

Four Grand Challenges for System Dynamics¹

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Abstract

In 2007 Jay Forrester challenged the field of system dynamics to address the big issues. This paper discusses four “big issues” as “Grand Challenges” in the DARPA sense, which meet the criteria of 1) impacting lives or livelihoods of millions or billions of people, 2) currently being governed by mental models that are seriously flawed, and 3) being addressable by system dynamics and seemingly few other disciplines. These are:

- 1. Insurgency, governance and political stability*
- 2. Acting on global warming*
- 3. Global financial stability*
- 4. Harmonious Chinese growth*

For each of these, the paper discusses the flaws in governing mental models, briefly indicates the scope of analysis needed, and gives a representative causal diagram showing some of the loops that are complicating and obscure correct and widespread understanding of each issue.

Key words: Grand challenge, Insurgency, governance, global warming, China, economic crisis

1. Introduction: Why Grand Challenges?

Jay Forrester, in his speech to the 2007 International System Dynamics conference, suggested that the field of System Dynamics has stagnated (reaching “a rather aimless plateau”).² It is reasonably verifiable that the system dynamics approach as articulated in 1961 in *Industrial Dynamics* has changed little over the last twenty years.³

¹ The views expressed herein are the author’s own, and do not necessarily reflect those of PA Consulting Group or its customers around the world.

I believe Jay Forrester and others are correct in believing that system dynamics will not penetrate society in any substantial way without penetrating K-12 education. I believe this because over the forty-plus years of history of Pugh-Roberts Associates and then PA's dynamic modeling practice, despite the huge increases in SD teaching in universities around the world that have happened during that time span, the group has stayed at about the same size and level of business.

For professional system dynamicists in universities and practicing consultants, the long-term choices seem stark:

1. Continue to "get by", without prospects for major growth, with professors doing research that is minor variations on traditional system dynamics practice, and consultants finding work through one-at-a-time individual contacts.
2. Wait many years for K-12 teaching to create awareness and receptivity
3. Change research and teaching practices

The third alternative seems best. In this paper I'll discuss topics for research and teaching that seem like "game changers" for the field. Another paper discusses the methodological changes that seem part and parcel of the shift in topic focus.⁴

"Grand challenges" is a process used by the Defense Advanced Research Projects Agency (DARPA) to bring important technologies out of (sometimes many) laboratories and into useful application. DARPA's most famous result is of course the Internet (which, to be accurate, was not created through a "grand challenge" process as such). DARPA publically defines its "grand challenge", establishes specific and tangible criteria for meeting the challenge, and offers a prize. The grand challenge process, for instance, gave birth to autonomous robot vehicles that, unaided, can safely and quickly navigate in urban traffic, a feat that had evaded researchers for decades (and some human drivers all their lives).

I looked for "grand challenges" candidates for the System Dynamics community that meet three criteria:

- Better or poorer handling of the issue impacts the quality of life and even life itself for millions or billions of people
- The mental models that seem to govern policy-making on the issue are seriously in error
- The body of system dynamics methodologies (possibly with methodological extensions) have the means to constructively analyze the problems and design solutions

The four Grand Challenges I would offer are these:

- Insurgency, governance and political stability (which includes corruption and political and economic reforms)

- Acting on global warming (starting from the view that demonstrating that the average temperature will keep rising was the easy part of the problem)
- Global financial stability (which subsumes the current worldwide economic meltdown)
- Harmonious Chinese growth (which history has placed at a point in time when numerous conflicts in many dimensions have become possible)⁵

Certainly these problems are being worked on. However, having watched government-sponsored seminars on current economic and national security issues, I've seen that the nature of the grand challenge problems became clear only when experts in diverse fields interact. And even after they interact, little about that dialog results in general movement closer to solution. Political leaders don't get clear messages from such conferences, any more than they do, for example, from the elite experts at the Davos conferences. Expert knowledge has to be integrated to be usable. This creates a unique responsibility for system dynamics practitioners.

Pretty much alone among academic or applied disciplines, system dynamics practitioners know how to find all the knowledge needed, capture it, arrive at validated conclusions and (at least in principle) express it in widely accessible terms. Look around—is there another profession that can make that claim? And if we don't find anybody else in the world able to tackle these problems with the comprehensiveness and believability required, what is our responsibility to the rest of the world?

2. What would it mean to meet a system dynamics grand challenge?

Let me suggest that, for the field of system dynamics, meeting a “grand challenge”, practitioners must not only publish research that shows the way out of an important morass, but also publish popularizations, talks, games, teaching materials etc. to engage both the lay public, their politicians and scholars, *in their own terms* to change the way the problem is understood and acted on. The tangible criterion for success is that the ideas spread by the field's practitioners visibly influence public perceptions and opinions, to the extent that populations and governments take actions consistent with those ideas, which avert at least the worst consequences of the problems being addressed.

In the System Dynamics community, there are perhaps one and conceivably two examples of successful grand challenges being met, where knowledge went from laboratory to routine application.⁶ The one clear example is of course *Limits to Growth*, which brought issues of growth and environmental cost into the public awareness at a time when “environmentalism” didn't exist, and only a pair of works (*Silent Spring* and *The Population Bomb*) had even brought the issues to public awareness. In a very real sense, *Limits to Growth* first linked serious scientific investigation to environmental issues. Many of the needed countermeasures discussed in the book of limiting economic expansion and reducing environmental impact are now institutionalized. And so, in the nature of dangers adequately foreseen, the ecological disasters analyzed in the book haven't (yet) come about. Moreover, protection of the environment is not

only enshrined in law, but embedded in school curricula, all the way from primary school to professional disciplines. “Green” has become political orthodoxy.

To provide a clear example of failure, consider *Urban Dynamics (UD)*. I feel no qualms about throwing stones in this particular glass house, as I spent as much time working on urban dynamics as anyone, and coauthored one of the four books on the topic⁷ On the face of it, *UD* was much more actionable than *Limits to Growth*. *UD* depended only on knowledge about how commonplace urban events took place. At the time, it was addressing an acknowledged crisis. There were billions of dollars being thrown at the issue. The action implications were within the power of city and national governments to influence if not simply execute. But those actions, with one or two exceptions of cities where the MIT UD team were personally involved, did not happen at all.

So what did *UD* not do? First and foremost, it provided no sound bytes, elevator stories, or story lines—nothing short and sweet that would start to change the way even those who hadn’t read the books would start to understand the issues. (Consider four book titles and ask which one says what the message of the book is: *Urban Dynamics*, *World Dynamics*, *Limits to Growth*, and *Dynamics of Growth in a Finite World*. That’s right: *Limits to Growth*. And to back up the scientific books and textbooks, *UD* had no presentation of facts and figures to support the logic. Only lengthy strings of common sense, embedded in very dense (and truly well-crafted, but dense) prose. (Albert Einstein took a similar approach in most of his *annus mirabilis* papers of 1905, and there, too, it was decades before relativity became more than something that physicists were having difficulty disproving⁸)

Second, *Urban Dynamics* also did not give enough accessibility to even interested and sympathetic researchers to create a community of research and knowledge. Two examples: The proposition that the population of a fixed urbanizing area grows, peaks and eventually declines is easily testable (and was found to be true whenever it was tested), and doubtless the exceptions to that behavior would have created a stream of (admittedly, scholarly) activity devoted to studying the urban life cycle. Similarly, the proposition that the drivers of in-migration shift over the life cycle of an area is also quite testable, and indeed may well have been documented already. But testable hypotheses weren’t spelled out, and none of the books or articles really laid out the propositions as testable hypotheses (let alone characterizing the important versus unimportant facets of model behavior). So the initial work, with a few exceptions, has seen little follow-on research, even though there were many avenues of research to be had for the asking, each of which would have had a straight-line connection to the important political issues of the day.

The grand challenges of system dynamics, unlike the case for DARPA’s physical grand challenges, will likely not be achieved by a small team of researchers. Even though there will always be identifiable pioneering research, the entire corpus of materials and human interactions that meet a grand challenge will need to form a community of interest.⁹ The scope required for model-building, scholarship, field investigation, teaching, publicizing, and crafting mass-market games and K-12 curricula is simply too great for a reasonably-sized team to achieve within a reasonable time frame.¹⁰

It would be well beyond the scope of any paper to do justice to even defining the respective problems properly. These grand challenge touch upon many relevant fields of academic inquiry,

and as one person I cannot begin to do adequate scholarly justice to these fields. So with apologies to the experts in fields, I will instead

- Characterize the apparent mental models that currently govern behaviors (with their obvious flaws)
- Simply list some of what appear to be key elements in addressing the problem, as a simple way of indicating the scope of the issues
- Give a causal diagram, illustrative rather than definitive, for a few of the feedback loops involved in each challenge issue, sufficient to demonstrate that important facets of the problem are governed by feedback loops, and hence should be most amenable to analysis by system dynamics (and little else)

3. Grand Challenge: Insurgency, governance and political stability

Full-blown insurgencies, and their out-of-control descendants, revolution and civil war, are every day killing people, burning billions of dollars of expenditure, and where insurgency is suppressed by totalitarian government, degrading the quality of life of millions of people. Even disregarding insurgency, poor governance has crippled economic development for at least two centuries over an entire continent, Africa. This is an important topic.

Ideological terrorism, such as practiced by Al-Qaeda, is somewhat a separate phenomenon. It overlaps issues of insurgency when an ideology is picked up by an oppressed group, for example when the communist ideology promised to give the oppressed ethnically-Chinese Malays a blueprint for a fairer social order during the 1950s.

