Technological Forecasting & Social Change xxx (2008) xxx–xxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

FROM MY PERSPECTIVE

Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds

Fred Phillips

Alliant International University and Maastricht School of Management, San Diego, CA, USA

ARTICLE INFO

Article history:
Received 19 November 2007
Received in revised form 19 February 2008
Accepted 20 March 2008
Available online xxxx

As the newly named Senior Editor of Technological Forecasting & Social Change, I welcome this opportunity to thank Editor-in-Chief Hal Linstone for being a good friend and mentor these many years, and for his confidence in my work. Hal, I am acutely aware of this journal's venerable history and unique value! Its unitary view of technological and social change, its international orientation, and its cautious forays into technology policy drew me to it, kept me fascinated, and created my commitment to its future.[1]

This essay presents my thoughts on current imperatives and future directions in TFSC's areas of inquiry. I'll start by reiterating a definition of those areas — "reiterating," because I believe my vision of the journal's mission is the same as Hal's. I will go on to characterize our new global socio-technical environment in terms of the Multis, the Biggers (and Smallers), and the More Connecteds, and argue that our challenge as researchers is to respond to these three features of our changing world. I will note several research emphases that I believe will help forge this response. I'll mention, as well, a few research thrusts that probably will not help.

The last part of the essay presents additional views of where our field will go and should go, in light of these new challenges, with recommendations for modelers. The views are, as this page's header announces, "perspectives," and not a statement of editorial policy. They add to those of Coates et al. [1] and Gordon, Glenn and Jakil [2], which appeared in these pages a few years ago.

1. Multis, Biggers, and More Connecteds

In 1990 former DARPA Director Craig Fields [3] observed that we were living in an age of eight "Multis." The new enterprise environment was:

- Multi-product
- Multi-country
- Multi-culture
- Multi-company
- Multi-industry
- Multi-technology
- Multi-career
- Multi-tasking

E-mail address: fphillips@alliant.edu.

[1] Thanks also to Peter Bishop, Joseph Coates, Andrew Donoho, Bob Flood, and Ted Gordon for comments on earlier drafts; to Hal Linstone for details on the early days of the journal and for thought-provoking questions; and to Reita Fridman for timely newspaper clippings. Any errors herein are my own responsibility.

doi:10.1016/j.techfore.2008.03.005

The multiple talents of individuals and teams were implicit in this list. Fields urged his audience to recognize the Multis and learn to tolerate them. I later argued [4] for more proactively embracing the Multis in order to combine them in profitable ways. Today five more Multis have emerged:

- Multiple mechanisms for innovation diffusion. I will discuss the multiple business models now pushing new products forward, and why we must learn to anticipate them.
- Multiple stakeholders with multiple objectives and agendas. I'll note the difficulties of identifying stakeholders in a globalized world. And identifying them doesn't always help: the most conspicuous current example is digitized patient records in the United States. Automated medical records would result in better health outcomes at a higher risk to patient privacy. Those who could be sued are making sure the technology, which is already in place in the UK and the Netherlands, languishes in the U.S.
- Multiple sources of research results and technical information.
- Multiple research perspectives and methodologies.
- Multiple ideologies within and across cultures.

I'll also put forth some ideas about multiple histories that complement our usual notion of multiple futures. The Multis should be not only embraced, but encouraged and sometimes deliberately created, for example, multiple scenarios in planning, multiple decision bodies exercising checks and balances in politics, new alternative business models, and multiple methodologies in research studies.

I'll venture that we are living also in a world of Biggers:

- Bigger national economies that even strong political and corporate leaders cannot steer.
- Bigger perspectives on bigger problems (global warming, global terrorism, rogue asteroids), leading *inter alia* to new multinational and NGO actions.
- Bigger technological creations (dams, canals, etc.) having bigger impacts on people and societies.
- Bigger models for doing research and advising policy makers. (For years now, models for logistics and for database matching have commonly featured millions of variables and hundreds of thousands of constraints.)
- Bigger companies growing as they merge and expand throughout a bigger global marketplace.

Each of these entities displays increasing interconnections, both internally and externally. Though we could call these "multi-" interactions, I prefer a third descriptive category for today's world, the "More Connecteds." This helps us distinguish good from bad connections (an example of the latter being "technology colonization," discussed below) and facilitates discussions of systems modeling later in this article. Our telecomm and data networks, our social networks, our environmental problems, our organizational structures, and our regional economies become More Connected as each day passes.

As Biggers become more omnipresent, so do Smallers. Microcircuitry now pushes the boundaries of quantum effects (and with, e.g., the Josephson junction, makes use of these effects), and nanofabrication represents, in effect, a convergence of mechanical engineering and analytic chemistry. In a wonderfully illustrative table, Linstone [5] summarized how economic power is being pushed to the individual desktop and to micro-enterprises even as global conglomerates continue to merge and grow. (And the micro-enterprises, whether digital wedding photographers in India or textile designers in Ghana, are connected to suppliers and customers via the Internet.) History is driven by local languages, neighborhoods, ethnicities, and new states, Hal's table shows, even as Hollywood, McDonalds and NAFTA consolidate a global culture.

This article will discuss the discontinuities and challenges implied by the complex interplay of the Multis, the Biggers, the Smallers, and the More Connecteds.

2. TFSC's focus

In 1968, Hal created a journal titled Technology Forecasting. The first issue came out in 1969, and in 1970 "Social Change" was appended to the journal's name. Technology assessment, that is, evaluating and predicting the effects of new technologies, "was just becoming a concern in Washington," Hal says, "and I promptly added it as a most appropriate subject in the statement of areas covered by TFSC."[2] An official of the old US Office of Technology Assessment gave me this definition:

> Technology assessment is the identification and examination of the direct and indirect impacts of technology on people, institutions, and society. [It] includes consideration of likely or possible economic, social, political, and other effects of technology, and analysis of the range of policy options that might address these effects as well as the technology itself.

TFSC papers discover who is influenced by a new technology. They measure costs and benefits of the technology, including soft costs involving quality of life, environment, and ethics, and payoffs in jobs, knowledge, and human rights, etc. as well as wealth.[3] TFSC papers are concerned with the innovation's technical performance only insofar as that affects its adoption (market) potential, its safety, and its synergies with other technologies. The papers are oriented to the public interest, sometimes to a study of history, and more frequently and explicitly nowadays toward strategies for commercial gain or toward the growth and sustainability of regions. TFSC papers may begin with recognition of a social problem and go on to investigate the feasibility of technological solutions.

[2] TFSC Advisory Board member Joe Coates was influential in the early development of technology assessment as a discipline.
[3] The helpful acronym ELSI recalls the "ethical, legal, and social implications" of new technologies.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

Bimber and Guston [6] note the field has increasingly emphasized the potential for social change inherent in new technologies — in other words, that it has taken on a larger scope and become more future-oriented. The mention of forecasting in our journal's name indicates a focus on the nature, timing (including time windows of opportunity), function, market prospects, and costs of new technologies.

Not all submitted papers have hewn to this (admittedly porous) definition of the journal's focus. The TFSC Advisory Board, however, helps the editorial team stick to the unique and clearly identifiable niche where rest the strength and reputation of the journal.

3. Promising directions for dealing with Multis, Biggers, and More Connecteds

Entrepreneurship is now a significant mechanism for diffusion of innovations. Our Asian contributors seem to be taking the lead on papers addressing entrepreneurship in the context of socio-technical change. See e.g., Contractor and Kundu [7], Lin, Li and Chen [8], and Liu, Hung and Chu [9].

Old industries are transitioning to new business models, and entrepreneurs in new industries, particularly digital businesses, are flailing about in search of workable models. It is no longer enough to forecast technical advances and the demand for them. Today's (intermediate, or business-to-business) market demands are for disaggregated chunks of delivered benefits. New business models demolish old value chains and reassemble them to deliver different combinations of benefits through different channels. We must learn how to forecast business models. Possibly this will be done with large combinatorial simulations.[4,5]

These forecasts will address, *inter alia*, the strategic management of intellectual property in the entrepreneurial context and the policy context (e.g., the WTO's Trade-Related Intellectual Property Agreement). We can hope for a blossoming of quantitative models for intellectual property management.

