full Professors	Associate becoming Full +New Full Professors from Industry-Full Profs leaving Academia-Professor Retirement Rate ,Initial Professors	Staff
Full Profs leaving Academia	Professor exit Rate*(1-Professor Retire fraction)	Staff/Year
Gap between contracts[TRS Phases]	Contract Time Limit-Average Duration of TRS Phase[TRS Phases]	Year
Gap between desired and capacity PhDs	Yearly Competitive Research Funding*(1-Fraction of Funds obtained from Project Funds)/Temporary Researcher Costs-PhD candidates	Staff
Gap between desired and capacity TRS	Temporary Research Staff capacity-Temporary Research Staff without Subscripts	Staff
Gap between number of desired and the permanent capacity	Faculty capacity-Permanent Researchers	Staff
New Assistant Professors from Industry	Total Faculty Openings*Assistant Application Fraction	Staff/Year
New Associate Professors from Industry	Associate Application Fraction*Total Faculty Openings	Staff/Year
New Full Professors from Industry	Professor Application Fraction*Total Faculty Openings	Staff/Year
New Temporary Research Staff outside Academia	MAX(Total TRS openings-PhDs becoming Postdocs,0)	Staff/Year
"Not-Promoted PhD candidates leaving Acadia"	PhDs Hiring*Unsuccessful PhD candidate fraction	Staff/Year
Number of Applications	Total Academic Staff*Researchers Applying for Project Funds Fraction	Applications
TRS openings to fill exit rate	SUM(TRS becoming Assistant 1[TRS Phases!]+TRS leaving Academia[TRS Phases!])	Staff/Year
Performance Based Funding	Yearly Competitive Research Funding/Yearly Academic Research Budget	Euro
Permanent Researchers	Assistant Professors + Associate Professors +Full Professors	Staff
Permanent Researcher Hiring	PhDs becoming Assistant Profs2+New Assistant Professors from Industry +New Associate Professors from Industry	Staff/Year

Table 16: Model Formulation part 2

Notation	Formulation	Unit
Permanent Researcher Leaving	Assistant Profs leaving Academia or Retire +Associate Profs leaving Academia or Retire +Full Profs leaving Academia +Professor Retirement Rate	Staff/Year
Permanent Researchers Openings for Adjustment	Gap between number of desired and the permanent capacity/Permanent Capacity Adjustment Time	Staff/Year
PhD candidates	PhDs Hiring- "Not-Promoted PhD candidates leaving Acadia"-PhD graduates leaving Academia-PhDs becoming Assistant Prof-PhDs becoming Postdocs ,initial PhD	Staff
PhD graduates leaving Academia	PhD candidates/PhD Promotion Time*(1-Academic Career Promotion Fraction)	Staff/Year
PhD Graduates provision	(PhD graduates leaving Academia +PhDs becoming Assistant Prof +PhDs becoming Postdocs)*PhD provision	Euro
PhD openings for adjustment	Gap between desired and capacity PhDs/Time to Adjust the Gap between Capacity and Nominal Value	Staff/Year
PhD Residence Time	PhD candidates/("Not-Promoted PhD candidates leaving Acadia" +PhD graduates leaving Academia +PhDs becoming Assistant Prof +PhDs becoming Postdocs)	Year
PhDs becoming Assistant Prof	MIN(PhD candidates/PhD Promotion Time*Academic Career Promotion Fraction*Successful Permanent Application Fraction, Total Faculty Openings	Staff/Year
PhDs becoming Postdocs	PhD candidates/PhD Promotion Time*Academic Career Promotion Fraction-PhDs becoming Assistant Prof	Staff/Year
PhDs Hiring	PhD openings for adjustment	Staff/Year
PhDs Leaving	Not-Promoted PhD candidates leaving Academia +PhD graduates leaving Academia	Staff/Year
productivity	Yearly Academic Research Budget/Research Activity	Euro/hours
Professor exit Rate	Full Professors/Professorship	Staff/Year
Professor Residence time	Full Professors/(Full Profs leaving Academia +Professor Retirement Rate)	Year
Professor Retirement Rate	Professor exit Rate*Professor Retire fraction	Staff/Year
Promoted PhDs	PhDs becoming Assistant Prof+ PhDs becoming Postdocs	Staff/Year
Publications per Year	Research Publications/Total Academic Staff	Paper/Year
Research Activity	Research Hours per Researcher*(Permanent Researchers*Productivity of Permanent Researcher +Total Temporary Researchers*Productivity of Young Researchers	Year
Research Hours per Researcher	Total Research Time-Time Applying for Project Funding	Year/Staff

Table 17: Model Formulation part 3

Notation	Formulation	Unit
Research Publications	SMOOTH(Research Activity/Research Hours per Published Paper, Average Paper Publication Delay)	Paper
Researcher Productivity	Research Activity/Total Academic Staff	Year/Staff
Researchers Applying for Project Funds Fraction	Effect of Project Funding on Applications	Applications/Staff
Student/Staff Ratio"	Student Population/Total Academic Staff	Student/Staff
Temporary Research Staff[TRS Phases]	Aging[Phase 1] + New Temporary Research Staff outside Academia +PhDs becoming Postdocs-TRS leaving Academia[Phase 1]-TRS becoming Assistant 1[Phase 1], Aging [previous cohort]-Aging[older]-Aging[older]- TRS becoming Assistant 1 [older] - TRS leaving Academia[older], Initial TRS/3	Staff
Temporary Research Staff capacity	Yearly Competitive Research Funding*Fraction of Funds obtained from Project Funds/Temporary Researcher Costs +Fraction of Funds Obtained from Institutional Funds	Staff
Temporary Research Staff without Subscripts	SUM(Temporary Research Staff[TRS Phases!])	Euro/Staff
Tenure Openings to fill exit rate	Assistant Profs leaving Academia or Retire +Associate Profs leaving Academia or Retire +Full Profs leaving Academia +Professor Retirement Rate	Staff/Year
Time Applying for Project Funding	Applications per Researcher*Time Required for Applications*Application for Project Funding Switch	Year/Staff
Time in TRS Phase	SUM(Average Duration of TRS Phase[TRS Phases!])	Year
Time in PhD Phase	PhD candidates/("Not-Promoted PhD candidates leaving Academia" +PhD graduates leaving Academia + PhDs becoming Postdocs +PhDs becoming Assistant Prof	Year
Total Academic Staff	Assistant Professors +Associate Professors +Full Professors +Temporary Research Staff without Subscripts +PhD candidates	Staff
Total duration[Phase 1]	Average Duration of TRS Phase[TRS Phases]*Temporary Research Staff[TRS Phases]	Year
Total Exit Rate[Phase 1]	MAX(TRS becoming Assistant 1[TRS Phases]+TRS leaving Academia[TRS Phases],1)	Year
Total Faculty Openings	MAX(Permanent Researchers Openings for Adjustment +Tenure Openings to fill exit rate,0)	Staff/Year
Total Lateral Hiring	New Assistant Professors from Industry +New Associate Professors from Industry +New Full Professors from Industry	Staff/Year

Table 18: Model Formulation part 4

Notation	Formulation	Unit
Total TRS leaving academic	$SUM(TRS \text{ leaving Academia}[TRS \text{ Phases!}])$	Staff/Year
Total Residence Time Academic Career	Assistant Residence Time +Associate Residence Time +Professor Residence time +PhD Residence Time +TRS Residence Time	Year
Total Student Grants	student Grant allotment*Student Population*Student Grant Size	Euro/Year
Total Temporary Researchers	PhD candidates + $SUM(Temporary \text{ Research Staff}[TRS \text{ Phases!}])$	Staff
Total TRS openings	TRS openings to fill exit rate +TRS Openings for adjustment	Staff/Year
TRS becoming Assistant 1[TRS Phases]	$MAX(Temporary \text{ Research Staff}[TRS \text{ Phases}]/SUM(Temporary \text{ Research Staff}[TRS \text{ Phases!}]) * Total \text{ Faculty Openings} * (1 - Successful \text{ Permanent Application Fraction}) / Contract \text{ Time}, 0)$	Staff/Year
TRS becoming Assistants	$SUM(TRS \text{ becoming Assistant 1}[TRS \text{ Phases!}])$	Staff/Year
TRS Hiring	New Temporary Research Staff outside Academia+ PhDs becoming Postdocs	Staff/Year
TRS Leaving	$SUM(TRS \text{ leaving Academia}[TRS \text{ Phases!}])$	Staff/Year
TRS leaving Academia[TRS Phases]	$(Temporary \text{ Research Staff}[TRS \text{ Phases}]/Contract \text{ Time} - TRS \text{ becoming Assistant 1}[TRS \text{ Phases}]) * Effect \text{ of Time on Motivation}$	Staff/Year
TRS Openings for adjustment	Gap between desired and capacity TRS/Time to Adjust the Gap between Capacity and Nominal Value	Staff/Year
TRS Residence Time	$SUM(Total \text{ duration}[TRS \text{ Phases!}]) / SUM(Temporary \text{ Research Staff}[TRS \text{ Phases!}])$	Year
Turnover of Academic Staff	$(SUM(TRS \text{ leaving Academia}[TRS \text{ Phases!}]) + Professor \text{ Retirement Rate} + PhD \text{ graduates leaving Academia} + "Not-Promoted PhD candidates leaving Acadia" + Full \text{ Profs leaving Academia} + Associate \text{ Profs leaving Academia or Retire} + Assistant \text{ Profs leaving Academia or Retire}) / Total \text{ Academic Staff}$	1/Year
Turnover Temporary Research Staff	$(SUM(TRS \text{ becoming Assistant 1}[TRS \text{ Phases!}] + TRS \text{ leaving Academia}[TRS \text{ Phases!}]) / Temporary \text{ Research Staff without Subscripts}$	1/Year
Yearly Academic Research Budget	Yearly Competitive Research Funding+ Yearly Institutional Research Funding	Euro
Yearly Competitive Research Funding	$SMOOTH(Change \text{ in Funding Regime, Budget Adjustment Time, Initial Project Funds}$	Euro
Yearly Institutional Research Funding	$SMOOTH(Research \text{ Provision} + Desired \text{ Change in Research Provision} + *Desired \text{ Publication Switch} + PhD \text{ Graduates provision} - Change \text{ in Funding Regime, Budget Adjustment Time, Initial Institutional Funding})$	Euro

Table 19: Model Formulation part 5

APPENDIX 5: PARAMETERS AND EXOGENOUS VARIABLES

Notation	Value	Source	Unit
Academic Career Promotion Fraction	0.3	(Goede, Belder et al. 2014)	Dmnl
Assistant Application Fraction	0.37	WOPI	Dmnl
Assistant Promotion fraction	0.39	WOPI	Dmnl
Associate Application Fraction	0.063	WOPI	Dmnl
Associate Promotion fraction	0.44	WOPI	Dmnl
Demotivation Lookup	$[(-100,0)-(-100,1)],(-100,1),(-10,1),(-5,0.8),(-2.5,0.6),(0,0.4),(2,0.2),(4,0),(100,0)$	Table function to represent effects of time pressure on leaving TRS	Dmnl
Fraction of Funds Obtained from Institutional Funds	0.011	Calibration	Dmnl
Fraction of Funds obtained from Project Funds	0.355	Calibration	Dmnl
Fraction of PhD for Academic Career	0.5	(Goede, Belder et al. 2014)	Dmnl
Growth Goal	0.01	Calculated based on the gradual increase of research publications over the Years 2006-2010	Dmnl
Productivity of Permanent Researchers	0.85	Rathenau Institute, 2015, estimate	Dmnl
Productivity of Young Researchers	0.6	Rathenau Institute, 2015, estimate	Dmnl
Professor Retire fraction	0.325	WOPI	Dmnl
Response of Researchers on Project Funding Lookup	$[(0,0)e+009,1),(2.5e+008,1000),(5.50504e+008,3552.63)],(0,0),(7.06422e+008,0.153509),(1.30275e+009,0.513158),(2.25688e+009,0.894737),(3.00917e+009,0.991228)$	Calibrated S-shape Function	Dmnl
Successful Permanent Application Fraction	0.35	(Goede, Belder et al. 2014)	Dmnl
Unsuccessful PhD candidate fraction	0.25	(Goede, Belder et al. 2014)	Dmnl
PhD provision	93000	(van Dalen et al., 2012)	Euro/Staff
Initial Institutional Funding	2.2e+009	IBO	Euro/Year
Initial Project Funds	1,02E+12	IBO	Euro/Year
Permanent Research Costs	250000	Rathenau Institute, 2015, estimate	Euro/Year
Contract Funding	Time Series	VSNU, IBO	Euro/Year

Table 20: List of parameters and Exogenous Variables part 1

Notation	Value	Source	Unit
Project Funding	Time Series	VSNU, IBO	Euro/Year
Institutional Research Funding	Time Series	VSNU, IBO	Euro/Year
Temporary Research Costs	88000	Rathenau Institute, 2015, estimate	Euro/Year
Initial Level of Research Output	38000	VSNU	Paper
Initial Assistants	4539	WOPI with Medical Correction	Staff
Initial Associates	1972	WOPI with Medical Correction	Staff
initial PhD	3417	WOPI with Medical Correction	Staff
Initial Professors	2013	WOPI with Medical Correction	Staff
Initial TRS	5024	WOPI with Medical Correction	Staff
Assistantship	7.5	(Goede, Belder et al. 2014)	Year
Associateship	6	(Goede, Belder et al. 2014)	Year
Average Paper Publication Delay	0.5	Authors' assumption	Year
Average TRS Time	7.5	(Goede, Belder et al. 2014)	Year
Budget Adjustment Time	1	(OCW, 2014)	Year
Contract Time	2	(De-Jonge-Akademie, 2010)	Year
Goal Adjusting Delay	2	Authors' assumption	Year
Permanent Capacity Adjustment Time	2	Authors' assumption	Year
PhD Promotion Time	5	(Goede, Belder et al. 2014)	Year
Professorship	11	(Goede, Belder et al. 2014)	Year
Research Hours per Published Paper	0.3	Authors' assumption	Year
Time Required for Applications	0,21	Rathenau Institute, 2015, estimate	Year
Time to Adjust the Gap between Capacity and Nominal Value	1	Authors' assumption	Year
Total Research Time	0.7	Researchers spend on average 30 hours a week on research and research oriented activities (Goede, 2012)	Year
Professor Application Fraction	0.132	(Goede, Belder et al. 2014)	Dmnl

Table 21: List of parameters and Exogenous Variables part 2

APPENDIX 6: EXTREME VALUE TEST RESULTS

The Extreme value test will be conducted by substituting several important, sometimes uncertain, parameters with extreme values. The graphical output will be based on the Key Performance Indicators based on the 9 different tests. These tests are chosen system analysis and stakeholder interviews (Rathenau-Institute, 2015a). Some graphical representations can be omitted if they do not cause any alternative effects over time or included it clarifies the impact of the parameter change. Table 22 shows the main expectations of the extreme value test, where ++ represents a major increase, + represents a minor increase, 0 represents an insignificant change, - represents a minor decrease and -- represents a major decrease. Through analysis it was found that these assumptions match the observed behaviour in the graphical tests shown below.

Key Performance Indicator	Extreme Value Test					
	Temporary Staff	Permanent Staff	Ratio of Temporary to Permanent	Staff Turnover	Research Output	Residence Time
(1): High Permanent Researcher Cost	0	--	+	+	-	+
(2): Low Permanent Researcher Cost	0	++	b-	-	+	-
(3): High Temporary Researcher Cost	--	-	-	-	--	0
(4): Low Temporary Researcher Cost	++	+	+	+	++	0
(5): High PhD Promotion Time	--	+	-	+	-	-
(6): Low PhD Promotion Time	+	-	+	-	+	++
(7): High TRS Contract Time	-	+	0	0	0	-
(8): Low TRS Contract Time	0	-	0	-	0	+
(9): Extreme professor Residence time	0	0	0	--	0	++

Table 22: Extreme Value Test Assumptions

EXTREME COST OF PERMANENT STAFF

Test 1 was conducted by multiplying the amount of permanent researcher costs by a hundred. The results can be observed in Figure 54. The graphical output was expected and show the amount of

permanant reseachers decreasing over time. The reason why this is a graudual change over time is because professors who already have an permanent appointment are allowed to stay untill they leave academia, for other jobs or retirement, which is one of the model assumptions. There is a insignificant change in temporary reseachers, mainly the ones that remain in academia for a extended period to acquire a permanent position. The number of research publications also decreases as expected due to the number of total research hours. The turnover and residence time increases as expected as TRS remains longer in the position. Note that the total residence time needs a year to stablise and therefore does not start in 1999.

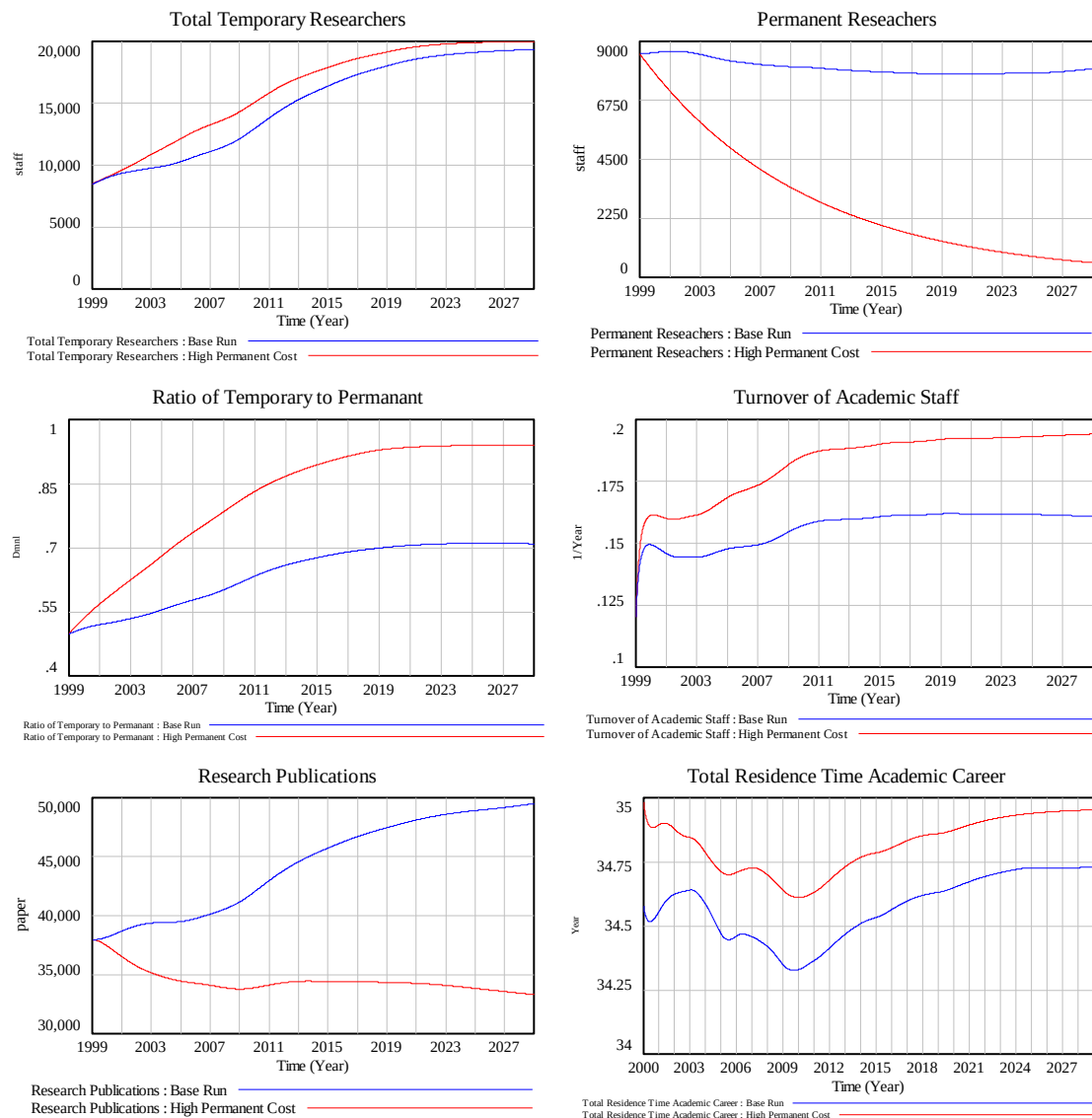


Figure 54: Extreme Value Test - High Permanent Costs

Test 2 was conducted by dividing the amount of permanent researcher costs by a hundred. The results can be observed in Figure 55. The graphical output was expected as the number of permanent reseachers increases substantially which has it effects on the ratio of temporary to permanent staff. The turnover decreases because the main focus will be on permanent staff that change positions less often. As aspected, it also leads to more research output as more reseachers can conduct research.