How have insurgencies been dealt with?

3.1 *A mental model of law and order, crime and punishment, seems to dominate policy on insurgency and government.*

It is quite consistent with everyday experience of citizens in developed countries to think of insurgency as violation of the law, and hence correctable by force. If civil authorities aren't up to the task, then military should be used to put down the insurgency.

In nearly any religious or moral system, the destructive and terrorist tactics typically used by insurgents are wrong. And societal norms say that wrongdoing should be punished. Natural and justifiable as this “crime and punishment” mental model is, it is not only not helpful, but can be a hindrance to effective counterinsurgency and good government.

The foremost deficiency of the “crime and punishment” mental model is¹¹ that most insurgencies begin with “groups with gripes”—ethnic or religious minorities that are in fact discriminated

against by either the majority, or the governing elite. Discrimination takes many forms, from unequal treatment by law enforcement (especially regarding property), unequal treatment in hiring, or disbursement of public services (especially health and education), or suppression of religious practices. Discrimination may be the path of least resistance if the minorities are out in the boondocks, and the majority of voters are nearby. And it is all too often the easiest means of maintaining political power to either demonize some minority, or to reward supporters with economic goods obtained corruptly (or forcibly) from a minority.

In the extreme case, “groups with gripes” expands into civil war, with each group hostile toward, and attacking other groups. Danger and defense (and the best defense is offense) comprise self-fulfilling prophecies. This dynamic is why civil wars so often start with three or more antagonists.

A second deficiency of the crime-and-punishment model is that, unlike the way law enforcement usually works in developed countries, counterinsurgency operations are intrusive and even if there are conscientious efforts to control collateral damage, counterinsurgency efforts sometimes harm innocent civilians. At the same time, the willingness and courage to turn in insurgents is in far shorter supply in developing-country insurgencies than in developed countries. So the balance between efforts to stamp out insurgents and efforts to “win hearts and minds” is enormously different in counterinsurgency operations.

A third deficiency of the crime and punishment model of insurgency, related to the second, is that this mental model doesn't bother with the question of where insurgents come from, and whether counterinsurgency actions are in fact alienating a sufficient portion of the population that more insurgents are created than are incapacitated.

A final deficiency, which will be elaborated shortly, is the associated mental model in developed countries that corruption, like the insurgencies it sometimes spawns or at least makes more likely, should likewise be addressed in a law and order fashion: To eliminate corruption, the governments should simply enforce anti-corruption laws. But of course the government is itself corrupt, almost always including law enforcement and the judiciary. Corruption is a pernicious component of many situations where insurgency is not being dealt with successfully. Corruption, specifically political control of media, allows populist politicians to blame the insurgents and downplay the government's shortcomings.

In the developing world, the government of record can be far more corrupt than other authorities, which may well have more legitimacy in the eyes of the populace. Religious organizations, tribes and clans, or even warlords can be far less corrupt and more trustworthy than the government. Hamas ousted Fatah in the 2006 elections less because of its extreme anti-Israeli position, and more because of the corruption and ineffectiveness of the incumbent Fatah organization. In the words of one aid worker who worked in Northern Afghanistan 2005-2007, “most Afghans regard government as a protection racket.”

The crime and punishment mental model applied to corruption neglects the inconvenient fact that law enforcement itself is almost always heavily complicit in corruption. The obvious “law and order” cure for corruption (obvious to the casual observer from the developed world, that is) cannot possibly work. More of this shortly.

3.2 *Effective counterinsurgency spans political, economic and military issues*

Figure 1 identifies many variables and issues that are arguably associated with the origins of and cure for poor government and insurgency.

Grievances	Discrimination	Rule of law	Property rights
Corruption	Nepotism	Racism / Tribalism	Ideologies
Economic investment	Natural resources	Intelligence sources	Fear of reprisal
Professionalism of police, military, courts		Backlash from police & military action	
Freedom of press and political debate		Illicit activities to raise funds	
Government Legitimacy & support		Insurgency legitimacy & support	
Geopolitical importance		3rd & 4th party interventions	
Alignment of political groups			

Figure 1. Elements involved in insurgency and good government.

3.3 *Representative feedback loops around corruption illustrate the dynamic nature of the larger issues of insurgency and good government.*

Rather than attempting to connect all these elements in a complex and impenetrable causal diagram, let me show representative feedback loops within the relevant system that illustrate briefly why system dynamics is needed for proper analysis and explanation of the issues around good government, corruption and insurgency. Let us begin with the “law and order” views of corruption, and shortly insurgency.

One thing needs to be said at the outset: The economic life of developing nations began relatively recently the transition from family, tribal or clan non-market distribution of goods and services to a market economy. So many acts that are “corrupt” in the rich world are seen as normal and proper actions that are simply looking out for one’s family, clan or tribe, and these values are clearly more important than obedience to the laws of a government whose legitimacy and authority are still questionable. Consequently, the law and order view of corruption may have a much weaker foundation upon morality and ethics in the developing world than in the developed world.

The top negative loops of Figure 2 shows how law enforcement (and media exposure) is supposed to work against corruption. If there is political or judiciary corruption, the media and law enforcement expose it and the judiciary punishes it, which acts to reduce corruption (loop a).

Analogously, a negative loop (b) at the bottom has law enforcement against insurgency controlling insurgency.

But the ability of the top loops to control corruption is reduced when Judiciary and Law Enforcement Corruption reduces the Ability to Expose and Punish Corruption.¹²

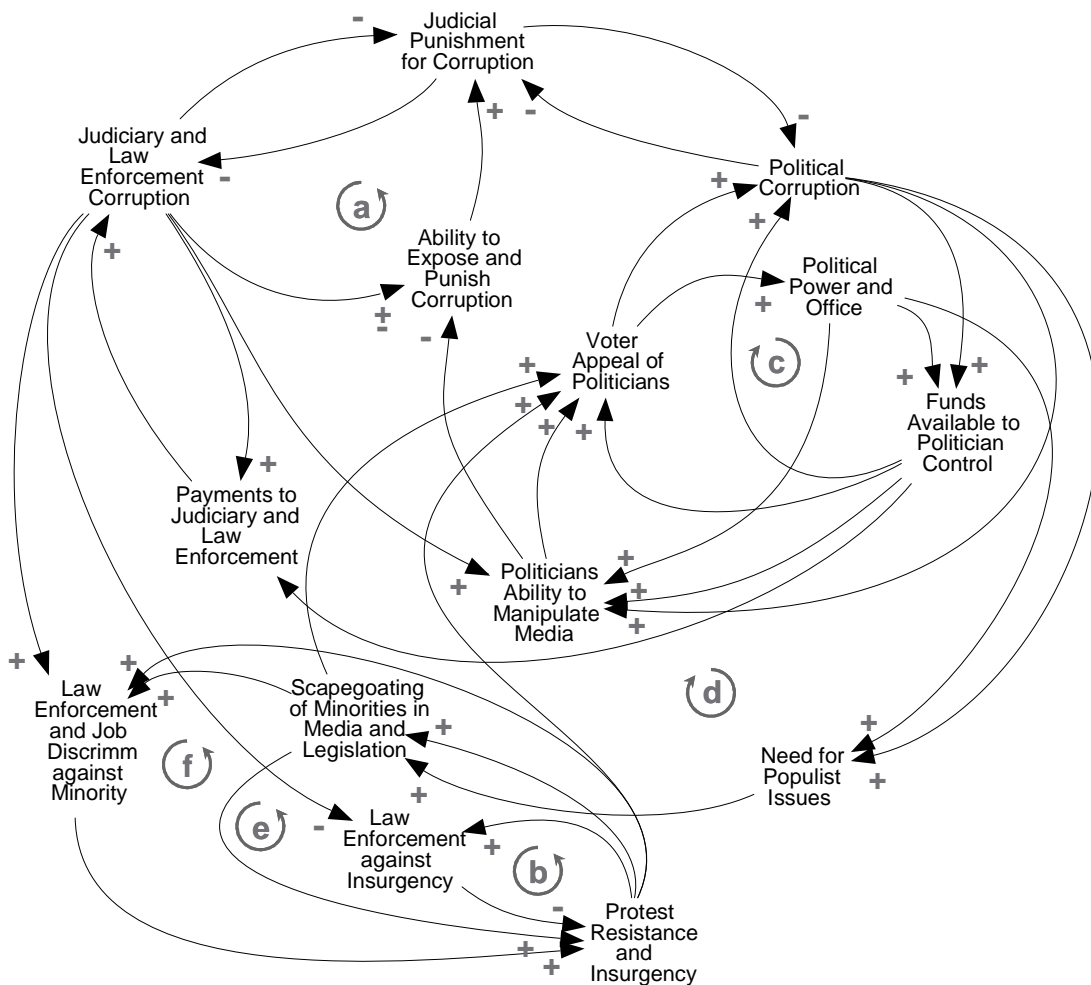


Figure 2. Representative feedback loops around insurgency and governance.

Corruption is often economically self-sustaining, through the numerous vicious circles on the right side of the diagram (loops around c). Political Corruption allows officials to control much larger funding flows, both through private bribes and through control of who receives public spending. Through many channels, politicians in turn spread benefits to different segments of society, which ultimately creates Voter Appeal,¹³ continued high Power and Political Office, and the economic ability to deliver the payments needed to sustain corruption.