3.1. Dealing with a huge and growing volume of technical information: requirements and avenues[6]

The notion of "technology fusion," defined by Kodama [11] in 1992, helps us understand the technical information problem.[7] Today's innovators snap together components from diverse sources. It is not enough to master one thread of progress conducted by a small circle of researchers; instead, the needed components will come from "Multi" research threads and diverse labs in diverse industries. How can a Lego innovator find out what is pertinent to his or her project — what can be learned and what can be licensed? Some of the answers lie in text mining, bibliometrics, and Extensible Markup Language (XML) (Kostoff et al. [13]; Porter [14]; Daim et al. [15]), as well as new intermediaries publishing indices, reviews, improved search engines, and digests.

Keywords are not enough; someday we will write our papers' abstracts in an artificial, formal language that the semantic net can scan. Machine "understanding" of photos, diagrams, videos, and digitized voice will deliver more relevant stuff to the innovator's bench and less of the irrelevant, making innovation more efficient and faster. How much faster? How much more efficient? When will it happen? This is what TFSC authors will be investigating in coming years — or at least, that is my prediction.

Another unappreciated consequence of complexity arising from globalization and information and communications technologies (ICT) presents an allied problem. In a connected world, an observer doesn't know how to identify the multiple parties that have an interest in a transaction, much less how they may form coalitions and send (true and false) signals to each other. To state this in a game-theory framework, computing a game's equilibrium, or even constructing its payoff matrix, becomes less of a chore than identifying all the players!

3.2. Sociology

No modern developments have given researchers in our field so much to work with as Rogers' innovation diffusion theory [16], Coleman's [17] and Fukuyama's [18] social capital theory, Granovetter's social network theory [19], and Wendell Bell's [20,21] work on futures studies. Brilliant stuff, all contributed by sociologists, it far outshines any work in the same era by economists or other social scientists. Shall I add that demographic analysis is usually taught in sociology departments? Taken together, these advances go a long way toward explaining high-tech industrial clustering, technology transfer mechanisms, development of the knowledge work force, and technology-based economic development. They may go even further as sociologists continue to investigate the "Multis."

3.3. Attention to perceptual biases and behavioral probability, in the Kahneman/Tversky tradition

People make up the "socio" in socio-technical systems, and we need to understand people better. Even the finance literature is now dealing seriously with "investor sentiment" as a driver of stock prices, foreshadowing the death of the "random walk down Wall Street." Other examples:

- Population growth depends on fecundity, and fecundity depends on "selective memory" (our incomplete recollection of past pleasurable and painful experiences). This is simply because if the pain of childbirth were remembered accurately, few women would bear a second child. See the forthcoming [22].

[4] Coates et al. [1, p.11] foreshadowed this kind of analysis in their discussion of "scenario management."

[5] In late November, 2007, Verizon changed its business model in the face of rapid innovation throughout the cellular telephony and allied industries. Consumers demanded a choice and range of cellular services that Verizon could not satisfy either solo or via alliances. The company changed to an open architecture, allowing customers to buy ringtones, movies, etc., from unaffiliated vendors [10].

[6] See http://www.youtube.com/watch?v=xHWTLA8WecI.

[7] IBM's Andrew Donoho, in a personal communication, called it "Lego entrepreneurship." Henderson and Clark [12] prefer "architectural innovation."

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

- For lack of a few cents a day each, many thousands succumb to malaria, while we prefer to spend a small fortune rescuing one person in (for example) a cave-in.

I do not pass value judgments on these preferences. I just note that any rational futures our authors concoct will be stymied by human nature's bounded rationality and innate biases. Let's understand these, and forecast accordingly.

3.4. Discussion of a greater variety of technologies

Though it's essential to keep pace, as our journal does so well, with the ICT and energy industries, other technology and industry areas also produce social change. They include biotechnology, advanced materials, space technology, transportation, nanofabrication, and medicine – and their interactions with one another – and they all deserve continued (see e.g., [23]) and increased attention in these pages.

3.5. Multiple-methodology studies

I have been glad to see papers in TFSC that combine methodologies. For example, Winebrake and Creswick [24] combine the analytic hierarchy process with scenario planning. These papers show the value of multiple-methodology studies. They are a straightforward way of showing construct validity, and generally increase confidence in the research results [26]. Papers like Winebrake and Creswick's are doubly pleasing to me because they also show the convergence of technology forecasting/assessment with my original field of operations research. They also (see Grubler, Ermoliev and Kryazhimskiy [25]) minimize errors due to the assumptions and biases inherent in any single methodology. Nakicenovic's [27] "integrated assessment" – a combined quantitative and qualitative treatment of the human, economic, technological, and environmental aspects of a socio-technical system – is an admirable extension of the idea of multiple-methodology studies.

Valuing multi-methodology research implies that scholars should generously share data sets with other researchers who are expert in complementary methodologies.

3.6. Human potential

Some events we will predict incorrectly, and some are inherently unpredictable. Once we accept this, it becomes logical to:

- Build models that elucidate or minimize the cost of being wrong.
- Focus on robust decisions, that is, those that will be "pretty good" or "not too bad" under a wide range of the event's outcomes (see e.g., [24], and the work of Lempert, Groves, Popper, Bankes and others at RAND Corp.)
- Investigate the human ability to rebound from the unexpected and take positive new action.

After all – as every good carnival fortune-teller knows – the real point of forecasting is not to be "right," but to deal with the future in a maximally positive and economic way.

Today I focus on the third of these bullets. The human ability to rebound encompasses individual characteristics of flexibility, resilience, creativity, initiative, persistence, and even Zen non-attachment and Korzybskian (non-Aristotelian) thinking. It encompasses group characteristics like team spirit and mutual support.

As a fan of, and marginal participant in, the human potential movement of the 1960s, I have argued [28] that it uncovered much useful knowledge. It is hard to envision where a renewed round of research on human potential will take us – or how – but the new instrumentation that aids the convergence of psychology and neurology should open many new doors. The (multi-technology) marriage of sensors, transmitters and computers that analyzes the body's gross athletic movements and minute physiological reactions will open still other doors notwithstanding that the current economic "killer application" for these technologies is the creation of commercial animated movies.

Hal Linstone[8] points out that "the military are trained to work through many scenarios, not so that they will pick 'the most likely' (as business usually does) but to make them able to react well to unanticipated ones." This is a perfect example of the direction I'm advocating.

3.7. Bio-mimetics

It seems that each day we find the adaptation strategies of organisms and ecosystems are more complex and "clever" than we imagined — or than we imagined possible. We rely on biological systems for models for everything from innovation strategy and product design to "genetic algorithms," therapeutic regimens, and our search for a sustainable economy. Here is a field in which we understand very little, but see great promise. Kauffman's [29] work is ground-breaking.

[8] In a private communication from Linstone. Robert Flood, editor of Systemic Practice & Action Research, adds that this is also the major thrust of the Learning Organizations movement.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

3.8. The circle unbroken

New technologies create new markets and new product usage modalities, which spur social change, which results in new demands, and ultimately still more technological innovation. The latter link in the circular chain is usually recognized in this journal in terms of trends in corporate and government R&D budgets. But there are ways to look at this link that are more down-to-earth, more enlightening, and more fun. For example, continued crowding joined with increased affluence in Japan led to the bathroom appliance that combines the functions of commode, bidet, and warm-air dryer all in one — ideal for small apartments.

It is said that the world was ready for relativity theory and that if Einstein had not devised it someone else would have. Similarly, social and cultural situations can seem ideally poised to receive certain innovations (including innovations much less trivial than the Japanese toilet; the Mercury and Apollo space programs come to mind). What light can our analyses shed on this phenomenon?

4. Less promising directions

The research directions listed in this section will be less useful – or at least should be applied with great caution – in dealing with Multis, Biggers, Smallers, and More Connecteds.