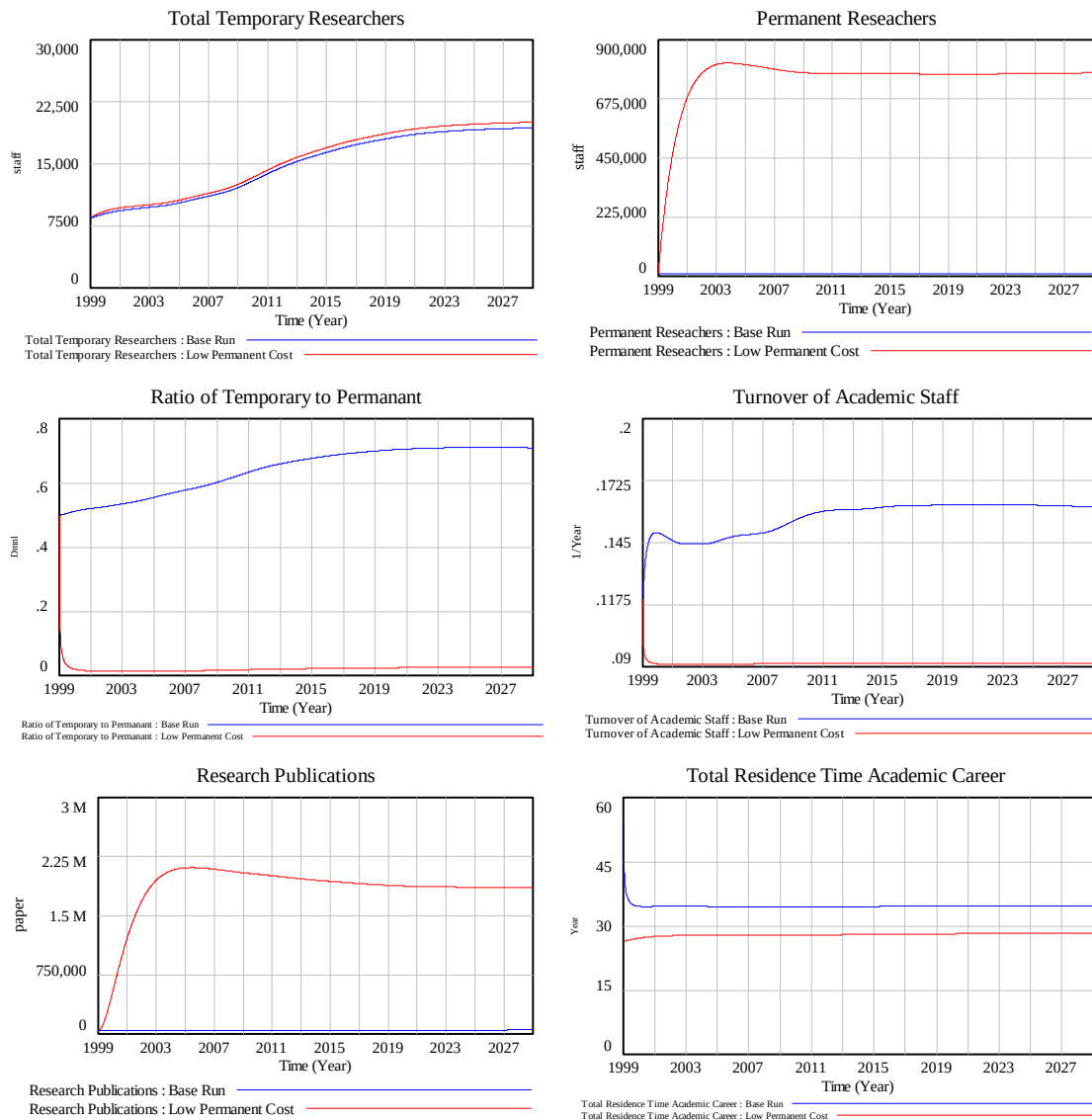
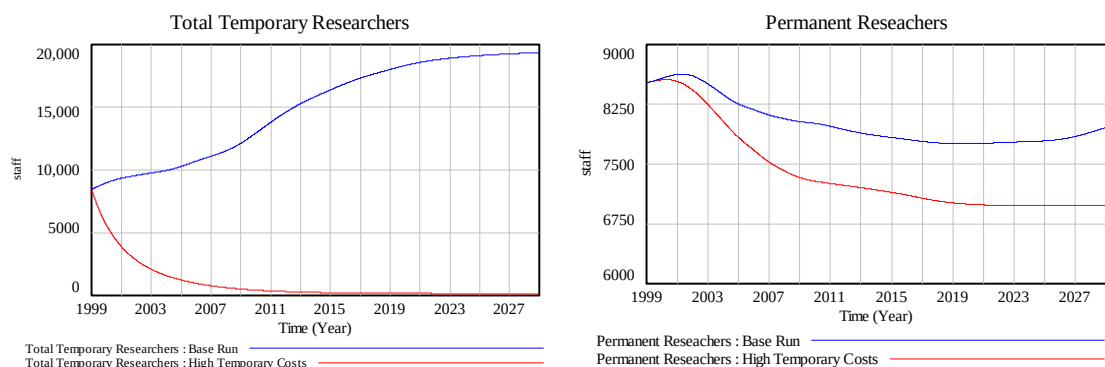


Figure 55: Extreme Value Test - Low permanent costs

EXTREME COST OF TEMPORARY STAFF

Test 3 was conducted by multiplying the amount of temporary researcher costs by a hundred. The results can be observed in Figure 56. Note that this extreme test has an influence on both the temporary and permanent staff. If there are no temporary staff, less vacancies from within the system can be filled. While this is only a relative small proportion, it does have its impact on the workforce and research output.



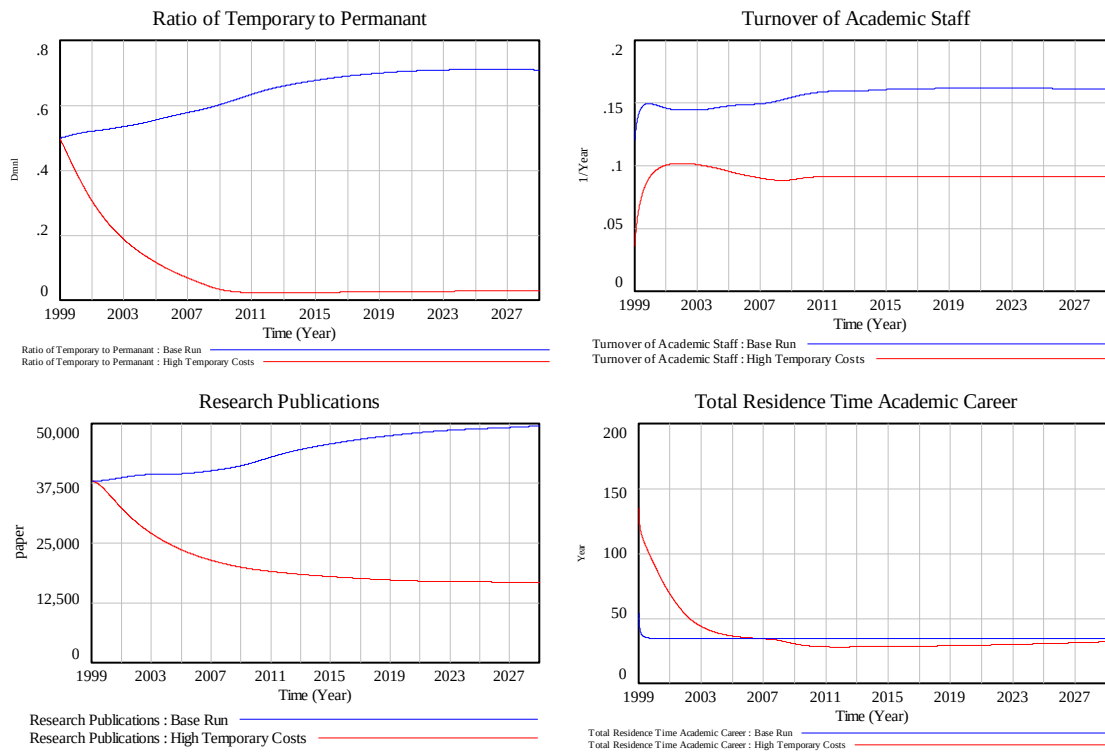
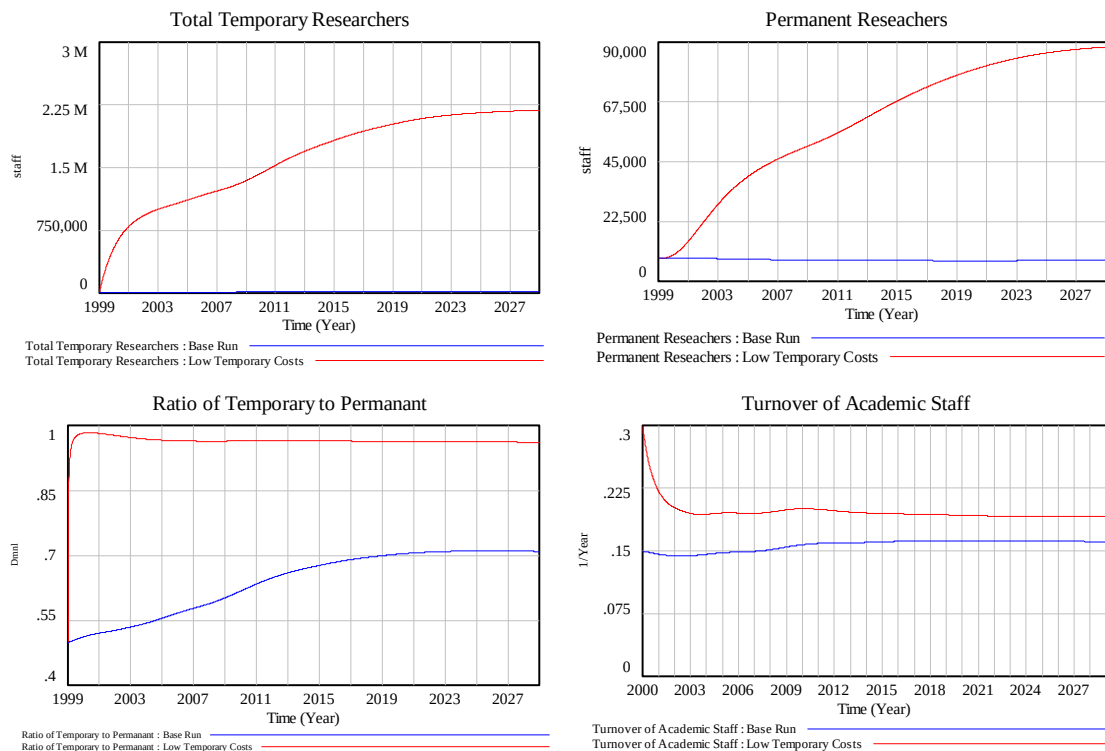


Figure 56: Extreme Value Test - High temporary costs

Test 4 was conducted by dividing the amount of temporary researcher costs by a hundred. The results can be observed in Figure 57. Both the temporary researchers and the permanent researchers increase over time. To accommodate the costs of these researchers, the matching mechanisms will transfer funds from the institutional side to the project side



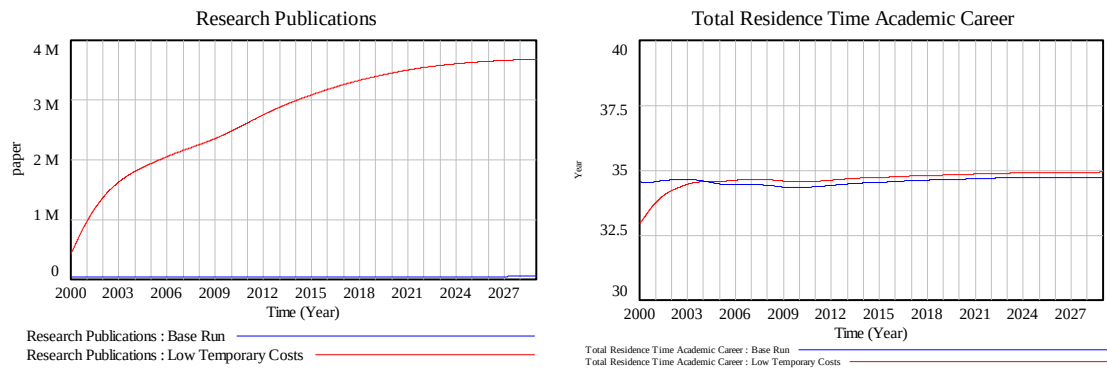
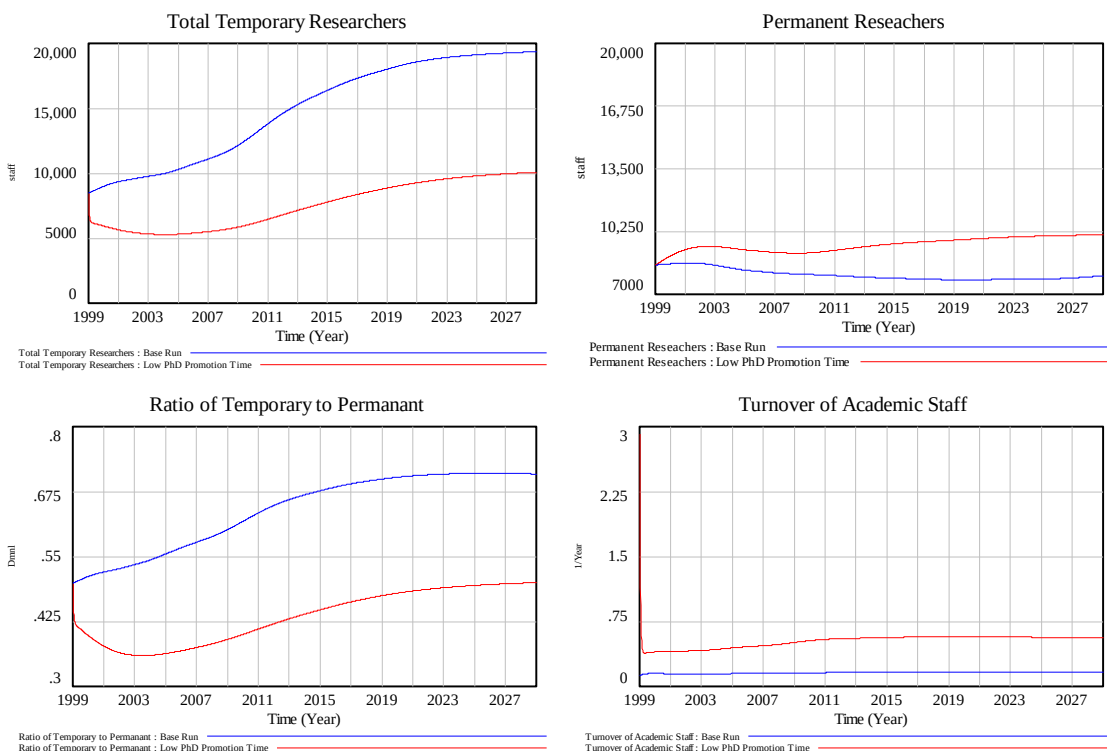


Figure 57: Extreme Value Test - Low Temporary Costs

EXTREME PROMOTION TIME

Test 5 was conducted by dividing the promotion time of PhD candidates by 10. The results can be observed in Figure 58. As expected, a lower promotion time leads to less temporary researchers. The inflow of PhDs quickly flows out into the Postdoc stage, assistant professorship or go outside academia. It also has a substantial influence on the number of temporary research staff that will increase over time, after an initial decrease. This is caused by a transfer of funds from the PhD to the TRS phase. The number of permanent researchers increases under the effect of funding and more TRS that are available.



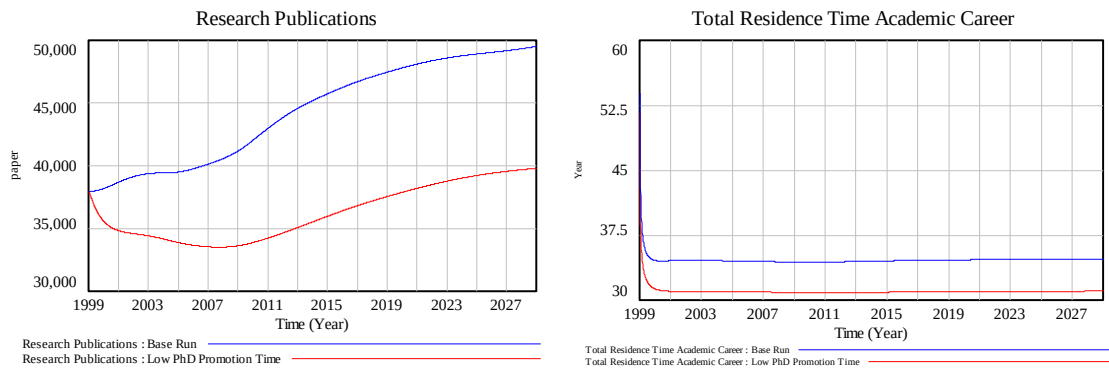


Figure 58: Extreme Value Test – Low Promotion Time

Test 6 was conducted by multiplying the promotion time of PhD candidates by 10. The results can be observed in Figure 59. In comparison, a high promotion time makes PhD candidates reside longer in the stock, therefore accumulating tremendously. The financial burden of accommodating these PhD will fall for the other temporary research staff stage. Less people will be attracted. As in the previous extreme value test, the permanent phases and the research activity only marginally changes.

