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AC 2008-1063: THE S&T ECO-SYSTEM: PRESSURES FROM KINDERGARTEN TO GLOBALIZATION

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Michael Richey is a Boeing Associate Technical Fellow supporting Learning Training and Development group. Michael has 30 years experience in tool design and metrology, analyzing commercial aircraft (767, 777, 787, B2, F18-EF) and has developed many advanced CAD/CAM and Product Lifecycle management standards and engineering educational programs. Michael is the industry representative for the FAA AMTAS Center of Excellent at the University of Washington and is the Chair of their A&A Department's Aircraft Structures Composite and Manufacturing Certificate Programs. Michael received his B.S. in International Business from ESC Lilli, Graduate School of Management. He is currently working on a Masters of Science in Program & Project Management, focusing on Aerospace Engineering and Learning Science research. He often represents Boeing internationally and domestically as a presenter and has authored PLM integration patents primary relating to advanced aircraft construction, PLM-CAD-CAM metrology and Learning Science research.

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As an Operational Concept Analyst for the Complex Systems Analysis and Simulation group in Phantom Works, The Boeing Company's research and development organization, Paul uses System Dynamics to understand and improve the dynamic behavior of Boeing businesses. Since joining Boeing in December 2005 Paul has lead the application of System Dynamics to projects for both Boeing's Commercial Airplanes and Integrated Defense Systems businesses, as well as for their supporting organizations. Paul also teaches System Dynamics modeling to Boeing engineers for the Ed Wells Partnership between Boeing and SPEEA, the Society of Professional Engineering Employees in Aerospace. Prior to joining Boeing Paul applied System Dynamics to World Bank, United Nations Development Program, and U.S. Navy projects. He also designed and taught a full semester graduate course in System Dynamics at Cornell University. Paul received his System Dynamics education at the Massachusetts Institute of Technology, the University of Bergen in Norway, and Worcester Polytechnic Institute. Paul is also active in helping K-12 teachers learn to use System Dynamics through the Creative Learning Exchange (clexchange.org). His previous major employment, most recent first, has been self-employed consulting (11 years) in business process modeling; sales and marketing director with HiTech Control Systems, a control and information systems integrator (1 year); plant floor information systems and computer aided engineering with IBM sales and marketing (8 years); and construction project management and structural engineering with C.R.S. Sirrine, a large design-build firm (8 years). Paul has a Master's degree in Structural Engineering from N.C. State University and lives near Seattle, Washington.

Rick Stephens, The Boeing Company

Richard (Rick) Stephens is Senior Vice President, Human Resources and Administration for The Boeing Company. Stephens also is a member of the Boeing Executive Council. A 27-year Boeing veteran, Stephens oversees all leadership development, training, employee relations, compensation, benefits, Global Corporate Citizenship, and diversity initiatives at the Chicago-based, $61.5 billion, 158,000-person commercial airplane and defense company. Stephens was appointed to lead companywide Human Resources and Administration in September, 2005. He previously served as senior vice president of Internal Services and president, Shared Services Group. Prior to these assignments he was vice president and general manager, Integrated Defense Systems Homeland Security and Services and has led a number of service and support-related programs such as Space and Communication Services, Reusable Space Systems, Naval Systems and Tactical Systems, Space Shuttle and submarine combat systems. Stephens serves on a number of non-profit and business focused boards and has been recognized for his long-standing leadership to local and national organizations. He is an advocate for aligning and integrating community leaders' actions to develop a future workforce capable of the complex critical thinking and skills necessary for success in aerospace and other innovative industries. Stephens was appointed to the Secretary of Education's Commission on the Future of Higher Education and also serves on the Department of Homeland Security Advisory Council. In 2006, Stephens was appointed by President Bush to serve as a member of the President's Board of Advisors on Tribal Colleges and Universities. He is a Fellow of the American Institute of Aeronautics and Astronautics, a member of the National Science Resource Center Advisory Board, and is chairman of the Illinois Business Roundtable. Stephens also serves as the Boeing executive focal for the University of Southern California and is vice chair of Healthcare for the Orange County Business Council. Stephens received his Bachelor of Science degree in mathematics in 1974 from the University of Southern California and his Master of Science degree in computer science in 1984 from California State University, Fullerton. He has completed the bulk of units necessary to receive a Master of Business Administration from the Claremont Graduate School of Business. Stephens is an enrolled member of the Pala Band of Mission Indians and served as its chairman from 1988-89. He is a former U.S. Marine Corps officer.

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George Backus is a project manager in the Exploratory Simulation Department of Sandia National Laboratories. He has over 30 years of experience in industrial and national policy analysis and simulation. Both international and domestically, he has worked on energy, environmental, and macroeconomic policy, including National Healthcare, Climate Change, and Economic Development. He was president of Policy Assessment Corporation for over 20 years, previously the Research Director at Cambridge Econometrics, Ltd. (UK), and managed research at Dartmouth College, Purdue University, the Control Data Corporation, and General Atomics. He has provided testimony to Congress and received his doctorate in Policy Simulation and Business Economics from Dartmouth College.

Barry McPherson, Boeing - Learning, Training & Development

Kenneth McPherson has over thirty years of technical and managerial experience in advanced engineering processes and tools. His experience ranged through many facets of manufacturing engineering including NC Programming, Tooling, systems design and structures design. He was instrumental in leading the LTD (Learning, Training & Development) group to the PLM (Product Lifecycle Management) V5 suite of tools at The Boeing Company. This was a "game-changing" implementation which provided the engineering community on the 787 program a very comprehensive training curriculum. These learning solutions were tailored to their new processes in order to design and manufacture a new generation of commercial aircraft. Kenneth has also collaborated on several initiatives both inside and outside The Boeing Company to bring innovative PLM training solutions to the Boeing engineering community at large.

THE SCIENCE &TECHNOLOGY ECO-SYSTEM: PRESSURES FROM KINDERGARTEN TO GLOBALIZATION

Abstract:
The National Academies' 2007 report "Rising Above the Gathering Storm": Energizing and Employing America for a Brighter Economic Future," was a response to a bipartisan request by Congress. It proposes a coordinated set of policy actions consisting of four recommendations and twenty specific actions to "enhance the science and technology (S&T) enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st century." Early chapters of the report describe the authors' perceptions of the structure and behavior of the S&T eco-system that led to the report's recommended set of policy actions. The S&T eco-system structure in the report includes global forces that affect U.S. employment; U.S. K-12 education, higher education, corporate research, and federal funding for physical sciences and engineering research; U.S. reactions to 9/11 including visa policies, export controls, and sensitive but unclassified information; as well as underlying U.S. attitudes that influence the behavior of these structures. This report has become the nucleation point for the broad debate on the future of US prosperity and its international policy ramifications. Formal simulation of the logic within the report can test the validity and efficacy of proposed measures. This paper utilizes the report to illustrate a method for assessing 1) the reality of the hypothesized problem, 2) proposed solutions, and 3) the most promising areas of future discourse.

The conceptual model described herein attempts to simulate general tendency behaviors and is not intended to capture the complete science and technology ecosystem. Instead it is the authors' intent to describe the learning opportunity by first modeling the relevant "whole" system with a very broad brush, and then co-develop with other industry, academic, and government stakeholders, a causal structure which captures the relevant system in more detail. Such a multi-stakeholder co-development modeling process can evolve into an expanded strategic conversation to identify the social and cultural self-imposed constraints that contribute to the declining S&T enterprise. The focus of this discussion is on the report's stated system of engineering education and its role in workforce development and training. Engineering education is herein viewed as a complex system of parts that are hierarchical and interdependent. These include formal educational institutions (e.g. K-12, community college, and post-secondary institutions), as well as vehicles through which informal education is accomplished. As would be the case for any optimized solution space, each component has a role to play. A discussion of these various roles and possible future strategies follows. It is our belief that if collaborate and co-develop a common paradigm and collective observations, we can better coordinate policy action decisions, including the allocation of intellectual and critical resources toward a common national strategy.

