The Impact of Social Theory on Model Development

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Abstract

What impact — if any — have modern theories from the social sciences had on simulation models? I argue here that most forms of macro-level social theory are not well adapted to the needs of the modeling and simulation community. Although a few notable social theories have had an influence in several specific cases, we still find massive lacunae in the fabric of contemporary social theory, often in application areas of greatest interest to modelers. This paper begins with an identification of precisely how and where social theory can be brought into dynamic spatial models of complex social processes. Since the most interesting models are those that produce unexpected "emergent" phenomena, I have included two speculative sections. The first shows how dynamic models can reasonably be constructed so that tipping points, thresholds, and similar emergent phenomena appear naturally. The second is even more speculative, dealing with the topic that I consider to be the single greatest need in social theory in the present day: the effects of epidemic levels of PTSD on social institutions.

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Introduction

This paper has a very simple outline, though the problems are manifold and difficult. I will attempt to answer three questions, in order:

1. What are the special needs of macro-scale simulation models?
2. What can we learn from the approach taken by epidemiology?
3. How can we build models that are likely to display emergent phenomena?

Before we delve into these three questions, let us define some terms.

> **SOCIAL THEORY**, for the purposes of this paper, will be understood to include any well-developed and coherent set of ideas that describes the structure and functioning of society, and its ills. These may come from any of the social sciences (psychology, anthropology, sociology, economics, political science, jurisprudence, linguistics), or from history or philosophy. Social theories may deal with raw human behavior, or with social ideas, or with systems of symbolic meaning employed by a society. They may be structural or dynamic; they may be deterministic or fuzzy or stochastic; and they may be expressed in the medium of mathematics, diagrams, or ordinary language.

> **MODELING**, for the purposes of this paper, refers to the creation of highly simplified representations of society (the models), for the purposes of study or simulation. Models generally take the form of diagrams, flow charts, equations, or computer code. Simulation is the use of a computer to animate a model, so that its behavior can be observed and compared to data or experience.

As a mathematical sociologist, my particular interest has long been in the development of dynamic models of human society. Unlike most, I came to this area not from one of the social sciences but instead from mathematics itself. At the very start of my studies, more than forty years ago, I learned rather abruptly that social theory was not providing the fundamental elements and building blocks from which one could build a decent simulation model. This came as a bit of a rude shock, made all the worse as it gradually dawned upon me just how much social theory was either dead on arrival or missing in action.

With the sole exception of economics, the domain of social theory 40–50 years ago was still dominated by theoreticians with the grandest of ambitions yet not a hint of mathematical ability; they were men such as Karl Marx, Talcott Parsons, Claude Levi Strauss, and B. F. Skinner. Even in economics the more verbal form of grandiose theorizing was dominant, though the more mathematically inclined economists under the leadership of Paul Samuelson and Kenneth Arrow were beginning to make themselves known. It is hard to avoid the conclusion, however, that social theory at mid-century was woefully inadequate to the needs of the modeling and simulation community that emerged during the next 50 years.

While it is certainly true that the utility of social theory for modeling and simulation has improved dramatically over the intervening fifty years, there is still a very long way to go before social theory can be said to offer sound and reliable guidance to those who would construct useful models. To see why this is so, let us take a look at what social theory *should* offer, in an ideal world, strictly from a macro point of view.

In Section 1, immediately following, we take a careful look at the meeting point between social theory and two-dimensional mathematical modeling of social processes. In Section 2, we look deeper into the kinds of social theory offered by nonlinear relationships. In Section 3, we take a quick look at an undeveloped area of great promise: the social epidemiology of trauma. These topics are presented here to show how and where social theory needs to develop in the near future.

1. From the Macro Point of View...

Seen from space, the earth exhibits no national boundaries, and indeed almost no perceptible traces of human habitation or influence. Nevertheless, the global perspective is the right psychological perspective from which to start a macroscopic analysis. The following screen shot from a macroscopic social simulation that focuses on Afghanistan:

Figure 1: A "macro" view of Afghanistan, as if seen from the Moon's perspective.

The unit of social analysis at the micro level is usually the individual, or even smaller. Erving Goffman, for example, made a career of analyzing social interaction in terms of gestures and movements; he called this the "dramaturgical" approach to microsociology (Goffman, 1959).

At the macro level the unit of analysis is usually an administrative grouping: a nation, a province, a metropolitan area, etc. This may make a certain limited amount of sense from the perspective of data analysis, since these are the sources of aggregated data, but it makes much less sense from the point of view of social theory. Zooming in on Afghanistan, here are the provincial boundaries.