4.1. Market-based predictions

Though there was a flurry of academic papers on this topic in the early part of this decade (many are cited in [30]; see also [31]), some writers trace the idea to John Brunner's 1975 novel Shockwave Rider. Prediction markets are "betting windows," usually virtual, at which large numbers of people can put down money on the outcome that they expect, for any event that is under study. This somewhat interesting notion got a black eye in 2003 when DARPA rolled out its "Policy Analysis Market," which appeared to allow anonymous people to bet on terrorist attacks. Widespread disgust at the perceived purpose of the DARPA model confused discussion of its scientific validity. However, I find Hanson's [30] unemotional defense of its validity unconvincing.

My additional objections to predictive markets are three. First, if markets could predict, then a horse with nine-to-four odds at the track would actually win about four of every thirteen races against a similar field, and this is demonstrably not true. (The historical database for horse races is far vaster than any for 21st-century artificial predictive markets.) Second, the markets depend on the Law of Large Numbers, which as Taleb [32] demonstrates, is not valid for rare events such as terror attacks. Third, the betting markets that have shown predictive success have been constructed in a way that makes them nearly identical to the existing mechanism for deciding the outcome. For example, a predictive market for stock prices looks like the options market, and the predictive market for a political election looks just like a real ballot or a poll that asks "Which candidate would best further your interests?" Thus, workable predictive markets are superfluous at best.[9] As a sage once said, "Why buy champagne when you can get real pain?"

4.2. Economic theory

An eminent economist himself, DeLong [34] skewers the recent crop of popular books, written by economists, that purport to explain all kinds of social phenomena via economic reasoning. Their titles include Freakonomics (2005), The Economic Naturalist (2007), More Sex is Safer Sex (2007), and Discover Your Inner Economist (2007). Overwhelmingly, DeLong claims, these facile explanations are "just-so stories" (etiological myths based on ad hoc fallacies). They reinforce the old saw that economists will gladly make predictions about anything except the economy, and they help me understand why my old academic advisor would not let me take economics courses as an undergraduate. ("Wait until you're a graduate student," he said. "You'll be less impressionable then.")

The economics profession's focus on price mechanisms, and the ready availability of price data, used to be reasons for turning to economic reasoning in socio-technical analysis. When the quantity of real interest seemed unmeasurable – or when measures were unobtainable – we used a seemingly pertinent price as a proxy for it. A Google search on "price as a proxy" turns up dozens of uses of "price as a proxy for quality," a ploy that is familiar to anyone who has done industrial research. In addition, we find "corn futures price as a proxy for feed costs," "long-maturity futures price as a proxy for the long-term price" of a commodity, company "stock price as a proxy for the price of gold," "stock price as a proxy for general confidence in… banks," "transaction price as a proxy for unobservable market value" and "market price as a proxy for fundamental value," and "Houston Ship Channel gas price as a proxy for the market price."

There are now databases of time series of a huge range of social and technical measures.[10] Measurement of attitudes, opinions, intentions, and beliefs are more highly developed than in the past, and diverse attitudinal measurement scales have been convincingly validated, making primary research on trends all the easier. Formerly fuzzy terms like product quality and customer

[9] Sunstein [33] applied Condorcet's Jury Theorem to show that markets for binary decisions only work when most participants have a better-than-even chance of betting on the right answer. Though Condorcet's theorem does depend on the law of large numbers, it reinforces the present conclusion that these markets "work" only in the least uncertain, and hence least interesting, cases.

[10] Gordon, Glenn and Jakil [2] noted the advent of "new sources of social data." Another good sign: "Rather than assuming that because a university spends more it must be better, or using other proxy measures for quality, we will look at learning outcomes," says Andreas Schleicher, head of education research for OECD, quoted in The Economist (November 29, 2007, p.69) on a new scheme for ranking international universities.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

satisfaction now have rigorous operational definitions. Thus, there is now little reason to use price as a proxy for anything; we can measure almost any desired quantity directly.

Finally,

- Technology that is patented implies a monopolistic market that is not subject to the competitive price equilibrium of economics.
- The normal distributions underlying economic equilibrium equations do not capture the phenomena that concern us in technology assessment, where quantities (e.g., the distribution of company sizes in an industry, or the severity of disasters) follow power laws ([35]; see also [36] for a problem in point that is cleverly analyzed using the wrong probability functions).
- I have advocated increased attention in this journal to human biases in probability assessment, and these belie the economic assumption of fully rational self-interest.
- Later in this essay I will pick up on an idea of Hal Linstone's that emphasizes looking at signals farther afield than simple local market prices.
- There have been many critiques of the assumptions of economic theory; no need to rehash them here. Most recently, Prestowitz [37] listed the orthodox assumptions of trade economists, concluding bluntly, "Most of these assumptions obviously are wrong."

For all these reasons, there is now less justification than in the past for applying theories of economics to the questions with which this journal is concerned. Contributions from that discipline remain, of course, highly welcome[11]; it's just that economics (especially the neoclassical sort), never the only game in town, is even less so now.

Apropos of More Sex is Safer Sex and its ilk, it seems to me we are more susceptible to just-so stories in this age of complexity and networks. We are aware that everything is systemically connected to everything, so it's easy to come up with a startling but plausible connection between any *X* and *Y*. It remains as necessary as ever, though, to demonstrate that the connection is strong enough to affect *Y* materially, and indeed stronger than the effect of any other connected factor *U* or *V* that might also account for unexplained variance in Y.

4.3. Plans

Forecasters should adopt a principle from the venture capital industry: Plans *per se* (and I emphasize that I am referring to any particular plan documents) are trash. They won't come to pass. Their only purpose is to demonstrate that the planners can write a plan. This is a valuable purpose, but it is not sufficient for dealing effectively with the future. If the same planners show they can turn on a dime and react to new information by producing an appropriate new plan overnight, that is sufficient. The future is best served by people who can write a plan, perceive that the world has subsequently changed in an unanticipated way, throw away the plan without regret, quickly assemble a new plan, and instigate its implementation even while gathering further feedback. This advice seems especially applicable to makers of regional innovation plans and the like.

That said, it is interesting that in some focused areas, long-range planning is back. Questions of nuclear waste storage, environmental remediation, and archiving of digital information can be answered by plans that extend over multiple generations. These plans are very much worth making, but can still be obsoleted by newer scientific and engineering knowledge.

4.4. "Evidence-based" research

What I'm about to say does not apply in any way to the great majority of papers in TFSC. However, it does apply to many recent publications (e.g., [38,39]) in medicine, education, strategy, organizational studies, and even marketing — fields which are not central to but often touch on our concerns at Technological Forecasting & Social Change.

When a discipline shows sudden enthusiasm for "evidence-based research," it means the field has become so theory-driven and self-referential that (i) its conclusions become absurd and its leading researchers are ridiculed, or (ii) young researchers in the field, steeped in its orthodoxy, accidentally discover the joys of real data and field observation, say "gee whiz," and start a reform movement. (In either case, no alternative theory is immediately forthcoming, so we are not talking here of Kuhnian paradigm shifts.)

Picture four frogs in a line. One frog is named "Theory." Another is named "Methodology," the third is "Data," and the name of the last frog is "New Problems." As the leap-frog game progresses and Theory is temporarily in advance of Data, scientists enjoy Theory's guidance on where to look for new data. Then Methodology jumps to the front of the queue; a new lab instrument has been invented that for the first time allows researchers to capture the desired data — and to reveal unexpected kinds of data. Then the New Problems of industry and government decision-makers jump to the fore, highlighting new urgencies for theorists, experimentalists, and methodologists.

The leap-frog game is the central characteristic of scientific progress (see [40]). It is how science advances in an ongoing but somewhat unbalanced manner. No researcher should be so attached to theory (or to any of the other frogs, for that matter) that he or she ignores (or denies) the progress of the game. No discipline should drift so far from evidence that it has to stage a loud recovery, much less try to dignify its recovery with a ridiculous term like "evidence-based research."

