Presenting System Dynamics to Social Scientists: An economics example

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Abstract

The social sciences provide a rich repository of open, interesting, and unsolved questions that can benefit from the application of system dynamics (SD). After "solving" a problem, SD researchers must present their results, which is not as straightforward as it might seem. This study describes lessons learned presenting system dynamics results to an economics audience during the publication of Lofdahl (2002) and is organized according to the four dicta of Repenning (2003): 1) size your model appropriately, 2) build the intuition of your reader, 3) do your homework, and 4) choose your audience wisely. The study finds that the skills necessary to perform and to communicate system dynamics research are different and can work at cross-purposes.

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Keywords

trade, environment, deforestation, economic dynamics, spatial modeling, geographic information systems (GIS)

0. Introduction

Social and natural scientists have a relationship that is long-lived, intellectually distant, and often contentious. This relationship has become closer and more parallel with the advent of ubiquitous, powerful computing that allows apparently unrelated problems to be addressed using similar quantitative techniques and methods. Naturalist E.O. Wilson writes in *Consilience* that the division between the social and natural sciences is artificial, a remnant of vestigial disciplinary divisions and the institutions that support them:

> The greatest enterprise of the human mind always has been and always will be the attempted linkage of the [natural] sciences and the [social] humanities. The ongoing fragmentation of knowledge and resulting chaos in philosophy are not reflections of the real world but artifacts of scholarship. The propositions of the original Enlightenment are increasingly favored by objective evidence, especially from the natural sciences. (Wilson 1998, 8)

The study of complexity – whether cellular automata, complex adaptive systems, agent based simulation, system dynamics (SD), or another advanced computer technique – implicitly acknowledges the fundamental unity of the social and natural sciences. Complexity studies use computation as a cognitive prosthetic, a research component coequal with data and theory that not only links data with theory in new and interesting ways but also connects the social and natural sciences. Their respective contributions to this emerging, computer-enabled relationship however are not equal, with the social sciences offering interesting, important, and unsolved problems and the natural sciences creating new methodologies with which to tackle them.

Addressing and solving social science problems is difficult however as the process is comprised of three non-trivial steps:

1. Master natural science methods and complex systems techniques,
2. Find an interesting, unsolved, and well-specified social science problem,
3. Use complex systems techniques to "solve" the social science problem.

Upon successful completion of these steps, the researcher might feel a sense of accomplishment after a job well done. However, much work remains –namely presenting, packaging, convincing, and selling. Because the results pertain to a social science problem, they should be reported back so that they can be understood. In this regard complexity reveals itself to be a double-edged sword: while the power of complex analytic techniques allows unsolved problems to be tackled in new and interesting ways, that same complexity can become a barrier to the reporting of research results. Successful researchers will acknowledge and overcome this communication challenge.

This study presents lessons learned from the publication of Lofdahl (2002), a trade and environment study, organized by the four research organization suggestions of Repenning (2003): 1) *size your model appropriately*, in which the system dynamics simulation is presented, 2) *build the intuition of your reader*, in which the study's statistical model, visual display of quantitative information, and narrative clarity are discussed, 3) *do your homework*, in which the challenges of interdisciplinary work and the concept of computational equivalence are presented, and 4) *choose your audience wisely*, in which economics is contrasted with SD research. This study addresses the various stages of the research process, from the structuring of the initial research to the review process and post-publication presentations, and concludes that the skills necessary to perform complexity research and to communicate its results can be quite different.

1. Size your model appropriately

Before undertaking a system dynamics study, the researcher must have an interesting, unsolved, and well-specified problem. The example used in this study concerns trade and the environment. The topic has a pedigree as economists and environmentalists have long debated the relationship between trade and the environment with economists holding the analytic edge. A concise synopsis of this debate appears in the November 1993 issue of *Scientific American* with Columbia University free-trade economist Jagdish Bhagwati squaring off against University of Maryland environmental economist Herman Daly. Bhagwati (1993) argues that free trade improves the environment as GNP increases are consistently correlated with environmental improvements. Because rich countries tend to have better environments, and because trade helps make countries rich per Ricardo's law of comparative advantage, economists hold that increased GNP leads to environmental improvement. Economists therefore maintain that trade should be endorsed by environmentalists as it helps the environment (Economist 1999).

Daly (1993) takes the opposite position, that trade contributes to the development that causes environmental degradation. The problem however is that while environmentalists hold that trade and economic growth are historically coincident with environmental degradation, they have not yet been able to marshal empirical evidence to support this position. Thus economists generally and the World Trade Organization (WTO) specifically have ignored environmentalists because their arguments are seen as grounded in transient emotions and poor economics. Environmentalists took to the streets in Seattle in the fall of 1999 in part because of the traditional unresponsiveness of economists to their concerns.