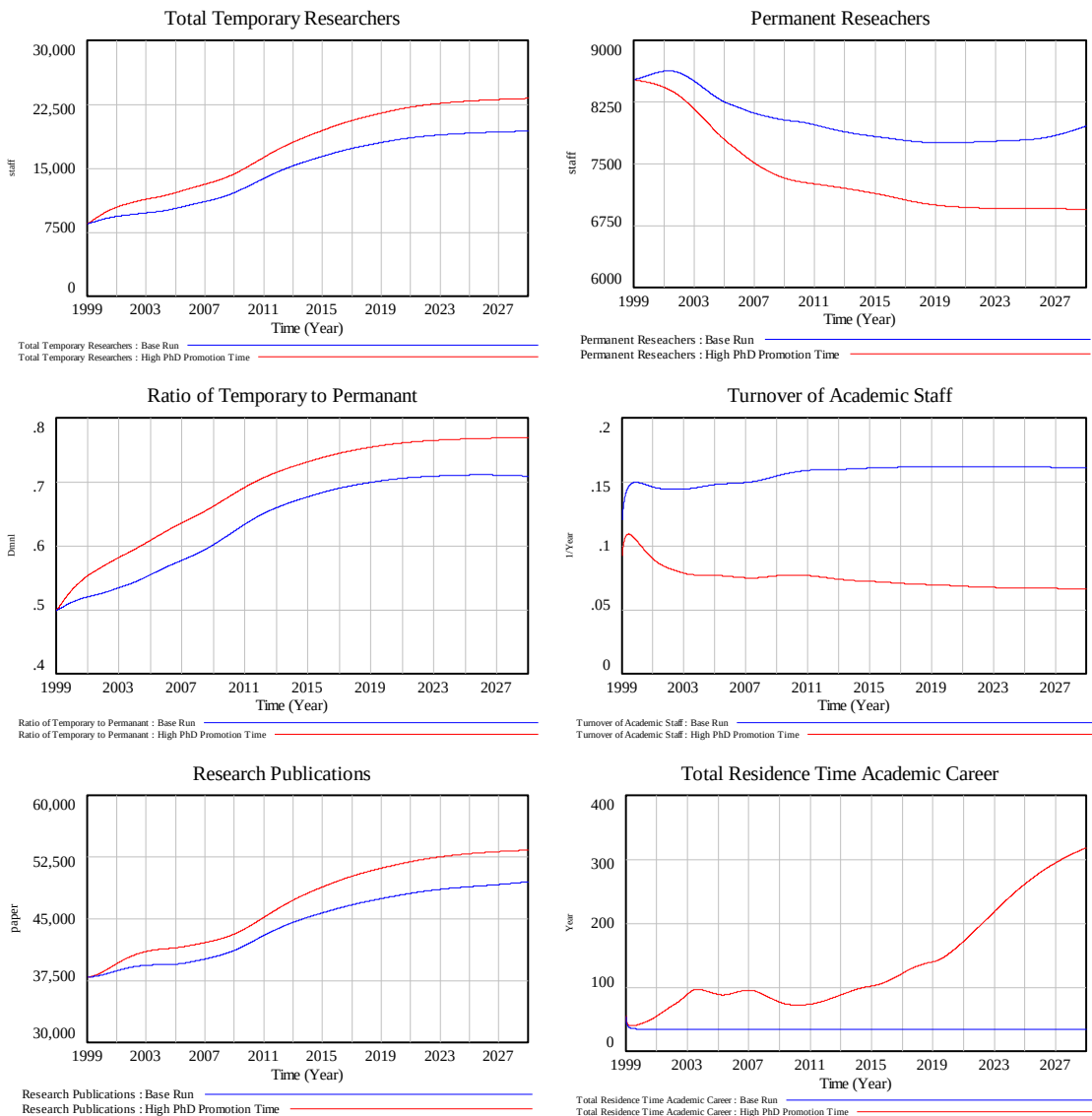


Figure 59: Extreme Value Test – Long Promotion Time

EXTREME TRS CONTRACT TIME

Test 7 was conducted by multiplying the contract time of TRS by 10. The results can be observed in Figure 60. While the total amount of TRS decreases significantly, the total turnover does increase. Because the residence time in this phase is low the outflow will mainly contribute to the accumulation of the permanent research staff. Another interesting observation in the sixth graph is that when the residence time decreases, temporary researchers have the tendency to have more contracts before moving into the permanent phases or finding a job outside academia. With short contract there is a high turnover of academic staff making the academic ranking system more flexible.

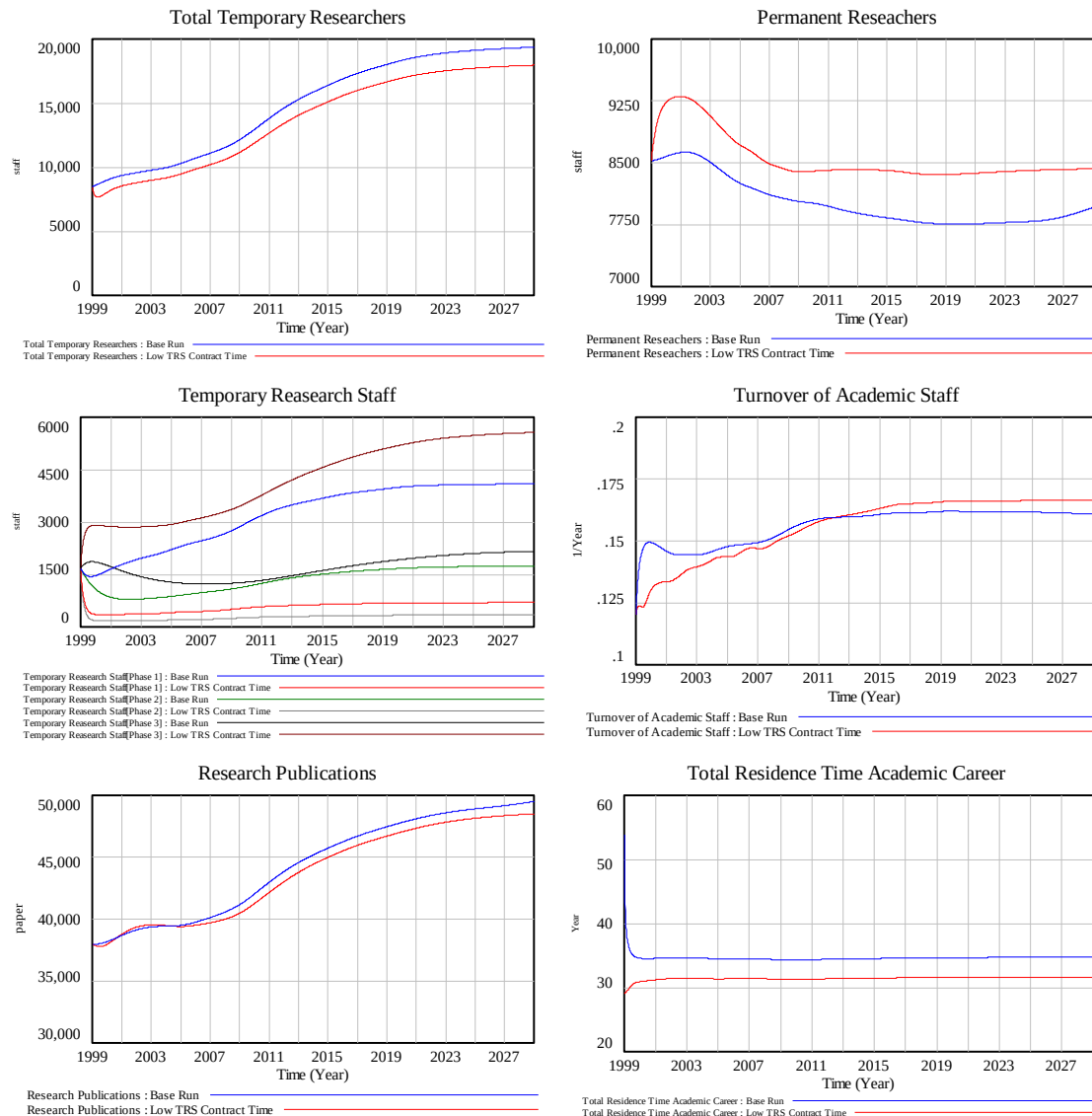


Figure 60: Extreme Value Test – Low TRS Contract Time

Test 7 was conducted by dividing the contract time of TRS by 10. The results can be observed in Figure 61. The total amount of TRS increases significantly, as the total turnover drops and more staff accommodates in this phase. However the total TRS does not increase tremendously. Note that here the biggest outflow will be to outside academia as most TRS will remain long in the stock and become demotivated. This has also an influence on the total amount of permanent researchers. Note

also here that phase 3 of the TRS contracts will have the highest leaving rate. Finally, it makes the academic research world less flexible as there is less turnover in academic staff.

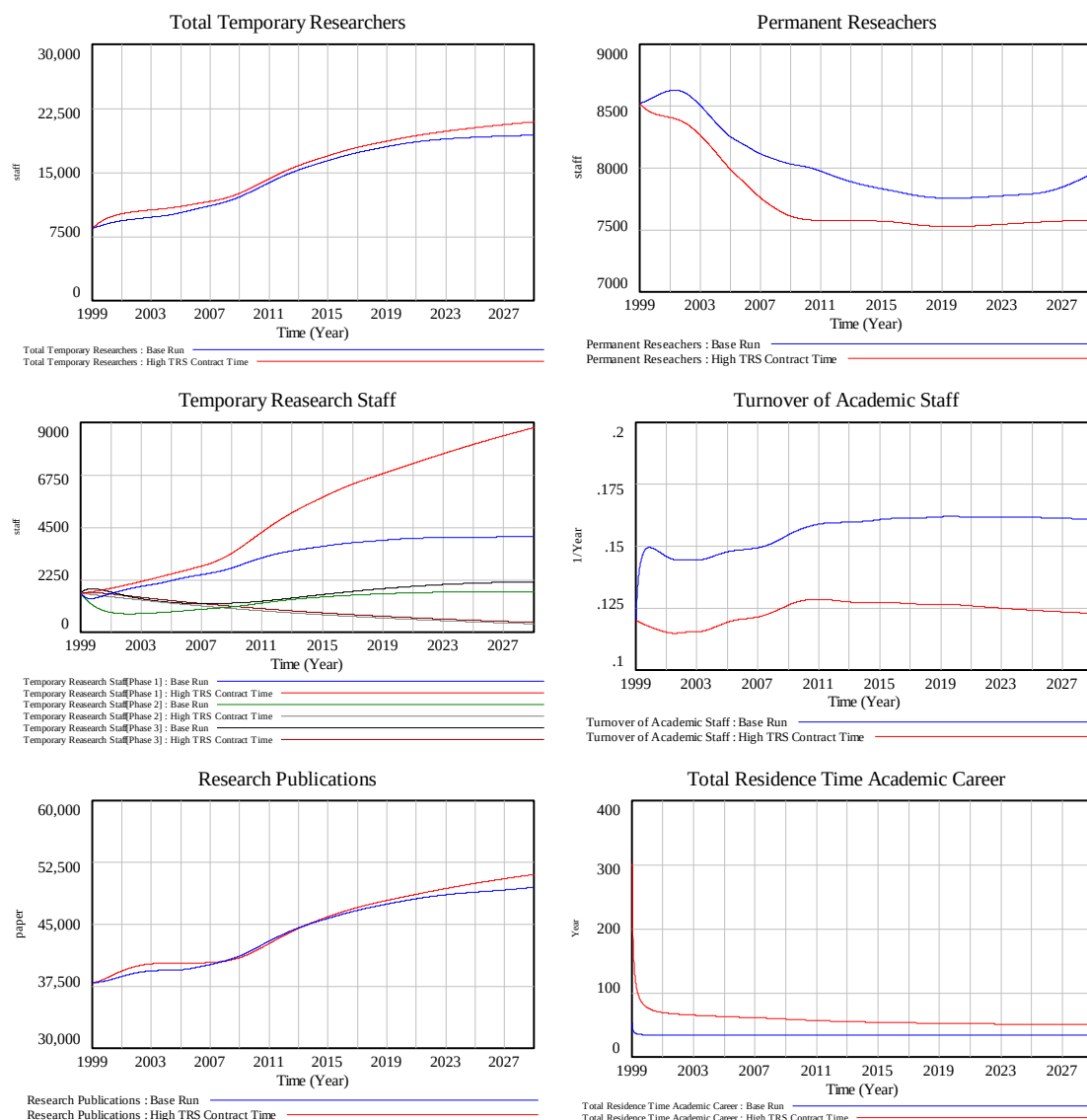


Figure 61: Extreme Value Test – High TRS Contract Time

C5 Extreme professor residence time

Test 9 was conducted by multiplying the contract time of Professors by 10. The results can be observed in Figure 62. While the number of professors increases tremendously, it just have little effect on the total academic workforce. In that sense only the proportionality between the functions changes. However, the turnover of academic staff decreases significantly, giving meaning to a smaller change of acquiring an academic position

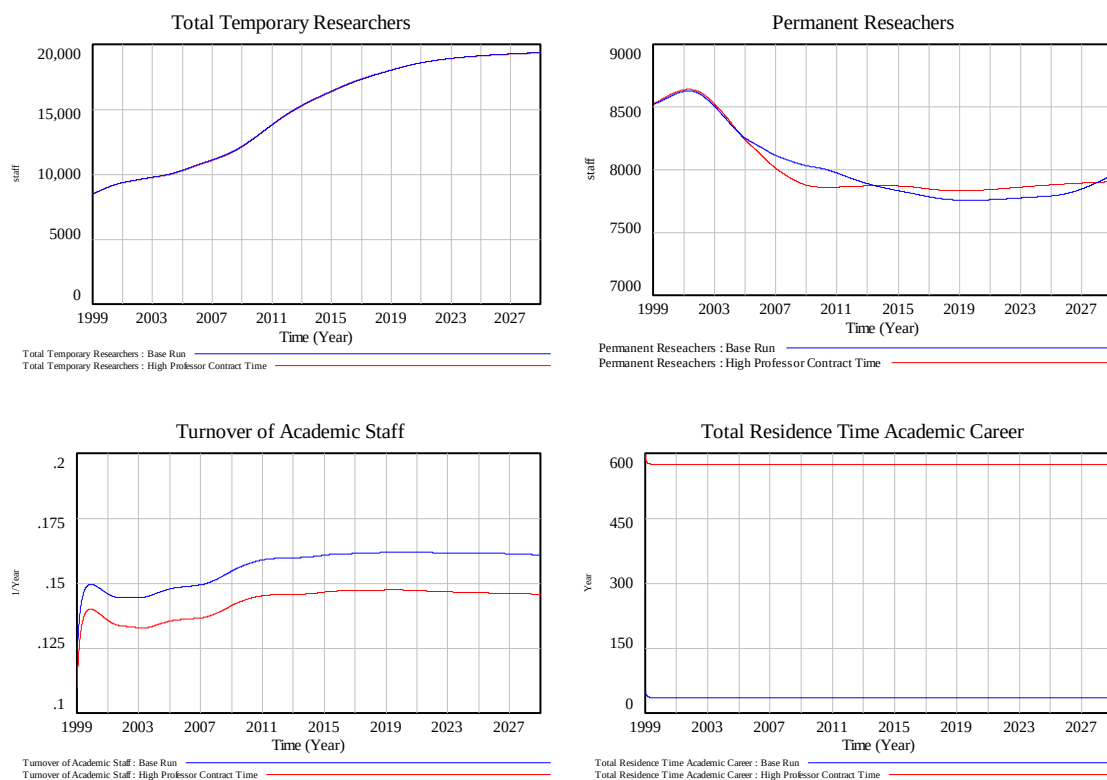


Figure 62: Extreme Value Test – Long Professorship

APPENDIX 7: SENSITIVITY ANALYSIS

RESULTS

The sensitivity analysis will be conducted with 10 per cent increase and decrease for the value of each parameter. For the univariate analysis each parameter will be analysed based on 500 runs with a random uniform distribution. The multivariate sensitivity analysis, to compare a combination of parameters, will be conducted by using 1000 runs each. The graphical output will be based on the Key Performance Indicators. Sometimes these indicators are omitted if there the effect on the parameter is negligible. Sometimes other important parameter will be shown. The main model KPIs are as follows:

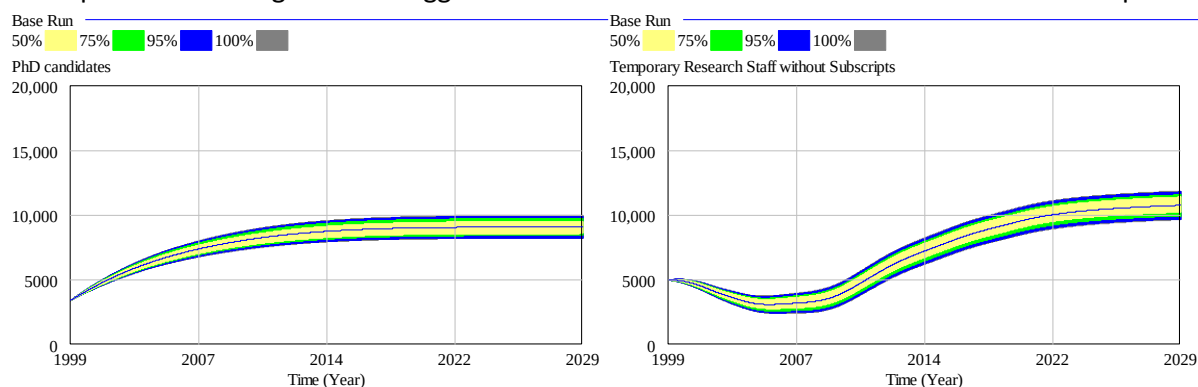
<i>Key Performance Indicator</i>	<i>Unit</i>
<i>Temporary Research Staff</i>	<i>Staff</i>
<i>Permanent Research Staff</i>	<i>Staff</i>
<i>Ratio of Temporary to Permanent Staff</i>	<i>Dmnl</i>
<i>Staff Turnover</i>	<i>Dmnl</i>
<i>Research Output</i>	<i>Publications/Year</i>

UNIVARIATE SENSITIVITY ANALYSIS

First the univariate sensitivity analysis will be conducted by changing important parameter constants to analyse how sensitive the model is to change. The parameter constants that are chosen are based on the relevance to the stakeholder, obtained through interviews, and relevant from a policy making perspective.