[11] I particularly admire the European empirical economics tradition, which holds theory at arms length.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

TFSC authors have been wise not to hurry to institutionalize a theory for our field. Those who have begun to formalize a Body of Knowledge for the field (e.g., Glenn and Gordon [41], Martino [42], Dahle [43], and Slaughter [44]) have, again wisely, focused on its methodologies and on the problems that need to be addressed, rather than on theory. This does not imply that "the field lacks the consistency and coherence that mark more scientific fields" [2], but only that, like the fields of operations research and optics, its greatest contributions may be in methodology, guiding responses to real-world and laboratory problems, and supporting other scientific fields by directing attention to the best next question to ask.

Practicing forecasters inject intuition and judgment into their product. This is proper and does not mean forecasting is unscientific; it just illustrates the difference between research and practice in our field. See [45]. The existence of an active, commercially successful professional practice in technology forecasting is fortunate, and not just because it lends credibility to our research. I will reveal the more subtle reason in this article's conclusion.

4.5. Lean, flat organizations

Flat organizations lead to burnout and neurosis, not nimble efficiency. The important issue is empowerment, creativity and initiative, not efficiency. Let's fall out of love with flat organizations.

Compare, for example, Dell Corporation and Southwest Airlines. Dell deserves great credit for its successes, but basically the company has had one good idea: custom-assembled (but otherwise commodity) PCs coming out of a lean supply chain, made efficient by the World Wide Web. This idea and its offshoots are at the end of their life cycle. Dell has discovered it doesn't want individuals to order computers from its web site after all, because customers are not as susceptible to up-sells when they are not speaking with a live salesperson. Dell has similarly discovered unexpected competition from Apple, which has churned out product innovations at a steady clip and has moved customers beyond the desktop and laptop.

In the process, Dell has become known as a pressure-cooker workplace. Smart, amiable young people go to work at Dell and emerge as nervous wrecks. Their sacrifices have not kept Dell's stock price anywhere near its historic peak. This is not exclusively a Dell problem. Lean organizations, by virtue of eliminating layers of management and work-in-progress inventories, are more communications-intensive than any historic enterprises. Emails arrive at a pace that forces managers to be modern equivalents of Lucy and Ethel in the chocolate factory.[12]

Southwest Airlines is only somewhat lean (it never embraced the efficient hub-and-spoke route system), but its employees are empowered. Any employee at any level may have an idea and run with it, even spend money on it. Was the employee's idea a good idea? The company worries about that later, after the customer's problem has been solved. Almost uniquely in the industry, Southwest is solvent, it attracts creative employees whose ideas ultimately save the company money, and its fares have remained reasonable. It is among the few airlines that customers actually enjoy flying.

Most companies, of course, debate ideas before they are implemented. Here's a research project that would advance organizational science: One employee has an out-of-the-box idea. How many people should s/he "run it past" before the idea is spiked, or massaged into bland uselessness? What is the magical length of a communication chain, below which an idea can turn into a useful experiment, and above which initiative is (inadvertently or not) punished?[13]

5. Where our science needs to go

This section details just a few of the directions technology assessment researchers need to take in order to meet the challenges of the Multis, the Biggers, the Smallers, and the More Connecteds.

5.1. Agent-based simulations with smart agents, not stupid agents

About six years ago a luminary from the Santa Fé Institute lectured Intel's Oregon staff on the virtues of agent-based models in which the agents are myopic and able to access very limited information. The audience was lukewarm and the atmosphere was strained. The speaker was oblivious to the fact that his hosts, who bowed to and were driven by Moore's Law, strived to make every agent in the real world (whether human or machine) a smart agent — a far-seeing and well-informed agent.

My web browser tells me the weather (and an RSS[14] delivers traveler security advisories) minute by minute from the other side of the world. Google Earth lets me inspect the roof of your house from the comfort of my study. A manufacturer's computer can scan the full logistic chain of each of the company's suppliers. Let's get over the idea of simple agents, and develop models of systems of intelligent agents. The math will be harder, but that's no excuse not to try.

In particular, it would be nice to jettison the definition of a cellular automaton as "a collection of … cells on a grid … that evolves through … discrete time steps according to a set of rules based on the states of neighboring cells."[15] In this definition, again, each cell is myopic. In the Internet age, we might well model automata with clairvoyant cells! Few images could illustrate this as well as that of Indian farmers clustered around a village Internet kiosk to view daily crop prices in the nearby market cities. (Anticipating

[12] This scene from the classic television show is on YouTube, http://www.youtube.com/watch?v=4wp3m1vg06Q.
[13] This idea, informally, underlies the corporate practice of "skunkworks." See [46] and [47].
[14] "Really Simple Syndication" (RSS) automatically feeds changes in one web page to other web pages.
[15] http://mathworld.wolfram.com/CellularAutomaton.html. "Neighboring" usually means immediately adjacent cells (as in Conway's Game of Life), but in some cellular models it means neighbors two or three cells removed.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

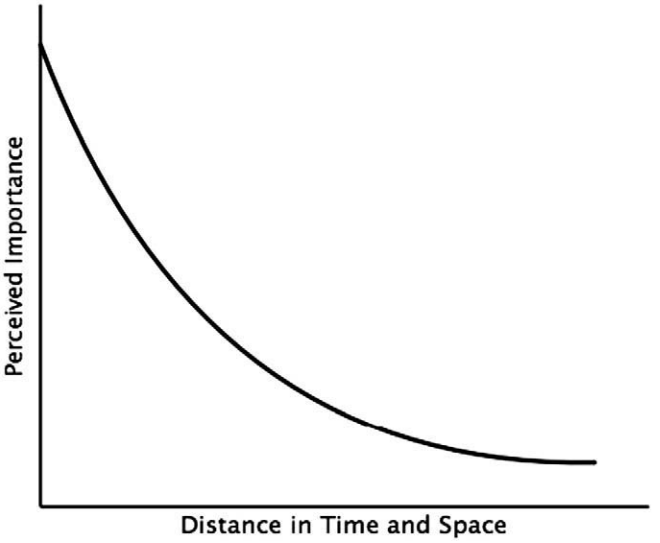

Fig. 1. The Linstone Principle: we discount the significance of people and events as their distance from us in time and space increases.

the counter-argument that quality of information attenuates with distance, I'll add that the Internet is said to abolish distance, and that in human systems we most often misunderstand the people closest to us.) How else can we know whether "Think Globally, Act Locally" actually works?

This is of particular interest because of an idea Hal has often presented in these pages; we might call it the Linstone Principle. Hal Linstone's idea [48,49][16] is that among the general population, the perceived importance and probability of an event drops off with its distance in time and space. Fig. 1 suggests that we give more weight to events that are in our own back yards, less about events on the other side of the world, more about things that happened today or will happen tomorrow, and less about what will happen ten years from now.

To Hal's conceptual abscissa (distance in time and space) we may add the scope of events, i.e., whether the event affects a single person or masses of people. We'll support an individual orphan in Ecuador, or victims of a single tsunami in the Indian Ocean, but discount endemic poverty in Haiti. A single incident of abuse at Oprah Winfrey's South African girls' school will move us, but we are cool to large-scale, ongoing domestic abuse in the US.

Hal conjectures that heavy discounting of distant events was a survival trait through most of our history, but he notes that discounting hinders public support for action against objectively dangerous futures.[17] He advocates [48,49] "(1) using telecommunications to bring a distant event, crisis, or opportunity closer (as the distant manned lunar landing was brought into our living room) and (2) using education to extend our perception out." Even as we admit the ethical reasonableness of this recommendation (it was telecommunications that brought the Winfrey school case to our attention), we must note that others (and these are ordinary people, not just Don Vito Corleone) believe the pinnacle of morality is to reserve passion for people and events that are close, e.g., family above all others. I admit to you that I see both sides of this question, rationally and morally.

What about empirically? A simulated cellular economy in which a certain fraction *f* of cells (the More Connecteds) may transfer resources to distant cells, and in which the remainder (like Don Corleone) shares resources only with immediately adjacent cells, ought to answer the question. What value of *f* results in an economy that displays, after many iterations, growth of resources, longevity of cell occupants, and other reasonable measures of overall fitness?

The design criteria for this simulation are in my desk drawer. If you know how to program a cellular automaton of the type I'm describing, drop me an email; I'm looking for a co-author.