Introduction

We read in the preface to the National Academy of Sciences, et. al.'s report, "Rising Above The Gathering Storm"[1] (hereafter referred to as the "Report."):

"*The prosperity the United States enjoys today is due in no small part to investments the nation has made in research and development at universities, corporations, and national laboratories* *over the last 50 years. Recently, however, corporate, government, and national scientific and technical leaders have expressed concern that pressures on the science and technology enterprise could seriously erode this past success and jeopardize future US prosperity. Reflecting this trend is the movement overseas not only of manufacturing jobs but also of jobs in administration, finance, engineering, and research.*

"*…we present … 4 recommendations and 20 specific actions to implement them. The committee members deeply believe in the fundamental linkage of all the recommendations and their integrity as a coordinated set of policy actions. To emphasize one or neglect another, the members decided, would substantially weaken what should be viewed as a coherent set of high-priority actions to create jobs and enhance the nation's energy supply in an era of globalization*"

Here we see a problem statement, and a "*coordinated set of policy actions*" proposed as a solution. The process the report committee used for arriving at these solutions is clear from the major section titles in Chapter 4 (entitled "*Method*") of the report:

4) Method

- *Review of Literature and Past Committee Recommendations*
- *Focus Groups*
- *Committee Discussion and Analysis*

This method, including the many supporting position papers that the Academies' committee solicited from many experts, is a highly qualitative process, and appropriately so, given the uncertainties in this large and complex social system.

However, as a Large Scale Systems Integrator (LSSI), Boeing believes that the method can benefit from further analysis to better understand the potential effects of such a set of policy actions. We propose using the feedback loop perspective of system dynamics[2] to better understand both the development over decades of the Gathering Storm problem and potential effects over time of the proposed policies. The feedback perspective is "the realization that tough dynamic problems arise in situations with lots of pressures and perceptions that interact to form loops of circular causality rather than simple one-way causal chains"[3].Indeed, the feedback perspective of System Dynamics has already been used to address policy issues related to the Gathering Storm.[4,5] As a LSSI, Boeing has used this approach, in concert with other approaches, to address broad social systems involving many stakeholders from multiple U.S. government and multi-national business organizations[6], as well as stakeholders from multiple internal Boeing organizations around the world.[7] Although taking a feedback perspective on the policies can improve them, we do not believe that the USA should wait to begin implementing the Report's proposed policies. Rather this analysis should be seen as part of the "continuing evaluation and refinement" activity recommended by the Report (page 111).

Boeing applies the feedback perspective of System Dynamics, with its origins in controls engineering, to better understand and improve the performance of the social systems involved in the execution of large projects. System Dynamics is both "a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems," and "a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations."[8] In this paper we show how the System Dynamics' five-step modeling process (Problem Articulation, Formulation of Dynamic Hypothesis, Formulation of a Simulation Model, Testing, and Policy Design and Evaluation)[1] could be used to test the policy actions proposed by the National Academies to address the Gathering Storm problem. The purpose of such testing is to avoid "policy resistance, the tendency for interventions to be delayed, diluted, or defeated by the response of the system to the intervention itself."[9]

This paper is a first step in advocating this process, bounding this "ecosystem," and providing a start on using a collaborative feedback perspective to evaluate the proposed policies. The work should be carried much further, in collaboration among industry, academia, and government. Boeing has a method that we call the Focused Strategic Conversation which could support such collaboration.[7] However; this paper will not address the Focused Strategic Conversation to any great extent, but will instead begin a feedback dynamics analysis of the USA's potential prosperity-security problem as it relates to the USA's science and technology enterprise (STE). This approach also acknowledges, indeed seeks out, valid contrarian views[10, 11] but most writers seem to agree that the problems are real and will threaten the economic position of the US. In this context, the Gathering Storm report serves as a common nucleation point. The authors' intent is to illustrate a collaborative feedback approach that will help us avoid "policy resistance" and will attract a broad spectrum of industry, academia, and government so that together, we can continue this work, either in a collaborative format using the Focused Strategic Conversation or other approaches. Furthermore, this approach supports the view that: until a model is quantified (and compared to data), it remains conjecture.

Our research objectives include:

1. The development of a multi-stakeholder model describing the S&T Education process which includes organizational, cultural, business and national policy constraints and their intended and unintended consequence.
2. Develop a holistic "Ecosystem " approach that can be leveraged to model the declining S&T workforces demographic trends
3. Model the domestic and international market forces and understand how these forces are reshaping the nature of S&T Education, collaboration and learning.
4. Develop cause-effect linkages detailing the interdependency between independent societies and model these new societies and economies.
5. Develop policy and measurable actions that will convergence and change in the way we educate our future global engineering workforce.

Feedback Dynamics

Problem Articulation: Problem articulation is the first step in the feedback dynamics approach.[1] A critical component of problem articulation is defining the problem in terms of its historical development over time, as well as feared and preferred futures over time.[12] Such historical and future developments over time can be seen in the first "*Gathering Storm*" quote above, and are roughly sketched in Figure 1. Note in the Figure the lags in the response of prosperity to science and technology enterprise, both historically (the leftmost lag in Figure 1) and in the future (the rightmost lag in Figure 1). The middle lag is the response of science and technology enterprise to policies presumed to be implemented at the present time (denoted as "Now" in the figure).

Formulation of Dynamic Hypothesis: The feedback dynamics approach then requires development of a sketch of a plausible and relevant feedback loop structure hypothesized to create the behavior-over-time shown in Figure 1. A sketch of one possible such "dynamic hypothesis,"[1] based on the Gathering Storm report, is shown in Figure 2. For the purposes here, this sketch is highly idealized, focusing on loops rather than details. More details are shown in the Appendix.

In Figure 2, first observe loop R1 (standing for Reinforcing Loop 1) in which the USA's Scientific and Engineering Enterprise and the USA's Prosperity (respectfully represented by "SE Enterprise" and "Prosperity,") are locked in a mutually reinforcing relationship. It is mutually reinforcing because more (less) SE Enterprise causes more (less) Prosperity causes more (less) SE Enterprise, etc., ad infinitum, creating exponential growth or decay in both. The "S" on each arrow signifies the polarity of the causal relationship represented by the arrow; the variable at the arrowhead moves in the same direction as the variable at the tail of the arrow. Note the delays; it takes time for an increase (decrease) in SE Enterprise to cause an increase (decrease) in Prosperity, and vice versa. In a dynamic thought experiment beginning, say in the 1940s or 1950s, imagine the exponential growth that has occurred since, hypothesized here to be a function of the action of this feedback loop.

The concern expressed in the Report is that "*pressures on the science and technology enterprise could seriously erode this past success and jeopardize future US prosperity.*" Four of the many pressures expressed in the report are shown in Table 1, along with a description of how they are represented in the feedback hypothesis sketch in Figure 2.

