Insights into Complex Dynamics of Sustainable Development

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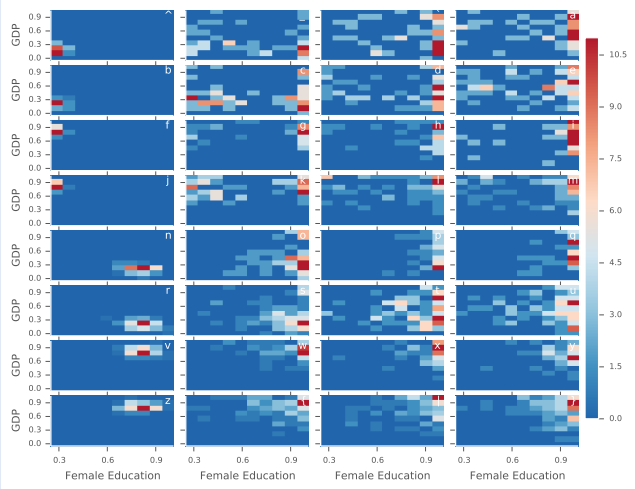

2015

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1 Introduction

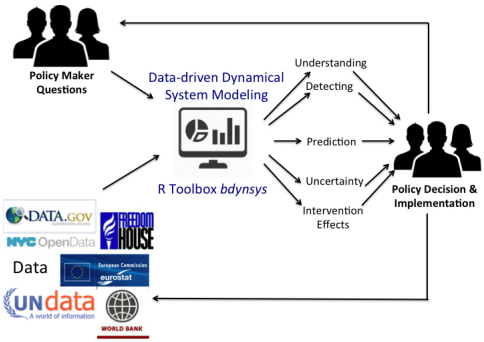

Figure 1.1: Development Research for Policy Making

We are an interdisciplinary research group at Uppsala University using mathematical modeling techniques and specifically dynamical systems modeling, Bayesian statistics and open data provided by World Bank, UN, Freedom House, Human Rights Data Project and World Values Survey to study development. It is our aim to do research that policy makers will find useful for their work. We want to receive input from policy makers in terms of research questions and possibly data that their institutions collect. In return, we want to contribute with our research to an understanding of development processes. Moreover, our research allows to detect critical states, to make predictions accounting for uncertainties that policy makers can use for making decisions and to evaluate intervention effects. Ideally, a collaborative cycle can be established between researchers and policy makers (see Figure 1.1).

2 Millennium Development Goals

The Millennium Development Goals (MDG) gave clear targets for countries across the world. Reducing child mortality by two thirds, universal primary education, halving extreme poverty and ensuring environmental sustainability were all targets set for 2015 (from a 1990 base level). We have been using a data-driven methodology inspired by complexity science called dynamical systems modeling (Ranganathan et al. 2014a) to explore the development of countries in terms of the Millennium Development Goals, analyzing the factors that contributed to achieving the goals and factors that prevented countries from reaching the target. Our approach is unique because it accounts for nonlinear dynamics of development. As such it helps to understand development as a complex phenomenon and to make more realistic predictions about future trajectories of various countries based on their initial conditions.

2.1 Reducing Child Mortality

In one of our papers (Ranganathan et al. 2014b), we build a dynamical systems model of the interactions between economic growth, child mortality and fertility. Figure 2.1 shows a plot called phase portrait. The phase portrait depicts the dynamical system interaction of child mortality (C) and log GDP per capita (G). The left plot in Figure 2.1 shows data trajectories over 30 years (1980-2009) for various countries, with six countries highlighted. The right plot in Figure 2.1 shows trajectories for the same countries and the same time period but based on model predictions. The model predictions are based on mathematical models (ordinary differential equations) for changes in child mortality and for changes in log GDP per capita that were derived from the data. The models can be equally used to make future predictions. Our

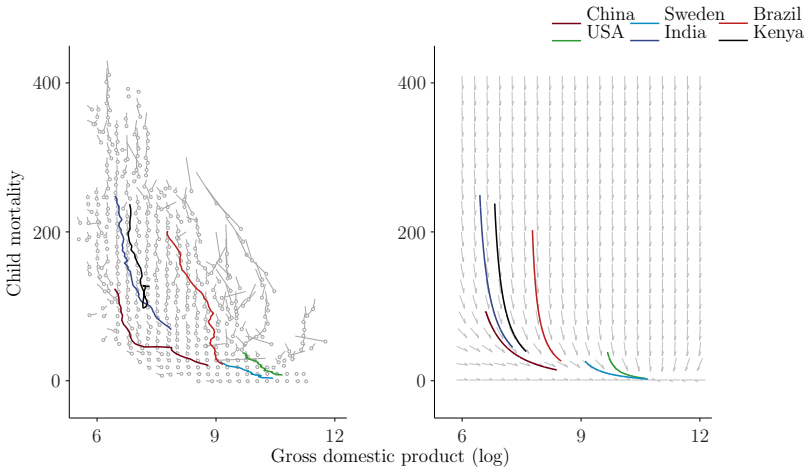

Figure 2.1: Phase portrait of the dynamical system of child mortality (C) and log GDP per capita (G). The yearly changes in the indicator variables C and G are plotted as vectors in the C and G plane based on data (left plot) and on model prediction (right plot). The yearly change is different for different countries and in different years. In general, the yearly changes are a function of current levels of C and G.