Meanwhile, Hal's idea has consequences for innovation policy and for our editorial policy. Governments set social agendas, with technological agendas subsidiary to the social agendas. Technological Forecasting & Social Change respects diversity in this regard. Some governments want to send a man to the moon; others want to improve sewage services at home. The technology assessment problems are as valid and challenging for the efforts that benefit "all mankind" as for those that benefit primarily a local community.

The Linstone Principle explains why most people fail to learn from history. It explains why primary school teachers receive low salaries. The shape of Fig. 1's curve differs for different people, and perhaps for different kinds of people. What does the Principle imply about the kinds of people who should be our political leaders? Corporate leaders? Academic leaders?

[16] Joe Coates notes that the Linstone Principle was put forth independently by the late science journalist Anthony R. Michaelis.

[17] And the Linstone Principle means that clairvoyant agents are not *always* the best approach. However, it cannot be denied that acting on non-local information can produce great efficiencies. We used to waste time and gasoline circling the "arrival" lanes at the airport, looking for our arriving friend; now, we can wait out of traffic until s/he calls us on the mobile phone to say s/he's waiting with luggage at a certain spot. Breslow [50] quotes Harvard sociobiologist Edward O. Wilson, "'Long-term thinking is for the most part alien to the American mind.' That must change, [Wilson] insists, or else 'we will permanently harm ourselves.'"

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

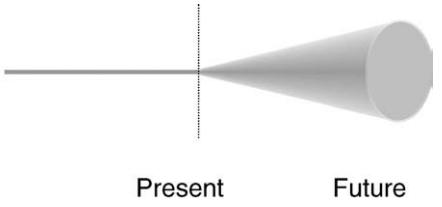

Fig. 2. A view of the past as determined, with a knowable present and uncertain future.

5.2. When does technology colonization end

The first automobiles were called horseless carriages because the carriage concept colonized the automobile concept, in the minds of producers and customers, limiting the auto's early usage modalities. By and by, users discovered that autos could perform functions that horse-drawn carriages could not, and society and infrastructure evolved accordingly.

The Internet can do things that the post, the phone system, and town hall meetings cannot. Internet entrepreneurs understand this very well, and have floated exciting new products that reflect the fact. But the post, the phones, and in-person meetings have colonized the Internet in the mind of the market at large. I conjecture that this was one reason for the dotcom bust.[18] The online businesses that now thrive help people perform familiar, cozy functions – auctions, romantic introductions, job searches – more easily and quickly. Few people are using the net to do truly new things; everybody loves joining LinkedIn, but nobody knows what to do with it.

I hope to see research that sheds light on when Internet users (and users of any revolutionary technology) will throw out the colonizers. The colonizers are not malevolent people, but rather, old concepts of usage and functionality!

In the same vein, and not to insult only endusers: Industrial repackagers of a technology can slow the diffusion of innovation by misusing the technology. Consider transponders on toll roads. The toll operator tells the customer that the transponder is working to spec; the customer drives through a toll booth with a radio-frequency reader; the transponder doesn't work and the toll is not paid; the toll operator imposes a three hundred dollar penalty; the customer can't resolve it through the toll operator's "customer service system"; the customer throws the transponder away and goes back to tossing coins into the toll basket. But I suppose we shall not be able to model the technological stupidity and irresponsibility of organizations.

Leibowitz [53] thinks the Internet bubble burst because we ignored basic economic principles. I think it burst because we ignored colonization. If we can develop a rigorous understanding of colonization, in the pages of TFSC, it will be a better leading indicator of the Internet than the fevered gossip in Silicon Valley bars; we can answer the question (notwithstanding that some consider it already answered) of whether Meg Whitman of eBay paid too much for Skype.

5.3. Undetermined past, fuzzy present, uncertain future

One rarely hears a historian utter the standard scientific disclaimer "at the present state of our knowledge, we tentatively believe the proposition might be true." Irreducible uncertainty in a historical study is not portrayed as a statistical residual, but rather as … religion! "We believe the artifact served ritual purposes." "The complex appears to have been used for worship." In other words, the historian simply doesn't know what function was originally served by the excavated site.

As a result, history books are written without acknowledgment of uncertainty, and an uncritical reader would conceive of history as determined. A picture of this conception, with the uncertain future portrayed as a cone in space-time, is in Fig. 2.

The courts, of course, see it differently. Witnesses deliver conflicting testimony about a past event, and physical evidence is ambiguous. Juries deliver a consensus picture of the past, based (in US civil cases) on "preponderance of evidence" or in criminal cases "beyond a reasonable doubt." Physicists, likewise, tell us Schrödinger's cat is only dead or alive after its box is opened; before it is opened, the cat's status is "undetermined." The legal and physical view of time looks like Fig. 3.

Psychology and neurology now tell us there is a time lag between an event and our perception of that event, and moreover that perception is colored by our biases and prior expectations. Time therefore looks like Fig. 4.

Appropriately enough, time looks like an hourglass (laid on its side, in Fig. 4), widening as we go farther back or forward, and narrow – but definitely not the dimensionless point that would denote full certainty – at the "present moment."

Why is this relevant for technology forecasters? First, because it recognizes the difficulty of explanation. A butterfly may cause a hurricane, but you can't identify the butterfly by analyzing the hurricane. A current trend may arise from multiple histories, and Fig. 4 allows multiple possible histories. Second, multiple histories (explanations) allow more latitude in extrapolation, and perhaps therefore a more realistic view of what extrapolation can and can't do.

Fig. 5 shows (conceptually) two extrapolations of the same phenomenon from two different but perhaps equally plausible histories. Neither of these trajectories would be possible if time were viewed as in Fig. 1.

[18] A straightforward instance of the double-humped life cycle curve that is caused by over-hyped initial expectations among a minority. See [51] and [52, p.50].

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

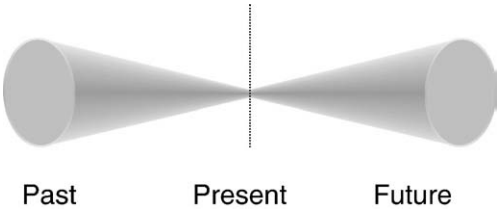

Fig. 3. The past is based on uncertain evidence.

It understates the matter to say that constructing time in this way adds to the challenge of forecasting. Yet it seems to be a realistic way of viewing time, and may help prevent hubris on the part of forecasters. It is also practical; Callick [54] makes the chilling allegation that the government of the People's Republic of China forces academic historians to take the view of history shown in Fig. 1. Fig. 5 shows that this policy will constrain that country's view of its future as well as of its past.

5.4. Sustainability

I've never seen a precise definition of it. I probably wouldn't recognize it if I saw it. It sounds like a good thing, though.

The eminent dean of a leading school of environmental science snorted when he was asked about sustainability. The whole notion, he replied, seems to run counter to the second law of thermodynamics. At another extreme are advocates of minimizing the impact of people on the planet. Their subtext implies minimizing the number of people on the planet (see [55, 56] for further comment on this). At still another extreme are economists like Robert Solow [57], who believes everything is sustainable because the price mechanism moderates input substitutions.

We can suspect the dean of taking too literal a view, and suspect the earth advocate of hating people. The economic theorists continue to ignore the externalities that create the environmental problems in the first place. The City Club of Portland [58] cited one source that advised, "Decouple economic development and population growth from environmental impacts." I am convinced this is a physical impossibility. Is there a constructive middle ground that is scientifically feasible?

Nothing we do will be sustainable for the very long run. We depend on solar energy (as the dean was no doubt thinking), and the sun will eventually die. Meanwhile, every social process degrades energy, in the aggregate.