Lofdahl (2002) attempts to resolve the Bhagwati and Daly debate using system dynamics. The motivating intuition was that the causal complexity of nonlinear, stock-flow, and feedback relationships (Forrester 1961; Sterman 2000) in the trade and environment system led both to the debate and its impasse. A workable system dynamics simulation is developed in Lofdahl (2002, ch. 5), and while it is simple by system dynamics standards, understanding it remains daunting for the uninitiated. My advisor, Michael Ward, suggested that, to aid the reader's understanding, the simulation be simplified still further and made more graphical by condensing its key concepts into a single diagram, which is shown in Figure 1.

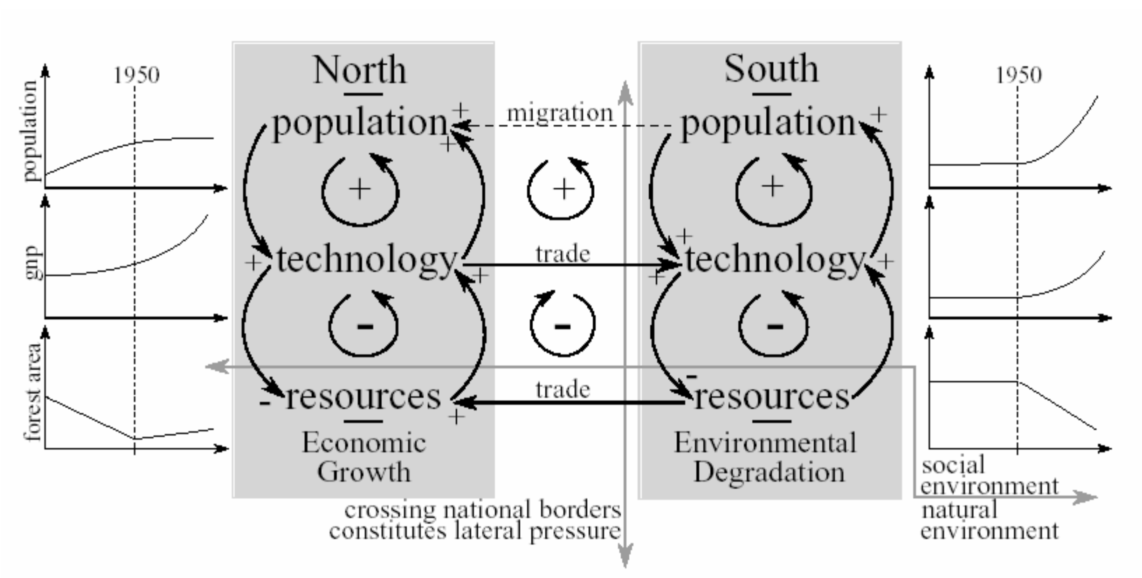

Figure 1: Trade and the Environment as a Complex System

Figure 1 presents the key concepts of Lofdahl (2002) as well as the intuitions that motivated the study. The diagram represents a fundamental disaggregation of the world economy between the developed North – that is, the United States, Western Europe, and Japan – that exhibits economic growth and the developing South – that is, Latin America, Africa, and Southeast Asia – that exhibits environmental degradation. This is in contrast to the whole world perspective of *The Limits to Growth* (Meadows et al, 1972), which critics said averaged away the concerns of the world's poor.

The key measures for this model are also presented: *population*, *technology* as measured by its proxy *GNP*, and *resources* as measured by its proxy *forest area*. The dynamic response for each of these variables is presented to the far left and right, with GNP increases outpacing population growth in the North and economic stagnation accompanying environmental degradation in the South. Finally, the complex causal relationships that lead to these behaviors are presented, with two positive, reinforcing loops between the social variables the population and technology variables and three negative, balancing loops between technology and resources. Note that the three negative loops transcend and connect the social and natural environments.

Taken together, Figure 1 depicts a developed North pushing off its environmental costs to the developing South through trade. Before 1950, around the end of World War II, the North exhibited significant environmental degradation. As trade expanded after the war, the North was able to enjoy economic growth, relatively stable population growth, and significantly reduced environmental degradation by importing its raw materials from the South in exchange for technology and manufactured goods. The South however experienced rapid population growth, comparatively stagnant economic growth, and significant environmental degradation. That these dynamic responses are recreated through the system dynamics simulation gives increased confidence that the model accurately represents the real world and says something important and true about trade and the environment.