Politicians, especially high-ranking politicians like national leaders, also need popular issues for which to rally support, and to appear to be doing urgently needed tasks. Often, the need for

populist issues results in identifying an ethnic or religious minority as working against the well-being of (or simply hostile to) the rest of society—for want of a better term, scapegoating. Taking a stand against these bad elements (which usually equates to playing to the prejudices of the majority) enhances the voter appeal and political power of the incumbent politician. And if that creates more Political Power and Office, there is more need for scapegoating to secure that power (positive loop d).

The scapegoating in the media and discriminatory legislation create resentment in the targeted minority, which leads to protest and resistance, and if matters become extreme, insurgency. Those actions increase the opportunities for scapegoating tremendously (positive loop e). In addition, Protest Resistance or Insurgency create more opportunities for law enforcement to treat the minority members especially poorly in both law and order actions and in the broader civil context (e.g. regarding property rights), which intensifies and broadens resistance (positive loop f).

Even if the problem at hand were narrowly defined as corruption, the loops discussed thus far demonstrate that the simple “enforce your own laws” view of how to combat corruption is naïve. Simply boosting enforcement efforts may well increase the level of corruption, as corrupt officials will need larger payments to assure continuing operation of the system.¹⁴ Doubtless a quantitative study of a specific country could start to identify feasible actions that reduce corruption and scapegoating, where “feasible” probably implies that politicians will need to see a way to maintain power or depart without danger, and corrupt officials will need some economic transition. No one will support changes that leave them without a livelihood.

Readers may be connecting this discussion to the conflicts in Iraq and Afghanistan. It is instructive for Iraq, less so for Afghanistan¹⁵. In Iraq, the conflict was more somewhat more complex than minority vs majority. Much of the violence pre-2007-8 “surge” was Sunni minority acting out against the Shia majority, and the more radical and militant Shia responding by violence toward Sunnis. The level of violence was reduced by strongly controlling the discrimination of law enforcement / military actions first, by supplying more US troops (neutral to the sectarian conflict) and second, by continuing to expand and professionalize the Iraqi military and police. That policy (and numerous refinements) in fact resulted from a more systemic view of insurgency and its sources.¹⁶

The system thus far described has in it sufficient structure (in the form of many positive loops) to show policy resistance to the policies implied by the apparently-prevailing mental models of how to solve the problems. As well, this starts to provide an explanation for why corruption is such a persistent and damaging problem for so many nations in the world, and blocks many paths toward peace.

Regrettably, the study corruption is still in its infancy with respect to actionable results. Studies of corruption are dominated by efforts to measure it, and cross-sectional studies on factors that make corruption more likely.¹⁷ This is a golden opportunity for the system dynamics community to step up to the plate and do research and publication that is actionable.

4. Grand Challenge: Acting on global warming

The consequences of failing to act vigorously on global warming are decades and centuries in the future, but dire. The impacts are huge but diffuse. For example, climate change will cause more rainfall in some geographies and less in other geographies. The populations of the world have located for agriculture in one set of areas will gradually be faced with major damage to the agricultural areas, with either too much water (flooding, topsoil loss) or too little (drought). Changes in climate also increase ability of diseases to propagate. Developed countries probably have the economic means to absorb these changes, but developing countries seem unlikely to do the same. One somewhat respectable report attributes 150,000 extra deaths each year to global warming.¹⁸ (More on respectability shortly.)

4.1 A mental model of “wait until it’s a major problem” seems to dominate decision-making on issues surrounding global warming

All of us grow up hearing sayings like “the squeaky wheel gets the grease” and “don’t borrow trouble”. Every day we are deluged with this or that expert promising disaster unless things are done. “Diet and exercise” is the proffered cure for most health threats, and “spend more money” is the proffered cure for most everything else. We learn to ignore both. Most attention goes to issues whose consequences are here and now, and that’s personal attention, media attention, and political attention.

At this point, among most environmental scientists and those who seriously study their work, global warming seems to be real and a done deal, and now it’s the politician’s fault or corporations’ fault that so little action is taking place. This may be true for academics as researchers, but the full story from academics as teachers has hardly begun to be told, because the whole problem of creating consensus for action about scientific issues has yet to be solved.

For most people, global warming isn’t a here-and-now issue, and won’t be for a while. While espoused values say that developed nations are foursquare behind taking action against global warming, the revealed preference for many years has been to do little, at least relative to the espoused scope and severity of the problem. To be uncharitable, these mental models driving action are caricatured in Figure 3.

Similarly the world seems likely to end up paying enormous costs in the future, that are today largely unexamined let alone quantified, which prolongs the discussion of appropriate carbon regulation around the world. And only a few SD analyses have seriously examined alternative routes to emissions regulation.

Governments and population at large	<p>“We’ll act when it becomes a serious problem.”</p> <p>“Global warming advocates are exaggerating, and shouldn’t be taken seriously”</p>
Advocacy organizations and NGOs	<p>“If everyone would only ‘do the green thing’ we’d be fine.”</p>
Corporations	<p>“We’ll act when government regulation is clear enough to make it safe to invest billions.”</p>
Scientists	<p>“We’ve done our part; it’s up to the politicians now”</p>

Figure 3. Mental models governing response to global warming.

Like development politics and economy, realistic public consideration of energy sources and conservation is still much in the moralizing stage—“if everybody just went green, we’d all be fine”. Yet realistic analyses seem to suggest that achievable conservation and achievable “green” sources do not come close to dealing with energy dependence and increasingly costly nonrenewable energy. For instance, can the developed world afford to be biased against nuclear energy? There’s no clear answer, or clear process for arriving at an answer. Much of the debate is still at the level of incomplete studies neutralizing each other. Without a simple, clear and validated articulation widely published and taught of why a given set of actions are needed now, the political system will default to waiting until the issue becomes a true crisis.

4.2 Effective action on global warming requires managing communications, research and funding among many stakeholders

In some sense, the fundamental difficulty with global warming and responses to it is that, by comparison to a problem that can be re-created in a laboratory, or even observed directly in an economy, the knowledge of the system that creates global warming is highly ramified. Global warming results from the interaction of a large number of physical systems that earlier were studied by and large independently. For the existing research community, it was a labor of decades to create a plausible hypothesis about global warming (in the form of unified but highly complex computer models) that fitted the facts available to the satisfaction of the various scientific communities involved.

But when the questions move to what the impacts will be, and how to mitigate the impacts, the system ramifies *again*. There are probably hundreds of chains of impact to mitigation. For example, which areas will experience less rainfall? What will the unmitigated impact on agricultural productivity be? Will neighboring areas become more productive such that food imports would solve the problem? Given the likely state of the region’s economy, could it manage a transition with reduced agriculture and more of some other activity to pay for food imports? Or is irrigation a feasible long-term solution? Or will saltwater contamination of

aquifers and coastal flooding cripple all economic activity well inland of the shoreline? Or is the only mitigation immediate and dramatic reduction of hydrocarbon emissions?

The complexity of the mitigation discussion calls into question the dynamics of the whole research establishment and political decision-making process, as suggested in Figure 4.

Development of effective technologies for mitigation	Articulation and testing of international institutions to share the cost of mitigations	Political sense of urgency on mitigation
Political consensus on domestic institutional arrangements to administer and cost-share mitigations	Success of initial attempts to mitigate	Development of institutions to channel funding, staffing and promotion to mitigation research at universities
Public education in mitigation concepts	Public education in scientific facts relevant to GW impacts	Corporate decisions to build “mitigation-friendly” technologies into investments
Legacy energy infrastructure	Legacy building location and transportation infrastructure	Political debate focus on single issues
“Wait and see” approach to spending—on anything	Belief in free-market solutions to problems	

Figure 4. Elements involved in acting on global warming

4.3 Representative feedback loops around credibility and action illustrate the dynamic nature of the larger issues of acting on global warming.

The dynamics of consensus are certainly an important nexus of the overall set of interactions that govern taking action on global warming. An example of similar dynamics may be helpful. The US electric power industry provides a case study of the interaction of prolonged political debate with commercial investment.

The California energy shortages and subsequent generation capacity glut are direct consequences of the long period earlier in which the particulars of deregulation were uncertain and being debated among state and federal regulators. As a result, energy companies—out of straightforward financial prudence—postponed needed investment in power plants until the new regulations were clarified and in place. During that waiting period of several years, electricity demand continued to grow. By the time the situation was resolved, demand had grown quite close to maximum capacity, and very little new capacity was under construction. So there was a prolonged period of brownouts and sometimes extremely high electricity costs, now known as the “California energy crisis”¹⁹

But the situation around mitigation of global warming is more complex than “hurry up and decide”.

The way we all would like to see the relationship between research, debate and action is shown around the top of Figure 5. Normal Incremental Research on Impacts of global warming by researchers applying for grants and doing the research eventually creates a Scientific Consensus on Impacts. That knowledge is diffused in the public’s knowledge of the issues, which in turn creates Political Sense of Urgency on Mitigation, which increases non-incremental research (i.e. more result-focused research). A positive loop (a) is formed of ever-increasing urgency and research until scientific work is pursued all the way to firm conclusions.