analysis of child mortality generally suggests that economic development contributes to a reduction of child mortality and that reducing child mortality would also decrease the fertility rate faster. In the context of the massive aid-driven push for improving (female) education levels as a means to reducing fertility rates in developing countries, our models suggest that it is more important to reduce child mortality levels to reduce fertility rates.

2.2 Reducing CO2 emissions

Sustainability, and in particular, prevention of a dramatic climate change has been a focus of international politics over the last two decades or more and has recently received increasing attention, including in development politics and research. We have used our complexity-science inspired approach to identify a gap of $17GtCO_2$ between the internationally set target of $44GtCO_2$ emissions by 2020 to limit global warming to 2 degrees Celsius above the pre-industrial level and the emissions that our models predict if the business-as-usual scenario persists. Moreover, we discuss mechanisms and option to reduce this gap (Ranganathan et al. 2014c). Specifically we identify the most effective com-

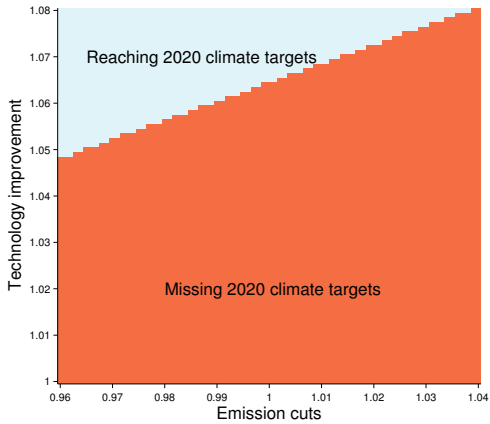

Figure 2.2: Predicted total global emissions in 2020 shown as a function of technological improvement and emissions cuts. The heat map with two colours depicts the two regimes, orange for missing the targets and blue for reaching the target. The border line represents the desired target of $44GtCO_2$.

binations of cutoff rates of emissions, technological improvement and changes in the environmental preferences of populations that would

make it possible to reach the target. Figure 2.2. shows the interaction of technological improvement and emissions cuts, including the critical values (threshold) that show the tipping between reaching and missing the climate targets. These critical values give us the minimum technological improvement and emissions cuts necessary to reach the target. Such results suggest which policies could be implemented by countries to contribute to a mitigation of the climate change.

2.3 Evaluating the Millennium Development Goals Achievements

One important and necessary aspect of development goals is that they be realistic. The MDGs gave a simple set of targets – for example, to halve extreme poverty and to reduce by two thirds the under-five mortality rate from 1990 levels. But these goals were set without reference to differences in the development trajectories of different countries and hence ended up being infeasible for the most vulnerable countries. Figure 2.3 shows that most countries actually will fail to meet the MDG target as has been suspected in the course of the last few years by development economists, including some by a reasonably high margin (e.g. in Sub-Saharan Africa) while a few will over-perform (e.g. China, Brazil, Mexico, Kazakhstan, etc.). This imbalance is due to a standardised goal setting, that does not acknowledge the different initial conditions in various countries.

Our mathematical models (Ranganathan et al. 2015b) allow us to identify typical developmental paths, but where a country will end up depends upon where it starts. We can use the developmental paths to identify what is a realistic future target. Numerical simulations of the estimated noise models also allows us to arrive at prediction interval bounds for the deterministic model predictions and hence policymakers are free to choose ambitious or conservative targets based on these bounds.