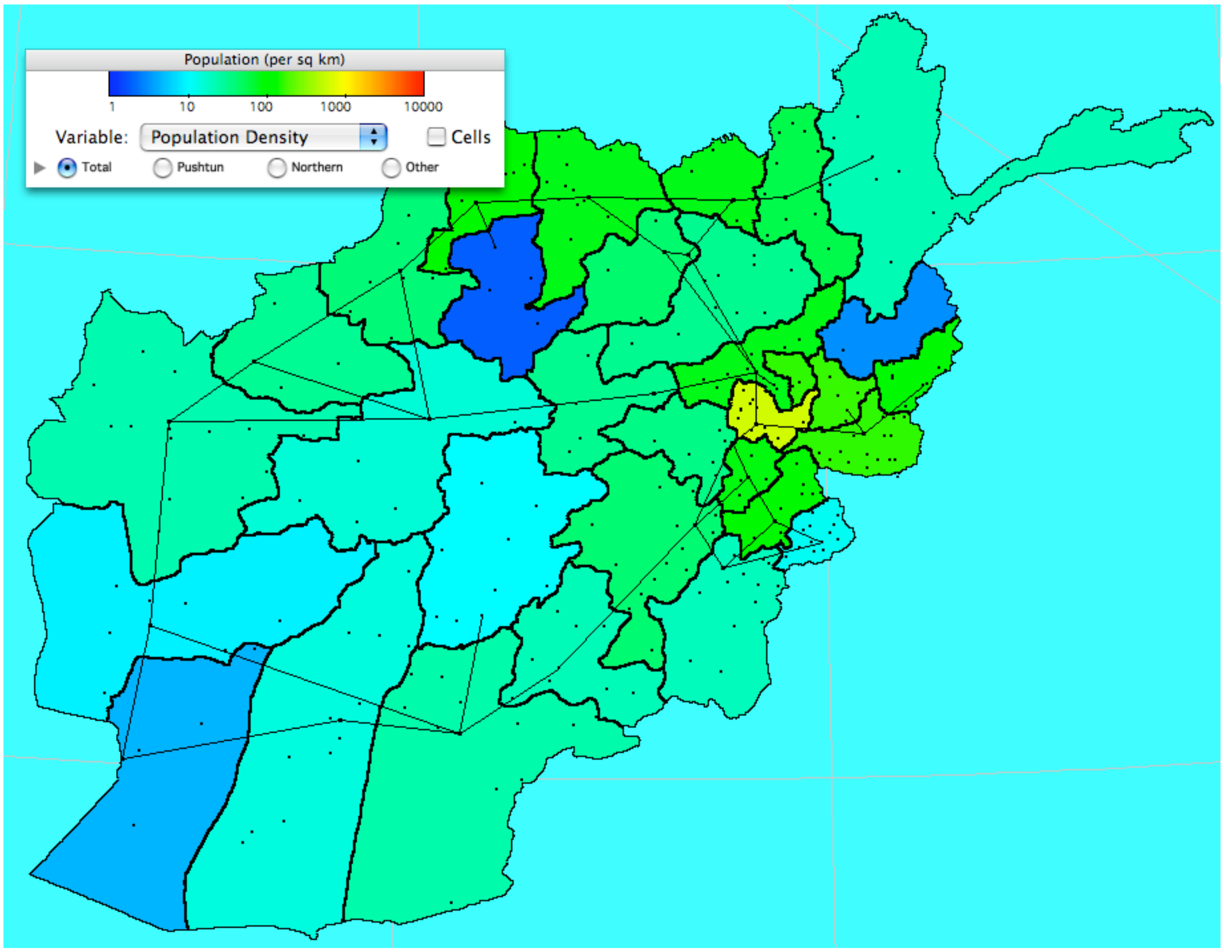

Figure 2: The population density of Afghanistan, with space divided into irregular provinces.

For the kind of macro-level simulations that I like to do, the unit of analysis is a square geographic cell of standard area. In any given map, these cells can be as small as one kilometer on a side, or as large as 50 kilometers.

The cellular view gives a finer-grained view of whatever variable is displayed, and it can show far more detail in the all-important rural areas. To reveal the details of the areas of low population density more clearly, I have found that it helps to map the colors of the spectrum (blue-cyan-green-yellow-orange-red) onto the underlying variable using a logarithmic scale.

Here, for example, is Afghanistan once more, this time divided into 15km cells:

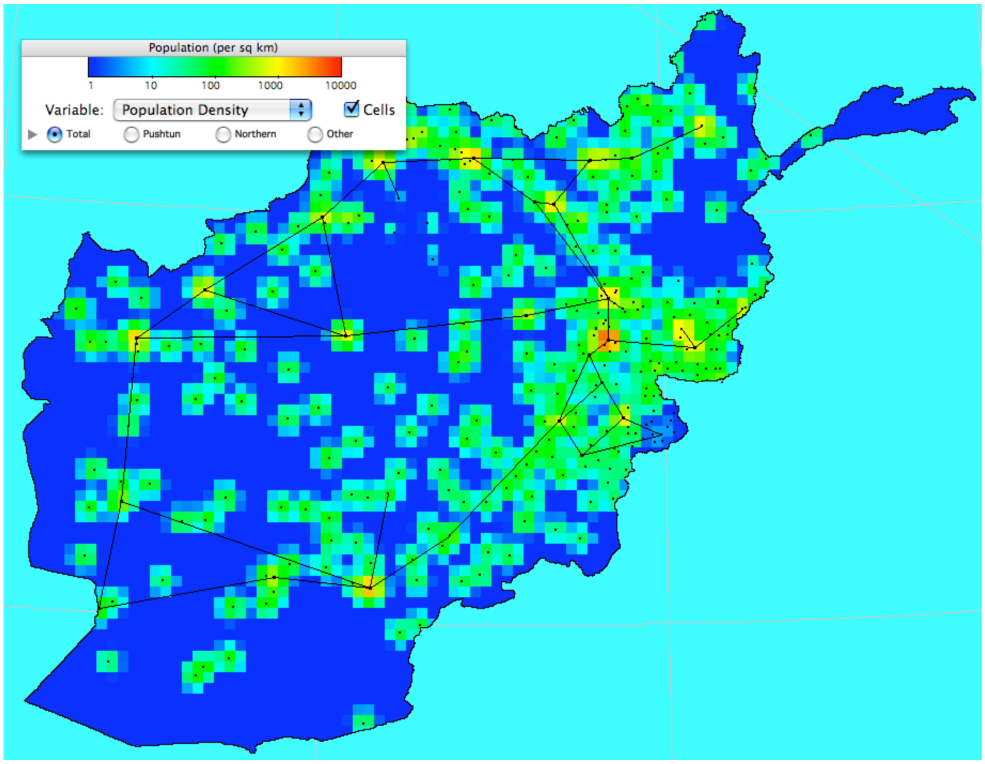

Figure 3: The cellular population density of Afghanistan, mapped onto a logarithmic color scale.

When large-scale social change really gets underway, as in wars and revolutions, or when great masses of people are on the move, then administrative boundaries count for nothing. In the Rwandan genocide and terror campaign of 1994, for example, an unstoppable tidal wave of refugees crossed the borders in search of safety. About one million of them ended up in a treeless, foodless, waterless volcanic plain near Gomah, in the Congo. Intermixed with refugees were soldiers and terrorists, wearing no uniforms and blending invisibly into the crowds. Some of these were deserters, others were sent specifically to stir up trouble later.

Why did they end up in these places, in particular? How and when did they decide to leave their homes? When do they stop moving? Why do some mass population displacements disperse across the countryside, others spread out along roads and highways, while yet others clump together into huge encampments? How will they react to further acts of terror from within their midst? These and many similar questions are the sort of problem that social theory should be able to address. Alas, as it exists today social theory does a very poor job of it.

From the perspective of macro-scale modeling, the modeler needs some very particular kinds of input from social theory, input that will tell him how the conditions in each cell on the map change in response to exogenous variables and the current conditions in the cell and its nearest neighbors. In the example of refugee flow, one can fairly easily imagine what the critical variables and conditions might be: density of refugees in each cell, food and water supplies, intensity of fighting, degree of personal danger, prevalence of epidemic disease, etc.

The following diagram shows in schematic form the domain on which social theory must be brought to bear: a cell together with its neighbors, with causal influences and flows of people crossing cell boundaries.

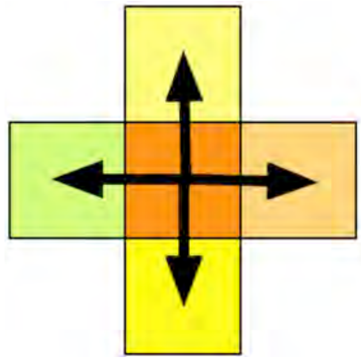

Figure 4: In a cellular model, population and causal influence flow from each cell to each of its nearest neighbors.

Each state variable, e.g. the degree of personal danger, is defined on every cell and must have an equation which describes how it changes in response to exogenous variables and current conditions in the cell and its neighbors. Here is the critical point:

> *The function of social theory is to provide that equation of change, or at the very least to provide enough information so that a suitable equation can be derived by the modeler.*

If the model is also to include infectious diseases — as it must in any realistic refugee situation — then the social theory (which is in this case includes an *epidemiological* theory) should specify, at a minimum, three rates within each cell:

- the rate of new infection,
- the rate of recovery of infected people, and
- the rate of death of infected people.

In the standard theory of infectious epidemiology, each of these rates is expressed as a function of several obvious state variables defined on every cell: the proportion who are susceptible to contracting the disease, the proportion who are currently infectious, the proportion who have recovered and are immune, and the number who have recently died.

For diseases spread by contact there is an additional critical parameter: the rate of mixing of the population, which determines how often, on average, a person in one cell comes in contact with a person in a neighboring cell. Theories of the propagation of water-borne diseases take on a somewhat different shape, but the essential structure of the theory remains the same.

Epidemic theories for the spread of infectious disease have used this basic structure since about 1907, when William Hamer and Ronald Ross began to codify this approach. These are, in fact, *social theories*, in the sense that they describe a dynamic phenomenon of mass society. One might naively think that the methods pioneered by epidemiologists would have been enthusiastically adopted within the social sciences, but the truth is otherwise. Apart from a small group who practice the art of what is known in sociology as "social epidemiology", this approach is almost completely unknown in mainstream social theory today.

Not to put too fine a point on it, it is my belief that most of what passes for "theory" in the social sciences is very poorly adapted to the kind of social, behavioral, and cultural modeling that is required by conditions in the world today. In particular, it is of little value precisely because of a failure to adopt the elementary cellular geographic structure within which any dynamic model of society must operate.

