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Global Dynamics and the Tools of Complexity Science

Alan Wilson

The populations and economies of the 220 countries of the world make up a complex global system. The elements of this system are continually interacting through, for example, trade, migration, the deployment of military forces (mostly in the name of defence and security) and development aid. It is a major challenge of social science to seek to understand this global system and to show how this understanding can be used in policy development. In this book, we deploy the tools of complexity science – and in particular, mathematical and computer modelling – to explore various aspects of change and the associated policy and planning uses: in short, global dynamics.

What is needed and what is the available toolkit? Population and economic models are usually based on accounts. Methods of demographic modelling are relatively well known and can be assumed to exist for most countries. In this case, we will largely take existing figures and record them in an information system. An exception is the task of migration modelling. National economic models are, or should be, input–output based. We face a challenge here, in part, to ensure full international coverage and also to link import and export flows with trade flows. In the case of security, there are some rich sources of data to report; in the case for development aid, the data are less good. In each case, we require models of the flows – technically, models of spatial interaction.

Flow models represent equilibria or steady states. Our ultimate focus is dynamics. There will be imbalances in the demographic and economic accounts, and these become the drivers of change in dynamic models. Typical combinations of systems and models that we explore are as follows:

- multi-layered spatial interaction models of trade flows – in the context of rapidly changing ship, port and route 'technologies';

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- dynamic models of trade and economic impact using a variant of spatial Lotka–Volterra;
- input–output models linked by spatial interaction models of imports and exports;
- spatial interaction models of migration combined with biproportional fitting;
- models of riots (i) using epidemiological and spatial interaction modelling, (ii) using discrete choice models, (iii) using spatial statistics and (iv) using diffusion models;
- models of piracy (i) using agent-based models and (ii) using spatial interaction models with ‘threat’ as the interaction;
- models of ethnic contagion using spatial statistics;
- modelling the impact of development aid through input–output models;
- spatial Richardson (arms race) models;
- Colonel Blotto game-theoretic security models.

We introduce each of these in a little more detail, noting the actual or potential planning and policy applications of each.

In the case of shipping (Chapters 2 and 3), we can use the models we develop to explore the consequences of changing patterns of trade and changing transport technologies. There are rich, albeit disparate, sources of data. The global trade system is complex – through the variety of goods, commodities and services that are carried and through the set of transport modes deployed – sea, air, rail, road and telecommunications. This means that we have to choose levels of resolution at which to work and particular systems of interest on which to focus. In making these decisions, we are, to an obvious extent, constrained by the availability of data. We also wish to connect – and make consistent – any predictions from a model of trade with the import and export data which form part of the input–output tables to be outlined in the next chapter. We focus on a coarse level of aggregation based on seven economic sectors, and we present these sectors and volumes of trade in money terms. We focus mainly on ‘container shipping’, though container routes usually include road and/or rail elements as well as sea. This covers 80% or more by volume of trade flows. We proceed in two stages beginning with a review of the evolution of the container shipping system (Chapter 2) and then by building a multi-layered model of international trade (Chapter 3).

A key component of an integrated global model will be a submodel that gives us the state of economic development of each country. The ideal model for each country is an input–output model and these, of course, would be linked through trade flows. It seems appropriate, therefore, to report our response to this challenge in this section along with trade (Chapter 4). The basis of this development has to be the existence of national input–output tables. WIOD (2012) provides an excellent source for 40 countries. However, there are enormous gaps of course – 40 out of 220 – and these gaps embrace the whole of Africa. We have sought to handle this situation by developing new tools, based on high-dimensional principal components’ analysis, which enable us to estimate the missing data. The detail of this method is presented in Chapter 5 of our companion book *Geo-Mathematical Modelling* (Wilson, ed., 2016).

The policy challenges facing governments associated with migration are essentially of three kinds: the effective integration of in-migrants; limiting the inflows of some types of migrant; encouraging inflows of others. There are forces driving migration which, from governmental perspectives, are more or less controllable in different circumstances. It is important, as ever, to seek to provide a good analytical base to underpin the development of policy. There has been extensive research on migration, and we first provide a background to our own work by surveying this research in the context of the policy questions that arise (Chapter 5).

A typical problem facing the global systems' modeller is the situation in which the data available are not sufficiently detailed. In this case, bearing in mind the nature of the policy challenges, in Chapter 6 we take on the task of estimating flows at a regional (sub-national) level. We do not have the data to achieve this on a global scale, but we have good European data and so we develop the methodology on this basis. This is a classical biproportional fitting problem. Migration data have to be assembled from a variety of sources and different ones are more or less reliable. In order to build as complete a picture as possible of global migration, we explore a variety of sources and seek to integrate them (Chapter 7).

Security challenges vary in scale from the urban – even street level – to the international, for example, through the global deployment of a country's military forces. These different scales, in general, demand different modelling methods and we seek to illustrate a range of these. Security has rich but disparate data. We have developed a two-pronged approach: first to develop some new theoretical models by taking some traditional ones and adding spatial structures, and second, we have assembled a wide range of data that has allowed us to carry out some preliminary tests. We recognise that in this case, there will be government agencies around the world who are modelling these systems with far richer resources than we can bring to bear. What we hope to have achieved is to demonstrate some new approaches to security modelling that may be taken up by these agencies. In this case as well, we have been able to develop models at finer scales in relation to riots, rebellions and piracy. A key concept in this work is the representation of 'threat' and in particular, threat across space. We introduce this in broad terms in Chapter 8.