2. Build the intuition of your reader

Three strategies were employed to support and clarify the SD model. First, a statistical model was developed based on the insights from the SD model (see Figure 1) because it would be more accepted by the economics community. Second, Geographic Information System (GIS) generated maps that were used to present quantitative, spatially related data in an intuitive manner. Third, the manuscript was rewritten to decrease technical complexity and increase narrative clarity. These three strategies are discussed below.

2.1 The Statistical Model

Again, Michael Ward argued that an SD simulation by itself would prove insufficient in persuading a non-SD readership that the model showing externalized environmental costs is correct as SD is too unfamiliar and abstract. Instead he argued for a supplementary statistical model that confirmed the SD argument directly based on empirical data. While not a statistician, I saw the logic of his argument and set about constructing a statistical test for this hypothesis. The results are provided in Table 1 (Lofdahl 2002, 123).

Table 1: Forest.change = f(TC×GNP + GNP.per.capita + Population.growth)

coefficients	$\hat{\beta}$	σ	t	pr(> |t|)
(Intercept)	0.0112	0.0228	0.4904	0.6239
TC×GNP	-0.121	0.0131	-9.26	0.0000
GNP.per.capita	13.9μ	1.78μ	7.81	0.0000
Population.growth	-0.0391	0.0063	-6.21	0.0000

note: pr(> |t|) denotes probability of null hypothesis; $\mu = 10^{-6}$.
F-stat.: 74.14 on 3 and 1925 deg. of freedom; the prob. is 0.

mean(TC×GNP)	=	0.935		T$(1985)/year
mean(GNP.per.capita)	=	4534		$(1985)/person-year
mean(Population.growth)	=	1.97		%/year
mean(Forest.change)	=	-0.120	(1.00)	%/year
$\hat{\beta}_1\times$ mean(TC×GNP)	=	-0.114	(0.95)	%/year
$\hat{\beta}_2\times$ mean(GNP.per.capita)	=	0.0630	(-0.52)	%/year
$\hat{\beta}_3\times$ mean(Population.growth)	=	-0.0770	(0.64)	%/year

note: Values in parentheses denote ratio to mean Forest.change; $T = 10^{12}$.

The strength of the economists' position that trade is good for the environment (e.g., Economist 1999) derives from cross-national statistical tests showing economic growth is correlated with environmental benefits. These results are recreated in Table 1 in the *GNP per capita* parameter estimate. The dependent variable is *forest change*, and the parameter estimate denotes a statistically significant positive relationship between it and *GNP per capita*. Thus the higher a country's GNP per capita, the more its forests are likely to grow, and since forest area is this study's measure of environmental health, then the better off the country's environment will be.

The problem with this logic is that the model is *pooled* – the spatial context among the countries in the cross-national dataset is absent. It is as if each country were treated as a billiard ball, independent and isolated from its neighbors. In an era of globalization, this assumption is clearly not tenable. The variable *Trade-Connect GNP,* or TC×GNP, captures this traditionally absent context using a *spatial model* that captures trade relationships (Cliff and Ord 1981). The calculation details can be found in Lofdahl (2002, 169–176), but the interpretation is relatively straightforward. TC×GNP represents the average GNP of a country's trading partners, weighted by trade percentage. So if a poor country trades mostly with developed nations, it will have a low GNP but a high TC×GNP; conversely, if a rich country trades mostly with developing nations, it will have a high GNP but a low TC×GNP.

Within Table 1, TC×GNP turns out to be the best predictor of a country's rate of forest change when compared with the more traditional explanatory variables *GNP per capita* and *population growth*. More importantly, the TC×GNP parameter estimate has a sign opposite than that of *GNP per capita*. So while increases in *GNP per capita* indeed lead to increases in *forest area*, increases in TC×GNP lead to decreases in forest area or *deforestation*, and the magnitude of the TC×GNP parameter is larger. Phrased another way, the best predictor of a country's deforestation is the GNP of its trading partners. It is this result that allows us to say that trade is bad for the environment, and though motivated by an SD sensibility, the argument here is presented in statistical form, the language of economics. Finally, note that Table 1 features a top and bottom half. The top features regression results, while the bottom restates the parameter estimates so that their magnitudes can be compared against each other. This additional analysis provides little new information but is provided, once again, to help build the readers' intuition by allowing them to experience, evaluate, and compare the data more directly.