- Sustainable cannot simply mean static; that would mean the end of innovation and the start of excessive regimentation in all spheres of life. Climate change (that portion that is not anthropogenic) would proceed in any case, and society and the ecology would have to change and adapt.
- Can "sustainable" mean "capable of evolving in a steady, manageable way?" No. There are always Black Swans. Global warming is only one example (see [27]), and it is one that is more predictable than most.
- People, profit, and the planet? We can all get along sweetly and live lightly on the planet, and still get hammered by a rogue asteroid. Only through technology can we hope to reduce the probability or consequences of an asteroid collision, and better technology will do it better. A static society, creating no new technology, is no answer.
- Notwithstanding that many subsistence economies have lasted for hundreds of years, and have been portrayed by historical writers as noble and fulfilling, we cannot equate sustainability with subsistence regimes. Without surpluses and redundancy, such economies are vulnerable to environmental change.

On what time scale is it realistic to speak of sustainability? How wide are the limits of change, within which we're still willing to say a system has been "sustained"? An impressive number of sources agree the time span is a few generations. The City Club of Portland [58], the President's Council on Sustainable Development, Sustainable Seattle and others say "for generations to come"; "present and future generations"; "our children and grandchildren." This view sensibly leaves scope for changing the plan when conditions and technologies change.

Whether the dialog is cast in terms of P^3 (people, profit, and the planet) or E^3 (Environment, Economy, and Equity), Technological Forecasting & Social Change can help advance it by attending to life-cycle perspectives on products and technologies, and to bio-mimetic technologies and market mechanisms for recycling/reselling "waste." P^3 also implies taking care of (providing

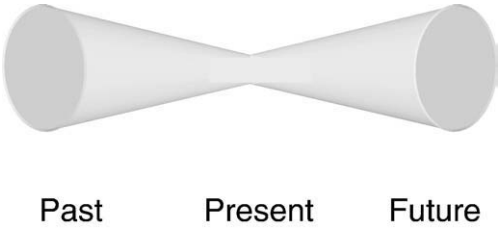

Fig. 4. The present is none too certain either.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

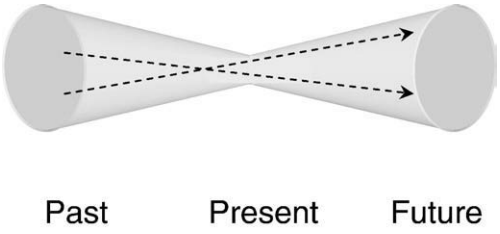

Fig. 5. Multiple valid explanations lead to divergent extrapolations.

new habitat for) the poor who will be left homeless by rising sea levels. Is renewed mining in warming north polar regions immoral? Of course not. If done carefully, it's part of P^3. Naturally, forensic investigations will reveal who some of the culprits are in anthropogenic climate change. But the excoriated NASA official who said the climate will change with us or without us, and our major challenge is adaptation, was correct.[19] Let's do less arguing about whose fault it is, and learn to do better as we invent adaptive strategies.

I don't think these adaptive strategies can rely totally on measuring and pricing externalities. (The carbon rights exchanges have been distressingly scandal-prone, according to *The Economist* magazine.) Does the idea of privatization of your city water supply scare you? If so, consider this more extreme example: you exhale CO_2 when you breathe…Will bourses for carbon rights lead to "pay for breath"? We will have to be very clever to design sustainable regimes that are not totally price-based. But we will have to design them.

All in all, sustainability is most workable as a concept when it is defined loosely. In any case, we will not be able to forecast with certainty the impact of a managerial act on people or on the planet any more than we can foresee the impact of a corporate activity on the financial bottom line. (Think about making a sales call on a new prospect, who may or may not purchase your product.) Why not? First, we don't know enough of the applicable science. Second, the complexity of environmental, medical, and psychological phenomena makes prediction error-prone. Third, the impacts on people, on profits, and on the planet will interact with one another!

5.5. Macroengineering

Every macroengineering project is a socio-technical system, involving and affecting large numbers of people and even entire and multiple societies. Prospects for macroengineering projects are changing. Global warming has put an end to the plan to build an ice highway (for trucks) across the North American arctic. 9/11 has halted plans for ultra-tall buildings, except in Japan and the Emirates. The Three Gorges Dam has created unanticipated environmental and social problems [60]. Though we're now reasonably good at building oil supertankers, spills still happen.

Despite these difficulties and tragedies, plans are afoot for widening the Panama Canal; for a transatlantic rail tunnel linking Canada to Scotland; and for a bridge across the Bering Strait.[20]

Astounding as these may be, still other challenges for very large, complex engineering systems also deserve our attention. These include space habitats, the Internet, large software projects, intelligent transportation systems, the financial networks of the expanding European Union, multi-country and multi-cultural military/political alliances like NATO, and (the best example of very large socio-technical systems) cities. The study of the future of cities can include the very tall buildings that have become the symbols of many cities but are now known not just as engineering/architectural marvels but also as targets for terrorism.

Most cities are remarkable in another way, as the longest-running examples of large "open-source" projects. Cities were open-source long before Linux. What can the study of cities teach us about the socio-economics of (for example) successful and very large open-source software projects?

6. The purposes and ends of our field

Lipsey [61] remarked that each of mankind's major technological steps — domesticated animals, writing, iron, agriculture, water power, printing, steam power, electricity, telephone, and onward:

- magnified power beyond the human arm
- enabled a greater scale of operations
- enabled greater geographical reach, new supply chains and factory layouts
- enabled further specialization of labor
- made new relationships between labor and capital

[19] The context of opinion and fact surrounding this statement is complex and contradictory. The British Stern Review concludes (on behalf of the British government) "it would be considerably cheaper to stop current climate trends than to try to adapt to a changed world" [59]. This is notwithstanding that, as Norris [59] notes, "it is really hard to get [heat-trapping] gases out of the atmosphere once we put them there."

[20] http://shopping.discovery.com/product-37057.html?endecaSID=1180045A72E1. This happens while we let our meso-scale infrastructure – city streets and bridges, sewers, etc. – deteriorate. Another reason for linked multi-level modeling and planning.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

- affected the centralization/decentralization of activities
- created new organizational forms
- increased fine control of materials and processes
- changed social relations between people.

These social and organizational changes, in turn, enabled and demanded further technological progress.

It is really only worth thinking about such things if by so doing we might help steer them in a direction of improvement, of greater benefit to people, profits, and the planet. In fact, an added appeal of being involved with this journal is the chance to work with authors and editors who exhibit idealism even as they strive for scientific objectivity. To deal with caring, optimistic and creative people is uplifting.

Indeed, mine was the generation that, in our university years, vowed to end poverty, war, and racism. Thirty-five years later, we can note modest, uneven, but definite progress against racism. At first blush, this seems to have nothing to do with technology. However, color barriers have fallen in science, engineering, and technology education and employment, adding to our prospects for continued innovation with wider human benefits. Poverty has somewhat diminished worldwide, but increased in the US. It's a fair bet that technology (including "appropriate technology") deserves much of the credit for the upside, and can be relied upon to underpin further progress.[21]

Of the three, it is war, against which we've made no inroads, that generates and absorbs the most new technology. (By the time you read this, for example, the US Army will have completed a dramatic competition to award contracts for the development of robotic automobiles. The machines will be deployed in the rubbled and restive streets of Baghdad.) The human cost of war is unspeakable, and defense contractors' profits are astronomical. In no other socio-technical arena is there such a disparity between the soft costs (the scientific jargon seems tasteless in this context) and the hard benefits. Investigating this, understanding it and helping the general public understand it, and designing challenges for society and technology that are attractive alternatives to war, deserve the urgent attention of citizen-scientists in the assessment field.

7. Conclusion: criteria for models and methods in technology forecasting—the Tao of research

Military leaders envision current and future wars in terms of Multis, rather than in terms of Biggers. Their technologies, ever More Connected, change the nature of command structures and missions. The technologies also change the nature of military transparency and accountability in unexpected ways, as Iraq-related events have demonstrated. As we become More Connected and interact easily with distant groups that share our own views (perhaps thus relieving our own feelings of alienation) we are at risk of losing our ability to get along with next-door neighbors holding more diverse beliefs. Does this increase the likelihood of social polarization (as seems to have happened in U.S. politics)? How does this risk balance against increased information efficiency and reduced alienation? The technologies of Multis, Biggers, Smallers, and More Connecteds offer pitfalls as well as promises, and in this way are no different from other technologies. The promises and pitfalls are always worth addressing, perhaps in Technological Forecasting & Social Change papers. The present essay, though, has addressed the question of how we can best expand our models and research approaches to encompass the new world of Multis, Biggers, Smallers, and More Connecteds. Its suggestions are summarized in Table 1.