And in the best of all possible worlds, Political Sense of Urgency would also lead in due course to Willingness (of both private and government organizations) to Build in (global warming) Mitigation-Friendly Technologies, which controls global warming. (Links #1 on Figure 5)

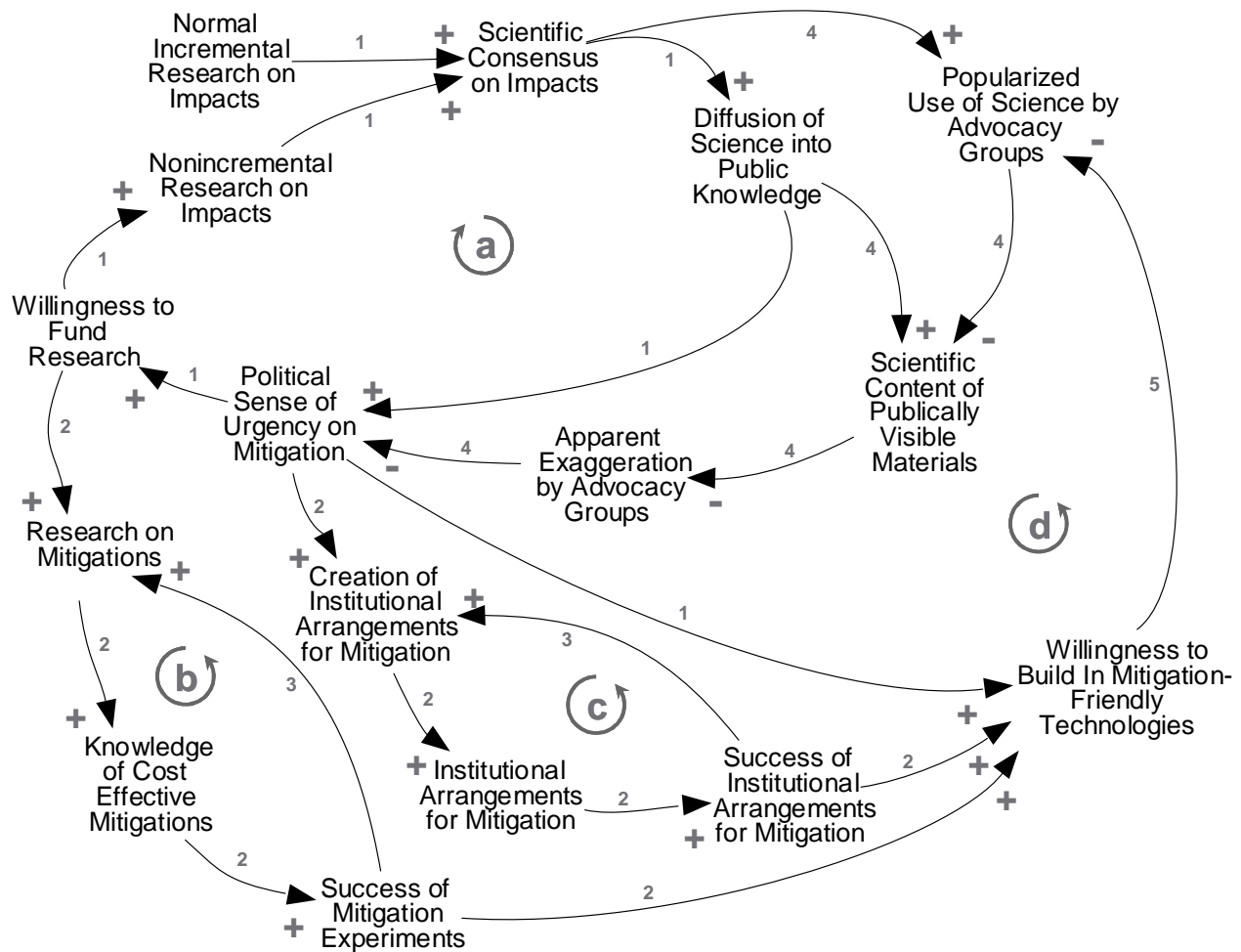


Figure 5. Representative feedback loops around mitigation of global warming. Numbers refer to links discussed in the text.

As in the electric power example, companies and people hesitate to make commitments of investment money when the rules or the economics may change as the technology, and more

importantly the institutions evolve. Still in the electric power industry, coal plants are being built with far less than the maximum “green-ness”, simply because the rules are in flux, and there’s very little certainty about whether additional investment in greener but more expensive equipment would be profitable.

Both institutional and technological know-how for GW mitigation are still evolving.

“Institutional arrangements” in this discussion is meant to include every facet of mitigation that is not a physical technology. It would include the various forms of carbon tax. It would also include the far more difficult question of paying for mitigations, both domestically in developed countries, and finding politically acceptable ways of paying for mitigations in poorer countries, if their economies can’t withstand the strain. Institutional arrangements would even include availability of products through distribution channels, and the marketing and job training needed to make, e.g., solar heating panels a normal part of building a house.

Still, one would hope that a steady pace of research and experimentation would yield effective technologies and institutional arrangements after a few quick iterations. (Links #2 on Figure 5)

Unfortunately, that orderly progress depends on continuity of research and experimentation, and there is a strong tendency for funding and political capital to be expended on activities that are predictably successful, but both mitigation technologies and institutional arrangements for mitigation are at first likely to be flawed and unsuccessful. The US government was funding a total of one experimental coal plant being built with first-ever clean technologies. It got behind schedule, and Congress cancelled it. This “success to the successful” system archetype creates a real chicken-and-egg problem for new technologies or institutional arrangements, whose effect is to elongate the initial research and experimentation phase, potentially for years and decades. (Links #3 and positive loops b and c on Figure 5)

But let me suggest that it gets worse. Relative to mitigation questions, the global warming questions were simple. Little wonder, given the redoubled complexity and newness (by academic standards) of the questions about mitigation (as opposed to the phenomenon itself of global warming) that a scientific consensus has been slow in even starting to arrive.

But advocacy groups (which include not only explicitly environmental advocacy groups, but also established Non Governmental Organizations, and international organizations such as the UN), have taken up the cause of global warning. They have proceeded to both popularize the science, and devote considerable “share of paper” to hitching global warming to their other causes. Regrettably, this creates a strong impression of “going off half-cocked” and exaggerating the seriousness of the issues for essentially ideological purposes. The overall impression to the population at large and their politicians is that the whole topic of doing things about global warming is controversial and premature. So although “green” has penetrated to political correctness in many countries, there isn’t a political consensus around a sense of urgency, the kind of urgency that funds research on impacts, mitigations and institutional arrangements to pay for mitigations. (Links # 4 on Figure 5)

Finally, the fact that corporations and households are not responding with investment dollars to the crisis perceived by advocacy groups can lead those groups to still more efforts to alert the

public to the crisis, which further adds to the perception of exaggeration, with the ripple effects on urgency and research funding.

Many will find this nexus speculative, and indeed it is thus far based on personal point observations and some general principles. The fact that there isn't publicized, solid research and modeling leading to consensus on the impact and implementation aspects of global warming underscores the grand-ness of this challenge.

5. Grand Challenge: Global financial and economic stability

This paper is written in March 2009,

- 2½ years after the peak in housing prices, now down 27% from the peak and still dropping,²⁰ representing a loss of trillions of dollars of value.
- Almost 1 ½ years after the October 2007 peak in the US stock market, now down almost half (48%) of its value from then.²¹
- 14 months after the (*ex-post*) official beginning of a “business cycle” recession in January 2008.²²
- 5 months after the bankruptcy of Lehman Brothers in September 2008 marked the semi-official beginning of the current crisis as more than just a financial industry problem

Despite months of interlude now and again, the overall pattern of behavior at this point is accelerating difficulties. The world is in a world of hurt, but the political debate is still polarized.

5.1 Mental models of “business as usual” are governing the responses to the ongoing economic and financial crisis (and future crisis prevention).

Depressions, even 80 years after the start of the Great Depression in the US, are still not well-understood. And globalization has made economic dynamics more complex, as international capital movements constrain the ability of national governments to respond to economic malbehavior.

Perhaps by virtue of knowing more about this particular topic area, the flawed mental models seem more diverse, and the flaws more interlockingly bad, here than for other challenges, so multiple stakeholders and their mental models are matched with flaws in Figure 6.

Investors	<p>Knowledgeable leaders will guide us.</p> <p><i>Except that conditions are extreme enough that experts and politicians need to avoid making self-fulfilling prophecies, by saying how bad things really are, or even publically revising their mental models</i></p>
Investment professionals	<p>Markets are always being shocked, and they recover</p> <p><i>Except the recovery depends on the nature of the shock. The Great Depression, the Japanese “lost decade” and the current economic crisis are all debt-deflation spirals, where balance sheet, not price dynamics, determine the length of recovery²³</i></p>
Economists and finance experts	<p>Prices contain all the information markets need about stocks</p> <p><i>Except when corporate and household spending are dominated by asset valuations and balance sheet considerations, and the investment community hasn’t grasped the nature of the current economic behavior yet.</i></p> <p>Financial crises happen, but theory tells us they’re rare</p> <p><i>And only a few in Wall Street reacted correctly, for example, to a 1 in 10,000 year event happening in three consecutive days. The correct reaction is that the theory has become wrong, and that market isn’t well-understood.</i></p>
Governments	<p>If problems haven’t happened in a while, it’s OK to yield to industry demands to relax regulations.</p> <p><i>Except that the expert opinion that weighed in had a vested interest in relaxing regulations, and the experimental trials took place during good times.</i></p> <p>Markets will recover by themselves; government intervention risks inflation and bloated government, and so should be done cautiously. Incremental intervention after careful deliberation is the right path</p> <p><i>These are good rules of thumb during normal growth, when labor is tight and stimulus easily creates inflation. Those conditions aren’t in effect now, and conventional wisdom is retarding adequate fiscal and monetary stimulus.</i></p>

Figure 6. Mental models governing responses to the global economic crisis of 2008 and beyond.