2.2 Visual Display of Quantitative Information

Considerable thought has already been given to the needs of the reader, especially insofar as two methodologies have been employed – complex systems simulation and statistical modeling – to make the case that trade is bad for the environment. Both methodologies however yield results that are decidedly abstract. A *Geographic Information System* or GIS tool (ESRI 1995) was used to display quantitative information in a highly visual, map-based representation to help readers further develop their intuition.

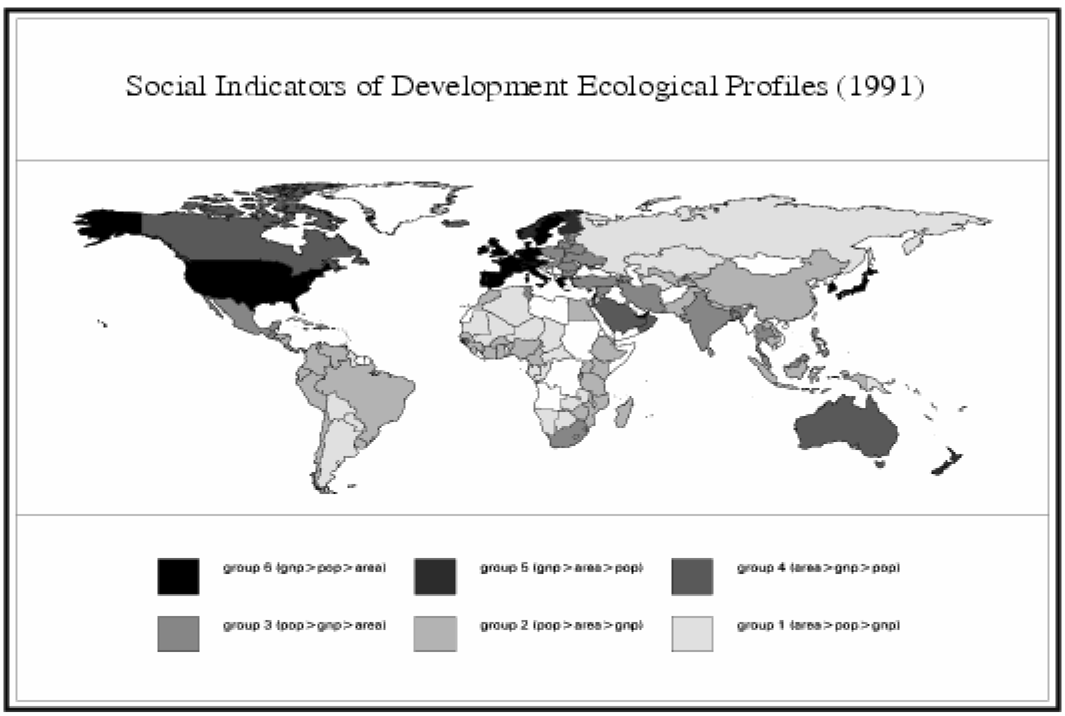

Figure 2: Geographic Distribution of Development

Figure 2 presents a measure of development as formulated by Choucri and North (1993). Figure 1 makes an explicit distinction between the developed North and the developing South, and this distinction is further developed in Figure 2. The North is defined as those countries with a greater global share of GNP than population, with global share simply the percentage of the world total, the three dark groups 4—6 described on the top row of the map legend. Basically, the darker countries have a higher GNP per capita. The South is defined as those countries with a greater global share of population than GNP, the three lighter groups 1—3 on the bottom row of the legend. Conversely, the lighter countries have a lower GNP per capita.

The important aspect of Figure 2 however is not the definitions but the intuitive feel that the reader gains when looking at the global distribution of developed and developing countries. The dark countries, the developed North, are primarily the United States, Western Europe, and Japan. The lighter countries, the developing South, are primarily found in Latin America, Africa, and Southeast Asia. While such geographic distributions can be described in text, presenting them in a visual and empirically defensible manner gives the reader a more intuitive feel for the topic.