Thought experiments reveal a range of dynamic hypotheses for how the behaviors-over-time in Figure 1 could develop from these pressures. As described earlier, first imagine exponential growth in the USA's Prosperity and SE Enterprise as they influence one another in reinforcing

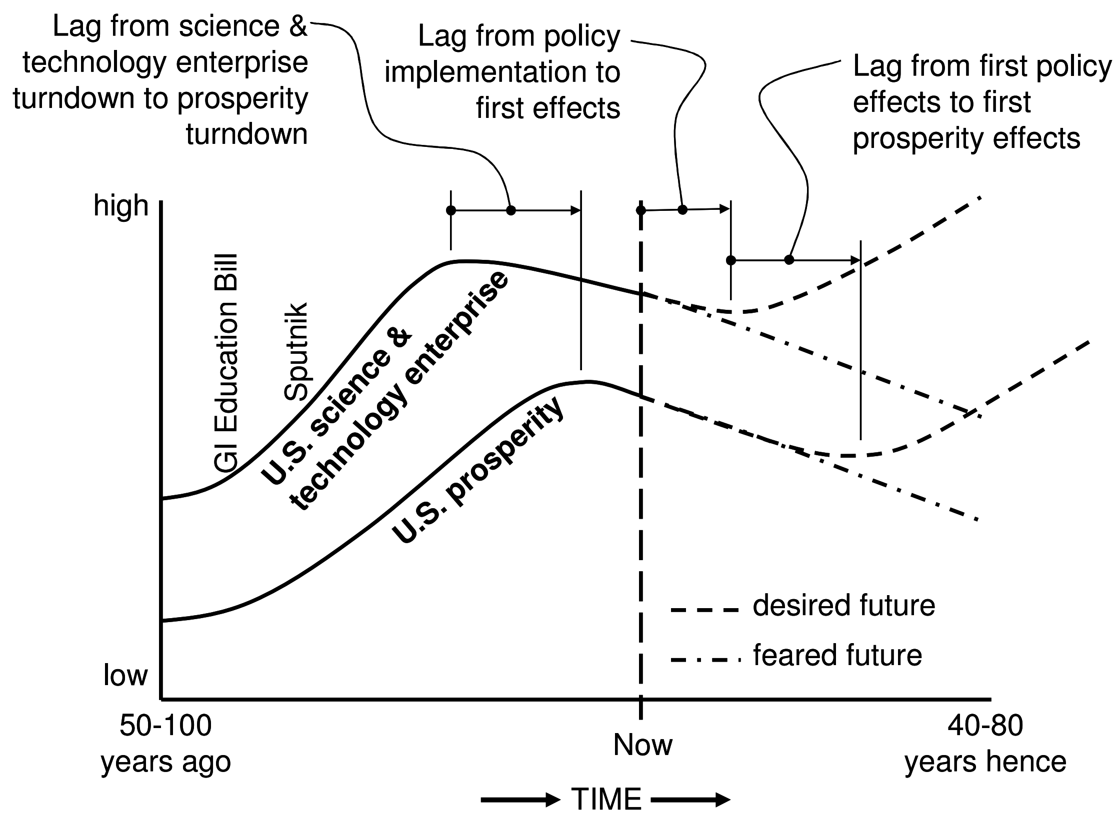


Figure 1: Development of the problem over time, derived from the first quote in this paper, showing the feared future, as well as a desired future in response to proposed policies. Note the lags.

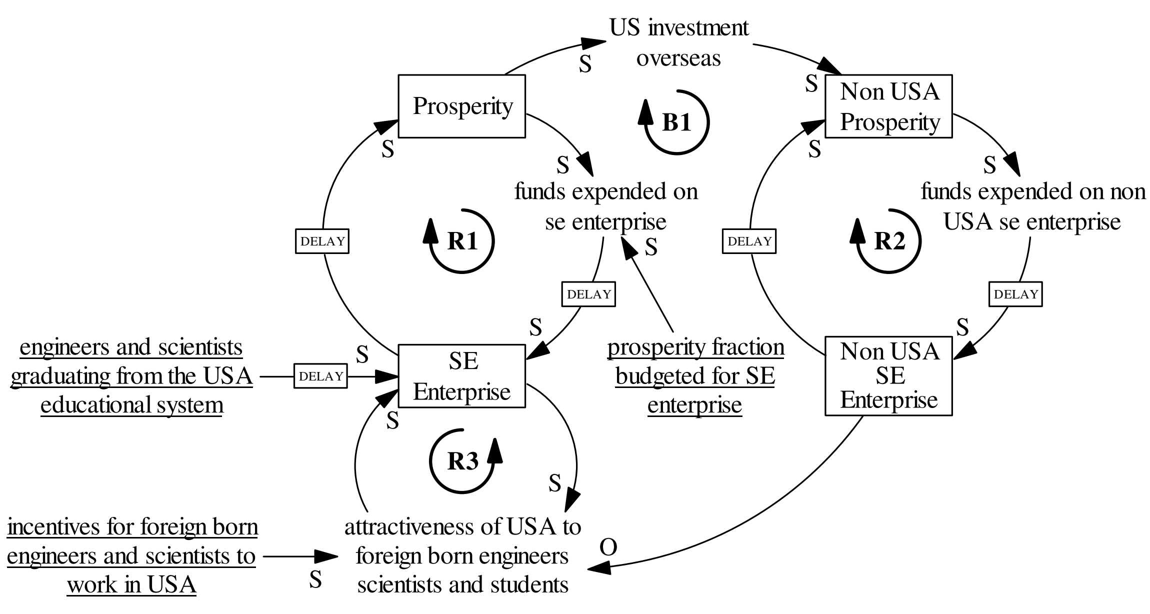


Figure 2 Feedback loop structure hypothesized to create the behaviors-over-time in Figure 1

feedback loop R1 shown in Figure 2. One extreme thought experiment surmises that a sufficiently large decrease over time in the *prosperity fraction budgeted for SE enterprise* could create the turndown shown in Figure 1. However, given the widespread evidence that the number of *engineers and scientists graduating from the USA educational system* has also significantly decreased over time, it is likely that both of these trends are responsible for the turndown in Figure 1.

Pressures Expressed in the Report	Representation in Figure 2
1) "*Educational Challenges:…K–12 student preparation in science and mathematics, limited undergraduate interest in science and engineering majors, significant student attrition among science and engineering undergraduate and graduate students, and science and engineering education that in some instances inadequately prepares students to work outside universities*," (p. 94)	*engineers and scientists graduating from the USA educational system*
2) "*Restraints on Public Funding*" (p. 89)	*prosperity fraction budgeted for SE enterprise*
3) "*Other Nations Are Following Our Lead – And Catching Up*" (p. 72)	Loop R2 as initially primed by *US investment overseas*
4) "*International Competition For Talent*" (p. 78)	The *attractiveness of USA to foreign born engineers, scientists and students* as influenced by both the relative sizes of *SE Enterprise* and *Non USA SE Enterprise*, and *incentives for foreign born engineers and scientists to work in USA*.

Table 1 Representations in the dynamic hypothesis in Figure 2, of some of the concerns expressed in the Report.

But the turndown due to these two pressures is probably not as bad as it could have been, because the USA has been able to take advantage of international science and engineering talent to fill the shortfall left by its shortage of domestically educated scientists and engineers. However, over time, as US investment overseas in low-cost manufacturing enabled the development of other countries' prosperity, these other countries became able and began to build their own Science and Engineering Enterprises (pressure 3 in Table 1). Eventually, competition for foreign-born science and engineering talent ensues (pressure 4 in Table 1), reducing the foreign-born talent available to fill the USA's talent shortfall.