Figure 5: Rwandan refugees arrive in Tanzania, 1994.

The earliest theories of infectious epidemiology were not spatial, but the striking way in which the great epidemics have swept in waves across entire continents soon encouraged the discipline to attempt to bring wave-like behavior into their models.

The analytical foundation was first laid down in a satisfactory way by N.T.J. Bailey in his *Mathematical Theory of Epidemics*, published in 1957. In this path-breaking work, Bailey developed both a deterministic and a stochastic theory, and showed how the stochastic theory produces the threshold phenomenon that characterizes so many real-world epidemic diseases, as well many other sociological processes.

The cellular geographic structure described above is implicit in Bailey's equations for the geographic spread of infectious disease. In these equations the state variable $x(t)$ is the density (number per unit area) of people susceptible to the disease, $y(t)$ is the density of infected people, and $z(t)$ is the density of people who have been removed from the epidemic, either through death or immunity. All three variables are functions of space as well as time. Bailey's elementary theory of epidemic wave propagation over a geographic landscape is simply this:

$$\frac{\partial x}{\partial t} = -\beta\sigma x\tilde{y}$$
$$\frac{\partial y}{\partial t} = \beta\sigma x\tilde{y} - \gamma y$$
$$\frac{\partial z}{\partial t} = \gamma y$$

The partial derivatives on the left-hand sides express the rates of change in the state variables of the epidemiological system. For the purpose of understanding the message of this paper it is not necessary to have any knowledge of partial differential equations. The important point here is that there is a compact way of representing the flow of influence, people, and disease across cellular boundaries — and that this representation is a natural way of specifying a social theory, whether it concerns the wave-like geographic spread of violence, disease, deadly weapons, or people.

As an example of this general approach to macro-level modeling, in first half of this decade Ted Woodcock and I developed a spatial model of a society in the throes of violence, famine, and disease. This model is known by the acronym STRATMAS, and it lives on in the National Defence College (*Försvarshögskolan*) of Sweden. I won't go into details; instead I want merely to use this simulation to illustrate how Bailey's spatial model of epidemics can be generalized into a very complex social-economic-political model.

Our first step in the design of this macro-level model was to go far beyond the usual three variables of the typical epidemic model. Each variable is defined on every cell, and varies over time. The variables that we employed were:

- Population density
- Displaced population
- Ethnic violence
- Perceived threat level (by the civilian population)
- Disaffection with the government
- Proportion of the population without shelter
- Proportion of the population without food
- Proportion of the population without potable water
- Proportion of the population without access to medical care
- Proportion of the population without employment
- Political polarization
- Proportion of the population who are recent victims of crime
- Adequacy of social infrastructure (roads, buildings, energy, etc)
- Stored food, in days
- Water capacity, in days

- Proportion of the population with dysentery (the epidemic disease)
- Daily civilian mortality