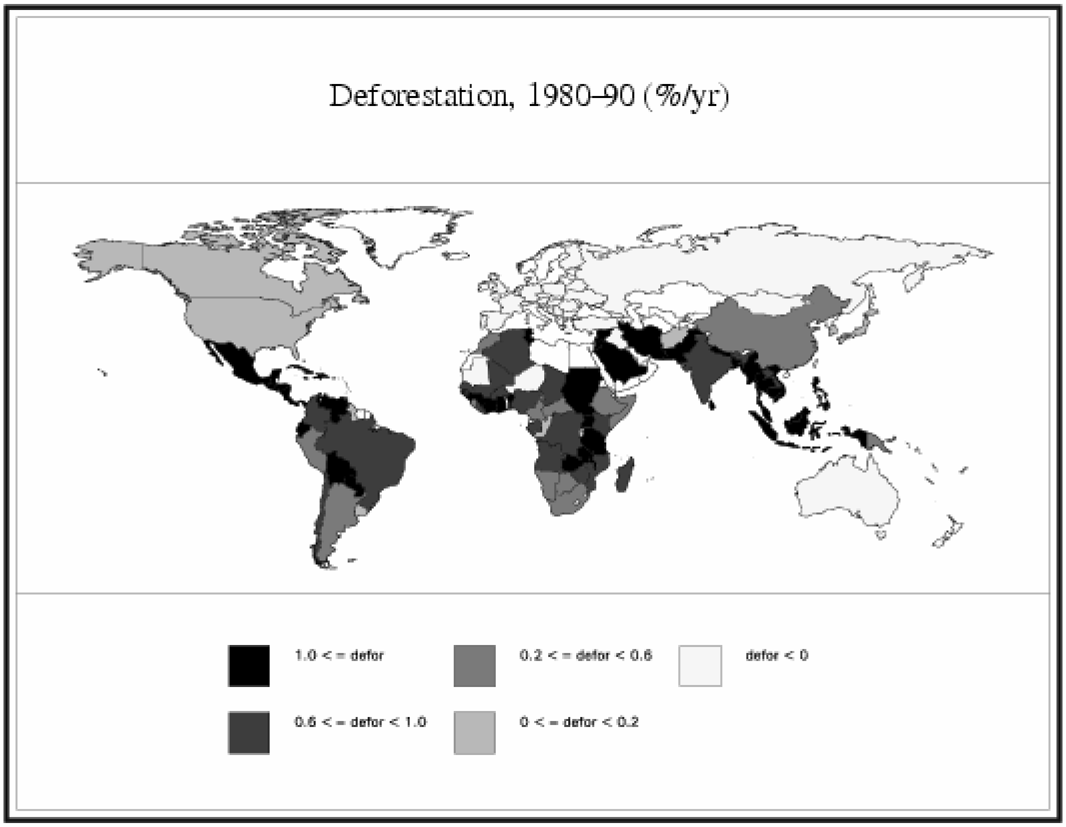

Figure 3: Geographic Distribution of Deforestation

Figure 3 presents the geographic distribution of the study's empirical measure for environmental degradation, *forest change* or its obverse, *deforestation*. As stated previously, Figure 3 confirms that deforestation takes place in those area that are developing, Latin America, Africa, and Southeast Asia. Consequently the areas that are dark in Figure 2 are light in Figure 3, and the areas that are dark in Figure 3 are light in Figure 2. These intuitive observations and geographic distributions are supported by the correlations in Table 1, especially the TC×GNP parameter. They are further supported by the system dynamics simulation depicted in Figure 1. Thus the GIS maps presented in Figures 2 and 3 do not by themselves contribute to the quantitative analysis; rather they display information already available but in a more visual and accessible manner.

2.3 Narrative Clarity

The tools and techniques described thus far – system dynamics simulation, statistical modeling, and GIS – were used in the writing of the manuscript. As part of the publication process, manuscripts are sent out for anonymous reviews, and the manuscript for Lofdahl (2002) was reviewed twice. The first set of reviews were consistent and clear; the second were less so, ranging from "trivial" to "too complicated" and "more research required." With no clear theme to the second set of reviews, it was not clear what improvements to make. On a more positive note, the Seattle World Trade Organization (WTO) riots of fall 1999 provided a tangible, policy-relevant introduction to the trade and environment debate.

While certain details of this impasse are particular to my own study and research, management professor Nelson Repenning provides a more general interpretation: "Any discomfort that readers do experience from not fully understanding a [complex systems] model is likely to manifest in indirect ways," such as comments that the study is too complicated, trivial, or that more analysis is needed (Repenning 2003, 315). A possible explanation comes in acknowledging that all concerned in the manuscript review process are trying to comment constructively on the research, with each person contributing a different set of skills and exhibiting different strengths and weaknesses. The reviewers, who were social scientists, were certainly trying to help, and they certainly had relevant expertise, but they also had gaps in their knowledge that they did not recognize, especially regarding their quantitative, methodological, and systems knowledge. Sometimes people don't know what they don't know. Repenning states,

> I doubt it ever occurred to the referees … that they missed elements of the story I was telling. Instead, they quite naturally (and implicitly) assumed that they had gotten from the model all there was to be had. (Repenning 2003, 315)

It is likely that my reviewers made similar decisions, and it is logical to assume that other system dynamicists have encountered similar criticisms because their insights or challenges were insufficiently understood.