Formulation and Testing of a Simulation Model: The next step in the feedback dynamics process[1] is to test the dynamic hypothesis by formulating and testing a computer simulation model to see if the dynamic hypothesis can reproduce the development of the problem over time as shown in Figure 1. However, if it does reproduce development of the problem behavior, this is not proof that the dynamic hypothesis is correct, but simply evidence that we can have more confidence in the hypothesis as a possible explanation. We have built and tested a simulation model of our dynamic hypothesis and its behavior is shown in Figure 3. A caution is that the simulation model is not yet calibrated to real data, so the y-axis values are suspect for now. What is important is that the dynamic hypothesis can reproduce the general tendencies of an initial exponential growth, a turndown, and the feared future shown in Figure 1. It also shows growth in Non USA SE Enterprise and Non USA Prosperity as described in our dynamic hypothesis. That the model reproduces these tendencies when simulated gives us more confidence in our dynamic hypothesis than we would have had in the absence of having tested the hypothesis in such a simulation.

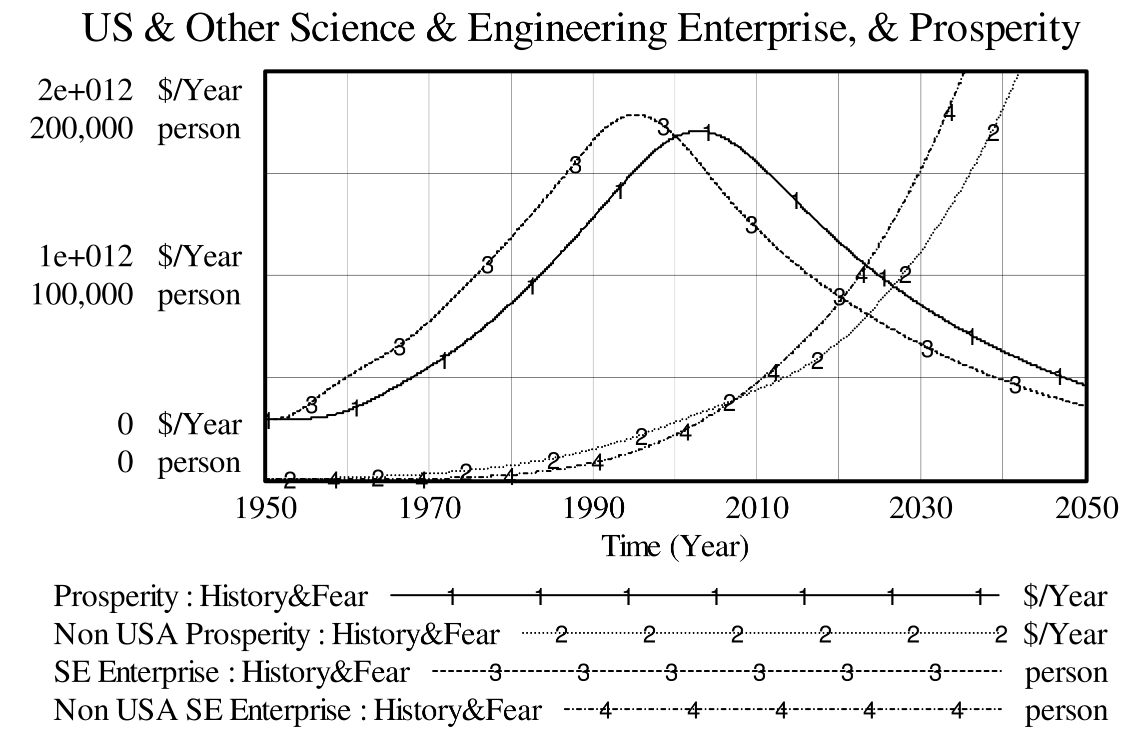


Figure 3 Replication, via simulation, of History and Feared future of Figure 1

Policy Evaluation: Figure 1 also shows a desired future, the result of implementation of policies to improve the situation, such as the policies proposed in the Report. We have tested three policies in the model in turn, and their test results are shown in Figure 4:

1) Increasing the *engineers and scientists graduating from the USA educational system* from 2010 to 2020 (called "EdctnPolicy" in Figure 4)
2) 1) plus an immigration policy to increase the *attractiveness of USA to foreign born engineers, scientists and students* from 2010 to 2020 (called "Edctn&ImmgrtnPolicy" in Figure 4). Note the almost ten year reduction in the upturn delay in Prosperity for this policy as compared to the first policy.
3) 1) & 2) plus a policy to permanently increase the *prosperity fraction budgeted for SE enterprise* (called "Edctn&Immgrtn&R&DInvstmntPolicy" in Figure 4)

Finally, Figure 5 shows that the simulation produces a complete replication of the historical and future trends from Figure 1, using the third policy above.

More Detailed Dynamic Hypothesis: Now that simulations have shown that it is possible for the dynamic hypothesis to reproduce the reference mode we now can confidently sketch a more complete dynamic hypothesis, such as that shown in Figure 6. Some variables in the sketch in Figure 6 can be thought of as being attributes of Prosperity (e.g. *income from jobs, industry profits,* etc.) and Science and Engineering Enterprise (e.g. *industry scientists*, *working engineers*, *academic and national lab scientists*, etc.). The sketch also contains industry, academia and education, and government elements. Note that Figure 6 begins the process of incorporating into feedback loops ("endogenizing") two of the underlined parameters in Figure 2, "*engineers and*