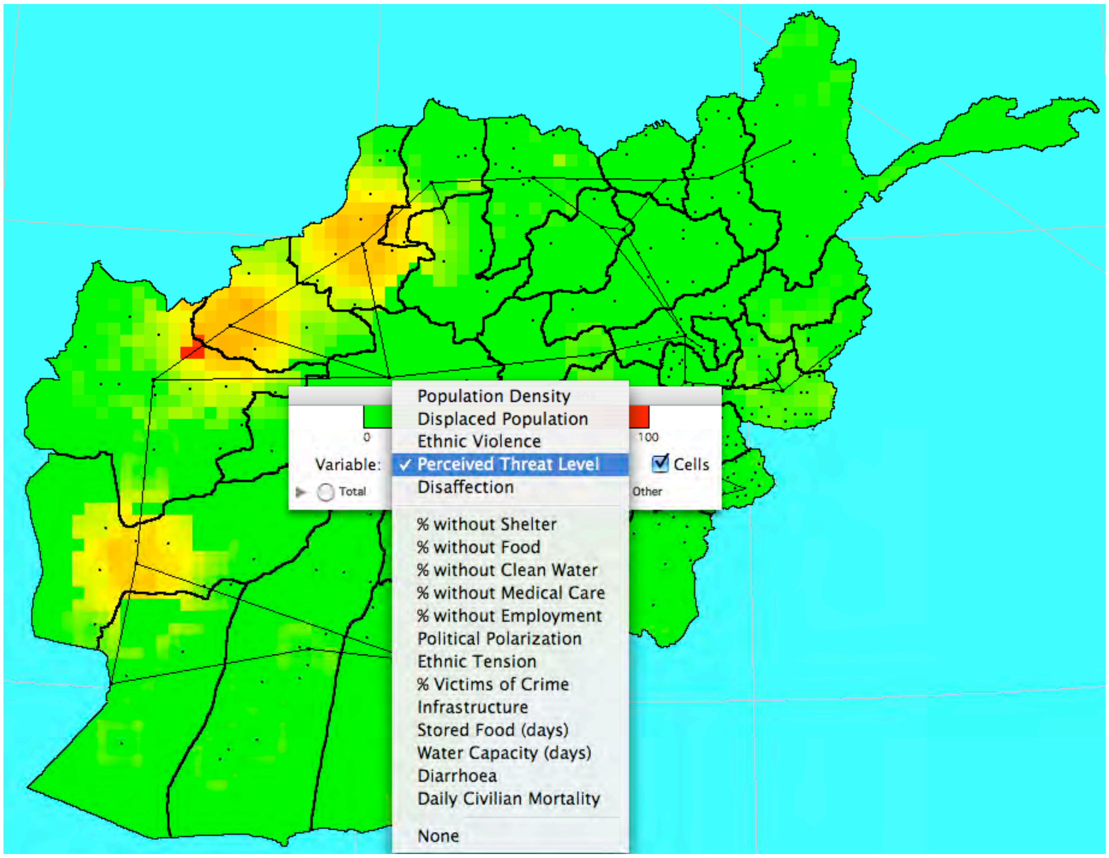

Figure 6: Displaying the geographic pattern of threat perceived by the civilian population.

Having constructed the interactive map display and the internal cellular geographic data structure for the model, it was time to use existing social theory to populate the model with its dynamics — the change equations symbolized above by Bailey's system of partial differential equations for infectious disease.

At this point we came abruptly and rather unpleasantly to the realization that, for the most part, adequate social theory simply does not exist for a model of this general shape and structure.

In some cases, e.g. the epidemiology of dysentery, or the movement of food supplies, or the exacerbation of ethnic relations, most of the dynamics are known or can be roughly inferred from the literatures of public health, developmental economics, and some basic principles of sociology and political science. But in too many interesting and vital cases the literature was simply and regrettably absent. Social theories of the required type are scarce on the ground, thus forcing modelers to weave their own *de novo* theories out of intuition, anecdotes, and moonbeams.

2. Tipping Points, Thresholds, & Emergent Sudden Change

In his paper for this workshop ("Bridging the Micro-Macro Gulf"), Lawrence Kuznar made the strong point that, in his words,

> *The aim of social modeling should be the emergence of macro-phenomena; these are the sorts of phenomena of most national security concerns (riots, revolutionary movements, insurgencies, terrorist networks, state collapses, genocides).*

I agree with and support this idea whole-heartedly. So much so, in fact, that I am going to begin the second section of this paper with a brief illustration of one way in which this goal can be achieved. In the conclusion I will then point out how these ideas can be incorporated into macro-level modeling and simulation.

First, let us take a look at a genuine real-world tipping point, one that has a bearing on the sequence of events that can result in breaking the seemingly endless cycle of poverty in the poorest nations of this planet.

Figure 7 shows the changes experienced in several selected countries over the past thirty years, with respect to (a) income per capita at PPP ("purchasing power parity"), and (b) total fertility.

Purchasing power parity is a device for adjusting the dollar value of an income figure to eliminate the profound inter-country differences in what a dollar can buy.

Total fertility is considered one of the most important variables in demography. It is the average number of children that each woman in a country would have over her lifetime, were she to bear children at age-specific rates that match the country's entire female population. Total fertility numbers close to 2.1 indicate a country in approximate demographic equilibrium. Historically, extremely poor countries have typically had total fertility rates in excess of eight children per woman.

You can see in this graph that Thailand and Chile turned the corner during the 1990s, Portugal turned the corner in the 1980s, while Sweden and the USA reached their tipping points prior to 1980.

Rwanda, Haiti, and El Salvador have not yet reached their tipping points, but El Salvador is so close that it will probably happen with the next ten years. Haiti, which too many people write off as a hopeless case, is moving rapidly towards its turning point, and should achieve it within a generation.

The statistics on which Figure 7 was based were measured on entire countries, yet these variables are, of course, definable on smaller regions. In particular, they can apply to individual cells in a cellular simulation. In that event we would expect to see certain regions (e.g. urban areas like Lima and Sao Paolo) take off long before rural areas.