Basic Reproduction Number

In the model, the BRN is determined by system calibration based on the historical numbers of PhD inflow over time. As such, the BRN value of 11 gives the most promising behaviour. Because this value is a not a real-world concepts special attention is made to its sensitivity. The results, shown in Figure 63, show that the model is only numerically sensitive to this parameter. However, the numerical sensitivity increases over time. This was expected as a stable constant influences dynamic variables over time making future estimations unpredictable. It also has a substantial influence on the permanent workforce. This suggests that small alterations to this constant have a big influence on the model. It also gives the impression that a static constant might not be right way to model the behaviour of the workforce. The research output and the staff turnover are largely unaffected by these parameter changes which suggests the BRN influences the distribution over the staff phases.



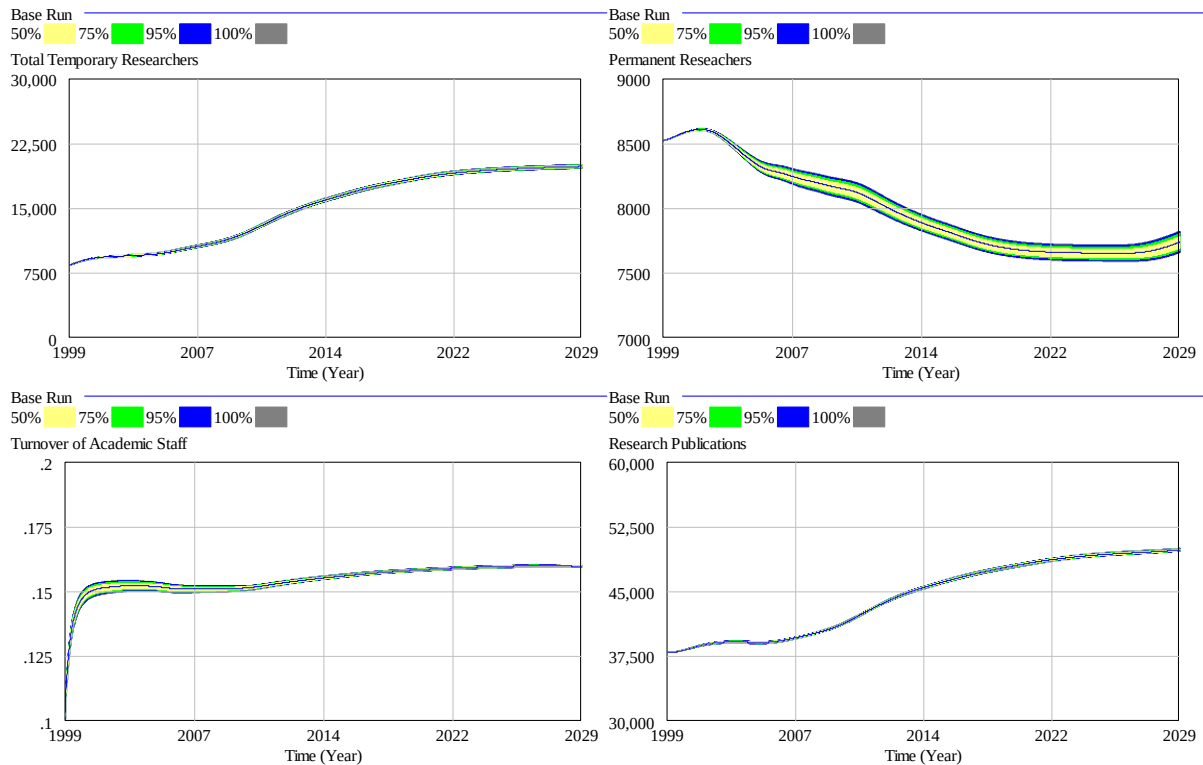


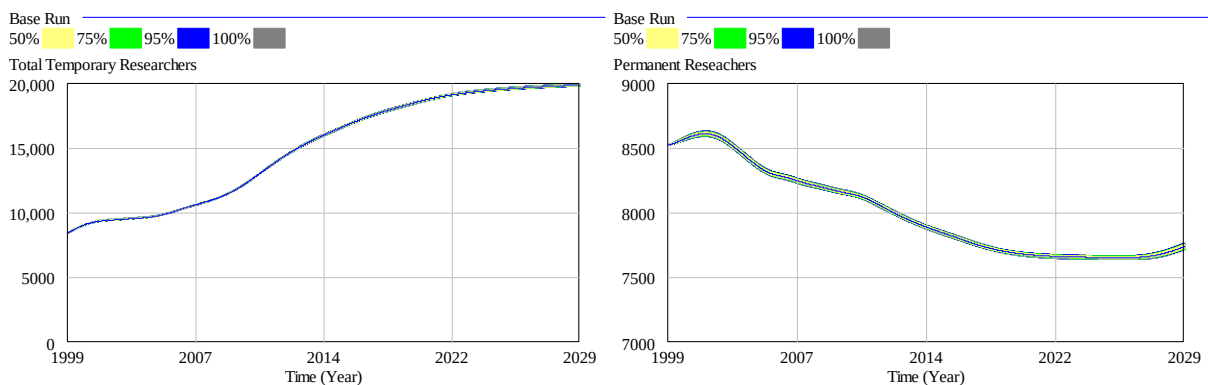
Figure 63: Sensitivity Analysis – Basic Reproduction Number

Temporary Promotion Fractions [PhD Promotion Fraction, Unsuccessful PhD Candidate Fraction, Academic Career Promotion Fraction, TRS Promotion Fraction]

Testing these promotion fraction individually did not lead to many sensitivity in the model. However, this was expected as these fraction are relatively small and only small fractions of staff are able to acquire a permanent position. Making these fractions stable also poses certain validation limitations. In the real-world system potential staff is elected based on their educational and academic history, so these fractions could change over time. This could make the results in these phases less valuable.

Contract Time Temporary Research Staff

In the model the contract time of temporary research staff is determined on 2 years with a maximum of 6 years under three contracts. However, the government will change the contract terms to 2 with a maximum of 4.5 years (OCW, 2014). As such, this sensitivity experiment is important from a policy perspective.



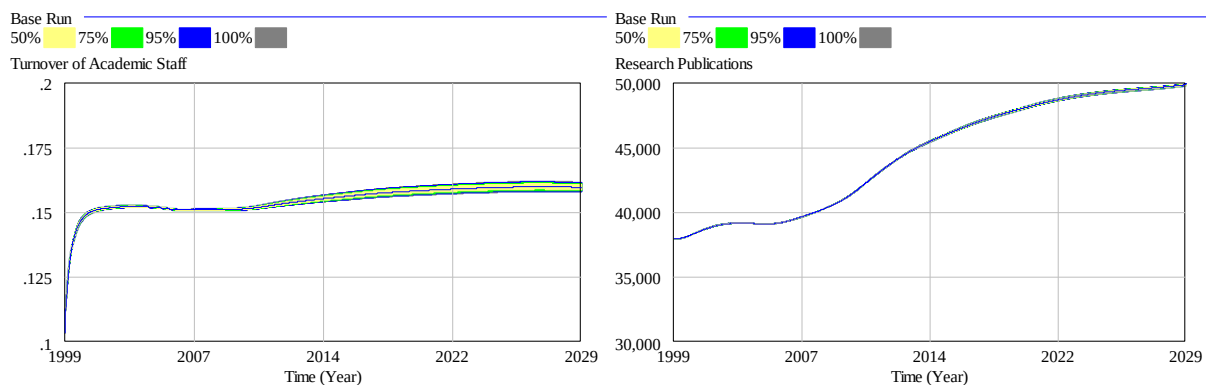


Figure 64: Sensitivity Analysis – Contract Time TRS

The results, shown in Figure 64, show that only permanent research staff is sensitive to policy changes in contract time. However a sensitivity of temporary staff was expected. To analyse this further, the sensitivity results will be shown of temporary research staff in the three consecutive phases.

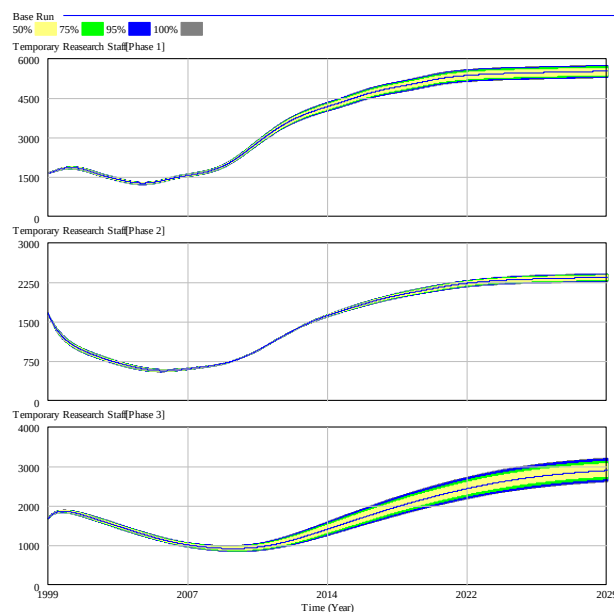


Figure 65: Sensitivity Analysis – Contract time TRS phases

The results of the TRS phases, as shown in Figure 65, show more parameter sensitivity in the individual phases. Phase 1 and 3 shows the most parameter sensitivity. This could suggest that changing the contract structure only changes the balance of staff over the different phases.

Time to Adjust the Gap Between Capacity and Nominal Value [Temporary Staff]

In the model, the time to adjust the gap between capacity and nominal value is determined on 1.3 years, which is calibrated over time to fit the historical observed behaviour. The results, shown in Figure 66, show limited parameter sensitivity for all model KPIs. The sensitivity to changes in the permanent section of the model are more volatile. This is caused by the differences in capacity adjustment times between temporary and permanent phases, the multiple inflows that are possible in these phases and the ad hoc capacity structure that is used in the model to model the temporary to permanent phase flow.

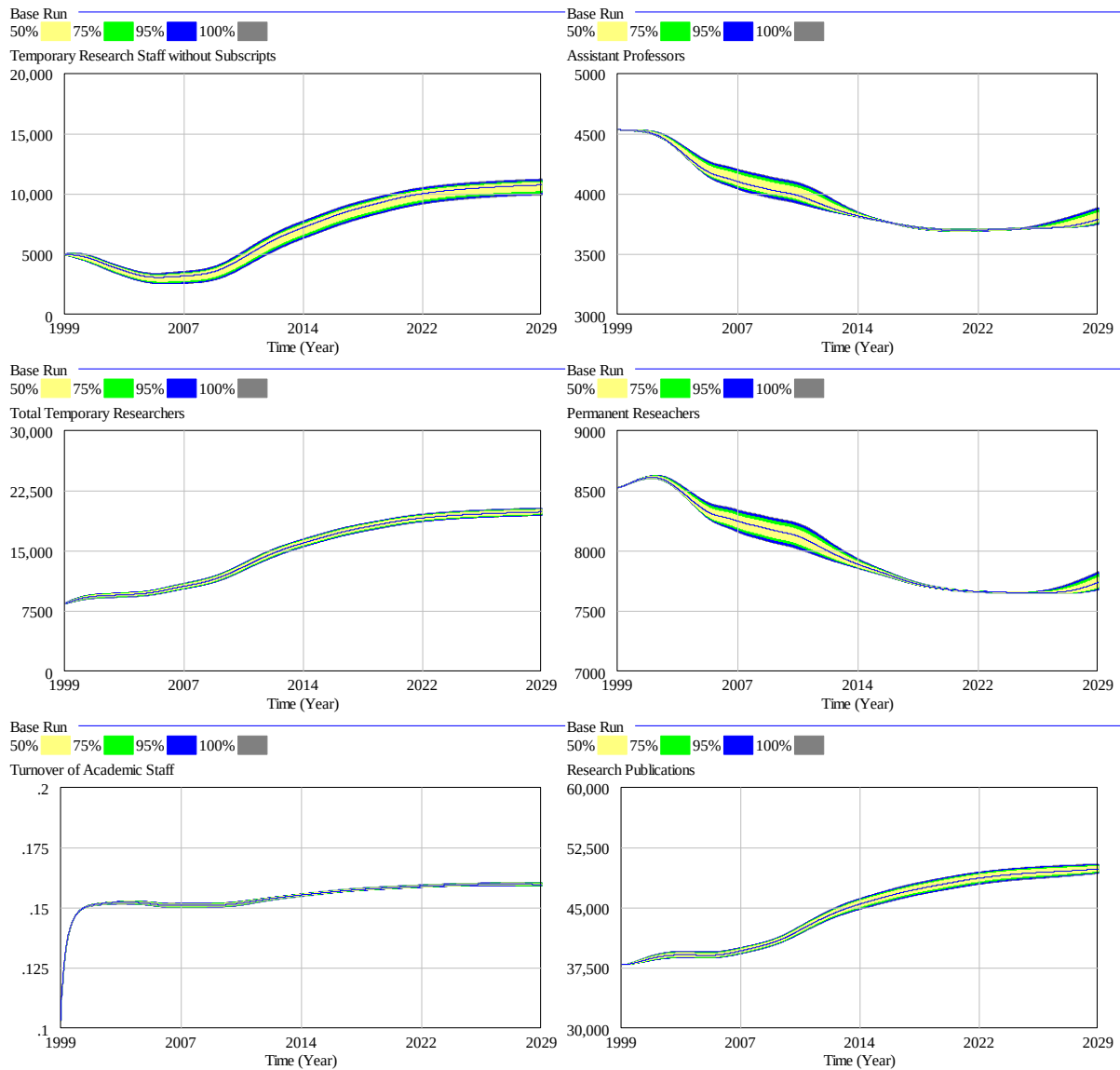


Figure 66: Sensitivity Analysis – Time to adjust the gap

Time to Adjust the Gap Between Capacity and Nominal Value [Permanent Staff]

In the model, the time to adjust the gap between capacity and nominal value is determined on 1.0 years, which is calibrated over time to fit the historical observed behaviour. The results, shown in Figure 66, show negligible parameter sensitivity for all model KPIs. Therefore the graphical representation is not shown.

Temporary Research Costs

In the model the temporary research costs is determined at 88.000 euro a year, which is authors estimate for the costs of this staff per year calibrated over time to fit the historical data. The results of the models KPIs are shown in Figure 67. It shows a substantial parameter sensitivity to temporary researchers and number of papers published. A small change of 10 per cent of the total value can have a difference in the range of 500 in the temporary research staff. This then also has an impact on how many papers are published. Permanent researchers react more volatile to this deviation which shows a direct connection to the temporary staff phases. Overall, this test shows that the

parameter, that is an estimate with a large uncertainty space, has a substantial influence on the model KPIs.

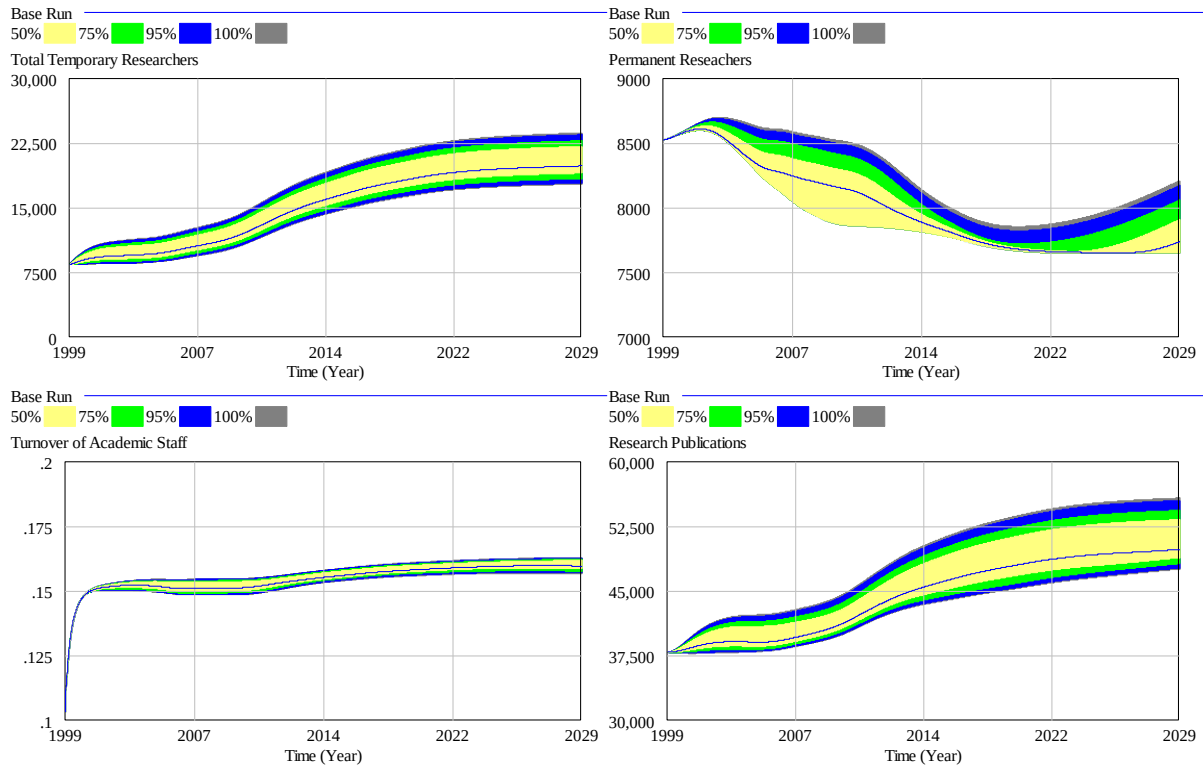
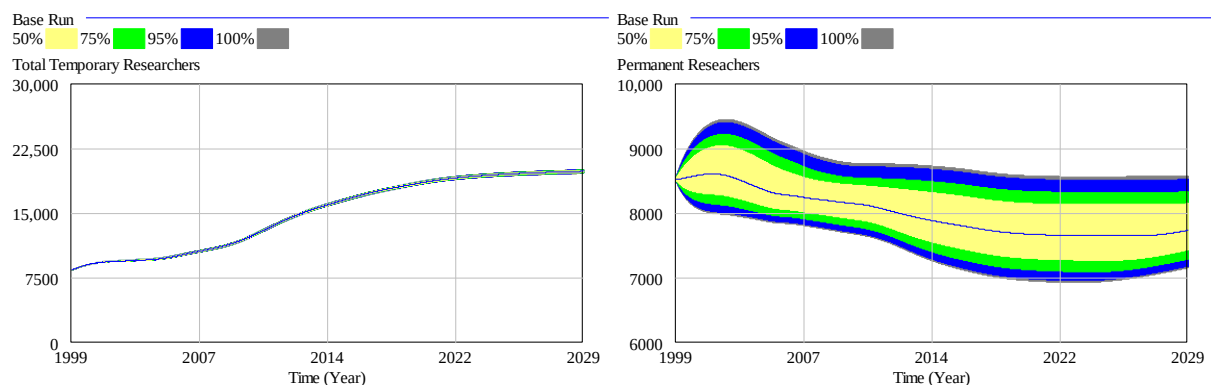


Figure 67: Sensitivity Analysis – Temporary Research Costs

Permanent Research Costs

In the model the permanent research costs is determined at 185.000, which is based on data from literature to satisfy the demand for stipends and overhead for professors and calibrated over time to fit the historical data and behaviour. Even more so, the cost of permanent researchers has a substantial influence on all the model key performance indicators, as shown in Figure 68, as there is a feedback loop between professors and PhD candidates. It shows an increasing sensitivity over time as there is a reinforcing feedback loops between aging chain based on delays.