Series editor Nazli Choucri provided the solution to this impasse. She edited the manuscript and had me concentrate on a single, simple, and consistent narrative thread to help the reader understand the manuscript's main points. To achieve this, she had me take the most technical portions out of the main text and place them into appendices: the manuscript had essentially one appendix, while Lofdahl (2002) has eight. Of the material that was left, she reorganized it to enhance the manuscript's narrative clarity by filling out and softening sharp transitions (that didn't seem so sharp), and writing extended captions that explained the complex graphics (that didn't seem that complex). These suggestions all worked against my natural inclination to provide more technical analysis and detail when faced with questions or criticisms. This technical tendency – which is probably common among complex system researchers – proved successful when performing the initial research but a hindrance when publishing the results.

What the reviewers wanted but did not explicitly ask for – not because they were deliberately opaque but because they did not know to ask for it – was *enhanced narrative clarity* that would help them build their intuition and understand the research. Clear explanations do this, while technical details that seem connected to the author but are interpreted as random and unconnected by the reader do not, no matter how true, unique, or insightful they may be once one understands. Once Choucri's edits were incorporated, the manuscript was quickly accepted and published. These suggestions would not have occurred to me on my own, and without her suggestions it is not clear that the manuscript would have been published.

3. Do your homework

Addressing social science problems with system dynamics is an inherently *interdisciplinary* enterprise. This study, which addresses trade and the environment, combines economics with global scale physical processes and thus spans the divide between the social and natural sciences. So far, three quantitative methodologies have been described: 1) system dynamics simulation, 2) spatial statistics, and 3) GIS. Also included in Lofdahl (2002) but not shown here is an extended time series analysis covering key social and natural environment indicators that depicts their dynamic responses for the years between 1965 and 1992. Left unmentioned however are the literatures of each relevant discipline, and it is to this topic that the discussion now turns.

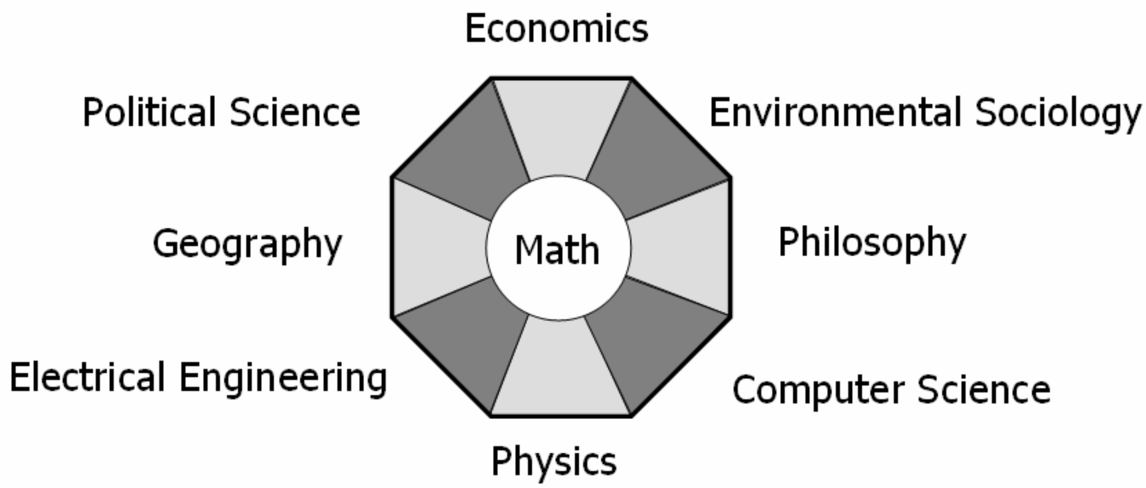

Figure 4 – Interdisciplinary Research and Computational Equivalence

Lofdahl (2002), while addressed to an economics audience, is written within the field of political science and the subfield of international political economy. The study draws from multiple disciplines besides political science including economics, geography, and philosophy, while the supporting methodologies draw from the natural sciences including electrical engineering, physics, and computer science. While the logic of and motivation for drawing from these divergent disciplines is clear, such interdisciplinary undertakings bring with them certain challenges and potential pitfalls.