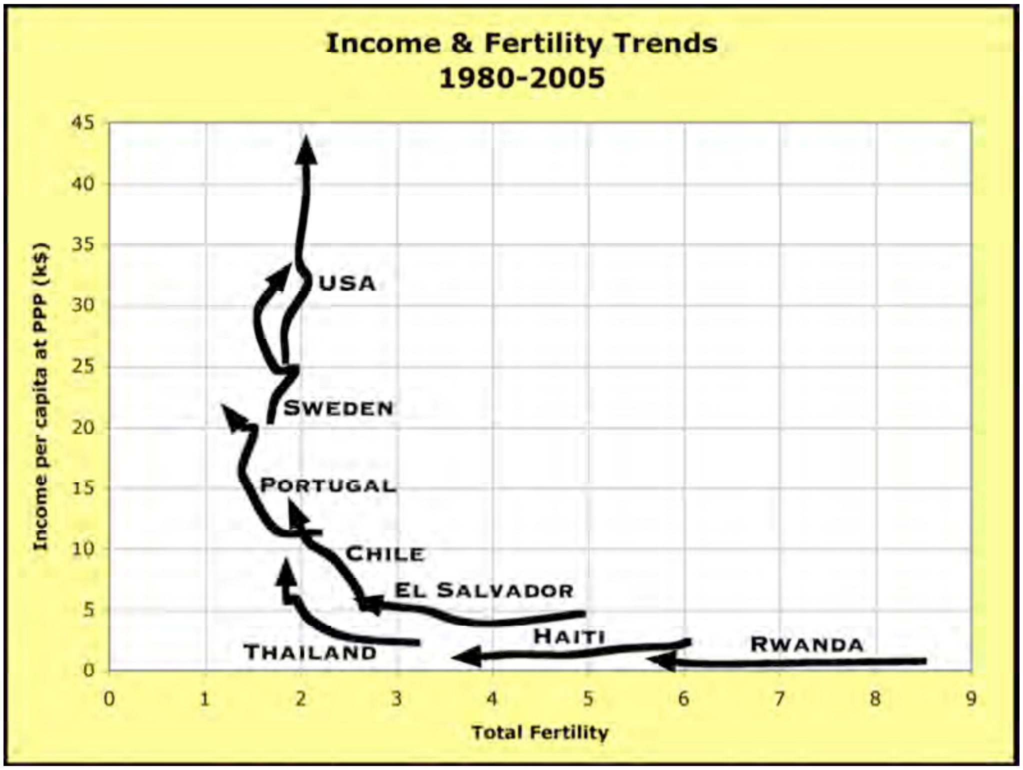

Figure 7: Trends of income (vertical axis) and fertility (horizontal axis) in selected countries, 1980–2005.
(Data source: World Development Indicators 2008, World Bank)

What might the equations of change look like for these two variables? Once again, our existing social and economic theory does not seem to provide an adequate answer, even though this is clearly a question of vital importance for understanding how to break the deadly grip of extreme poverty. For help, I turned to a purely empirical and statistical analysis of the underlying World Bank data.

Passing over all the statistical details of model identification and parameter estimation, here are the two change equations for total fertility, *x(t)*, and income per capita, *y(t)*:

$$\Delta x(t) = b_0 - b_1 x + b_2 x^2 + b_3 y - b_4 x \log(y) + (others)$$
$$\Delta y(t) = a_o + a_1 y + a_2 y^2 - a_3 y^3 - a_4 xy + (others)$$

These two fairly simple and mildly nonlinear change equations are sufficient to reproduce the "corner-turning" phenomenon that is so clearly visible in Figure 7.

In the case of income per capita (x), the "other variables" included average education population density, and participation in the labor force. In the case of total fertility (y), the "other variables" include education, child mortality, proportion living in rural areas, and female participation in the labor force. The statistical fit of this model to the World Bank data is superb — they explain better than 50% of the variance in the 5-year rates of change.

One can stare at such a pair of equations for hours, and still not fully understand how they interact with each other. Fortunately, however, one doesn't need to. It suffices to observe that the pair of equations is really determining a *vector*, or direction of motion, for every possible country. That gives us what is known as a *vector field* for the joint dynamics of income and fertility, as shown here:

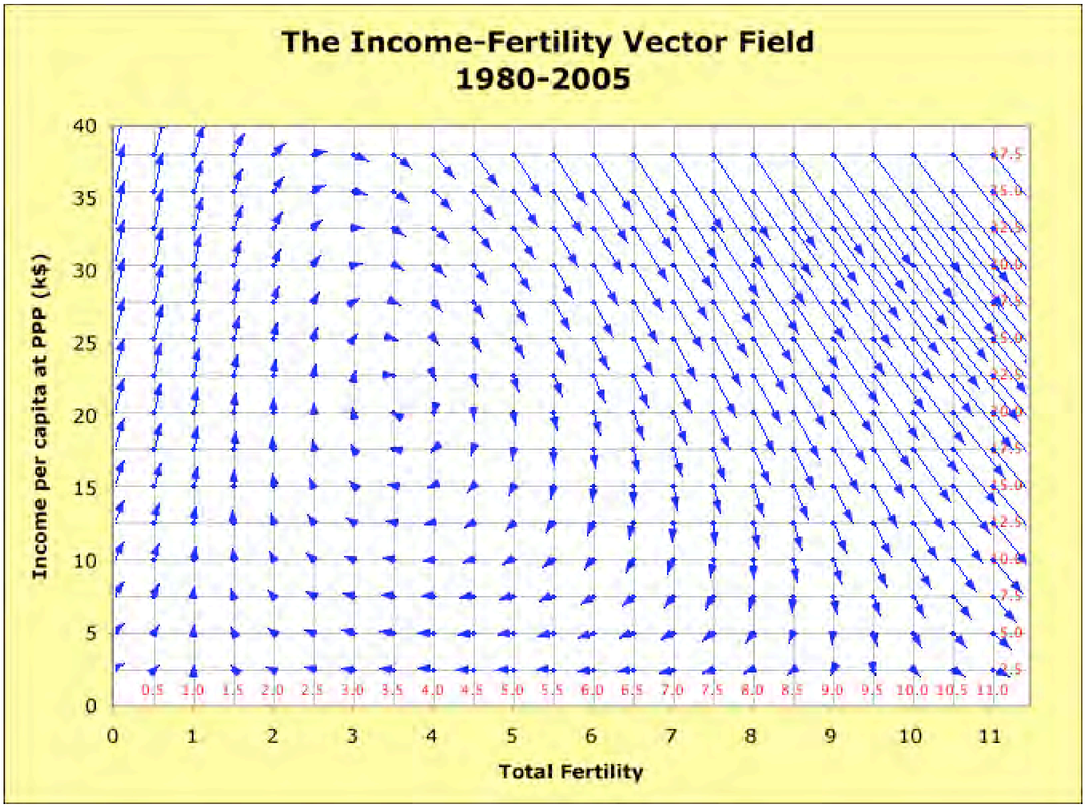

Figure 8: The directions of motion of countries in the Income–Fertility plane.