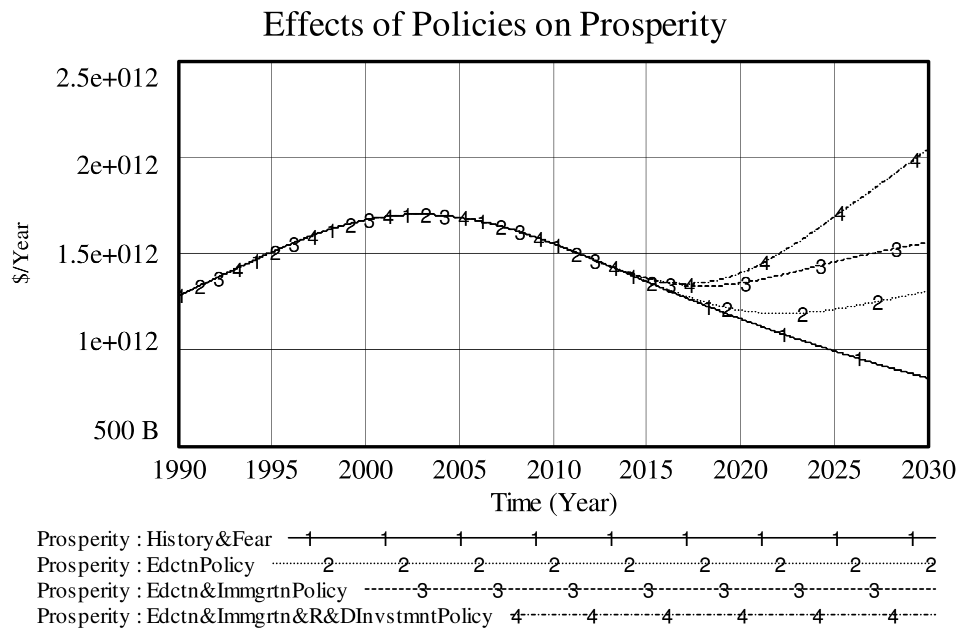


Figure 4 Effects of three policies on Prosperity

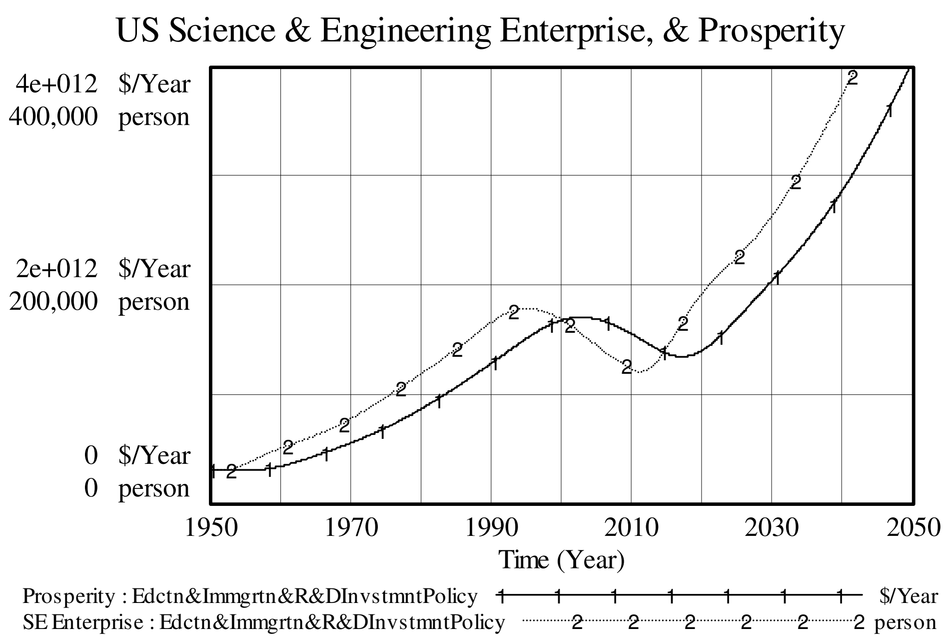


Figure 5: Replication, via simulation, of History and Desired future from Figure 1

Scientists graduating from the USA educational system" and "*prosperity fraction budgeted for SE enterprise*." Group thinking on whether and how to endogenize such parameters requires the group to ask what causes the parameters to change in the real world. This is an important part of expanding the boundary of a dynamic hypothesis that creates conversations that improve understanding and collaboration among stakeholder groups.

Caveats

Some people may read this paper as recommending that we boost S&E graduation rates, boost immigration of S&E graduates from other countries, and increase investment in S&E. The authors are not recommending these actions, but are simply using them as an illustration of how feedback simulation models can be used to test hypotheses and to help us think more explicitly and clearly about the implications of such policies. Before any recommendations can be made there are yet numerous other dynamic hypotheses, feedback loops and other structural details that should be tested and reconciled; parameterization, verification and calibration to available numerical data; and policies to consider. The model needs to test a greatly enlarged policy space, and touch points to the real world, such that it can be both tested to build confidence in its hypotheses, and will be seen as useful by specific relevant actors in academia, industry and government. The model should highlight the relevant political and societal considerations and feedbacks and policies that can weaken or strengthen them. We shouldn't expect "answers" from the model, but rather that our thinking about how to address the "Gathering Storm" problem should improve as a result of developing and exercising the model. In the end, the "answers," our policy choices, come from our thinking; the modeling process is simply a thinking aid requiring formalized confidence assessment and self-consistency.

Conclusion

The Gathering Storm problem is perceived as a developing "tragedy of the commons"[13, 14] problem, one that cannot be solved by any individual company, industry, or sector (whether public, private, academic or governmental) in the U.S. economy. Indeed, all tough (i.e. important) policy problems have multiple stakeholders who all have different value systems/perspectives. We argue that only when a simple, compelling simulation model includes the relevant parties to where they can "see" the impact of their decisions on the rest of the system, and then see the counterintuitive feedback consequence on them, does the door finally open for productive dialogue and true "system solution" exploitations.

As a Large Scale Systems Integrator, we at Boeing have developed such feedback models in a collaborative group process to cooperatively design strategic business policies, to improve internal organizations, and to create synergies of action among autonomous enterprises.[8, 9] We offer, to U.S. industry, academia and government, our expertise in facilitating a similar cross-sector collaboration to address the Gathering Storm problem. The process described within this paper uses an illustrative example based on the Gathering Storm report to propose an integrated stakeholder approach to modeling the S&T Educational "ecosystem." It is the author's intent to leverage a system dynamic process that can model the S&T system and develop multi stakeholder simulation which integrates the spectrum of stakeholder perspectives and constraints. This holistic approach will help us determine the forces that govern change and better understand the cause and effects of relational complexity between organizational culture, group performance and globalization pressures. A central tenet of our research is the belief that productive conceptual collisions across disciplinary and cultural boundaries will yield robust and tested theories on the efficiency of our educational system and national policies. In this paper we have shown how a simple feedback perspective can enable simulation and testing of policies proposed to address the Gathering Storm problem. Future work will expand this model to include contrarian viewpoint and build a shared representation of the S&T ecosystem.

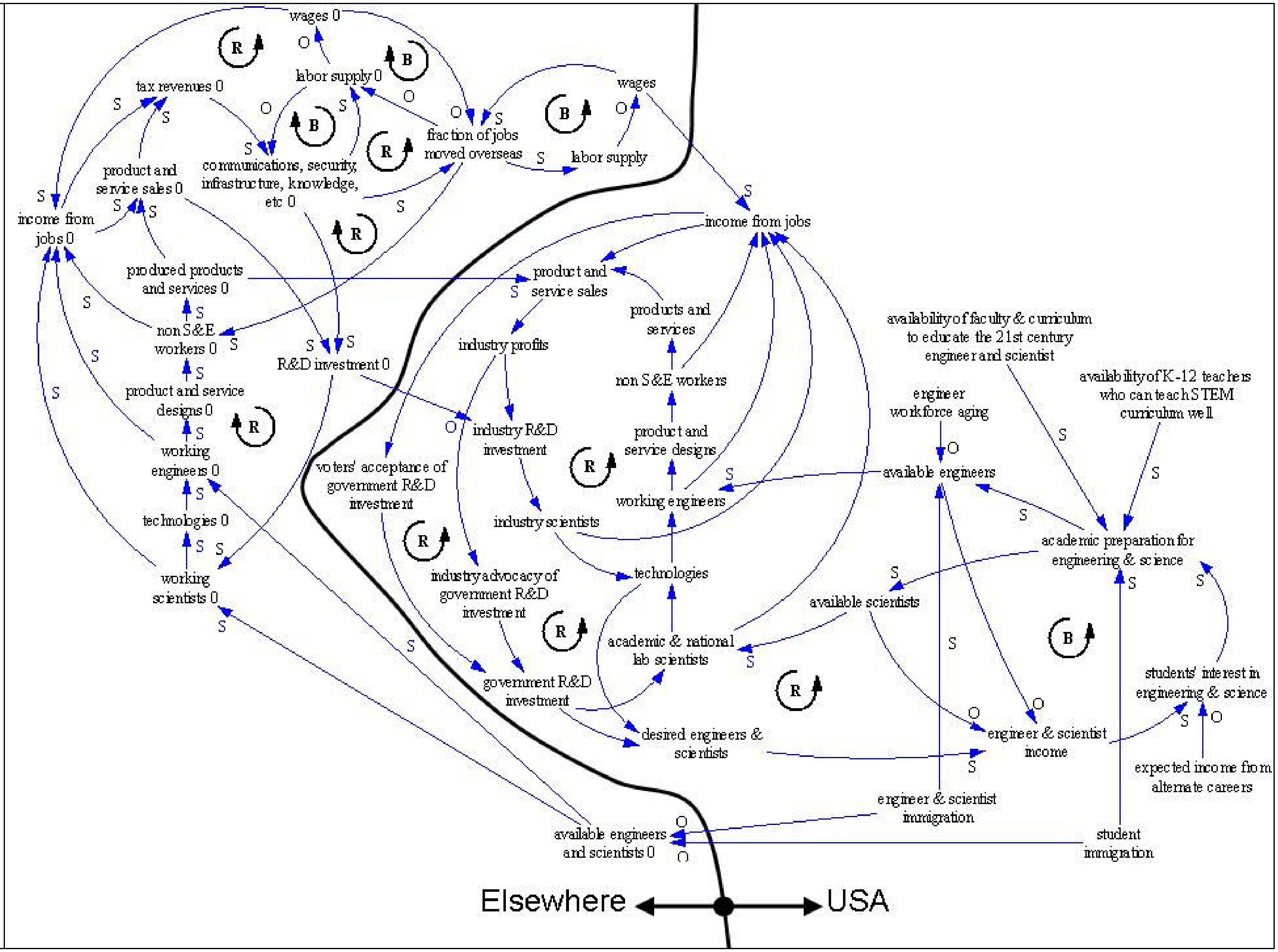


Figure 6 A more detailed dynamic hypothesis

Appendix: [GB: minor hang-up on my part, but make "from US prosperity growth" in to "US prosperity spillover" and edit in code listing below?