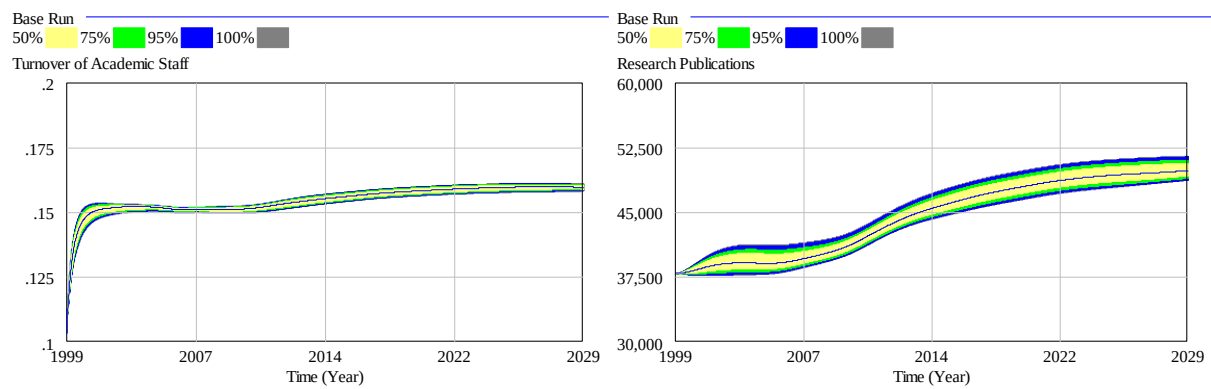


Figure 68: Sensitivity Analysis – Permanent Research Costs

Assistantship, Associateship and professorship [residence time]

The data regarding residence time of permanent researchers is gathered by using data from the Rathenau Institute (Goede et al., 2014).

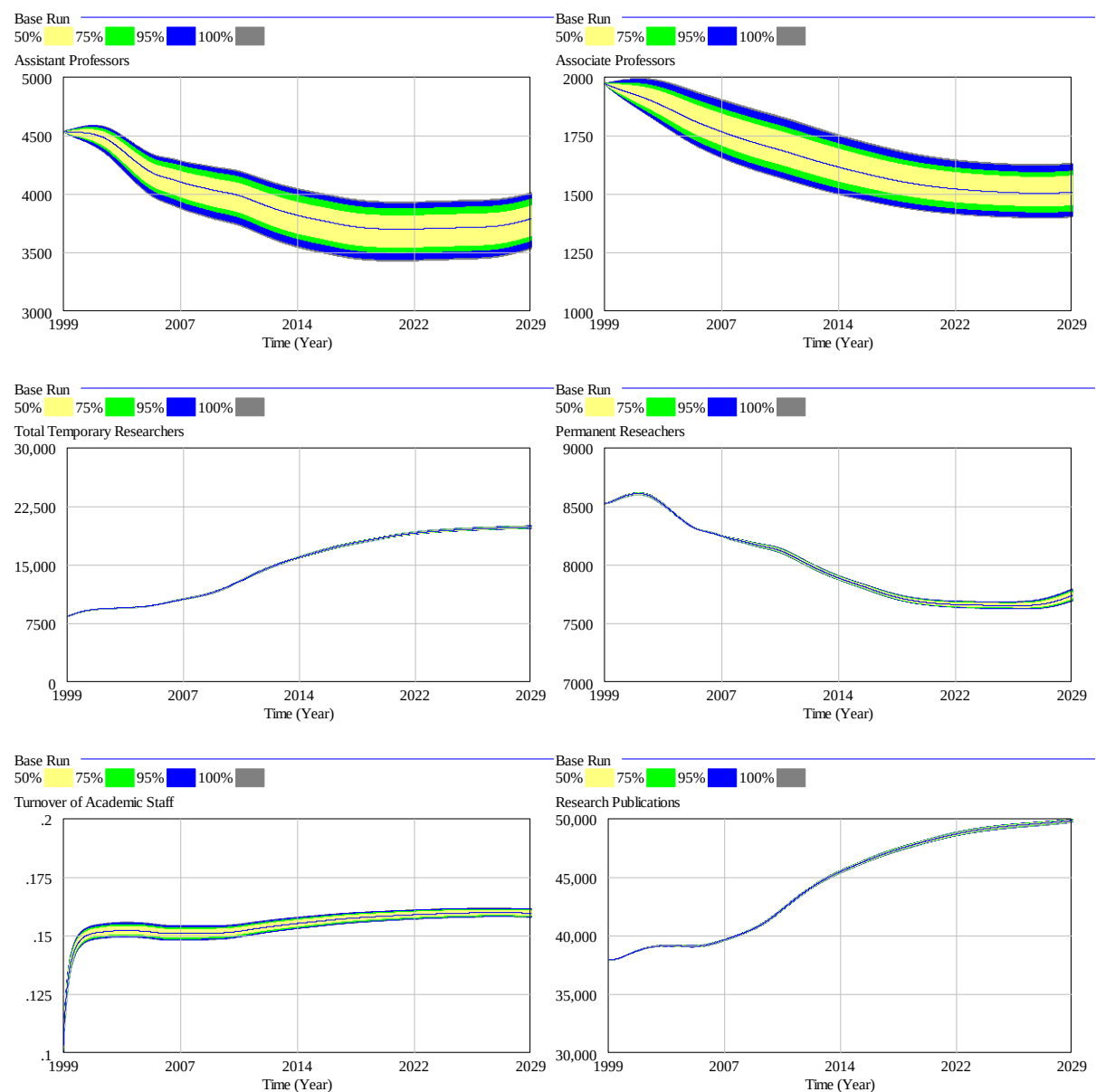


Figure 69: Sensitivity Analysis – Residence time Assistant

However a change in residence time could have a substantial impact on the model. In the model the residence time of assistants is 7 years. The results of all the models KPIs, as shown in Figure 69, show a limited parameter sensitivity to temporary and permanent staff but a large sensitivity to individual phases of permanent staff. The other KPIs are only limited influenced by this policy change. This suggests that the model balances it staff over the different permanent phases, as the total capacity of permanent staff does not change. The results of the of the residence time in the associate phase, which is 6 years is not different to the assistant phase. The same behaviour is observed apart from this phase being slightly less susceptible to change.

In the model the residence time of professors is 11 years. The results of all the models KPIs, as shown in Figure 70, show a parameter sensitivity to change in the professorship years. Noteworthy is the increasing uncertainty in the individual professor phase. This is an interesting observation keeping in mind the change of retirement age as a policy measure.

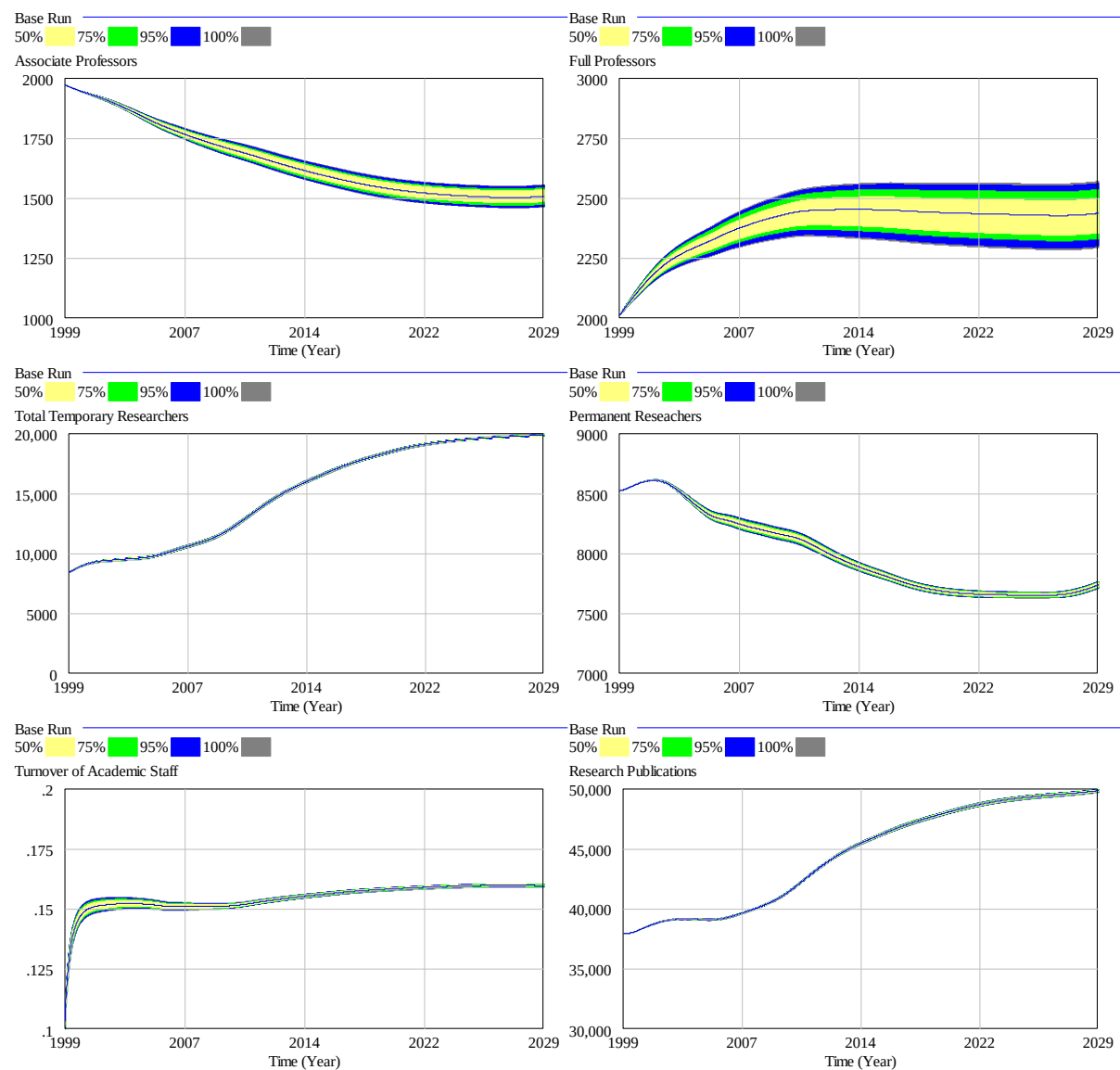


Figure 70: Sensitivity Analysis – Residence time Professor

Total Research Time

In the model the total research time is 1380 hours per year, which is based on data from literature. The results of all the models KPIs, as shown in Figure 71, show an increase in sensitivity over the years, especially in the permanent phases. This is due to the increased stagnation of funds for science and the call for additional funds. As such the permanent phases, who receive institutional funding, becomes volatile to change over time.

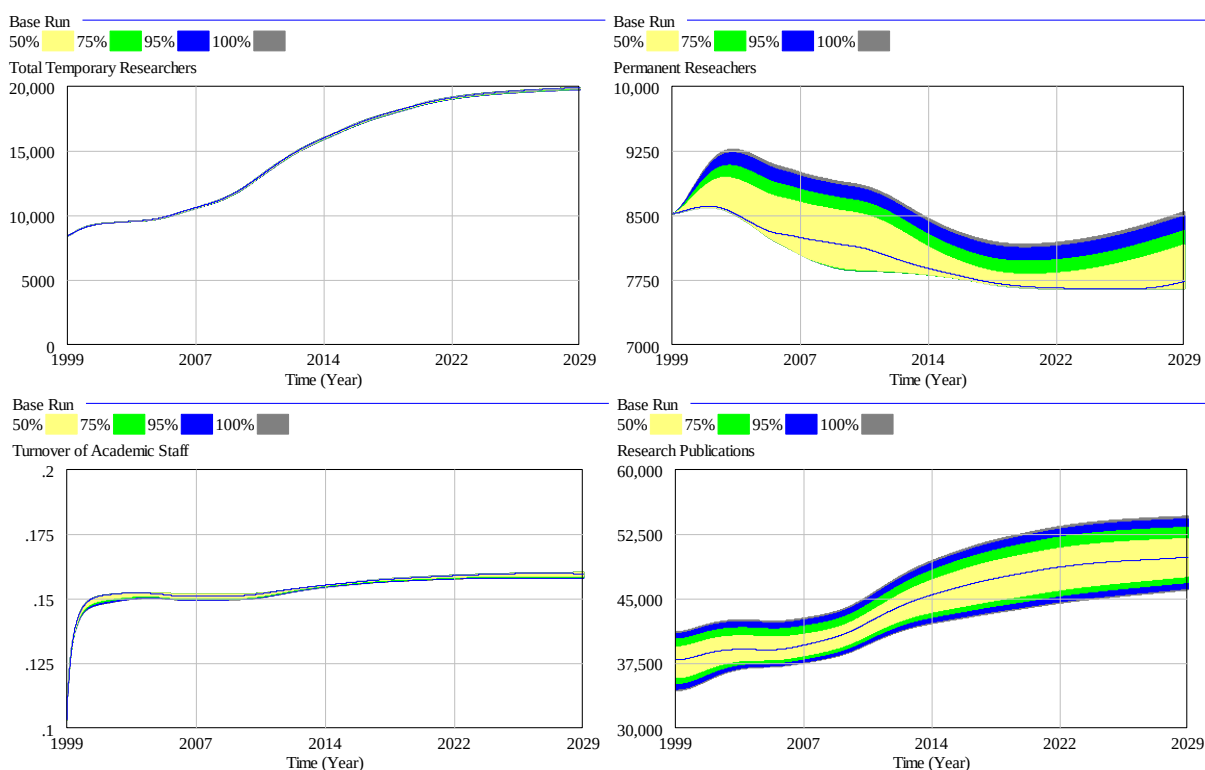


Figure 71: Sensitivity Analysis – Total Research Time

MULTIVARIATE SENSITIVITY ANALYSIS

After conducting univariate sensitivity analysis on the important exogenous variables, multivariate sensitivity analysis is conducted by combining related variables. The combined effects of these parameters on the models are investigated with this analysis. The description of these variables are given below.

- Multivariate Sensitivity Analysis for testing parameters related to residence time
- Multivariate Sensitivity Analysis for testing parameters related to cost structures
- Multivariate Sensitivity Analysis for testing parameters related to promotion fractions

Also with the multivariate sensitivity analysis the parameters are changes 10 per cent with random uniform distributions. This time the simulation is run a 1000 times.

Residence time [PhD promotion time, contract time TRS, assistantship, associateship and professorship]

The results in a combined residence time sensitivity analysis, as shown in Figure 72, show limited parameter sensitivity. This is in line with the univariate analysis conducted on individual residence time. Combined sensitivity shows that increasing the residence time does only affect the

proportionality between the phases. Only changing the individual residence time can change the number of staff within a specific phase.

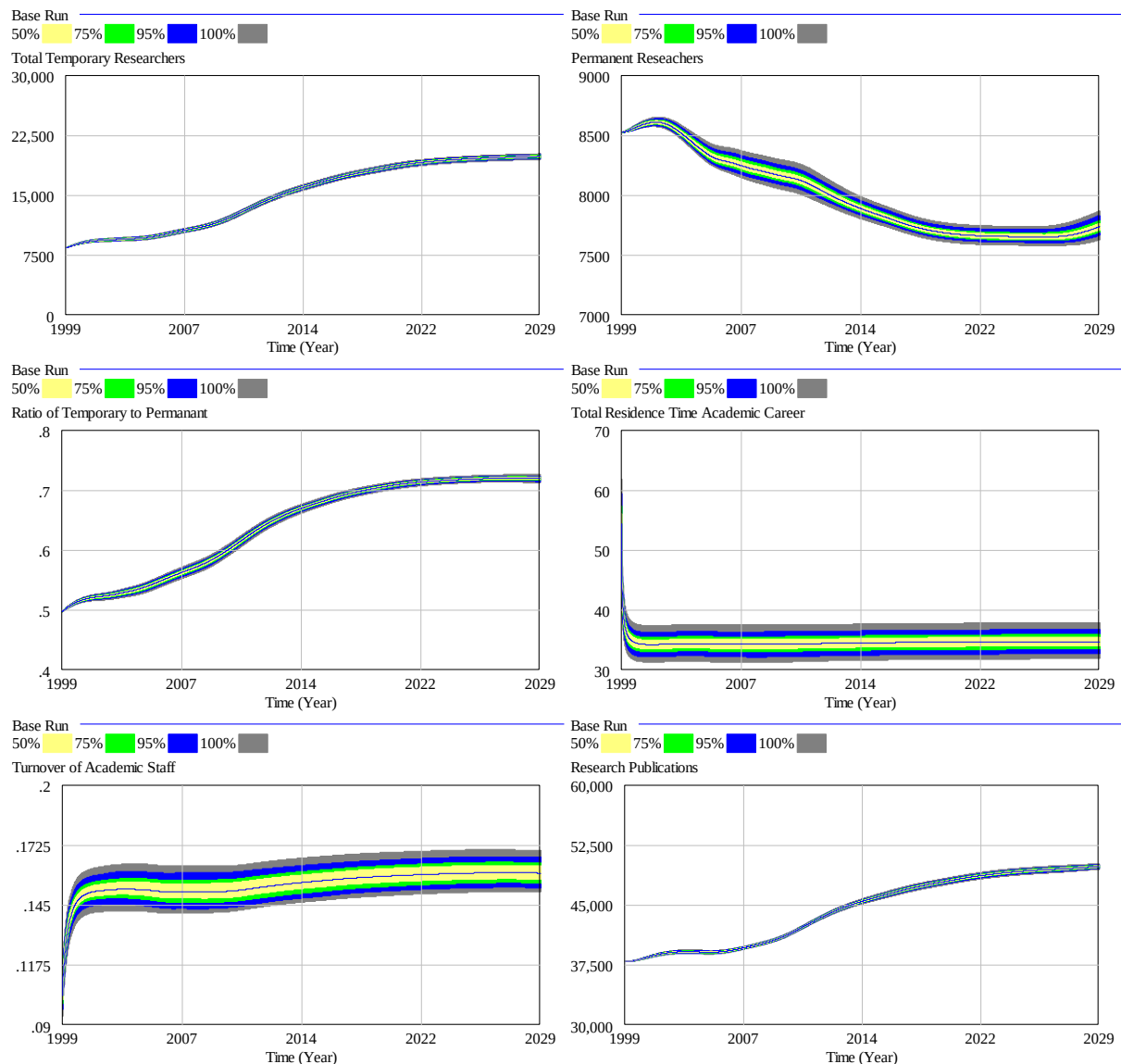


Figure 72: Sensitivity Analysis – Multivariate Residence Time

Cost Structure [Temporary researcher cost, permanent researcher cost, initial project funds and initial institutional funds]

The results in a combined residence time sensitivity analysis, as shown in Figure 73, show substantial parameter sensitivity. However, this was expected as it is an estimated variable that is calibrated over time to fit the historical data. Noteworthy is this analysis is the sensitivity to total residence time of the staff based on the cost structure. If there are limited funds available, TRS will remain in the temporary phases until it becomes frustrated and leaves academia. Because a delay between funding and the eventual departure exists, funding can have a volatile impact on residence time, with the focus on the temporary research phases.