When should we model (or recommend to a client) exploration of new knowledge, versus exploitation of existing knowledge? When should we think big and when is it wise to think small? When should we model at all? Clearly, research can make us expert in Biggers, and in Smallers, in exploration and in exploitation, and in every yin and every yang of our discipline. However, my now-long research career has led me to hypothesize that research cannot tell us when to focus on the big vs. the small, the local vs. the global, the yin vs. the yang. Only experience and practice can do this.

This is why it is fortunate that we have a vital professional practice community in technology forecasting and assessment. Practitioners shine a spotlight on the New Problems frog, and they are the key to understanding the interplay of yin and yang that constitutes the Tao of modeling.

Models that are too unconnected reduce costs in one department (for example) while pushing costs off to other departments. Models that take too many connections into account risk falling into just-so stories, or even conspiracy theories. Experience helps us balance the risk of suboptimization against the difficulties of modeling large and highly interconnected systems.

Joe Coates (who is now a practitioner) has urged me to endorse closely reasoned rhetorical works as another category of acceptable TFSC papers. My initial resistance to this idea – the line between scholarship and journalism would be blurred, we would risk running too many opinion pieces, etc. – dwindled when I recalled Robert McNamara's tragic over-reliance on quantitative systems analysis during the Vietnam War era, and his lengthy apologies [66] thereafter. We cannot ignore the human side of what we do, nor are some of our newer subjects areas susceptible to structured methodologies. Thus, historical, dialectical and even literary approaches to analysis and forecasting are parts of a balanced toolkit.

Through contact with practitioners, researchers will, I hope, show a fine sense of when to be monolithic and centralized and when to be Multi (distributed and decentralized); when to make small, simple, elegant models and when to be Bigger, detailed and

[21] The number of U.S. residents living in poverty has risen from about 23 million in 1973 to 36.5 million in 2006 ([62, p. 11]; see [63] for alternative measurements). The percent of Americans in poverty has remained constant at 12.3% over the same interval [62]. The Economist [64] actually blames technology for rising income inequality (though not for poverty). "In emerging markets the people best able to take advantage of new technology are those who already have an education and who are usually among the richest."

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

Table 1
Summary of modeling and methodological recommendations

Recommendations	Raised in this essay in connection with
Agent-based and cellular models with less myopic agents, allowing possibly long lag and lead effects.	Sensors, effectors, microcontrollers, and computers have more speed, capacity, and range. People (who may not be smarter but who do get information from wider sources than before) use smarter computers.
Models that can scale to very large numbers of variables and variate relationships.	Big problems can be attacked at an abstract level (simple models) or at a detailed level.
Models that eschew false equilibria and false distributional assumptions.	Let empirical data speak. Don't be afraid to invent (and validate!) new methodologies, and to apply multiple methodologies to any problem.
Models that can disassemble existing socio-technical processes and put them together again in novel and promising ways.	Different business models, organizational models, and diffusion mechanisms for different populations. Minimizing technology colonization.
Models that recognize diverse human and organizational biases, limitations, incentives, and talents.	Behavioral approaches to forecasting. Organizational designs that stretch but do not break human capacities. Multiple-stakeholder models (see e.g. [65]).
Models that interface with new data sources and new information and measurement technologies – using standardized interfaces but allowing flexibility for those researching emerging, unstructured problems.	Measure human potential. Strive for commensurability of models and databases. As with any technology, know when to institute standards. (New areas of study and breakthroughs tend to demand their own unique vocabulary.)
Models that fully recognize the mutuality of technological and social change.	Identify what makes a society 'ready' for a particular innovation. Model technological change as a function of social change, and vice versa.
Models that emphasize robustness and rapid recourse in response to new data.	Plans should not be enshrined; planning should be. Train resilient planners.
Models and communities of collaboration that never drift into narcissistic theorizing.	Avoid the need for 'evidence-based' revolutions.
Models that are bold yet ethical and in line with known laws of physics, chemistry, and biology.	Realistic views of sustainability. Bio-mimetics. Learn from biology.

messy; when to model objects of interest on a piecemeal basis and when to make models More Connected to communities of scholarship and practice, to diverse databases, to scientific instruments, and to other models; and when to make models mathematical, verbal, graphical, or physical. They will utilize theories from diverse fields, but expect rapid progress mainly in new methodologies, new data sources, and the structuring of new problems.

There is no shortage of new problems, but there are many new tools available and our authors will invent more. The second forty years of Technological Forecasting & Social Change will be every bit as exciting as the first.

References

[1] V. Coates, M. Farooque, R. Klavans, K. Lapid, H.A. Linstone, C. Pistorius, A.L. Porter, On the future of technological forecasting, Technol. Forecast. Soc. Change 67 (2001) 1–17.
[2] T.J. Gordon, J.C. Glenn, A. Jakil, Frontiers of futures research, Technol. Forecast. Soc. Change 72 (2005) 1064–1069.
[3] C. Fields, R&D Consortia, Speech at IC^2 Institute of the University of Texas at Austin, 1990.
[4] F. Phillips, Social Culture and High Tech Economic Development: The Technopolis Columns, Palgrave Macmillan, London, 2006.
[5] H.A. Linstone, Complexity science: implications for forecasting, Technol. Forecast. Soc. Change 62 (1999) 79–90.
[6] B. Bimber, D.H. Guston, Technology assessment: the end of OTA, Technol. Forecast. Soc. Change 54 (2&3) (1997), Special Issue.
[7] F.J. Contractor, S. Kundu, The role of export-driven entrepreneurship in economic development: a comparison of software exports from India, China, and Taiwan, Technol. Forecast. Soc. Change 71 (8) (2004) 799–822.
[8] B.-W. Lin, P.-C. Li, J.-S. Chen, Social capital, capabilities, and entrepreneurial strategies: a study of Taiwanese high-tech new ventures, Technol. Forecast. Soc. Change 73 (2) (2006) 168–181.
[9] T.-H. Liu, S.-C. Hung, Y.-Y. Chu, Environmental jolts, entrepreneurial actions and value creation: a case study of Trend Micro, Technol. Forecast. Soc. Change 74 (8) (2007) 1432–1445.
[10] L.M., Holson: Verizon expands options for users. New York Times News Service, in San Diego Union-Tribune, November 28, 2007, p. C1.
[11] F. Kodama, Technology Fusion and the New R&D. Harvard Business Review July-August, 1992, pp. 70–78.
[12] R. Henderson, K.B. Clark, Architectural innovation: the reconfiguration of existing product technologies and failures of established firms, Adm. Sci. Q. 35 (7) (2006) 925–952.
[13] R.N. Kostoff, D.R. Toothman, H.J. Eberhart, J.A. Humenik, Text mining using database tomography and bibliometrics: a review, Technol. Forecast. Soc. Change 68 (3) (2001) 223–253.
[14] A.L. Porter, QTIP: quick technology intelligence processes, Technol. Forecast. Soc. Change 72 (9) (2005) 1070–1081.
[15] T.U. Daim, G. Rueda, H. Martin, P. Gerdsri, Forecasting emerging technologies: use of bibliometrics and patent analysis, Technol. Forecast. Soc. Change 8 (73) (2006) 981–1012.
[16] E.M. Rogers, Diffusion of Innovations, 5th ed., Free Press, New York, 2003.
[17] J.S. Coleman, Social capital in the creation of human capital, Am. J. Sociol. 94 (1988) S95–S120, Supplement.
[18] F. Fukuyama, Trust: The Social Virtues & the Creation of Prosperity, The Free Press, New York, 1995.
[19] M. Granovetter, The strength of weak ties: a network theory revisited, Sociol. Theory 1 (1983) 201–233.
[20] W. Bell, Foundations of Futures Studies I: History, Purposes, Knowledge, Transaction Publishers, New Brunswick, NJ, 2003.
[21] W. Bell, Foundations of Futures Studies II: Values, Objectivity and the Good Society, Transaction Publishers, New Brunswick, NJ, 2004.
[22] M. Tadajewski, M. Saren (Eds.), Amnesia and Marketing Theory: Processes of Forgetting, a special issue of Marketing Theory, forthcoming in vol.8, 2008, http://ama-academics.communityzero.com/elmar?go=1580500.
[23] K. Eijkel, A.J. Groen, S. Walsh, Special section on nanotechnology policy, Technol. Forecast. Soc. Change 74 (9) (2007) 1631–1633.
[24] J.J. Winebrake, B.P. Creswick, The future of hydrogen fueling systems for transportation: an application of perspective-based scenario analysis using the analytic hierarchy process, Technol. Forecast. Soc. Change 70 (4) (2003) 359–384.
[25] A. Grubler, Y. Ermoliev, A. Kryazhimskiy, Coping with uncertainties. IIASA Conference Global Development: Science and Policies for the Future, Laxenburg, Austria, November 2007.
[26] J. Mingers, A. Gill (Eds.), Multimethodology: The Theory and Practice of Combining Management Science Methodologies, Wiley, 1997.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005