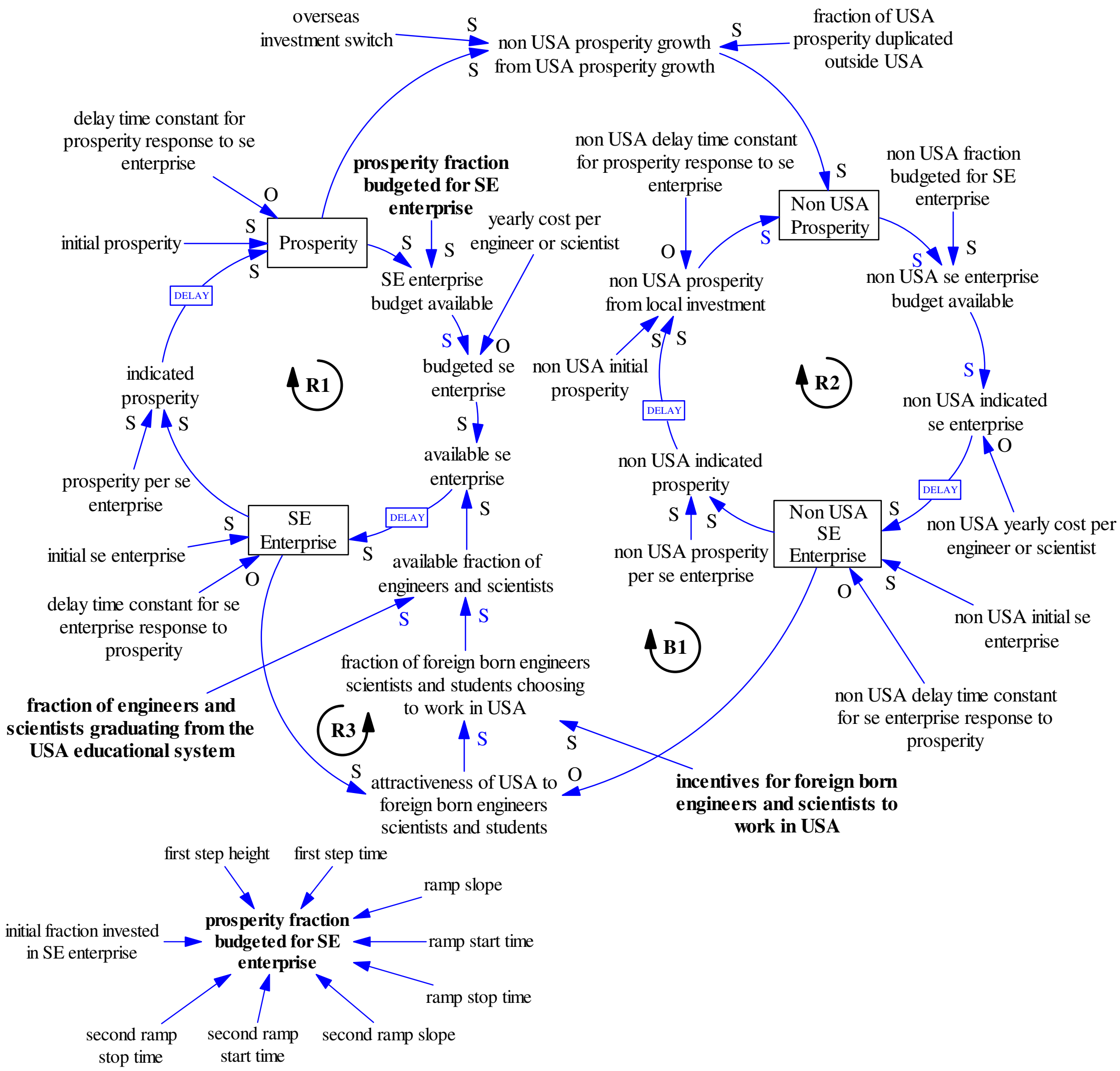
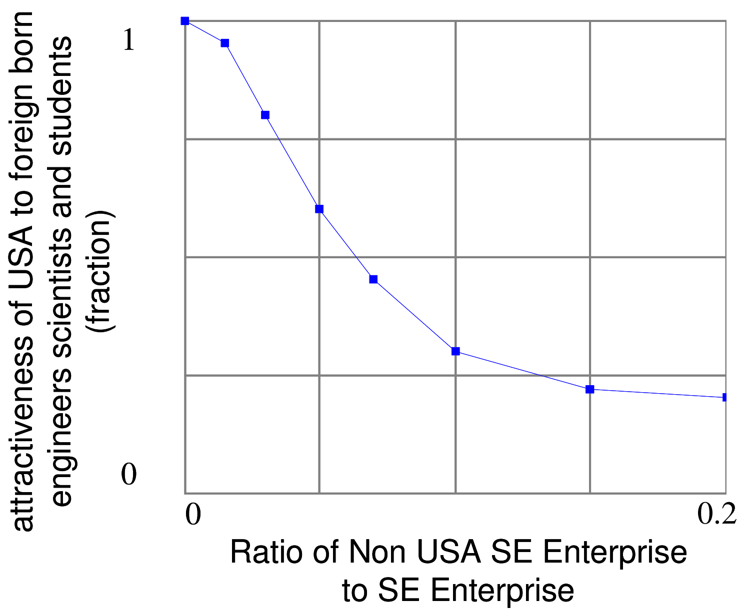


Figure 7 Full model sketch cartooned in Figure 2, and simulations of which produced the behaviors in Figures 3, 4, and 5.

Equations for model in Figure 7:

(01) attractiveness of USA to foreign born engineers scientists and students= WITH LOOKUP (Non USA SE Enterprise / SE Enterprise,([(0,0)- (0.2,1)], (0,1), (0.015,0.95), (0.03,0.8), (0.05,0.6), (0.07,0.45), (0.1,0.3), (0.15,0.22), (0.2,0.2))) Units: fraction

This is a nonlinear function that, when graphed, appears as follows:



(02) available fraction of engineers and scientists=MIN (1 , fraction of engineers and scientists graduating from the USA educational system + fraction of foreign born engineers scientists and students choosing to work in USA) Units: fraction

(03) available se enterprise=budgeted se enterprise * available fraction of engineers and scientists Units: person

(04) budgeted se enterprise=SE enterprise budget available / yearly cost per engineer or scientist Units: person

(05) delay time constant for prosperity response to se enterprise=8 Units: Year

(06) delay time constant for se enterprise response to prosperity=8 Units: Year

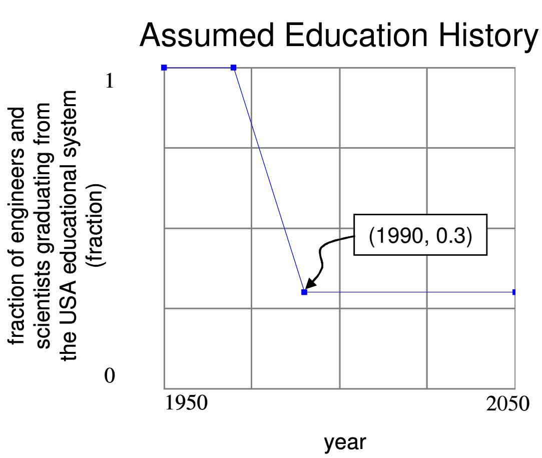
(07) FINAL TIME = 2050 Units: Year
The final time for the simulation.