5.2 *Effective action to control the global economic crisis and the stability of the global financial system requires expanding economics to consider the extreme-condition dynamics of debt-deflation spirals and regulation as endogenous to the dynamics*

Figure 7 gives an idea of the scope of the economic conundrum facing virtually everyone in the world right now.

Regulatory requirements for new financial instruments	Regulation of financial product insurance	Capital investment	Exchange trading of financial instruments
Home mortgage defaults	Household income	Home mortgage lending	Home equity
Government budget deficit	Open-market operations to influence money supply	Setting interest rates for borrowing from the Central Bank	Lending to businesses
Exports	Imports	Foreign currency values	Government debt
Foreign holdings of government debt	Household saving / debt repayment	Consumer demand	Unemployment
Consumer prices	Wages	Fear of big government	Fear of inflation
Government injections of capital into banking system	Bank balance sheets	Reputation of economists	Belief in consistency of economic positions

Figure 7. Elements involved in global financial stability

5.3 *Representative feedback loops around housing finance illustrate the dynamic nature of the larger issues surrounding global financial stability.*

Before discussing a representative sampling of feedback loops involved in the current economic crisis, it should be stipulated that the relatively simple diagram excludes a mass of economic “plumbing” that is well-known to economists. An attempt to capture all the known relationships produces a causal diagram more like that in Figure 8.

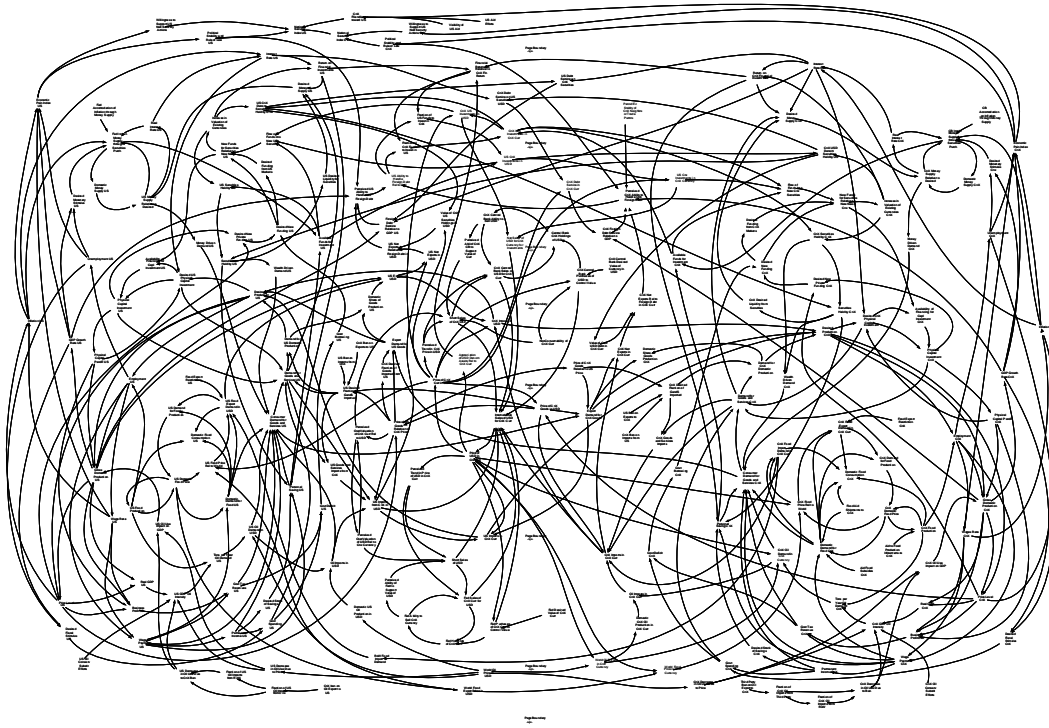


Figure 8. Example of what happens when all relevant “plumbing” of known economic interconnections is put on a causal diagram.

So clearly, a causal diagram may not be the most useful summary of what needs to be in a comprehensive simulation model.²⁴ But a simpler causal diagram, Figure 9, at least illustrates some of the challenges to conventional economics posed by the current crisis (and for that matter, the Great Depression, the Japanese “lost decade” or the Asian currency crises of the 1990s). Figure 9 gives a “low plumbing” picture of representative loops contributing to the current economic crisis. “Low plumbing” means that the diagram does not capture the full and correct accounting relationships involved, for example among consumer incomes, saving and demand, or financial sector assets, mortgage values, and capital reserves needed.

Beginning at the lower left, Consumer Demand drives production and Wage Payments, which come back as Household Income, one of the drivers of Consumer Demand. This forms a positive loop (Loop a on the Figure), but technically, it is a positive loop with steady-state gain less than one.²⁵ So it tends to amplify any outside disturbances to the loop, but in ever-decreasing amounts. Think of how a restaurant might start off quiet, but as people raise their voices to be heard over other people’s voices, the restaurant stabilizes at some high but non-growing noise level. Similarly, this loop creates a finite multiple of any initial disturbance, which the economics profession knows as the “income multiplier”.

As an aside, the value of this multiplier is watched carefully, because one of the outside disturbances to this loop is government deficit spending. If consumers spent all of their incomes on consumption goods, and companies paid out all their revenues in wages (and profits to

shareholders), the multiplier would be infinite. But this doesn't happen, because some of the income "leaks" out of this circle. In the textbooks, income "leaks" because people save some of their income, usually taken to be a fixed proportion of income in the example models. In addition, more income "leaks" into imports, and leaves the country. For any one country that imports, the impact of deficit spending is a much lower multiple than the simple textbook models imply.

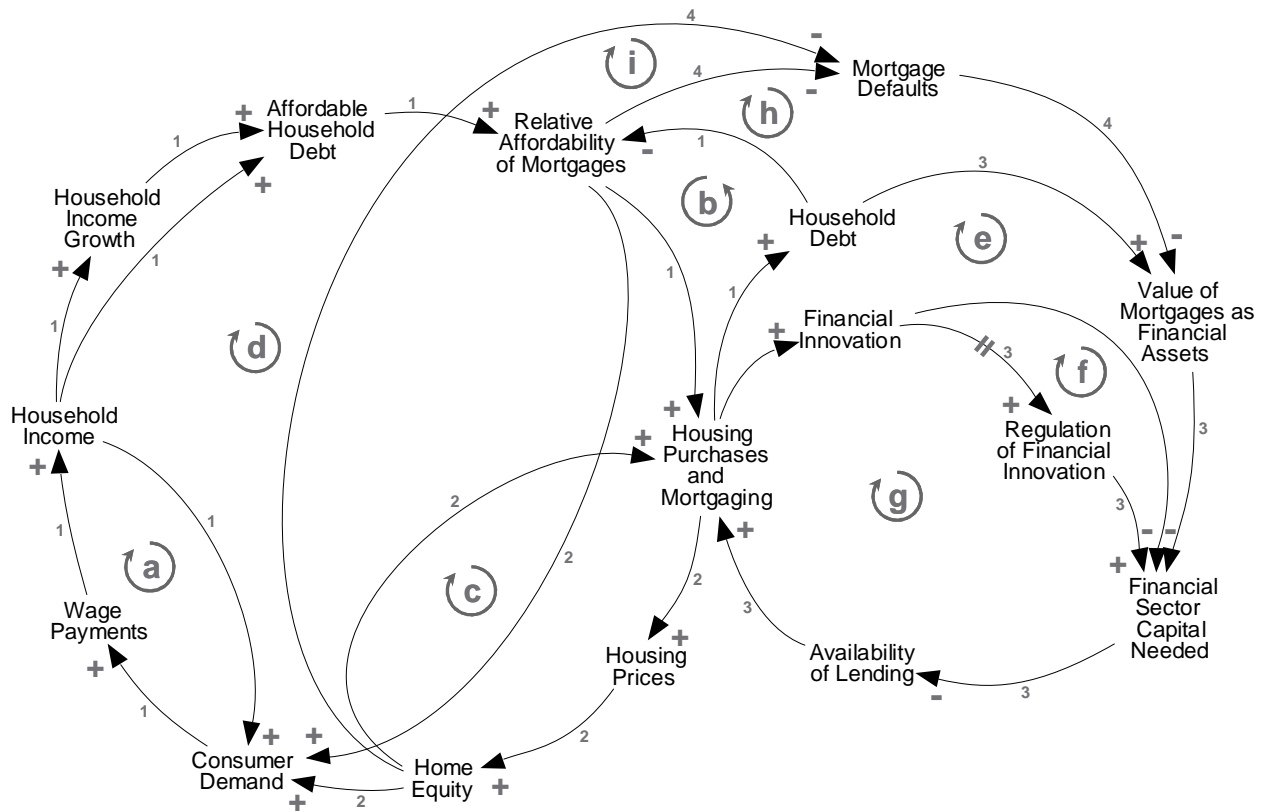


Figure 9. One nexus of elements involved in economic and financial stability. Numbers refer to links discussed in the text.

But incomes have generally been rising over time, which supports growing affordability of housing, both by virtue of the magnitude of income, and by the fact that it is growing (which means mortgages taken out now will become steadily more affordable for the individual mortgage borrowers). Affordability of mortgages of course modulates Housing Purchases and Mortgage Borrowing, forming a negative loop (Loop b and links 1 on Figure 9).