This section is titled, “Do your homework,” which is in a sense trite because it is so obvious. But in another sense, there are subtle ways in which researchers can be tripped up by the exigencies of interdisciplinary research. First, there is the time and effort necessary to learn new techniques and literatures. Time spent learning material outside one’s discipline takes away from the time one could spend doing work that would bring more recognition from one’s peers. However, the promise of solving important problems justifies this investment and risk. Second, incorporating multiple techniques and literatures requires coordinating them and weighing their relative contributions so that the result is coherent and well-proportioned. It should be remembered that readers will interpret the research using vastly different combinations of experience and interest, and while some may applaud the decisions made, others will criticize them. Third, the academy is sufficiently complex and variegated that it is possible and even likely to miss completely a relevant literature that should have been read. So regardless of how hard the researcher tries to "do your homework," it is likely that somebody is going to be left unsatisfied and unhappy.

Environmental sociologist Andrew K. Jorgenson provides an example of mismatched scholarly expectations. He observes in his review of Lofdahl (2002) that,

> An immediate fact of interest is that Lofdahl is not an environmental sociologist, let alone acquainted with relevant empirical works grounded in a world-systems perspective. Rather, he is trained as a political scientist, and works in the simulation and information technology sector. (Jorgenson 2003, 393)

Jorgenson, an environmental sociologist, is clearly surprised that someone with a political science and technical background would work in a field thought to be dominated by world systems theorists. It is true that environmental sociology was seldom mentioned in the book, a shortcoming that is at least partially rectified by its inclusion in Figure 4. While the unintentional exclusion of environmental sociology could be analyzed further on its own terms, it would be more interesting to consider the underlying methodological assumptions that justify its absence.

In Figure 4, at the very center of the disciplinary octagon is a circle containing the word "math." The subtitle of Lofdahl (2002) is, "a systems study," and a systems study or a systems sensibility assumes an underlying *computational equivalence* to the social sciences specifically (Richardson 1991) and the world generally (Wolfram 2002, ch. 12). This means that, in Figure 4, by addressing the problem of trade and the environment, the debate could have been entered through any of a number of disciplines – economics, geography, political science, environmental sociology, etc. – each with its own specific and relevant literature. Thoroughly covering each, while potentially useful, would also be impractical and if attempted, would lack interest. Lofdahl (2002) makes clear that it is grounded in political science, and a sympathetic, systems savvy reader would understand and acknowledge that the literature review will be different in detail yet broadly similar to more familiar fields, and then concentrate on the quantitative results that span disciplines. While this is obvious to those who have a systems sensibility and a feel for computational equivalence, many do not and so the concept remains controversial.

In conclusion though, and to be fair, I should point out one area in which more homework would have been both helpful and justified. In explicitly addressing this work to economists, I could have spent more time familiarizing myself with the core journals that trade economists themselves read. In stating this, it should be pointed out that much homework was done. I took several graduate economics and econometrics classes, read and researched Bhagwati (1993), recreated the economists' empirical results in Table 1, and cited key works from the closely related international political economy literature.

That said though, Lofdahl (2002) would have been stronger had I familiarized myself with the relevant trade and environment literature from the key economics journals. The simple fact though is, until it was pointed out to me, researching that literature never occurred to me. There was so much else to do.

4. Choose your audience wisely

Economics retains an ongoing allure for system dynamics. The most mathematical and methodologically sophisticated of the social sciences, economics is a logical source of unsolved problems for system dynamics, as illustrated by Lofdahl (2002). Although logical in the abstract, the relationship between economics and system dynamics is not so straightforward in practice. It is a relationship with history.

Waldrop (1992, ch. 4) reports illuminatingly and provocatively on the interactions between physicists and economists during the early days of the Santa Fe Institute. According to Waldrop, physicists use mathematics simply to solve problems while economists use it to establish dominance over other researchers. Repenning (2003, 321) notes that early system dynamics researchers have engaged economics back to the 1960s and that this debate has produced comments ranging from the relatively benign acknowledgement of different research methods to more personal criticisms. Even today, he notes, "… many SD scholars remain focused on upending economics, a discipline that is quite content with its existing assumptions and methods." (Repenning 2003, 322) Too often the heat of this debate overwhelms its light.

Part of the conflict rests in their differing methodological assumptions. Figure 4 implies that interdisciplinary computational equivalence is effortless: even though academic disciplines have separate literatures, the mathematics underlying them is the same. This is true in the abstract, but significant methodological differences remain in practice. Mathematics is vast, and some disciplines select one set of techniques, while another stresses a very different set. Sometimes a discipline's commitment to its methodological selections is so intense that it becomes computationally non-equivalent with other disciplines. The promise of complexity is that such differences will be overcome, but with each discipline's members thinking they have the correct methodological insights, significant progress towards interdisciplinary reconciliation will likely remain unhurried.