We then present five distinct applications which between them offer a wide range of methods. In some cases, we can apply different methods to the same problem and so discover the strengths and weaknesses in a comparative framework. Chapter 9 offers a variety of approaches to the London riots of August 2011. We built a three-stage model – propensity to riot (from epidemiology), where to riot (a version of the retail model) and the probability of arrest. We use Monte Carlo simulations to determine whether the counts of observed patterns are more or less frequent than might be expected under conditions in which the extent of spatio-temporal dependency of offences is varied.

In Chapter 10, we shift scale and location again and examine the Naxalite rebellions in India. The data on Naxalite terrorism include the date on which events took place and the district (of which there are 25) within which they occurred. Events include Naxalite attacks and police responses. A key idea in the insurgency literature concerns the contagion of events. This can occur for a number of reasons. For example, conflict may literally spillover from one locality to a nearby other, leading to an increase in the area over which the conflict occurs or moving from one location to those adjacent. In this case, we explore a number of hypotheses. We can test whether there are non-spatial effects of police action on insurgent activity. Moreover, we may test the hypothesis that police action is triggered by insurgent activity. If only the latter is observed, this would suggest that police action is reactive but has little effect on insurgent actions (at least on a short-time scale). For such models, the count of attacks per unit time is described by two components: (i) the first is a baseline risk – which may be time invariant or not, but where it changes it will tend to do so over a relatively long-time scale; and (ii) a self-excitation process, whereby recent events have the potential to increase the likelihood of attacks today considerably.

In Chapter 11, we explore a very different system of interest: piracy in the Gulf. An important question is the security of shipping in relation to pirate attacks. There are two possible approaches to this problem: first, to develop an agent-based model with a given (and realistic) pattern of shipping, and pirates as agents; and secondly, as adopted in this Chapter, to develop a spatial interaction model of 'threat' and to use this to explore naval strategies.

In Chapter 12, we explore a different kind of security issue with a different method: the impact of IEDs (improvised explosive devices) in Iraq. The null hypothesis is that they are independent in time and space. We use Knox's method of contagion analysis to seek evidence of clustering – an important issue in the assessment of response to this kind of threat – and find that there is evidence for clustering in space, time and space-time.

Another kind of security issue is posed in nearby countries where there is a threat of cross-border contagion fuelled, for example, by social networks and this is the subject of Chapter 13. We consider whether ethnic conflict is contagious between groups in different countries and if so, how? And then, whether governments react pre-emptively to potential conflict contagion by increasing repression of specific groups? The argument to be tested is that ethnic groups that are discriminated against in a society identify with groups fighting against the same grievance in other countries and become inspired by their struggle to take up arms against their own domestic government as well. For this process, information about foreign struggles is important, not geographic proximity as such. The empirical test involves using a statistical model on country-years from 1951/1981 to 2004 and this gives some support for the argument. The test will be repeated using data on the analytic level of ethnic groups in different years and improving on the measures of information flows. In the case of government reaction, the argument to be tested is whether governments pre-emptively increase repression against ethnic groups they expect to become inspired by foreign conflicts in order to deter them from mobilising. The empirical test in this case is through a strategic model using data on the behaviour of governments towards domestic ethnic groups.

Development aid (Chapters 14 and 15) offers different challenges: first, defining categories; and then assembling data from very diverse sources. In this case, the ultimate challenge is to seek to measure the effectiveness of aid, and a starting point is to connect aid to economic development. This creates a demand to 'measure' development, and we have done this by constructing input–output models for each country which can then be integrated with our trade model. It then becomes possible to compare the magnitudes of different kinds of aid flows with other trade flows and with flows within national economies. Not surprisingly, aid is much more significant in developing countries than in those with advanced economies. The value of the global input–output model now becomes apparent: in a selected country, we can compute the multiplier effects of increased demand or investment in particular sectors and then begin to address the question of whether investment aid is most effectively targeted. We model aid allocation in Chapter 16.

We finally seek to move beyond our investigation of the impact of aid on development in particular countries and explore the extent to which it has any impact on trade, on migration flows or on helping to maintain security. It has been necessary to drive our work in developing particular submodels by assembling relevant data in each case. Our global input–output and trade system then provides the basis for integrating the main submodels so that we explore the interdependencies which make the global system so complex. It is foolish to think that we (or anyone else) can offer a detailed and convincing ‘model of the world’ in all its aspects. But what we can do is to offer a demonstration model that reveals some of the complex system consequences of interdependence and points the way to further research, possibly to be carried out by government and inter-governmental agencies that can bring far greater resources to bear. In Chapter 17, therefore, we draw together the different submodels into a comprehensive model which enables us to incorporate the key interactions. Some of the most obvious interdependencies to be picked up are as follows:

- the impacts of net migration on economic development through the labour elements of the national input–output models;
- security-led pushes in outward migration;
- security-led changes in economic development – whether from damage from attack or because of more intensive development of the arms industry;
- many aspects of changing trade patterns – for example, from investment in new ports as well as changes in economic development levels;
- the re-targeting of development aid.

We proceed by establishing a base model and year – taking 2009 as the latest year for which input–output data are available at the time of writing. As noted in Chapter 4, the model is rooted in WIOD (2012) data but then enhanced through a principal components’ technique to cover all countries. The import and export flows are integrated with those from a trade model by a biproportional fitting procedure. We assemble base year data and models (as appropriate) for the flows of migrants, military dispositions and development aid. These become drivers of change for subsequent time periods (which we take to be years). At each year end, a number of indicators are calculated and particular attention is paid to imbalance as these will provide the basis for driving the system dynamics. Each year end ‘model run’, for this reason, is likely to involve iterations driving the system to a new equilibrium.

Reference

WIOD (2012) The World Input–Output Data Base: Content, Sources and Methods, Technical report Number 10.
Wilson, A. (ed) (2016) *Geo-Mathematical Modelling*, Wiley, Chichester.