At center-left is a *focus*, an equilibrium point with a circular inward-directed flow. Countries that have made the sharp upward turn towards prosperity move into the zone of attraction of this focus — and indeed, that is where all of the developed countries of the world now lie. A separate analysis shows that this focus has been moving steadily upwards, as the general prosperity of the world has improved, and is now located somewhere near $30,000 per person per year, at a fertility rate of about 2.5.

Near the lower-right-hand corner is a *separatrix*, a line that divides poor countries with decreasing (i.e. improving) fertility from those with increasing (worsening) fertility. The latter are the countries that are truly in trouble, trapped in a vicious system that keeps pushing them away from the trajectories that end in prosperity. Figure 9 shows why this happens, using the particular example of the five-year rate of fertility change for the 133 countries in the World Bank sample, between 1980 and 2005.

Observe that there are two equilibria in this graph. The first equilibrium, at a fertility level of about 1.4 children per woman, is "attracting" (in the sense that any perturbation away from this point will cause movement back to the equilibrium). The second equilibrium point, at a fertility of about 9.5 children per woman, is "repelling" (any perturbation away from this point will cause further movement away). In other words, any region of the world with a total fertility rate greater than 9.5 is in serious trouble, with a steadily worsening total fertility rate and an exploding population.

All countries caught in the *high-fertility—low-income* trap have the same basic dynamic. The high fertility means that families groan under the burden of ten to sixteen children per woman, with resulting very poor or non-existent education and miserable childhood health histories. Most of the women die at an early age, worn out by the stress of endless childbirths.

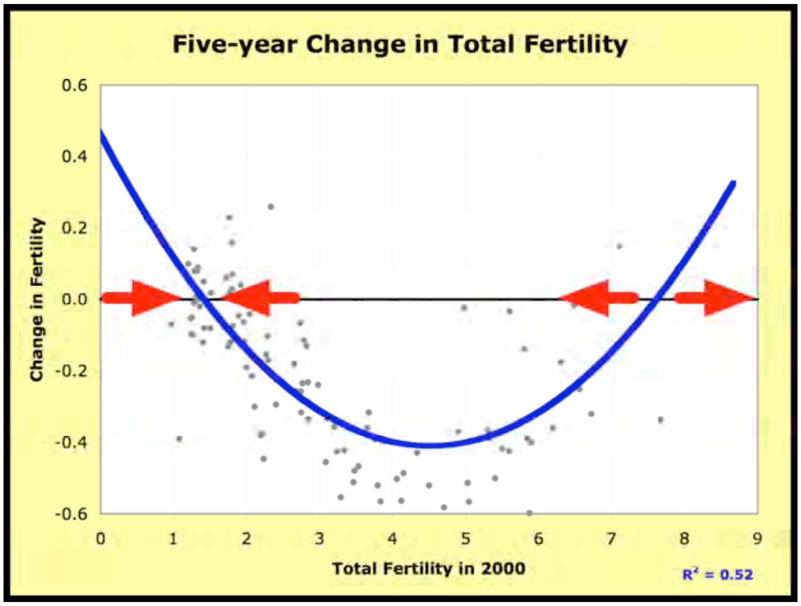

Figure 9: The rate of change in fertility, as a quadratic function of fertility.

Worst of all, these countries have pyramidal population pyramids, with vastly more teenagers than adults in their fifties. This creates a national security vulnerability: too many impoverished boys grow up to be angry, alienated, unemployed adults, and fall readily under the sway of criminal or terrorist organizations (Leahy, 2007).

I submit that a good theory of the poverty trap would have alerted us to the possible existence of these two *emergent* phenomena — the focus and the separatrix that are visible in the statistically-derived vector field for these two variables. These two features, and the very sharp upward turn of the vectors when fertility drops below 2.5, give us a richly detailed picture of how the poverty / violence trap operates.

Most important of all, it calls our attention to what needs to be done to launch poor countries into the prosperity of the developed world. From this and related analyses, we can confirm that the most powerful changes come about from efforts to (a) reduce fertility, (b) educate girls at the same level as boys, and (c) bring women into the labor force. In addition, Figure 7 clearly suggests that we should not lose patience as fertility rates are slowly reduced: when the corner is finally turned, then incomes will skyrocket.