For an example of intractable methodological differences, International Monetary Fund (IMF) economist Kenneth Rogoff (2002) presents six open economics questions:

- Current-account imbalances – the complex consequences of persistent trade deficits, including demographic trends,
- Government debt – the limits governments have to raise revenues in the era of globalization,
- Exchange rates – the consequences of floating versus fixed rates,
- Capital controls – the policies necessary to regulate the flow of capital across international borders,
- Persistent African underdevelopment – the continent's role as a commodity supplier in dynamic international markets,
- Moral hazard in IMF lending – the long-term consequences of national bail-outs.

Their details will not be addressed in this study, instead it is pointed out that each has a significant non-equilibrium, multivariate, and complex systems character. These characteristics are problems for economics and opportunities for system dynamics.

Economics generally maximizes a reduced set of variables assuming equilibrium; in contrast, system dynamics balances an expanded set of variables assuming non-equilibrium. These methodological differences make the two disciplines computationally non-equivalent and contribute to the prickliness of their history.

At the heart of this relationship are fundamental differences regarding optimization and research vision. Painting with a wide brush, economics works with reduced sets of variables so that they can be optimized and closed form solutions can be obtained. System dynamics, in contrast, works with a larger set of variables that must be simulated and for which only local optima can be found:

> What is required is a more multidimensional fashion of representing complex systems, one that allows analysts to value separate things separately and yet still connect and compare them in defensible and illuminating ways. Striving to keep multiple indicators of a complex system in balance rather than maximizing the value of a few results in more sustainable and mature economic policy prescriptions. (Lofdahl 2002, XIX)

Repenning (2003, 325) observes that the constrained research stance of economics leads to self-interested and local modes of thinking, but this simplification also contributes to, "the growing dominance of economics and economic logic in the social sciences."

I do not mean to criticize economics unduly, only to suggest that there are larger, more systemic reasons underlying its relationship with system dynamics. I do however agree with Repenning that economics, the most mathematical of the social sciences, may not be the most receptive to complexity-derived insights. Although economists and system dynamics researchers share the language of mathematics, the system dynamics worldview is more consistent with the more descriptive but less mathematical fields of psychology, sociology, and anthropology (Repenning 2003, 320). For example, Lofdahl (2002) was done within the field of political science, not the most methodologically sophisticated of the social sciences but sufficiently so to support this research.

5. Conclusion

In the introduction to this paper, it was stated that complex systems techniques like SD could be used to "solve" social science problems. Quotes are used because complex social problems are seldom solved totally, finally, and definitively. Instead, new tools and methods bring new insights and findings to classic questions and hopefully inspire future research. This study, using a larger trade and environment research program as its example, echoed and expanded the suggestions of Repenning (2003) to help future researchers avoid some of the difficulties and challenges encountered in presenting complex systems research results.

First, it was suggested that SD models be sized appropriately. This means not only keeping models simple but also presenting them simply. For example, Figure 1 shows the Lofdahl (2002) SD model in a single graphic. Second, build the intuition of your reader. This was done in three ways: first by developing a statistical model to complement the SD model, second by presenting quantitative information in a more visual manner using GIS, and third by increasing the narrative clarity of the presentation. Third, do your homework. This can be hard to do in interdisciplinary studies; yet such studies are becoming increasingly possible in an era of powerful computer-based tools and methods. Fourth, choose your audience wisely. Economics and system dynamics have a long and sometimes contentious history as their dissimilar methodological perspectives form a barrier to communication. Properly managed though, economics could provide a wealth of research opportunities for system dynamics.

E.O. Wilson (1998, 8) would say that the disciplinary division between economics and SD is an artifact of scholarship and that SD, because it is aimed at the social sciences but informed by the natural, has the analytic edge. The principle of computational equivalence (Wolfram 2002, ch. 12) argues that such analytic separations are specious, and the general applicability of SD to the social sciences is well documented by Richardson (1991). While the promise is great, complexity reveals itself to be a double-edged sword: the power of complex analytic techniques like SD allow hard, unsolved problems to be tackled in new and interesting ways, but those same techniques can become a barrier to reporting research results. The study concludes that the skills necessary to perform complex systems research and to communicate that research can be quite different. Technical tendencies that lead to quality research can hinder its publication. Successful researchers will acknowledge and overcome this communication challenge, and several strategies have been offered herein to help them address it.

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