The model also facilitates the estimation of the probability of any country achieving their MDG target, given their initial set of condi-

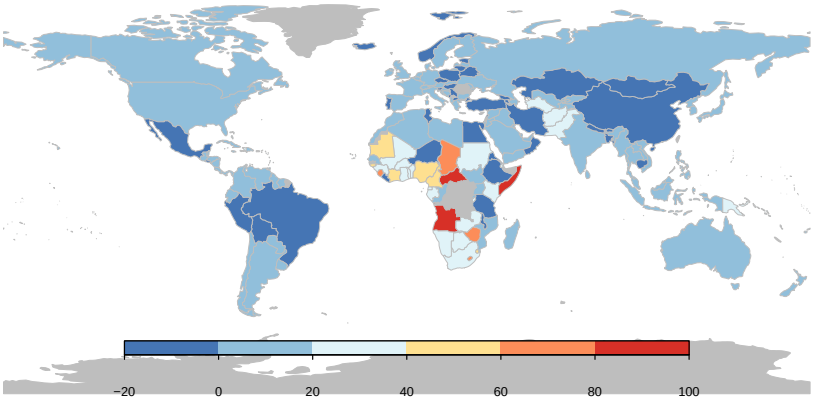

Figure 2.3: The Map shows the likelihood of countries reaching the 2015 MDG target of reducing child mortality by two thirds by showing how far the countries are from reaching the target.

tions. Our model shows that Brazil, and many other South American countries, were likely to succeed in a two-thirds reduction in child mortality because they had a lower level of child mortality to start from, as well as stronger economies, both of which predict further reductions in child mortality. On the other hand, if Sub-Saharan African countries were to succeed in reaching their target, they would need to experience both unusually rapid economic growth and health improvements. If these improvements had occurred, they would have been unprecedented in human history. Africa would have outperformed Europe, Asia and South America. This was never likely to happen, and we should not be too surprised that it did not.

3 Democratisation

Establishing stable democratic structures, accountable government institutions, the rule of law and human rights is often seen as an important goal of international politics. However, the world has also experienced that efforts to promote democracy may in fact be counterproductive and lead to destabilisation rather than to reliable democratic regimes. We use a data-driven mathematical modeling to explore the political trajectories of countries in tandem with their socio-economic performance and cultural development. Similar to our approach studying MDGs, we accounted for nonlinear dynamics in democratisation processes. This contributes to our understanding of how democratisation evolves and to making more realistic predictions about future political trajectories of various countries based on their initial conditions.

3.1 Transition to Democracy

Can democracy work in all national contexts? Our research (Spaiser et al. 2014) suggests that this is not the case unfortunately. Our mathematical models show that there is a threshold economic development that a country has to reach before it can establish democratic institutions. Attempts at democratisation in countries that have not yet reached this threshold economic level are unfortunately likely to fail, unless significant efforts are made to protect those democratic achievements. Figure 3.1 shows similarly as in the Figure 2.1. data trajectories for six selected countries in a plane defined by socio-economic performance (Human Development Index) and democracy. The right-hand plot shows the phase portrait depicting the dynamical system based on the two dimensions and model-based trajectories for the same countries. The data shows that (and this is also captured by the model)

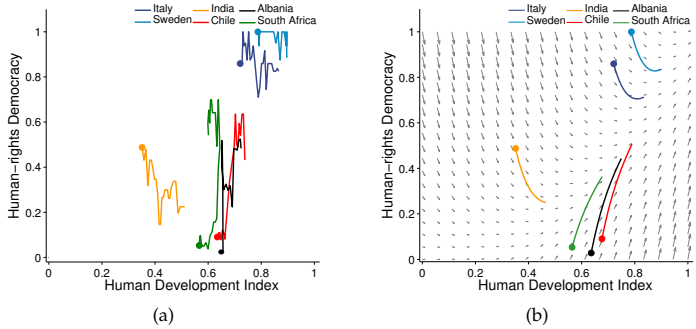

Figure 3.1: Phase portrait of the dynamical system of Human Development Index (HDI) and democracy (D). The yearly changes in the indicator variables HDI and D are plotted as coloured trajectories for six exemplary countries in the HDI and D plane based on data (a) and on model prediction (b). In (b) the arrows represent yearly changes as a function of current levels of HDI and D from different initial conditions.

poor countries like India, that have started with rather high democracy scores but which are still socio-economically poor experience a decline in democracy. On the other hand countries like Chile, Albania or South Africa, that have passed the critical socio-economic development threshold, experienced a fast democratisation in the period between 1980 and 2006.

Generally, we found that democracy grows faster in richer countries and in countries where citizens are better educated. Our models also suggest that once critical democratic institutions are established, a cultural democratisation, in terms of changes in peoples' cultural values and preferences for democracy and emancipation is likely to follow. On the other hand it is unlikely that such pro-democratic values can thrive widely in an authoritarian regime.

3.2 Democratisation Trap as a Development Trap

Why do some countries seem to develop quickly while others remain poor? This question is at the heart of the so-called poverty or development trap problem. Development economists have identified several potential causes of the economic development traps but the issue is complex.