Housing Purchases do interesting things. All other things being equal, more Housing Purchases will raise Housing Prices and increase Home Equity. That in turn allows consumers to spend more of their income on consumer goods, since the increase in housing values are in effect creating saving. Moreover, Relative Affordability of Mortgages means that consumers can

borrow more and need to save less, which again allows higher Consumer Demand. These form two positive loops (c and d, and links 2 on Figure 9), and explain much of the rise in housing prices since about 1993 in the US. Conventional macroeconomic models may contain many of these relationships.

But there has been more going on, in the financial services sector, shown in links 3 on Figure 9. Household Debt has been securitized, and will count as an asset somewhere in the financial sector (but not with the loan originator, who sold off the mortgages). These assets reduce the amount otherwise needed for Financial Sector Capital (reserves) Needed, and make it possible to continue to make Available Lending and continue Housing Purchases and Mortgaging. This is just accounting, and as a positive loop, it's not powerful by itself. More interesting and powerful, the volume of the housing market makes possible Financial Innovations (such as credit – default swaps) that allow financial institutions to utilize capital more efficiently, and in effect, create many more loans from the same original capital reserves. This forms a positive loop (e) that further tends to support Housing Purchases and Mortgaging.

Of course, Regulation of Financial Innovation as a general rule tends to create capital reserve requirements for new forms of financing, other things being equal, which forms a negative control loop (f), which is as it should be. But critically for this discussion, regulations tend to go through a long delay before increasing Financial Sector Capital Needed.

All of these positive loops were well-known and discussed in the media, at least qualitatively, and except for a few pessimists, they were seen as a good thing. But as the abrupt transition from Japanese economic hegemony to the “lost decades” should have shown the world (but didn't), *positive loops work on the downside, too*. All it takes is something to give sufficient pause to the “growth loops”, and the nature of growth loops is that as they continue working, they make an adverse event more and more likely.

For the current crisis, the adverse event was concerns about a tiny portion of the overall mortgage market, that of sub-prime (that is, low-income or high-risk) mortgages. Mortgage Defaults (upper right and links 4 on Figure 9) substantially reduced the previous valuations of mortgages, and substantially increased the Financial Sector Capital (reserves) needed. This is what drove the need for government injection of capital into the banking system. But in the meanwhile, Availability of Lending dropped sharply, Housing Purchasing and Mortgaging dropped, Housing Prices peaked then fell, and all of the positive loops started working in reverse.

As an aside, one major contribution that system dynamics could make to understanding the current economic crisis (and others) is properly tracking the levels as well as the rates, which economic and financial models tend not to do. In the extreme case, Modern Portfolio Theory (so-called since it was invented in the 1960s) uses only price volatility to rate riskiness of investments. It assumes that liquidity is always available both to transact portfolio manipulations, and to keep markets for financial assets liquid and their prices appropriate. But the whole crisis is that the balance sheets of the financial sector in the aggregate are not liquid, and financial institutions are not free to invest. Moreover, as just discussed, defaults have a large and immediate impact on valuation of assets, if expectations about future defaults shift.²⁶ Balance sheet dynamics need to be incorporated into economic analysis right now. Indeed “now” may already be too late.²⁷

There are additional feedback loops running through Mortgage Defaults that weren't in operation during the housing boom, because defaults don't go below zero. When Mortgage Defaults reduce Housing Purchases and Mortgaging, and Home Equity and Affordability shrink, they further drive up Mortgage Defaults (loops h and i on Figure 9). By analogy, think of driving a car, and resting a foot on the brake pedal while moving the seat. Moving the seat back creates no problems—the foot doesn't cause problems by coming further off the brake pedal. But sliding the seat forward depresses the brake pedal and the car slows, which moves the seat further forward, and further depresses the brake pedal. The car comes to a screeching halt.²⁸

Wouldn't it be a good idea to have some solid numbers on if and when our economies come to a screeching halt, and be able to sort out convincingly what actions can't have the impact needed, versus which can?

6. Grand Challenge: Harmonious Chinese growth

The role of the People's Republic of China in a world economy and ecology is the elephant in the room for discussions of the big issues for the next ten and twenty years. It is also awkward to discuss, in that part of the very dynamics that are problematical is very different perceptions of what is politically correct.

With apologies to both my PRC colleagues and developed-world colleagues, we have a challenge.

China happens to be the largest developing country to go through the economic development transition *en masse*, and as such, is creating strains of on natural resource use, the environment, and present arrangements of global finances. Natural resource use is growing exponentially, and as Chinese domestic sources become exhausted, imports will grow even faster than use. China recently made the transition from being a net coal exporter to a coal importer. Given that the developed world has already exhausted many geographically convenient sources for coal and iron ore, China is shipping, for example, iron ore from Australia and Brazil.

In the financial realm, China has in the past fueled its economic growth through exports. It has successfully avoided the currency crises that bedeviled other Asian economies by maintaining capital controls and a currency exchange rate that seems to many Western observers to be somewhat lower than a "market" rate. And so China has built up what to Western eyes is a shockingly large reserve of dollar-denominated financial assets, (even though they only cover about a year and a half's worth of Chinese imports).

All of this creates tensions, and they will continue to get worse for the foreseeable future.

6.1 *Mental models of mirroring entitlement and political correctness seems to drive decision-making around Chinese economic growth, natural resource usage and the environment.*

We must remind ourselves at this point of the difference common in marketing science between espoused beliefs and revealed preference. We know that too often, people say one thing and do another. As with all the Grand Challenges, the doubtless simplistic and conspicuously narrow-minded mental models about to be described are not espoused beliefs, but the revealed-preference beliefs that seem to be guiding action. Usually, the only explicit acknowledgement of such beliefs comes from the crudest of populist political rhetoric. But we must pay attention, because politically correct or not, these crude beliefs seem to be guiding political consensus and action.

<p>Developed country governments</p>	<p>Chinese are being greedy with their continuing imbalance of trade, accumulation of dollar reserves, and consumption of energy and raw materials</p> <p>The Chinese government should give more of the economic bounty to its population, by increasing consumption (and increasing imports to reduce that trade imbalance)</p> <p>Environmentalism has shown us the correct path, and the Chinese are being willfully ignorant in continuing their investment and growth that uses polluting technologies.</p> <p>The carrot and stick approach will motivate China to create less economic stress and human rights abuse by doing as we do.</p>
<p>Chinese government</p>	<p>Political stability is the primary job of government, and economic growth is the key to stability, well-being of the Chinese people, and extending good government through the whole country. Unpleasant actions may be necessary to maintain stability.</p> <p>Western governments and peoples are trying to maintain their past dominance of China, and China doesn't have to take that anymore</p>

Figure 10. Mental models apparently guiding decision-making about Chinese economic growth

The developed-country mental model is flawed in that it treats China as a “black box”, implicitly requiring that the PRC government behave for which there is no political rationale.

History is full of examples of “black box” view of nations utterly backfiring. France’s occupation of the Ruhr valley as retaliation for non-delivery of war reparations (timber deliveries, actually) comes to mind. That was the major event that knocked out the German economy, and any hope of political stability that the Weimar republic had. Or the US embargo

on scrap-metal shipments to Japan to protest its military activities in China, which triggered further military acquisition of much of the Pacific basin to obtain raw materials.

David Lane’s image of Scylla (a monster, easily visualized) and Charybdis (a whirlpool, hard to visualize, but much more fatal) is perhaps appropriate here, where people don’t see the invisible consequences of the “black box” view that can create a pattern of escalating behavior that whirls the unwitting participants into conflict, mutual reprisals, and sometimes war.

6.2 Effective action on harmonious Chinese growth depends on correct understandings of a complex web of economic and perceptual issues

Here are just some of the elements involved in potential disharmonies, when perceived differently by the Chinese public and its leaders versus the leaders of the developed world and their respective publics:

Food production	Balance of trade	Energy intensity and consumption
Exchange rates	Natural resources	Physical infrastructure
Foreign direct investment	Foreign Assets	Military security
Nationalities problem	Hong Kong	Taiwan
Impact of urban development patterns on energy use		
Local government and governability		
Antipathy to foregoing Western-style resource consumption for development		
Balance of economic freedom, political freedom, governability, and economic growth		
Nationalism and internal use of external tensions		

Figure 11. Elements involved in harmonious Chinese growth, when perceived and expected differently inside and outside.

The challenge of harmonious Chinese growth combines several elements of the first three Grand Challenges, with the economic challenges that are part of global economic and financial stability, the environmental implementation challenges of acting on global warning, all in a context of political stability and effective governance. But the context is quite specific, and perhaps the least developed facet of the issues is forming realistic expectations about behavior. Even if the People’s Republic has arrived at a thoroughly modeled- and thought-out understanding of the dynamics of social and economic growth, there is a related but separate body of knowledge needed about non-Chinese interests and actions. And vice-versa. If China, in Western eyes, is a

giant black box that has to be pushed to behave in certain ways, how will any Western public and government know whether demands are meetable, given internal constraints, and which pressures will only lead to confrontation and other undesirable outcomes?