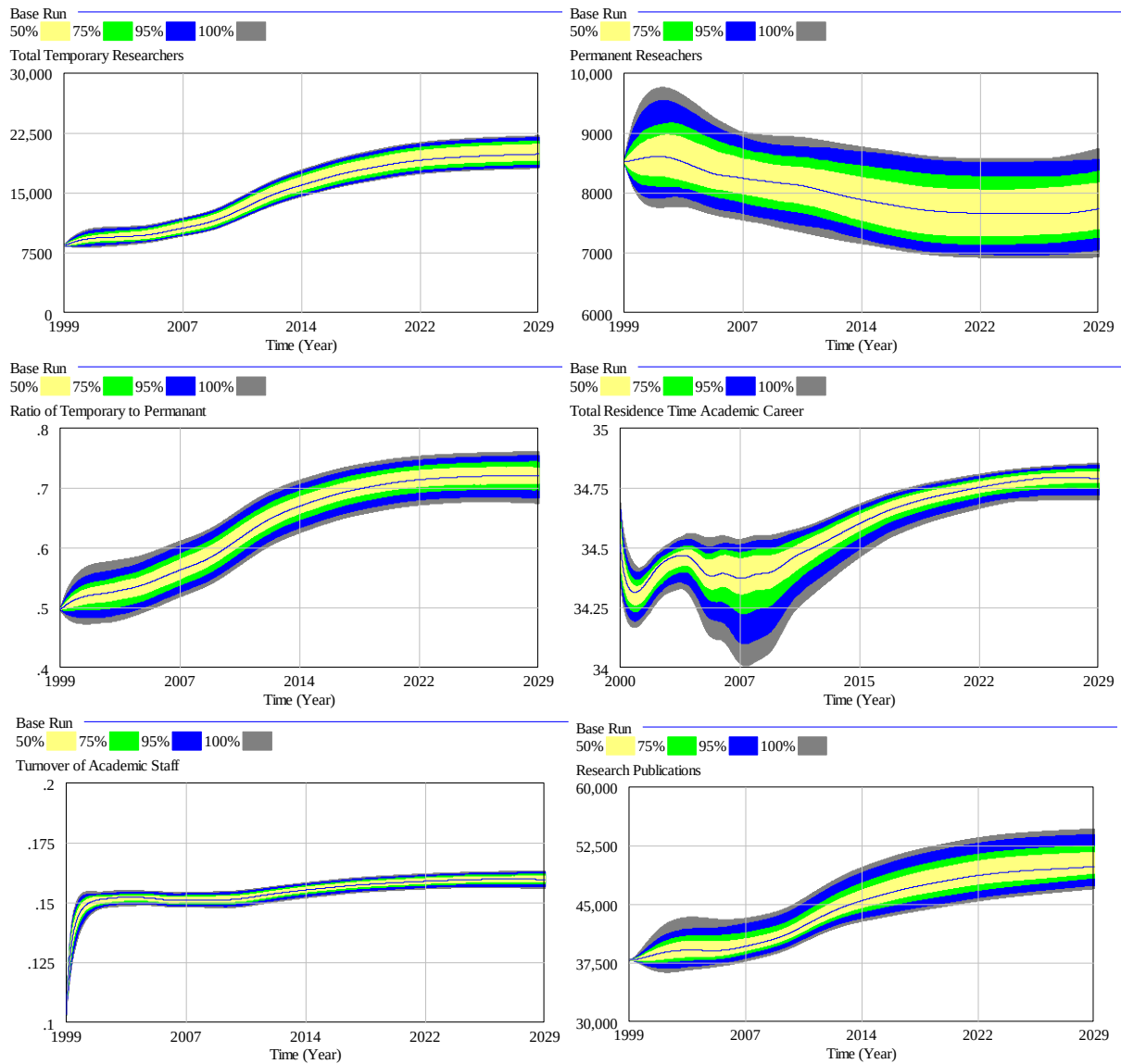
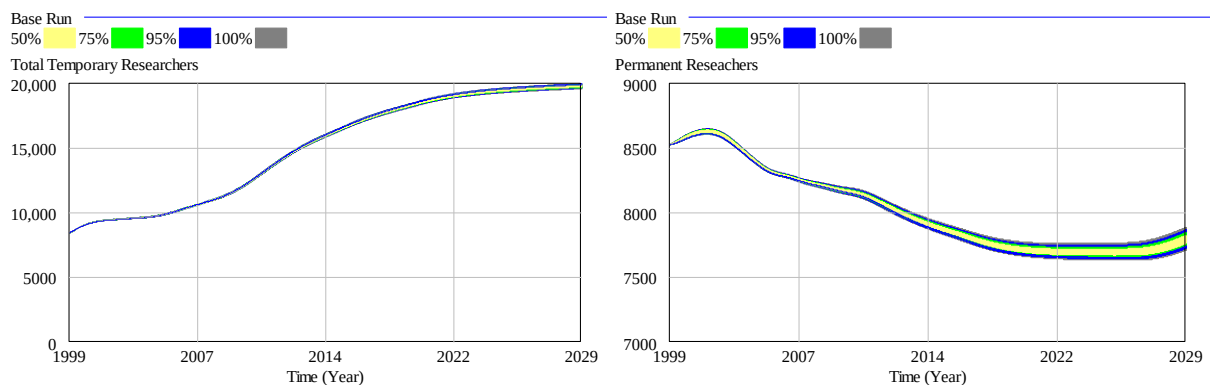


Figure 73: Sensitivity Analysis – Multivariate Cost Structure

Promotion Fractions [academic career promotion fraction, successful permanent application fraction, assistant promotion fraction, associate promotion fraction and professor retire fraction]

The results in a combined promotion fraction sensitivity analysis, as shown in Figure 74, show limited parameter sensitivity. This is comparable with the individual tested fraction that were also not very sensitivity to change.



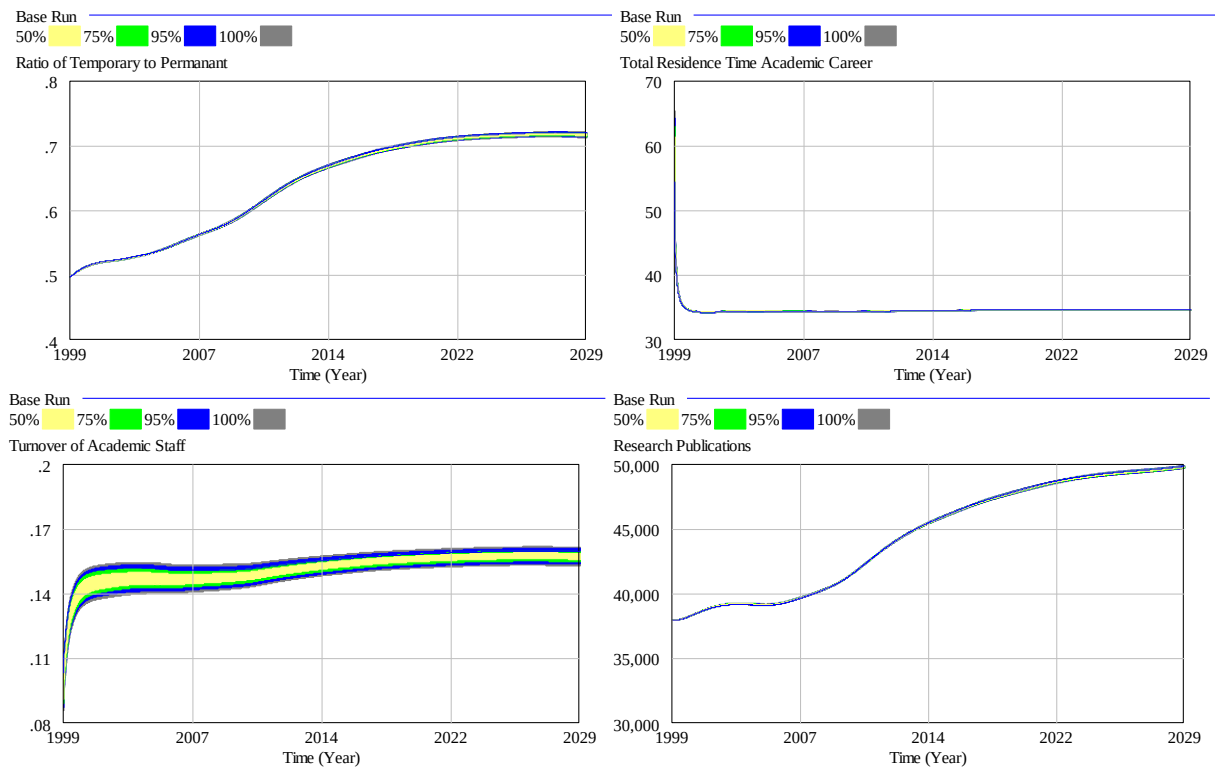


Figure 74: Sensitivity Analysis – Multivariate Promotion Fractions

APPENDIX 8: MODEL CALIBRATION RESULTS

The incorporated parameters and variables within the SD model environment did not research the desired behaviour. The model consists of a number of uncertain exogenous parameters that create the behaviour over time. While these uncertainties are explored in section 8.4, some uncertainties about the structure of the model and the parameter estimations can be identified during model calibration. The tests that have been conducted to optimise the model results are shown in the following 3 sections.

FAIR VALUES

Initially the model was created around the yearly real value change in research funding as shown in Figure 75. To correct the inflation and estimate the cost of hiring and maintaining researchers model stock variables were created to represent the cost increase. This created 4 not real-world parameters: initial temporary researchers cost, initial temporary research cost, yearly increase permanent costs and yearly increase of temporary costs. By calibration these parameters over their uncertainty ranges, limited behavioural resemblance with the observed historical data was obtained. To this extent, the exogenous real-value based parameters were substituted by their fair-value counterpart. This change was based on the CBS-fair value calculator. Based on real values and the decrease from 4 unknown parameters to 2 unknown parameters (temporary and permanent research costs) better model behaviour was computed.

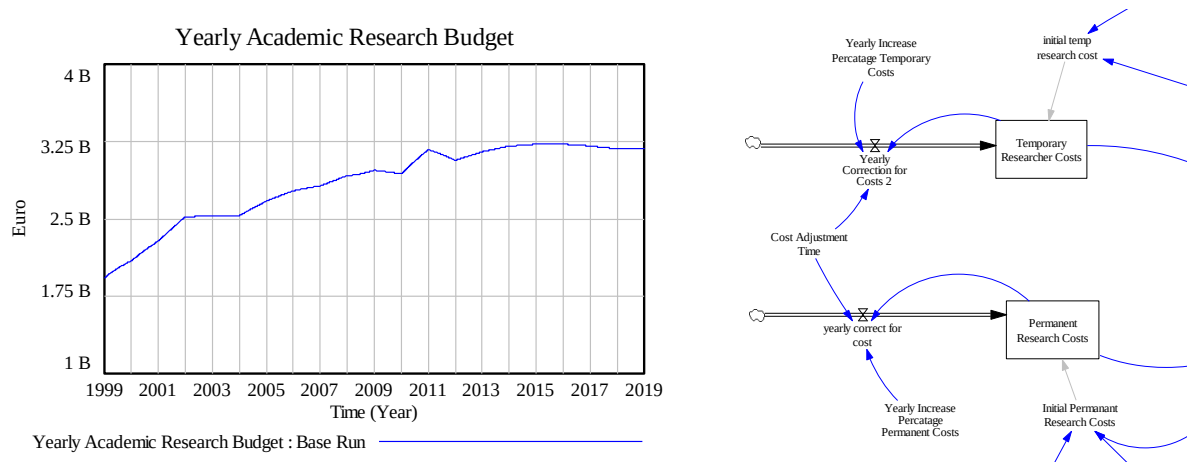


Figure 75: Calibration: Real-Value to Fair Value (a) old model and (b) old graphical output

FUNDING STRUCTURE

Initially the model was created around the stock flow structure of the different funding regimes as shown in . However these dynamics caused volatile behaviour in the capacity adjustment section of the model and consequentially the promotion of academic staff. To correct this behaviour, funding adjustment delays were created to represent the use of funds by public research organisations. This computed 1 not-real-world parameter. By calibration these parameters over the uncertainty ranges, limited behavioural resemblance with the observed historical data was obtained. To this extent, the

structure was adjusted and substituted by model stock variables: yearly amount of funding available. This implies a yearly sum of grants that has to be exploited on a yearly bases which could pose limitations. However, based on this structure and the decrease of one unknown parameter value better model behaviour was observed.

FACULTY PROMOTION

Initially the model was created with promotion fractions and average residence times based on the WOPI data obtained from the VSNU database. However, these fractions are based on yearly mobility data over the time frame 2003-2011, which is comparable with the info graphic in Figure 47. This data is only of limited validity as variety between years exist and some number are not included. The average data fractions are therefore calibrated and new fractions were obtained that created better model behaviour.

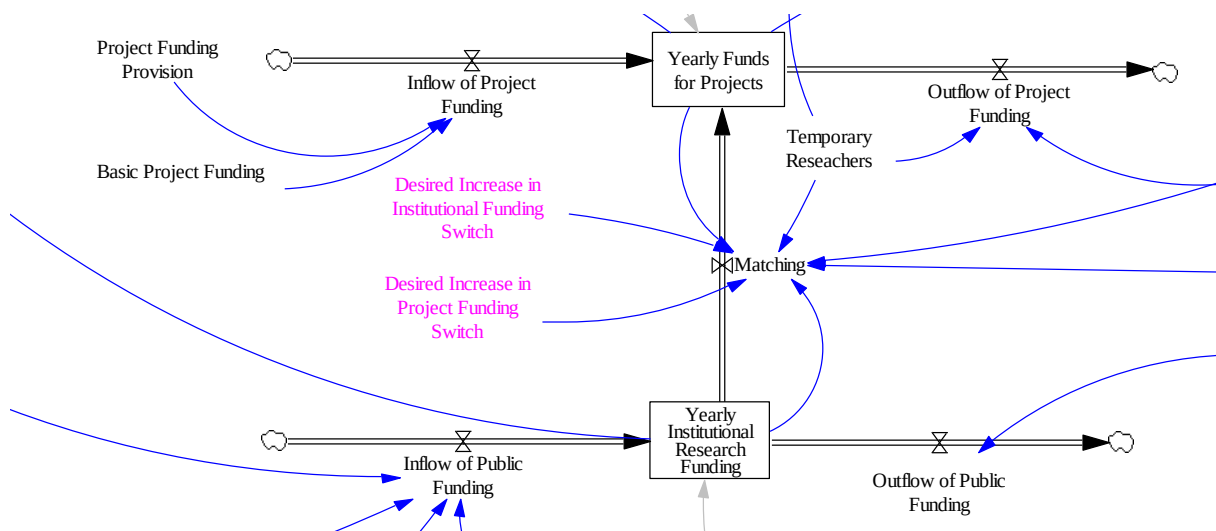


Figure 76: Calibration: Old Funding Structure

APPENDIX 9: BEHAVIOURAL PATTERN TESTS RESULTS

To validate the behaviour of the model, the output is compared with the historical WOPI data between 1999 and 2014. This Appendix shows a descriptive and a graphical representation of the historical validation. Note that the datasets between 1999-2006 and 2006-2014 are not completely comparable making behavioural validation difficult. The data representation can be found in Table 23.

DATA REPRESENTATION

	Full Professor		Associate Professor		Assistant Professor		Other Academic Staff		PhD Candidates		Publications	
	Historical	Model	Historical	Model	Historical	Model	Historic.al	Model	Historical	Model	Historical	Model
1999	2013	2013	1972	1972	4539	4539	5024	5024	3417	3417	-	-
2000	2089	2104	2001	1947	4434	4528	5386	4891	3908	4169	38951	38260
2001	2126	2175	1978	1925	4292	4512	4954	4513	5108	4880	39815	38780
2002	2166	2235	2027	1899	4309	4453	5047	4003	5698	5494	38784	39110
2003	2165	2274	1993	1869	4354	4352	5034	3561	6163	6031	39682	39190
2004	2182	2304	2009	1837	4153	4244	4838	3222	6556	6494	42205	39130
2005	2119	2333	1909	1806	3909	4167	5167	3122	6521	6893	43577	39160
2006	2181	2364	1925	1780	3969	4128	5347	3190	6686	7240	43423	39450
2007	2229	2388	1985	1755	4052	4086	5550	3277	6752	7543	45995	39890
2008	2321	2410	2015	1734	4184	4055	5631	3452	7170	7803	46321	40390
2009	2421	2428	2033	1713	4292	4025	5955	3879	7488	8039	45270	41060
2010	2504	2443	2076	1694	4376	3999	5977	4552	7697	8235	46240	42000
2011	2481	2450	2053	1675	4404	3955	5882	5370	8110	8410	46095	43090
2012	2482	2453	2046	1653	4386	3902	6126	6127	8140	8557	46981	44090
2013	2542	2454	2083	1635	4455	3858	6243	6725	8147	8672	47937	44860
2014	2529	2454	2097	1616	4539	3822	6516	7237	8160	8767	-	-
R ²	0,74		0,37		0,00		0,49		0,97		0,65	
MAPE	14%		39%		99%		30%		1%		19%	

Table 23: Data representation for calculation R2 and MAPE

GRAPHICAL REPRESENTATION

Historical validation is the process of comparing the model output to historical data in the Netherlands. Because two data-sets are compared, 1999-2004 and 2005-2014, and different sources and criteria are used to create these data-sets, it only offers a limited representation of the historical development of the academic workforce in the Netherlands.