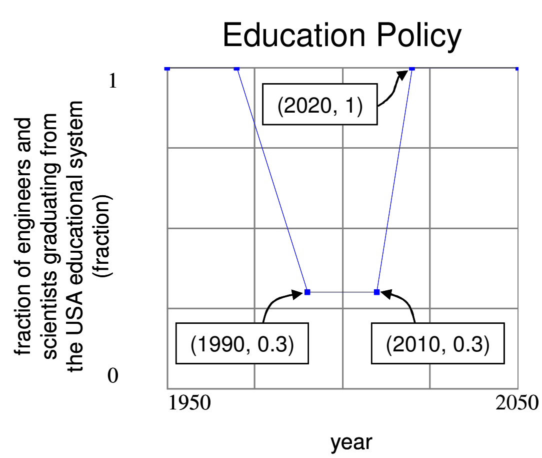
(08) first step height=0 Units: fraction

(09) first step time=1951 Units: Year

(10) fraction of engineers and scientists graduating from the USA educational system = WITH LOOKUP (Time / time in one year,([(1950,0)-(2050,1)], (1950,1), (1970,1), (1990,0.3), (2050,0.3))) Units: fraction

This is a nonlinear function that, when graphed, appears as follows:

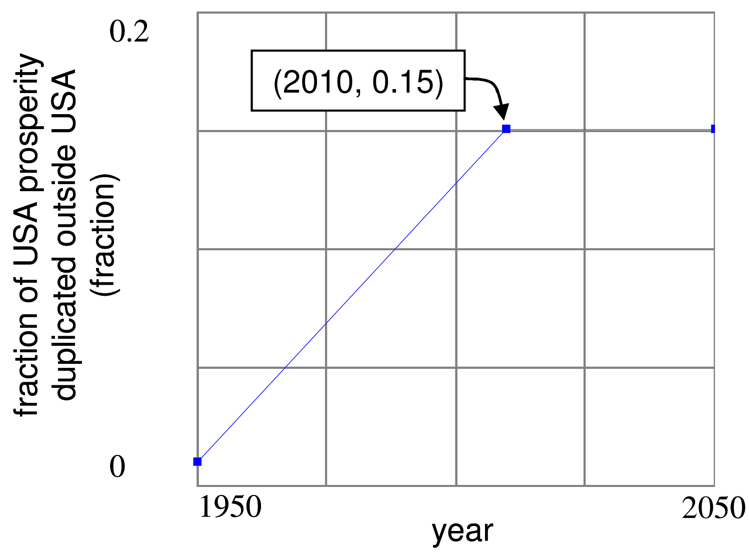




(11) fraction of foreign born engineers scientists and students choosing to work in USA=attractiveness of USA to foreign born engineers scientists and students * incentives for foreign born engineers and scientists to work in USA
Units: fraction

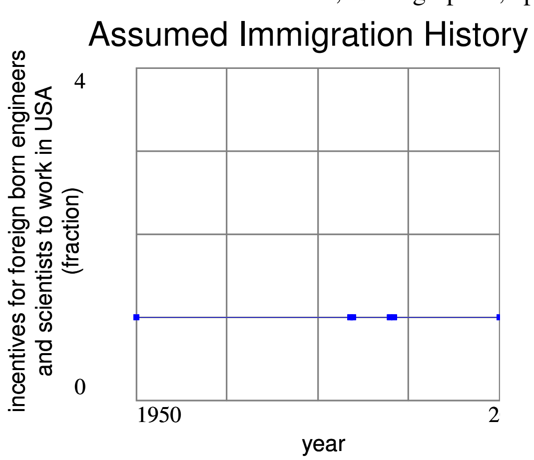
(12) fraction of USA prosperity duplicated outside USA= WITH LOOKUP (Time / time in one year,([(1950,0)-(2050,0.2)],(1950,0.01),(2010,0.15),(2050,0.15)))
Units: fraction

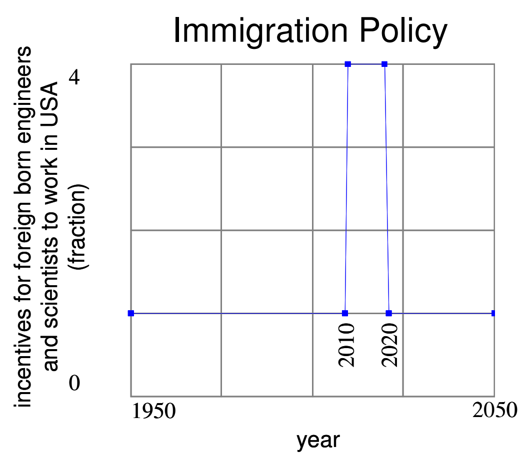
This is a nonlinear function that, when graphed, appears as follows:



(13) incentives for foreign born engineers and scientists to work in USA= WITH LOOKUP(Time / time in one year,([(1950,0)-(2050,10)], (1950,1), (2009,1), (2010,1), (2020,1), (2021,1), (2050,1)))
Units: fraction

This is a nonlinear function that, when graphed, appears as follows:





(14) indicated prosperity=SE Enterprise * prosperity per se enterprise — Units: $ / Year
(15) initial fraction invested in SE enterprise=0.01 — Units: fraction
(16) initial prosperity=3e+011 — Units: $/Year
(17) initial se enterprise= INITIAL(initial prosperity * initial fraction invested in SE enterprise / yearly cost per engineer or scientist) — Units: person
(18) INITIAL TIME = 1950 — Units: Year
The initial time for the simulation.
(19) non USA delay time constant for prosperity response to se enterprise=8

Units: Year

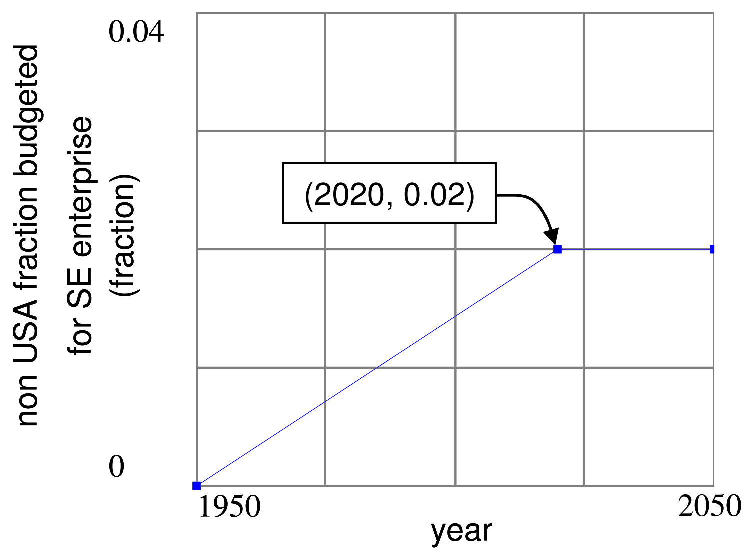
(20) non USA delay time constant for se enterprise response to prosperity=8