6.3 *Representative feedback loops around expectations during the economic crisis illustrates the dynamic nature of the larger issues surrounding harmonious Chinese growth*

I'll describe an illustrative causal diagram mostly about a Chinese view, admittedly drawn from interactions with "old China hands" from the US²⁹. Partly this choice presents a view not generally understood by developed-country audiences (which is most of the attendees of this conference). And partly this choice is made because dominant mental of the Chinese regarding global warming, good governance are probably quite similar to the mental models already discussed for the developed world.³⁰

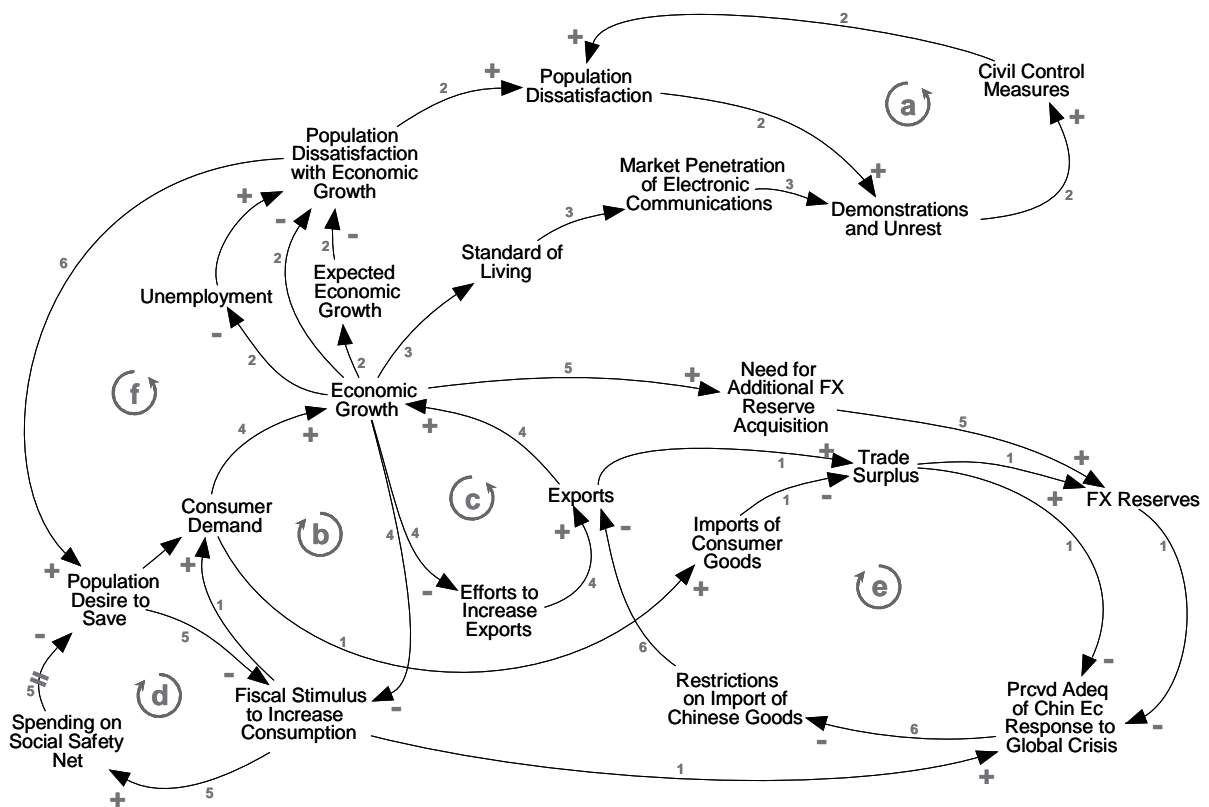


Figure 12. Representative feedback loops governing harmonious Chinese economic growth.

But let's start with the developed country view, since it's simple, shown on links #1 on Figure 12. China is running a Trade Surplus, with Exports too large, and (developed country) Imports of Consumer Goods too small. The responsible thing for China to do is use a Fiscal Stimulus to Increase Consumption, which will then increase (developed country) Imports of Consumer Goods. A simple, straight-line diagnosis.

But let's talk about what matters to Chinese leadership, starting with political stability (links #2). Economic Growth is a means to controlling Population Dissatisfaction and thus Demonstrations and Unrest. Using Civil Control Measures quickly, at low levels, is very important, because of the slippery slope (positive feedback loop a) created because Civil Control Measures, if used more extensively, also fuels Population Dissatisfaction.

Particularly unsettling is that rising Standard of Living has caused dramatically increased Market Penetration of Electronic Communication (which is the marketing term for "more people have cellphones and Internet"). And demonstrations are far easier to organize with electronic communications (links #3).

Eight percent per year growth is the generally accepted target for Economic Growth to keep the population (especially rural to urban migrants) employed and reasonably content. As of this writing, the growth rate is now well below that.

The Chinese government has a couple choices when Economic Growth is too low. As discussed, it can apply a Fiscal Stimulus to Increase Consumption, or by various means it can make Efforts to Increase Exports (links #4). These are both negative control loops (b and c). Given a choice between increasing Consumer Demand (which gives more stuff to the population) and increasing exports (which creates international tensions), the choice seems obvious to developed country governments.

In the developed country view, Chinese Population's Desire to Save is all very nice, but it's causing these trade imbalance problems, and the Chinese should save less and consume more. But this view neglects to analyze why the Chinese population is saving so much. Simply put, there is much less government Spending on Social Safety Nets like medical care, unemployment or retirement, and the availability of that safety net is much less certain. Chinese households look to their savings to support themselves in adversity. Even if the government spent a lot on social safety nets, it would be years and decades before Chinese households could feel confident about those institutional arrangements, and so feel less need to save.

Because of the Population's Desire to Save, the government will see very little benefit to Fiscal Stimulus to Increase Consumption, in comparison to the cost of increased government debt (links #5). This forms another "success to the successful" positive loop (d), where if the population didn't desire to save, the government would see a short-term benefit to stimulating consumer demand, which would include spending on a social safety net. But that is not the case; this loop locks the government into looking to exporting to achieve economic growth.

There is an additional wrinkle that as China's economy grows, the amount of foreign currency-denominated reserves should also be increasing. At the end of 2007, dollar reserves were less than 1½ times imports, which is to say that if China earned no more dollars through exporting, it could maintain imports for less than 1½ years. And in a country whose internal financial markets are shaky, having financial reserves is prudent. But developed countries, especially the US, are very uncomfortable with such large holdings, which helps the stage for conflict.

Protectionism is a real possibility, not because it will do much good, but because it is politically necessary in developed countries. The appearance is that if there were Restrictions on Imports of

Chinese Goods, the Trade Surplus would be controlled (negative loop e, links 6). However, that action fights the earlier control loop of Chinese policy attempting to keep exports high (loop c).

Moreover, the same economic conditions that cause (Chinese) Population Dissatisfaction with Economic Growth are also the economic conditions that create a greater need to save, which is one form of Keynes' liquidity trap (loop f). So even if the Chinese government were attempting a major fiscal stimulus, it would be unlikely to succeed, and the stage is set for escalating conflict.

7. Conclusion: What can you do?

Since the dominant population at the International System Dynamics Conference (and probably the System Dynamics Society) is professors and students, I'll focus on that group.

I describe in a companion paper to this some of the perverse incentives that work against having individual research and teaching activities add up to meeting a Grand Challenge. Nonetheless, there are things an individual can do within the existing system:

7.1 *Follow a research agenda that aligns with a Grand Challenge.*

This is a bootstrapping process that can take several years (and it's not too soon for first-year PhD students to move the selection process along with all due haste). The days are gone when a system dynamics modeler can waltz into a completely new situation and immediately make fundamental contributions.³¹

Alignment means choosing a research agenda that not only aims at doing research to meet part of a Grand Challenge, but also allows teaching subjects and developing curriculum materials that support the diffusion goals of a Grand Challenge, keeping in the good graces of ones home department and/or thesis advisor and/or tenure committee.

Following a research agenda means doing all the background stuff that prepare one to make contributions in an area: journal subscriptions for regular reading, professional society memberships, getting invited to good conferences (where non-academic experts give one a glimpse of what the mental models and perceived issues are—almost guaranteed to be different from the more academic conferences and publications. (Think *Foreign Policy* versus, e.g. *British Journal of Political Science*).

In the end, a dynamic modeler must at minimum be able to present himself or herself as a credibly knowledgeable person to both the relevant academic experts and practitioners in the field. For many facets of the Grand Challenges, that would be, for example, political scientists and upper-echelon State Department employees. This seems easier than in fact it is, because experts will know a great many things that they will believe that "everybody knows", and judge

a modeler's knowledge on that basis, whereas in fact people without extensive exposure to the field (hopefully not including the modeler) don't know most of those "everybody knows" facts.

7.2 Write papers that build knowledge about the Grand Challenges

Jay Forrester's paper on the future of system dynamics contains a sharp critique of system dynamics publications, in a list of nine characteristics that good papers should have.³² The list is actually a good proxy for "properties papers should have to really contribute to meeting a Grand Challenge", in that generally, they give a much richer context for making a model useful. (As opposed to many papers, which to be somewhat uncharitable, leave matters at "This seems important. Here's a model of it. It does some things." Period.)

Clearly stated model purpose is one of the best ways to both ensure a good modeling study and to efficiently build the knowledge in the paper into the wider Grand Challenge effort. This is the first item on Jay's list and on mine.³³ The first part of a paper should not be a mere literature survey, it should be a well-researched exposition about a wider problem (like a Grand Challenge or a subset) and the next bit of research furthers the overall effort—which is what comes next in the paper.

The other facet of papers I'll mention here is "next steps". This is how, step by step, experts and novices alike define the larger research agenda. If a useful paper starts with "this is what needs doing", a useful paper needs to end with "and here are the next things that need doing". The *System Dynamics Review* has a section for Research Notes, but the full context for why a given bit of research is interesting and useful is hard to develop independently, whereas the context of what needs doing is a natural part of a research paper.