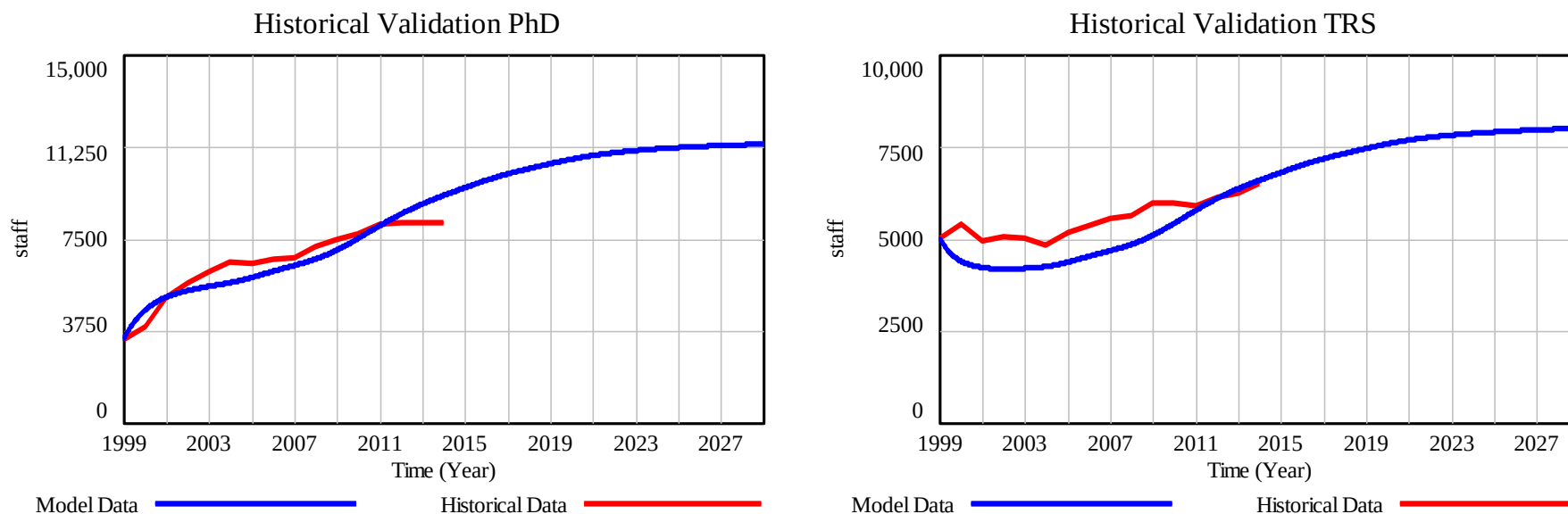


Figure 77: Graphical representation of PhD and TRS phases

In terms of PhD candidates, Figure 77 shows that the simulation results replicates the historical trends in the data. This is in line with the outcomes of the R square and MAPE test. The simulation does not exactly follow the same behaviour but has a similar increase over time. The steep rise in PhD candidates is mostly due to the policy initiative to add an additional bonus to graduates PhD candidates. Figure 77 also shows that development of the TRS limitedly corresponds with the historical data. The simulation does not exactly follow the same patterns, which is relatively unstable over time. Between 1999 and 2007 the historical data behaves in a volatile manner. The model data tries to follow that behaviour. From 2005 onwards the data follows the same increase in workforce, corresponding with the new data-set. Both graphical representations suggest that the model data response slowly to changes in the academic career system. This delay could have an effect on the outcomes. The volatile historical behaviour of TRS can also be described based on the temporary contract structures and the flexible in- and outflow of TRS in this phase (Goede et al., 2014).

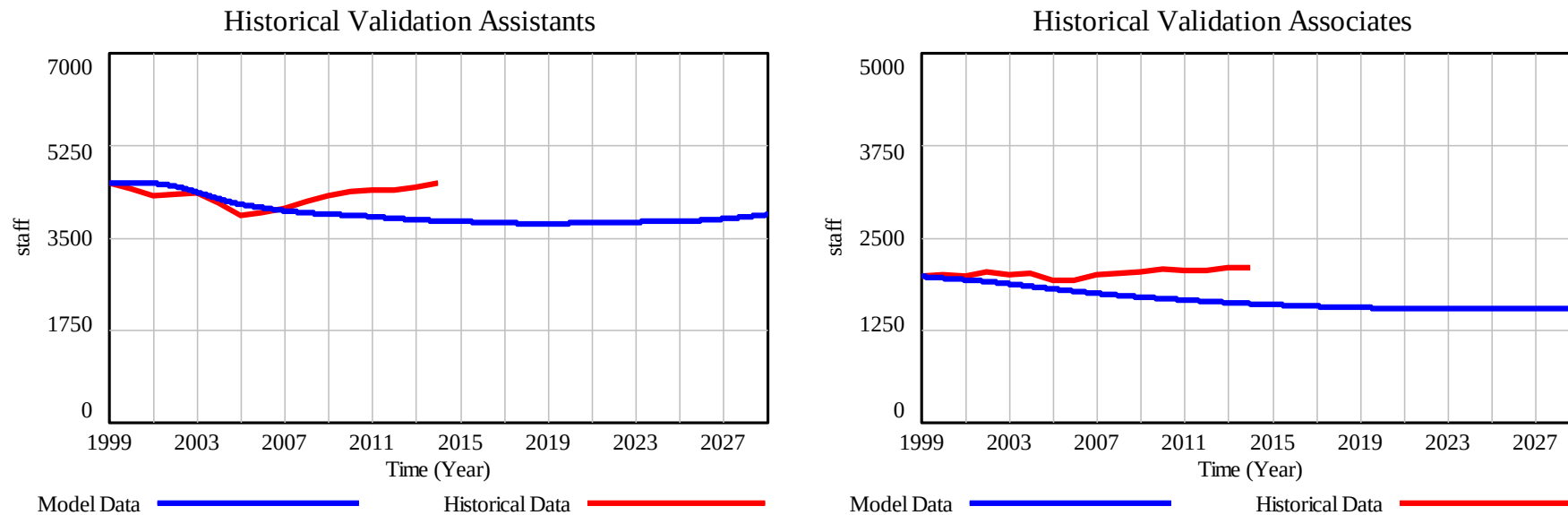


Figure 78: Graphical representation of Assistant- and associate professor phases

As for the number of assistant professors, Figure 78 shows how the simulation replicates the decreasing trend in assistants followed by a growth. Even though the numerical output does not capture the historical data entirely, it does represent the same kind of behaviour: a decline followed by a gradual growth. It is worth noting that the TRS and assistant phase is closely intertwined making it possible that the responses in the model do not occur simultaneously due to information delays. Figure 78 also shows the historical data of associate professors with the model data. However here the behaviour of the two stocks is slightly different. While the historical data remains stable over time, the model behaviour is decreasing with goal seeking behaviour. Optimising the behaviour of the stock, however, did increase the validity but decreased the validity of other stocks in the permanent phases. This suggests that the data used to model the stock is too limited to represent the historical behaviour over time.

Figure 79 represents the historical data of the professor phase with the model outcomes. It captures the behaviour of the professors stock from. Of all permanent academic staff, professors are the ones that most often change their positions. They do not only come from other positions, but also from outside academia. In the model professors are modelled relatively static over time, in correspondence with the formative system it is situated in. Figure 79

also shows the number of publications of research staff over time. It follows the same pattern, however, the historical data seems to increase more over time.

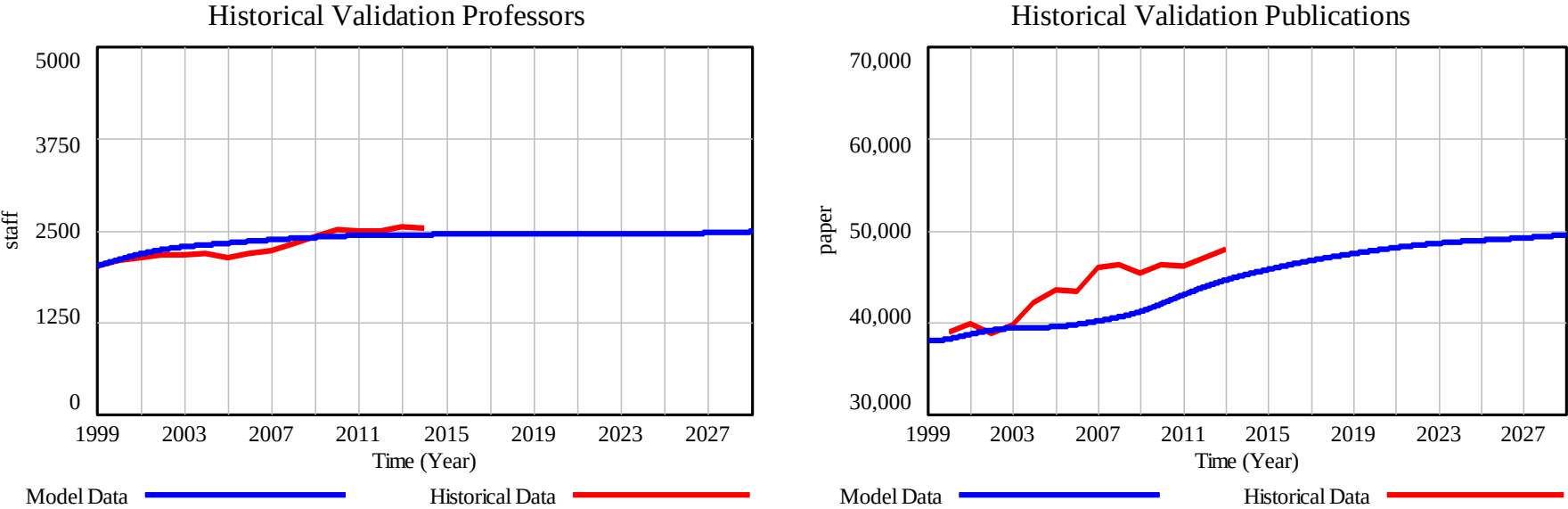


Figure 79: Graphical representation of the Professors phase and research publications

APPENDIX 10: UNCERTAINTY ANALYSIS

In this appendix the model uncertainties will be analysed. Input uncertainties will be tested with the use of Monte Carlo simulations within the SDM environment and structural uncertainties will be tested by comparing the nominal case with the alternative case. First the promotion fractions and residence times within the permanent faculty phase will be analysed. Then the structural uncertainties PHD promotion, TRS promotion and desired funding will be analysed.

PROMOTION OF FACULTY MEMBERS – RESIDENCE TIME

The individual residence time of different staff influences the promotion. The parameter data is now obtained from the WOPI database and shows a static average residence time. However these residence times can change over time based on external indicators. For instance, the perception on the position of assistants can change. Therefore, it is interesting to simulate the variations of residence time in the faculty stage. Because it is expected that most residence times are concentrated around the variable that was found in literature, a normal distribution is used with a multivariate component.

Residence Time [year]	Mean	Minimum	Maximum	Deviation	Justification
Assistants	7	2	9	2	Mean [obtained from WOPI], Minimum [USA System obtained from (Gomez Diaz, 2012)], Maximum [1/3 of total residence time if professorship is not obtained], Deviation [small due to high tendency to be promoted]
Associate	6	3	15	4	Mean [obtained from WOPI], Minimum [USA System obtained from (Gomez Diaz, 2012)], Maximum [2/3 of total residence time if professorship is not obtained], Deviation [medium as not all assistants will reach professorship]
Professor	11	5	15	6	Mean [obtained from WOPI], Minimum [USA System obtained from (Gomez Diaz, 2012)], Maximum [1/3 of total residence time if professorship is not obtained], Deviation [high due to high turnover, and variation in residence time tendencies]

Table 24: Uncertainty Analysis, Justification Individual Residence Time, partly based on empirical observations (Rathenau-Institute, 2015a)

The SD method already have standard information delays within its structure. However, these delays do not always compute the right behaviour for the outflows. Structurally, different delays can be included within the model, but do not give the range of uncertainty for the given parameter. Realistic uncertainty margins that have been found, and shown in Table 24, have been used to get a realistic uncertainty range for these variables.

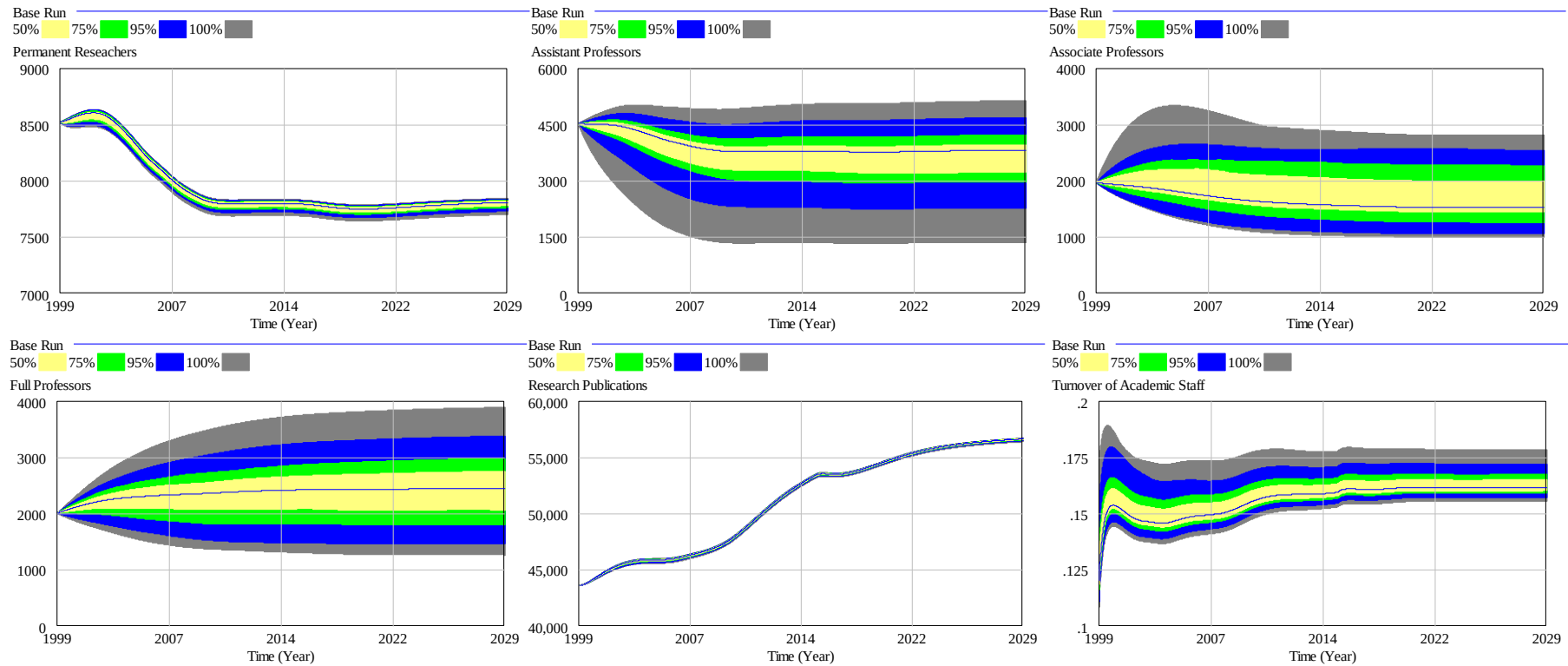


Figure 80: Uncertainty Analysis, Individual Residence Time

Figure 80: Uncertainty Analysis, Individual Residence Time Figure 80 show the results of the multivariate UA for average individual residence time. The individual staff sizes show a high uncertainty for the chosen ranges. These uncertainties were expected. More interesting is the small disturbance in behaviour for associate professors between 1999 and 2010 that could be rather large uncertainty margin in assistant professors. Additionally, the total amount of permanent staff only shows limited uncertainty suggesting that the distribution or turnover of staff changes but the amount of permanent staff remains the same.

The combined residence time of the faculty staff also influences the promotion. Due to limited information on average residence time a comparison with international counterparts is used. For this purpose two studies are compared. One, the US system with a total academic faculty time of 17.66 years (Larson & Gomez Diaz, 2012) and the total average total academic faculty time of 30.50 years (Goede et al., 2014).

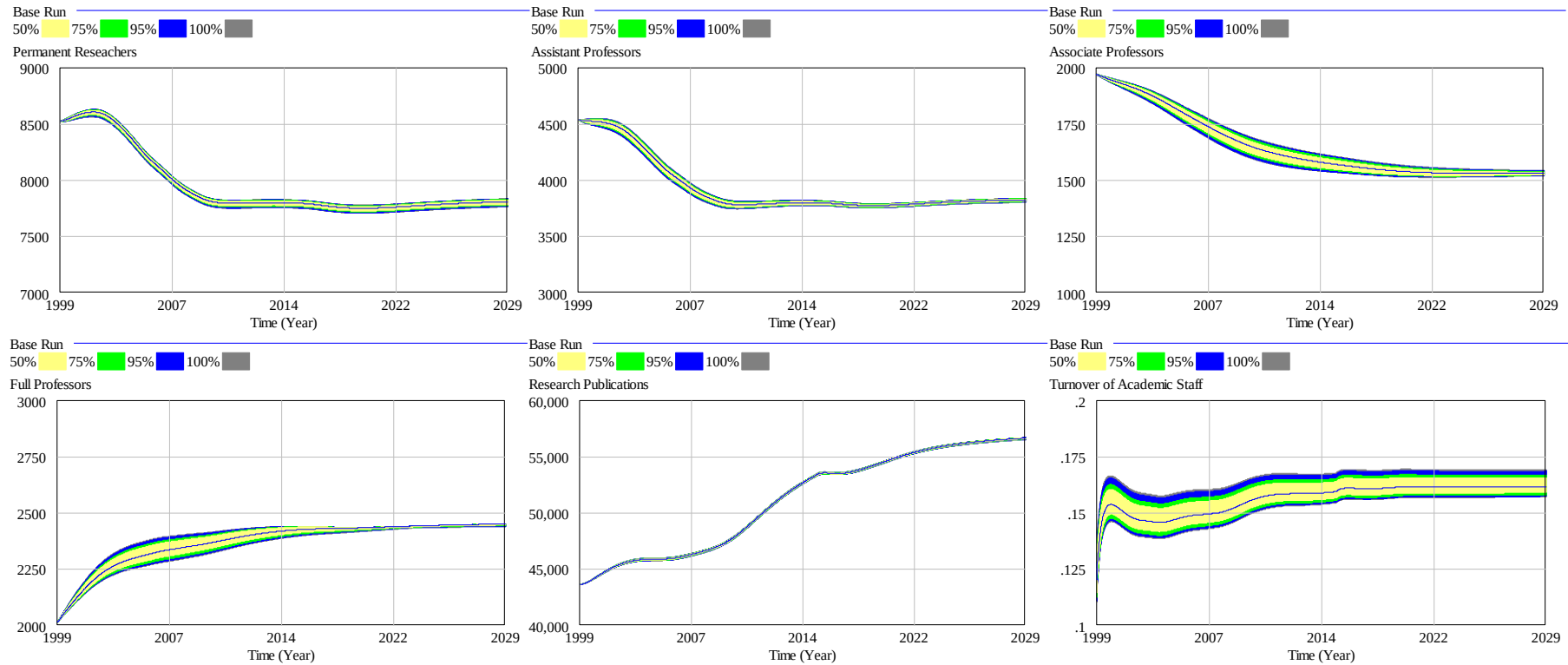


Figure 81: Uncertainty Analysis, Faculty Residence Time

Figure 81 show the results of the multivariate UA for average combined residence time. A univariate uniform distribution is adopted to see the uncertainties over the obtained uncertainty range. The uncertainties have a relative small impact on the individual stocks. It however has a significant impact on the turnover of the academic staff, suggesting that residence times changes the throughput but not the size of the stocks.

PROMOTION OF FACULTY MEMBERS – PROMOTION FRACTIONS

Promotion fractions are found within the WOPI database. The fractions are however static and therefore unchangeable over time. It is assumed that these fractions can change to an amount of 10 per cent of their nominal state based on a random uniform distribution. Additional research is needed to determine the ranges in which promotion takes place at PRO's. Table 25 shows the promotion fractions that are chosen to conduct the UA for the promotion fractions.