3. The Social Epidemiology of Trauma

Psychological trauma and its direct consequence —*post-traumatic stress disorder* (PTSD) — are topics of great interest to any nation that fights wars, or which has been invaded, or which has fallen into the depths of civil war. Many of the symptoms of PTSD were once thought to be signs of weak character or outright cowardice, and for most of history soldiers who suffered from PTSD were punished, cashiered, shamed, and ridiculed. These symptoms include depression, social isolation, serious sleep disturbances, and the (so-called) "hysterical" class of symptoms: loss of vision, loss of hearing, loss of movement in one or more limbs, or loss of memory, all without physical or medical explanation.

Shakespeare was a soldier enough to have clearly understood PTSD, even though the term and its medical description lay three centuries in the future. In this passage from Henry IV Pt 1, the speaker is a retired soldier's wife:

> O, my good lord, why are you thus alone?
> For what offense have I this fortnight been
> A banished woman from my Harry's bed?
> Tell me, sweet lord, what is't that takes from thee
> Thy stomach, pleasure and thy golden sleep?
> Why dost thou bend thine eyes upon the earth,
> And start so often when thou sitt'st alone?
> Why has thou lost the fresh blood in thy cheeks,
> And given my treasures and rights of thee
> To thick-eyed musing and curst melancholy?
> In thy faint slumbers I by thee have watched,
> And heard thee murmur tales of iron wars,
> Speak terms of manage to thy bounding steed,
> Cry, *"Courage! To the field!"* And thou hast talked
> Of sallies and retires, of trenches, tents,
> Of palisadoes, frontiers, parapets,
> Of basilisks, of cannon, culverin,
> Of prisoners' ransom, and of soldiers slain,
> And all the currents of a heady fight.
> Thy spirit within thee hath been so at war
> And thus hath so bestirred thee in thy sleep,
> That beads of sweat have stood upon thy brow,
> Like bubbles in a late-disturbèd stream…

Sadly, combat trauma is far from the only source of PTSD. From an epidemiological perspective, non-combat trauma far outweighs military combat as a generator of PTSD: the most common sources include domestic violence, child abuse, violent crime, sudden violent accidents, and natural disasters. Less than half of those exposed to violence ever suffer PTSD. Of those who do, some shake it off easily while others — especially those who have previously experienced severe trauma — develop serious cases which can last for decades.

Despite the serious impact of PTSD on the psychological health of an individual, what is of concern here is the impact *on the institutions of society* of large-scale epidemics of PTSD. In particular, five symptoms are problematic:

- hypervigilance,
- the tendency to think in simplified "Good-vs-Evil" terms,
- hair-trigger violent reactions to perceived threats,
- apocalyptic thoughts, and
- dissociation.

When PTSD is epidemic and persistent in an adult population, then these patterns of thought and emotion are likely to seep into the ideas expressed in the culture and social institutions of society. For example, if sufficiently widespread, then a tendency to think in simplified "Good-vs-Evil" terms may plausibly become institutionalized as a societal tendency to xenophobia, racism, and militant religious doctrines, and to give impetus to the growth of honor- and shame-based cultures.

Similarly, if a sufficient proportion of the adult population suffer from hypervigilance and hair-trigger violent reactions, then is it not also plausible that these same tendencies may be more likely to be adopted into governmental policies and military doctrines?

Apocalyptic thinking at the individual presents itself as ideas that one's life could end at any moment, that one is unlikely to survive to an old age, that an emergency of unimaginable severity lies just around the corner, that survival is so in doubt that all niceties of ethics and morality must be abandoned. When apocalyptic thinking grips a majority of a nation — as it did periodically in ancient Rome, for example — then religions that speak of an imminent violent end of the world will become more popular, and gain more converts.

From the point of view of social epidemiology, PTSD presents a particularly complex and fascinating dynamic. There are many natural causes of psychological trauma, but there are also human causes, most notably war, slavery, domestic violence, and child abuse and neglect. Many people who suffer from untreated PTSD self-medicate with alcohol or opiates; this leads to complicating addiction problems, and also to a number of self-reinforcing intergenerational cycles of trauma.

Arguably the most important of these intergenerational cycles comes from the link with alcoholism and opiate addiction. Almost by definition, parents who have an addiction to alcohol or opiates are neglectful parents, and a small but significant fraction may engage in serious and repeated episodes of child abuse. Thus the children of parents with untreated PTSD are themselves at risk for traumatization at a young age, which then sets them up for much greater susceptibility to retraumatization as adults.

If, at the same time, society itself is more likely to go to war because it has a prevalence of untreated PTSD, then a second and very serious vicious cycle comes into operation: war increases the prevalence of PTSD; if this reaches epidemic levels then the PTSD itself may eventually lead to a greater tendency to go to war. The medieval history of

Europe, when seen from the perspective of social epidemiology, reads as if it were a thousand-year history of a self-perpetuating intergenerational cycle of violence and PTSD.

None of this is captured in contemporary social theories of war. Only in the narrow academic areas of domestic violence and extreme criminality does PTSD figure as a contributing factor in existing social theory, but nowhere are its effects on social institutions considered. It is my opinion that one of the single greatest needs facing social theory — and its use by modelers who work in the areas of terrorism and stabilization operations — lies in the incorporation of the known medical, psychological, and epidemiological consequences of trauma into existing social theory.

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