Too often, "next steps" are very poorly thought out or executed, sometimes amounting to as little as "it's important so it should be studied more". Or they're obviously slanted to the next grant for the author alone ("this other thing should also be done with the data I already have").

The Boy Scouts in the US have a very practical rule of behavior that resists "tragedy of the commons" laziness: "Leave every campsite cleaner and better than it was when you arrived." If we apply approximately the same concept to "next steps" the rule of writing next steps would be:

- Define at least two (and preferably three or more) research topics that would result in a good published paper by a system dynamics graduate student.
- Give more ties to the literature and cautions about method for each "next steps" research topic than the author had at the start of the current paper

This seems like an ethos that would in a few generations of graduate student create a large body of relevant work and students becoming professors with vibrant teaching and research agendas that squarely address Grand Challenges.

And that would be something that changes the world.

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² (Forrester 2007, pg. 360)

³ (Forrester 1961) And what are the significant changes that have happened in the past *fifty* years? They are few: Better software, causal diagramming, and perhaps the body of actual applications.

⁴ (Graham 2009a)

⁵ To be explicit, henceforth when the text says “Chinese”, it does not refer to the cultural population of Chinese, but the People’s Republic of China “on” the mainland. My remarks do not apply to Hong Kong (same country, different system and economics, which, common phraseology to the contrary, lies partly on the Asian mainland), Taiwan, Singapore, or the overseas Chinese.

6 The other possible example of a grand challenge being met, admittedly in an arena to which “grand” might not be applied, is large project management, where dynamic models are fairly well-known as the only scientifically reliable means of analyzing large projects, either for forward-looking policy analysis, or backward looking assessment of final costs of actions. It is only in this arena that SD modeling has explicitly met the US legal requirements as a scientific method (Stephens, Graham and Lyneis, 2005).

⁷ (Alfeld and Graham 1976). The others were of course (Forrester 1969, Mass 1974 and Schroeder *et al.* 1975). For a retrospective (and prospective) on Urban Dynamics, see (Alfeld 2006)

⁸ Einstein’s methods of postulates and *gedankenexperimenten* created the new field of theoretical physics. Before Einstein, physics was very much based in extensive observation (which of course created the facts with which Einstein showed his theories to be consistent).

⁹ It would be useful to track the history of other major efforts toward “grand challenge”-like objectives, particularly in the social sciences. The only example that comes to mind is the revision of high school science curricula in the US, responding to the “space race” threat perceived from the Soviet Union, the PSST.

¹⁰ Actually, it seems unlikely that even a large number of researchers in government and academe are unlikely to meet the grand challenges if they rely on traditional methods of defining research areas, funding research and communicating results. The larger the number of people involved, the more planning and coordination is needed to achieve activities that dovetail together to achieve a larger goal. (Graham 2009b) discusses some of the present problems and innovations needed.

¹¹ Although the observations here come from several SD studies of insurgency and stability, the most accessible public document is the Army Field Manual 3-24, which came out late in 2006 over the names of David Petraeus and David Amos (Headquarters, Department of the Army 2006). More detail of the military side is to be found in the Joint Operating Concept for Stability, Security, Transition and Reconstruction Operations (US Department of Defense 2006). Interestingly, the latter lists as a risk item that in effect the lessons of Iraq will be forgotten (as stabilization lessons from Vietnam were repeatedly forgotten: “In the coming years, the U.S. military will abandon the very significant new approaches that have recently been implemented to prepare American military forces to effectively conduct multi-dimensional SSTR operations. (low risk). Both of these documents are available on the Internet.

¹² The interlocking, systemic nature of corruption was pointed out to the author by David Day, of the University of Hawaii at Manoa (Day 2007)

¹³ Political scientists are careful to point out that money and influence buy political support in different ways in different types of government. For simplicity, this paper describes popular democracies. In autocracies, political support is garnered by spreading money and influence to the controlling groups, for example the military and the ultra-rich (often indistinguishable from politicians themselves). See, for example (Bueno de Mesquita *et al.* 2002)

¹⁴ The negative loop around enforcement was noted as important to the dynamics of the drug market by (Levin, Hirsch and Roberts 1975)

¹⁵ In Afghanistan, the primary conflict is fueled not by classic “groups with gripes” as is described by Figure 2, but rather a radicalized fundamentalist minority being fueled by a radical ideology, a continuing infusion of foreign radicals as fighters and ideological advocates, and economic support from drug sales. That said, corruption was and is a significant problem with the elected government of Afghanistan, it just isn’t a first-order driver of the insurgency.

¹⁶ (Department of the Army 2006) is the formal basis for the “surge”. It gives a cause and effect description of insurgency that has in fact been translated into a useful system dynamics model. Distribution of reports on that modeling and analysis are For Official Use Only for the US government.

¹⁷ As one might expect of a field of study in its infancy, specific varieties of corruption aren’t sharply distinguished, and corruption is conflated with, e.g. human rights abuses and political instability. See United Nations Universal Human Rights Index (<http://www.universalhumanrightsindex.org/>), World Bank Governance Indicators (http://info.worldbank.org/governance/wgi/sc_country.asp), Internet Center for Corruption Research (<http://www.icgg.org/corruption.html>), Transparency International (<http://www.transparency.org/>), Freedom House (<http://www.freedomhouse.org/>), Human Rights Watch (<http://www.hrw.org/>) or Amnesty International (<http://www.hrw.org/>)

¹⁸ (McMichael 2003)

¹⁹ (Ford 2002, Kadoya 2005)

²⁰ Standard & Poors Case-Shiller National Home Price Index, www.standardandpoors.com

²¹ Dow-Jones Industrial Average

²² National Bureau of Economic Research (Cambridge, Massachusetts, www.nber.org) is the *de facto* judge of when business cycles reach their peak and trough.

²³ The causal diagram for this challenge will discuss some of the debt-deflation mechanisms (there are several more positive loops connecting deflation of various valuations and prices with various drivers. (Graham 2008) gives a concise description, and (Koo 2008) gives a book-length analysis of the Great Depression, the Japanese “lost decade” and the current situation, with abundant and relevant facts, and lucid description. (von Peter 2005) summarizes extant academic theories of debt-deflation mechanisms.

²⁴ (Graham 2009c) gives a survey of common economic behavior modes and structural causes, stipulating that the discussion there was selected for a purpose (military, aid, or investment planning) than macroeconomic policy.

²⁵ If you do the experiment of inputting a disturbance, after breaking the loop (“open loop”) and wait for it to come to a new equilibrium (“steady-state”), the ratio of the change at the end of the (former) loop to the change at the beginning of the (former) loop is less than one. (Forrester 1968) uses this concept in analyzing the dynamics of his well-known “market growth” model.

²⁶ Afficionados of counter-intuitiveness will appreciate this issue. In an effort to increase transparency of financial institutions’ balance sheets, accounting standards changed to a “mark to market” rule in November 2007, whereby asset holders had to continuously mark up or mark down the value of the assets they held, to match the current market price, regardless of how much they paid for them. (Purchase price was the previous way of asset accounting.) So if a firm’s assets lost value, it would have to sell off assets to raise reserve capital. In the aggregate, the selloff tended to reduce all asset values. This recession is the first recession under mark-to-market accounting. The accounting and regulation community is still in denial that the shift to mark-to-market could have had anything to do with the current crisis. Analytical horsepower hasn’t yet been brought to bear on the question of how to have transparency without market destabilization.

²⁷ One of the discussions that hasn’t really entered the public debate is what limits the US (or any) government has in propping up the financial sector. The “Iceland problem” is a known issue, where a banking system has grown to the point where its national economy is too small to bail it out. But no one seems to be doing the numbers publically. The numbers I’ve done on mortgage valuations with and without the current level of defaults suggest that the loss in value is already too large for the US government to handle by injecting capital.

²⁸ Don't try this. The positive loop makes the braking and stopping far more violent and surprising than a driver would expect from prior experience. This dynamic is surely one reason that car makers include a power-driven driver's seat on all but the very cheapest models. A power-driven driver's seat doesn't lurch forward when the brakes go on, which breaks (so to speak) the positive loop.

²⁹ (Graham 2009a) is a final report on a year-long effort in the US Department of Defense to understand economic and financial threats to National Security. Needless to say, China was often a topic of discussion and analysis.

³⁰ Even if the currently-prevailing mental models in China are similar to those discussed already, the representative feedback loops for Chinese energy and natural resource usage growth (or not) should be quite different from the loops for acting on global warming or governance, if for no other reason that representative loops should include loops around potential conflicts with the developed world.

³¹ It is an illusion that consultants "waltz into a completely new situation and create and make fundamental contributions". First, almost without exception, most elements of a new situation have counterparts in the body of previous work. Second, consultants rely on access to experts well beyond that of most academics. Third, consultants must adhere far more tightly to a narrowly-defined model purpose, so that even complex dynamics and the models that capture them are still manageable. Fourth, consultancies get economies of scale in both formalizing processes and accumulating unwritten learnings. Truly new situations require lots of reading, lots of interviews, lots of data collection, and a very iterative refinement process.

³² (Forrester 2007, pp. 365-366).

³³ The companion to this paper, Graham 2009b, describes in detail what goes into a clear statement of model purpose: Levers for action or decision that are to be considered, outcome metrics that define successful and unsuccessful policies, external scenario conditions under which policies should be tested, and puzzles, which can include hoped for / feared dynamic hypotheses. And avoiding at all costs using the words "understand" or "explain", which are far too vague for serious modeling.