[27] N. Nakicenovic, The changing world: energy, climate and social futures, IIASA Conference Global Development: Science and Policies for the Future, November 13-15 2007.
[28] F. Phillips, The conscious manager: Zen for decision makers, General Informatics, Beaverton, Oregon, 2003.
[29] S.A. Kauffman, The origins of order: self-organization and selection in evolution, Oxford Univ. Press, New York, 1993.
[30] R. Hanson, The policy analysis market: a thwarted experiment in the use of prediction markets for public policy, Innovations (2007) 73–88 (Summer http://www.mitpressjournals.org/doi/pdfplus/10.1162/itgg.2007.2.3.73?cookieSet=1).
[31] J. Surowiecki, The wisdom of crowds, Anchor (2005).
[32] N.N. Taleb, The Black Swan: The impact of the highly improbable, Random House, New York, 2007.
[33] C.R. Sunstein, When Crowds Aren't Wise, http://harvardbusinessonline.hbsp.harvard.edu/hbsp/hbr/articles/article.jsp?ml_action=get-article&articleID=F0609A&ml_issueid=null&ml_subscriber=true&pageNumber=1&_requestid=18424.
[34] J.B. DeLong, Maybe money does make the world go round, The Chronicle of Higher Education 54 (11) (November 9, 2007) B15.
[35] P. Andriani, B. McKelvey, Beyond Gaussian Averages: Redirecting Management Research Toward Extreme Events and Power Laws, Academy of Management Annual Meeting, August, Honolulu, 2005, http://www.isop.ucla.edu/cms/files/andriani_mckelvey.pdf.
[36] D.A. Samuelson, Mass egress and post-disaster responses, OR/MS Today 34 (5) (2007) 20–24.
[37] C. Prestowitz, Unfair trader? China and East Asia play by different rules, San Diego Union-Tribune, April 22, 2007, pp. G1–G5.
[38] W.F. Cascio, Evidence-based management and the marketplace for ideas, Acad. Manage. J. 50 (5) (2007) 1009–1012.
[39] D.M. Rousseau, S. McCarthy, Educating managers from an evidence-based perspective, Academy of Management Learning & Education 6 (1) (2007) 84–101.
[40] D.B. Learner, F. Phillips, Method and progress in management science, Socio-Econ. Plann. Sci. 27 (1) (1993) 9–24.
[41] J.C. Glenn, T.J. Gordon (Eds.), Futures Research Methodology, American Council for the United Nations University, Washington, D.C., 2003, http://www.acunu.org/millennium/FRM-v2.html.
[42] J.P. Martino, Technological Forecasting for Decision Making, 3rd ed., McGraw Hill, 1992.
[43] K. Dahle, 60 Key Works - A Beginner's Guide to the Futures Literature, Ideas Bank Foundation, Oslo, Norway, http://ide.idebanken.no/English/Framtidsbilder.html.
[44] R.A. Slaughter, The knowledge base of futures studies, Four volumes 1996-2000. DDM Media Group: Futures Study Centre, Hawthorn, Victoria, Australia, 1996.
[45] R. Frydman, M.D. Goldberg, Imperfect Knowledge Economics: Exchange Rates and Risk, Princeton University Press, 2007.
[46] B.R. Rich, L. Janos, Skunk Works: A Personal Memoir of My Years of Lockheed, 1st pbk. ed., Back Bay Books, 1996.
[47] H. Linstone, Review of Rich and Janos, Skunk Works, Technol. Forecast. Soc. Change 49 (1) (1995) 103–108.
[48] H. Linstone, On discounting the future, Technol. Forecast. Soc. Change 4 (1972–73) 335–338.
[49] H. Linstone, Decision making for technology executives: Using Multiple Perspectives to Improve Performance. Artech House, Boston, 1999, pp. 215–225.
[50] J.M. Breslow, Scholars and 'the American Idea.' The Atlantic, November, 2007, Chronicle.com/daily/2007/11/603j.htm.
[51] J. Wind, V. Mahajan, Marketing hype: a new perspective for new product research and introduction, J. Prod. Innov. Manag. 4 (1) (1987) 43–49.
[52] F. Phillips, Market-Oriented Technology Management: Innovating for Profit in Entrepreneurial Times, Springer-Verlag, Heidelberg, 2001.
[53] S.J. Leibowitz, Re-Thinking the Network Economy, AMACOM Division of the American Management Association, 2002.
[54] R. Callick, The China Model, From the November/December 2007, Issue of *The American* http://www.american.com/archive/2007/november-december-magazine-contents/the-china-model.
[55] F. Phillips, Public health and aesthetics in the environmental debate, Technol. Forecast. Soc. Change 55 (2) (1997) 193–195.
[56] F. Phillips, Trading down: the intellectual poverty of the new FTAs, Technol. Forecast. Soc. Change 71 (8) (2004) 865–876.
[57] R. Solow, Sustainability: An Economist's Perspective. Eighteenth J. Seward Johnson Lecture, Woods Hole Oceanographic Institution, June 14, 1991.
[58] City Club of Portland, Building a Sustainable Future for Portland. City Club of Portland Information Report, November, 2000.
[59] R. Norris, Global instability: climate change is about to come home to roost, San Diego Union-Tribune, December 6 2007, p. B1.
[60] A. Ang, Yangtze dam risks disaster. The Philadelphia Inquirer (Associated Press) December 30, 2007, http://www.philly.com/inquirer/world_us/20071230_Yangtze_dam_risks_disaster.html.
[61] R. Lipsey, Humans as technological animals: causes and consequences of sustained technological change, Steinhardt Lecture in Economics, Lewis and Clark College, Portland, 2002.
[62] C. DeNavas-Walt, B.D. Proctor, J. Smith, Income, poverty, and health insurance coverage in the United States: 2006, Current Population Reports #P60-233, U.S. Department of Commerce Economics and Statistics Administration, U.S. Census Bureau. Washington D.C., 2007.
[63] J. Iceland, Poverty among working families: findings from experimental poverty measures. U.S, Census Bureau Current Population Reports (Special Studies P23-203). Washington D. C., 2000.
[64] The Economist (no byline), Somewhere over the rainbow, January 26, 2008, pp. 27–29.
[65] G.O. Collantes, Incorporating stakeholders' perspectives into models of new technology diffusion: the case of fuel-cell vehicles, Technol. Forecast. Soc. Change 74 (3) (2007) 267–280.
[66] R.S. McNamara, J.G. Blight, R.K. Brigham, T.J. Biersteker, H.Y. Schandler, Argument Without End: In Search of Answers to the Vietnam Tragedy. PublicAffairs, 1999.

Please cite this article as: F. Phillips, Change in socio-technical systems: Researching the Multis, the Biggers, and the More Connecteds, Technological Forecasting & Social Change (2008), doi:10.1016/j.techfore.2008.03.005