Units: Year

(21) non USA fraction budgeted for SE enterprise= WITH LOOKUP (Time/time in one year,([(1950,0)-(2050,0.04)],(1950,0),(2020,0.02),(2050,0.02)))

Units: fraction

This is a nonlinear function that, when graphed, appears as follows:



(22) non USA indicated prosperity=Non USA SE Enterprise * non USA prosperity per se enterprise

Units: $ / Year

(23) non USA indicated se enterprise=non USA se enterprise budget available / non USA yearly cost per engineer or scientist

Units: person

(24) non USA initial prosperity=0 Units: $/Year

(25) non USA initial se enterprise=0 Units: person

(26) Non USA Prosperity= non USA prosperity growth from USA prosperity growth + non USA prosperity from local investment

Units: $ / Year

(27) non USA prosperity from local investment=SMOOTH3I(non USA indicated prosperity , non USA delay time constant for prosperity response to se enterprise, non USA initial prosperity)

Units: $ / Year

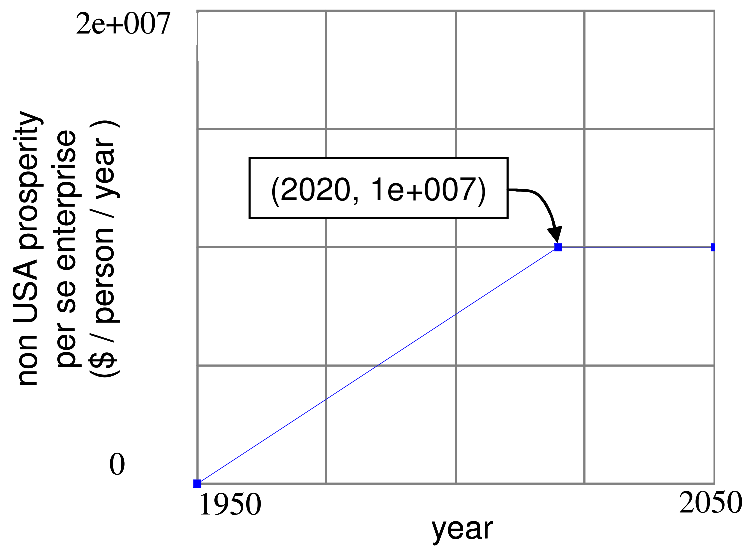
(28) non USA prosperity growth from USA prosperity growth=Prosperity * fraction of USA prosperity duplicated outside USA * overseas investment switch

Units: $ / Year

(29) non USA prosperity per se enterprise= WITH LOOKUP (Time / time in one year, ([(1950,0)-(2050,2e+007)],(1950,0),(2020,1e+007),(2050,1e+007)))

Units: $ / (person * Year)

This is a nonlinear function that, when graphed, appears as follows:



(30) Non USA SE Enterprise=SMOOTH3I (non USA indicated se enterprise , non USA delay time constant for se enterprise response to prosperity , non USA initial se enterprise)
Units: person

(31) non USA se enterprise budget available=Non USA Prosperity * non USA fraction budgeted for SE enterprise
Units: $/Year

(32) non USA yearly cost per engineer or scientist=100000
Units: $ / (Year * person)

(33) overseas investment switch=0
Units: dmnl

(34) Prosperity=SMOOTH3I(indicated prosperity , delay time constant for prosperity response to se enterprise, initial prosperity)
Units: $ / Year

(35) prosperity fraction budgeted for SE enterprise=initial fraction invested in SE enterprise + STEP (first step height , first step time) + RAMP (ramp slope , ramp start time , ramp stop time) + RAMP (second ramp slope , second ramp start time , second ramp stop time)
Units: fraction

(36) prosperity per se enterprise= INITIAL(yearly cost per engineer or scientist / prosperity fraction budgeted for SE enterprise)
Units: $ / (person * Year)

(37) ramp slope=0
Units: fraction / Year

(38) ramp start time=1970
Units: Year

(39) ramp stop time=2010
Units: Year

(40) SAVEPER = TIME STEP
Units: Year
The frequency with which output is stored.

(41) SE Enterprise=SMOOTH3I (available se enterprise , delay time constant for se enterprise response to prosperity, initial se enterprise)
Units: person

(42) SE enterprise budget available=Prosperity * prosperity fraction budgeted for SE enterprise
Units: $/Year

(43) second ramp slope=0
Units: fraction/Year

(44) second ramp start time=2010
Units: Year

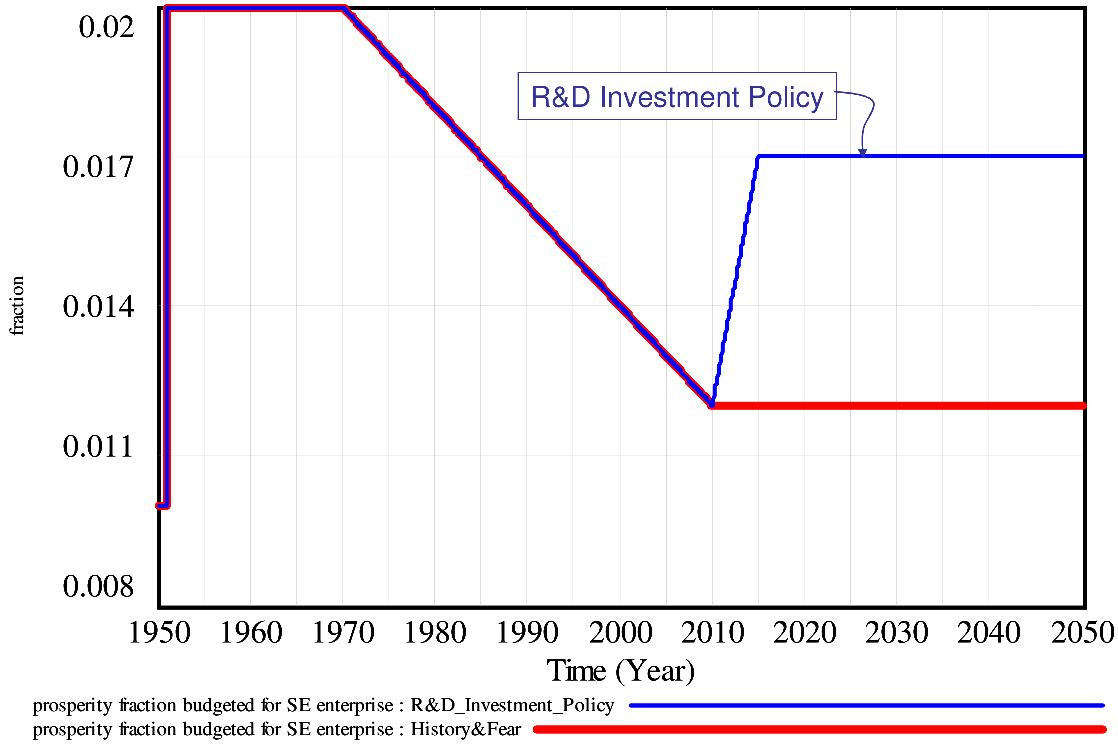
(45) second ramp stop time=2015
Units: Year

(46) time in one year=1
Units: Year

(47) TIME STEP = 0.0625
Units: Year
The time step for the simulation.

(48) yearly cost per engineer or scientist=100000
Units: $ / (Year * person)

R&D Investment Policy



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