Promotion Fraction [dmnl]	Assistant Application Fraction	Assistant Promotion Fraction	Associate Application Fraction	Associate Promotion Fraction	Professor Application Fraction	Professor Retire Fraction
Mean Value	0.37	0.37	0.06	0.44	0.13	0.34
Minimum	0.30	0.30	0.05	0,35	0,10	0.26
Maximum	0.44	0.44	0.08	0.53	0.16	0/39

Table 25: Uncertainty Analysis, Promotion fractions

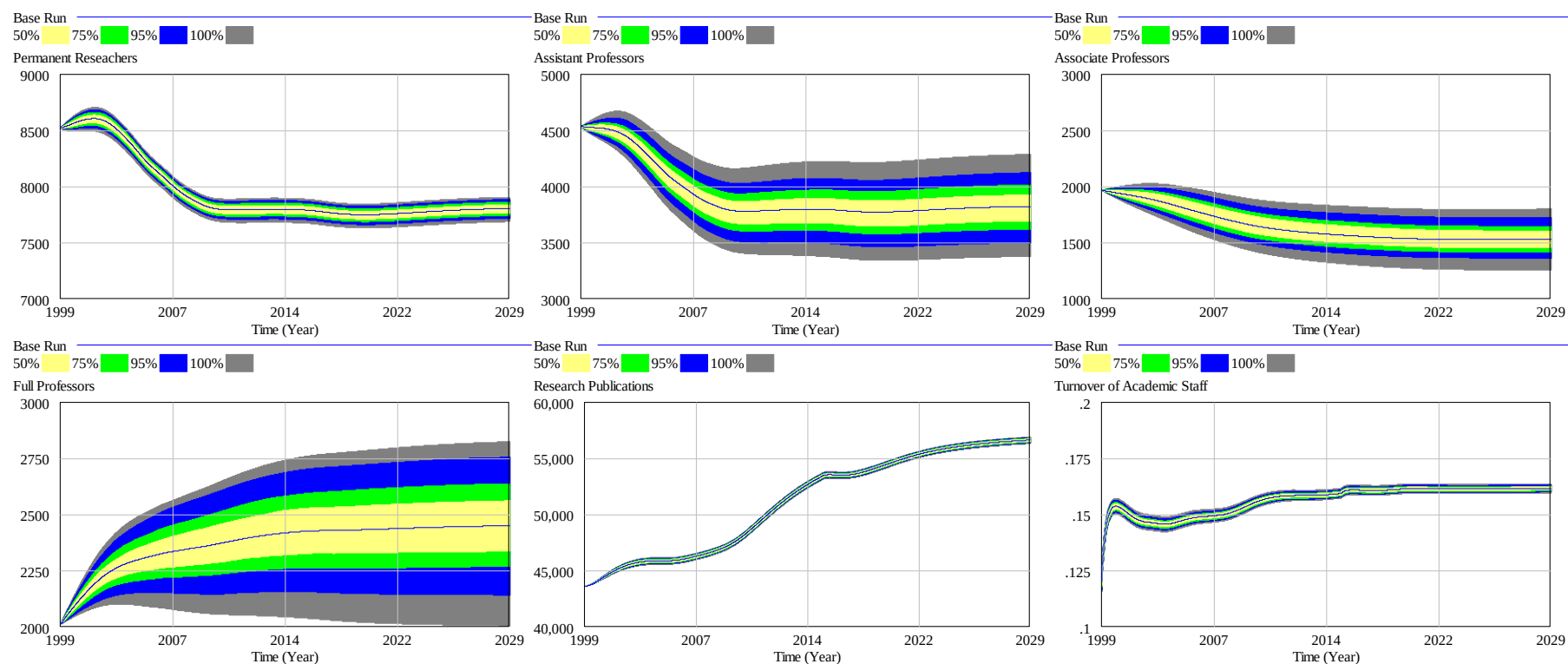


Figure 82: Uncertainty Analysis – Promotion Fractions

The promotion fractions all have an expected impact on the relevant variables, shown in Figure 82. The same conclusions for this analysis can be drawn: uncertainties in total amount or permanent researchers is marginal suggesting distribution changes.

PROMOTION OF FACULTY MEMBERS – COMBINATION

Here the combination of the input uncertainties within the faculty stage of the academic career is shown. Figure 83 shows the results who lead to the overall conclusion discussed in Section 8.4.

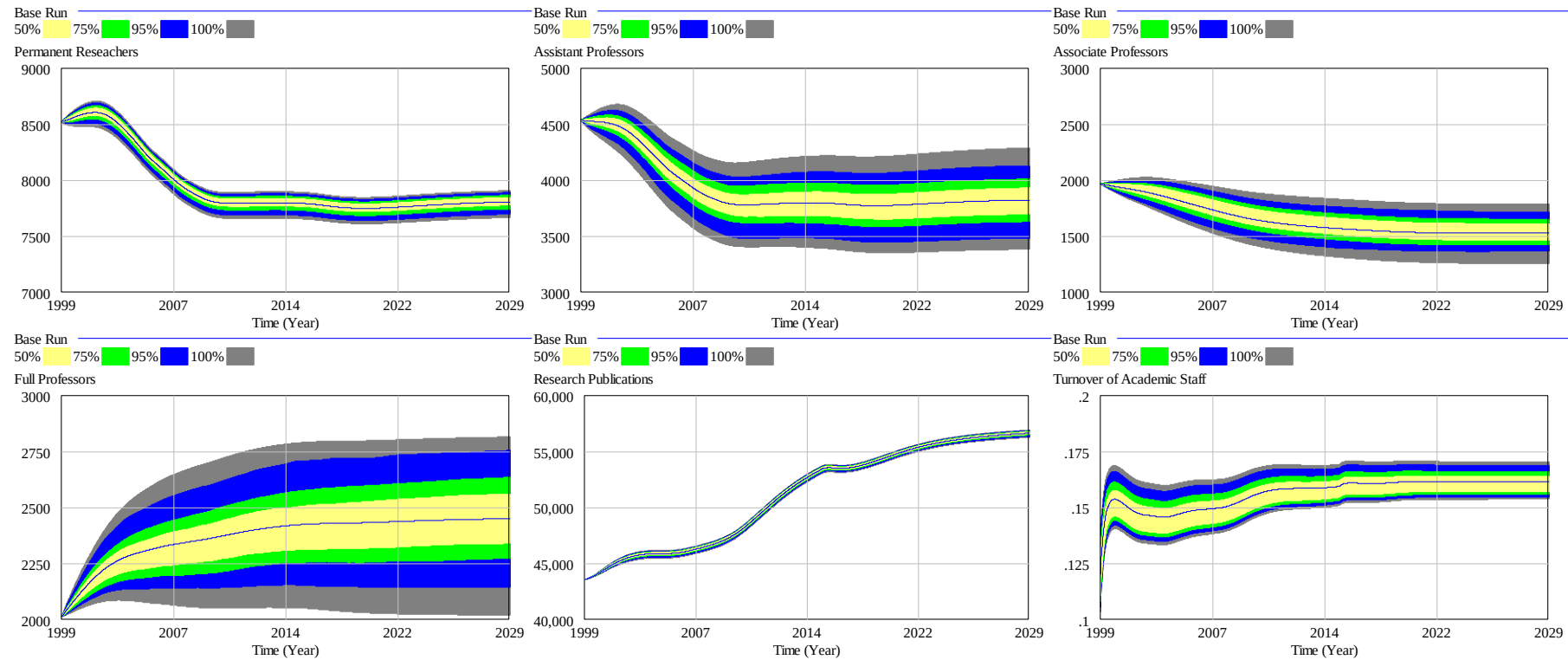


Figure 83: Uncertainty Analysis – Combined Input Uncertainties

STRUCTURAL UNCERTAINTY – PHD PROMOTION

Here the capacity mechanisms based PhD promotion is substituted with a reproduction rate. The results, shown in Figure 84, shows different behaviour for most important variables.

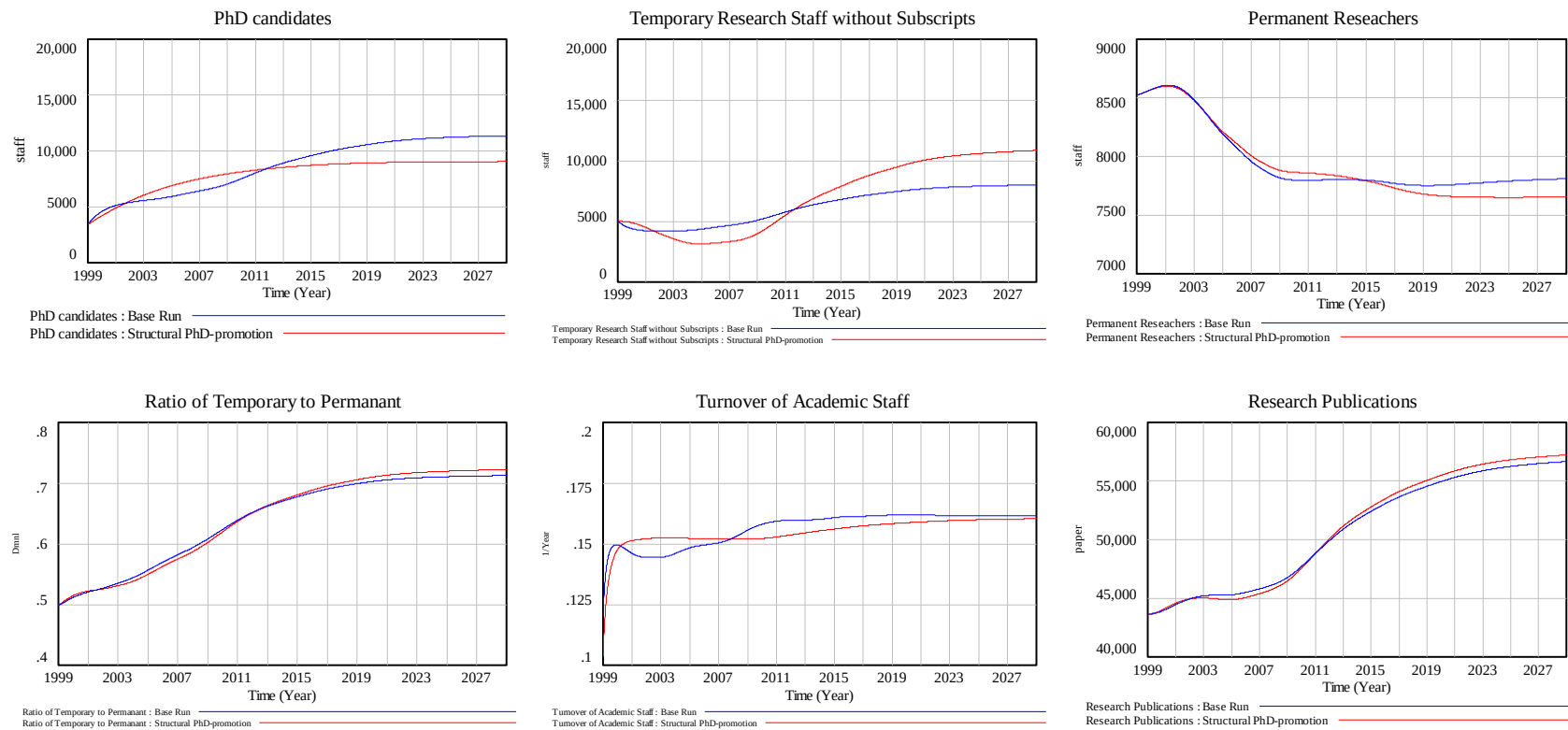


Figure 84: Uncertainty Analysis – PhD Promotion

STRUCTURAL UNCERTAINTY – TRS PROMOTION

Here the capacity mechanisms based TRS promotion is substituted with a choice factor. The results, shown in Figure 84Figure 85, show an increase in residence time for academic staff. Other variables only marginally change to this structural uncertainty.

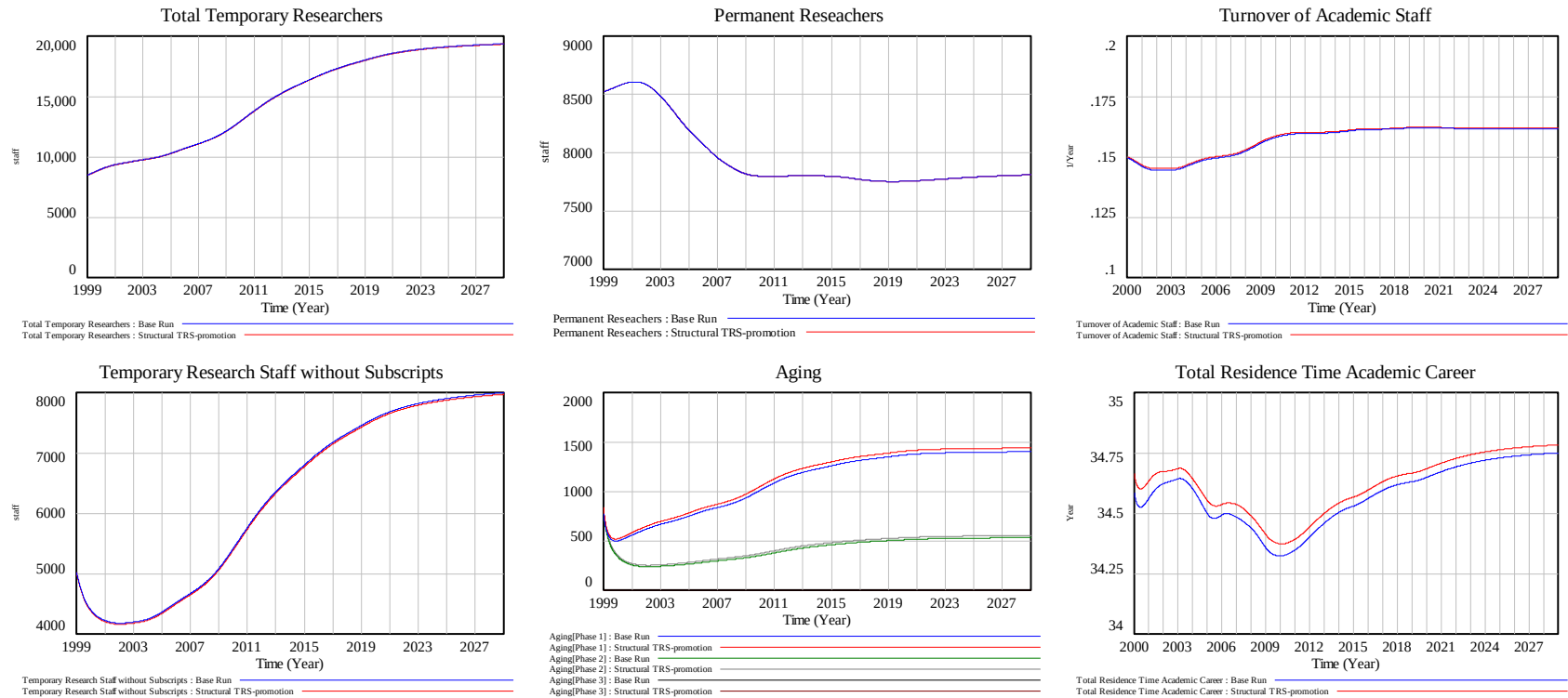


Figure 85: Uncertainty Analysis – TRS Promotion

STRUCTURAL UNCERTAINTY – DESIRE FOR FUNDING

Here the endogenous change in funding is substituted with an exogenous parameter which is based on growth estimations. Figure 86, shows small differences, suggesting that the incorporated model structure could describe the system.

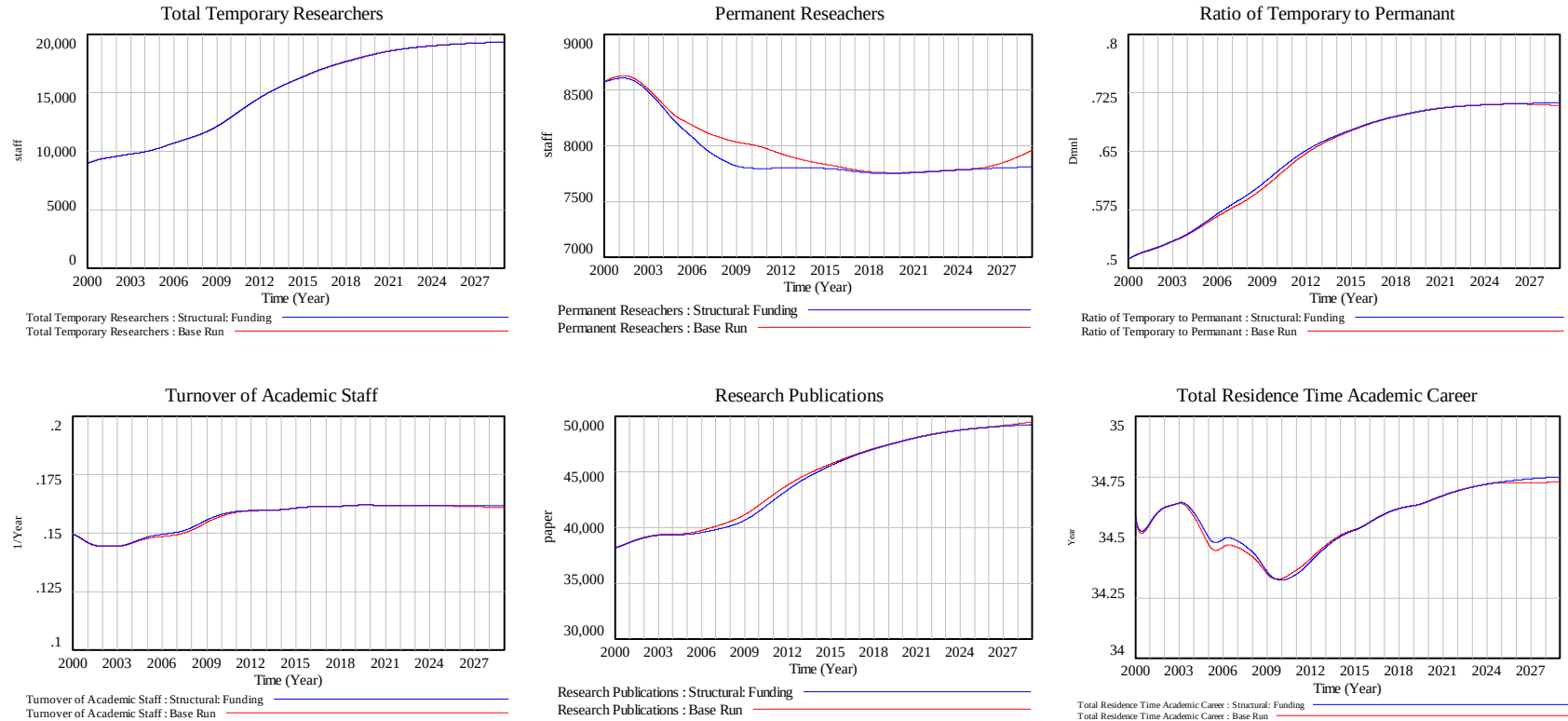


Figure 86: Uncertainty Analysis – Desire for Funding