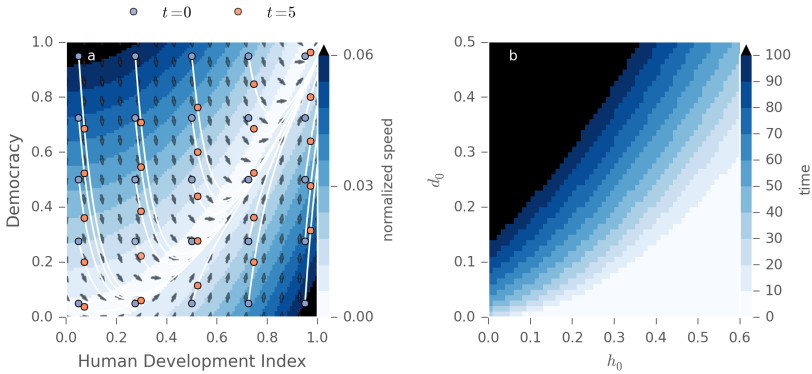

Figure 3.2: (a) Phase portrait of the dynamical system of Human Development Index (HDI) and democracy (D). The colours represent the speed of change, the darker the more quicker the change. The blue points represent potential countries' initial conditions and the red points where these countries would be in 5 years given the underlying dynamics.The white area represent the trap are, countries in this value space change only very slowly. (b) The heat map shows the same dynamic. The colours represent the time it takes for HDI and D to change given the scales on the x and y axes.

Some countries appear to be stuck not only in an economic development trap but also in a political development trap with a lack of democracy. So far there is a lack of understanding how the different types of development traps are related and how they interact, pos-

sibly reinforcing each other. In one of our papers (Ranganathan et al. 2015a) we have developed a new data-driven method to explore multiple traps. We identified two types of political development traps in addition to an economic development trap. One was institutional, where countries with low levels of economic growth and low levels of education fail to develop democracy (see Figure 3.2). The second trap relates to the values and norms of citizens, which develop more slowly in countries with low levels of democracy and life expectancy. We show that many developing countries like India, Egypt, Jordan or

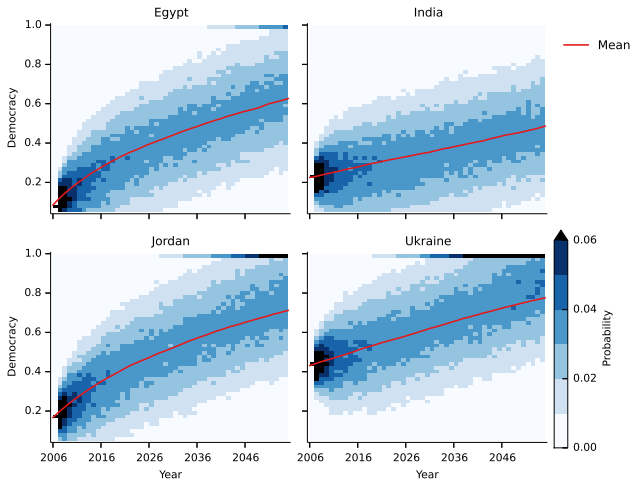

Figure 3.3: Democratisation predictions for four exemplary countries. The red line represents the mean trajectory, the blue areas around the mean trajectories represent uncertainty, that is, with a certain probably (colour scale) the county may also end up below (under-performance) or above (over-performance) the mean trajectory.

Ukraine lie near the border of a development trap. We also predict how long it will take for these countries to make a transition toward

higher democracy and socio-economic well-being (see Figure 3.3). We show that this time can vary a lot since investing a small amount in the right sector at the right moment could help the country to leave a trap. On the other hand, for countries farther from a threshold, a significant investment has to be made over a longer period of time. Although we identified relationships between democratic and socio-economic indices, we should not forget that there remain uncertainties. Events like political changes, conflicts, etc. can lead to sudden changes. So while in the long run of 50 to 100 years democratic and economic changes can be expected in most countries, the changes may be delayed or have potential temporal setbacks.

4 Post-2015 Sustainable Development Goals

The challenge now is to take what we have learnt and move towards realistic Sustainable Development Goals that the UN and other bodies are preparing for next year. It is already decided that the SDGs should focus on poverty, the environment, socio-economic inclusion and governance efficacy. These ideals envisage us simultaneously addressing the challenges of lowering poverty and increasing socio-economic inclusion, while minimizing environmental degradation. It is hard to encapsulate such ideals in terms of target percentages and numbers, and we believe that doing so would be a bad idea. Instead, we believe that models should be used to understand the dynamics that underlie the different targets and determine whether countries can meet them or not. That way the models can contribute to continuously examine and evaluate our progress. This will allow us to monitor and understand our progress, instead of labelling countries successes and failures on arbitrary goals and without accounting for differences in the initial conditions of different countries.

Currently, we are exploring the relation between the different SDGs and whether we can identify models and factors that would allow the pursuit of these goals simultaneously or by focusing on different factors depending on which goals receive priority.

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