Using a Hybrid Cognitive-System Dynamics Model to Anticipate the Influence of Events and Actions on Human Behaviors

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Abstract

Political dynamics often arise from within a political system, but can also be affected by outside forces. In order to understand the potential effects of these forces, we created a model to simulate political dynamics in a society under different internal and external conditions. The system dynamics model uses a cognitive modeling framework to determine human behavior. We present the results of the model under four different scenarios, including a base case, a case where an outside government provides support for the opposition, an information operations case, and a show of force case. The model shows that there is potential for these different conditions to have significant effects, including higher-order effects that may be unanticipated if a systems perspective is not taken.

Introduction

Political dynamics within a society depend on interactions between citizens and leaders, and can also be affected by external events. External influences can involve a wide range of events and actions, from election of new governments in neighboring countries to military operations and dissemination of information by foreign countries. The effects of these types of influences depend on the type and degree of the influence as well the structure of the society being affected. An understanding of the potential outcomes of both internal and external influences is important, since political systems can affect the functioning of a society.

To learn about the effects of different internal and external influences, we created a model to simulate political dynamics in a society. The model simulates the behaviors and interactions of leaders and their constituencies, as well as the political, economic, and environmental conditions that they live in. To simulate people's behaviors, we used a cognitive modeling framework embedded within a system dynamics model. The cognitive framework incorporates well-established theories of human behavior as well as data on culture, society, and individuals.

Our goal was to understand potential actions and counter-actions that people within a society might take in reaction to internal and external influences (such as social, political, environmental, and military). The model's potential uses include what-if queries concerning hypothetical situations, improving understanding of higher-order interactions in a political system, risk analysis, and risk management. We present here the results of the model under a base case scenario and three types of influences. The first is a situation where an external government provides support to the opposition of the current government. In the second scenario, information is distributed to voters to encourage support for opposition leaders. Finally, we present results of a simulation in which an external government initiates a show of force against the simulated society.

The Cognitive Framework

Our hypothesis is that human behavior can be modeled. Specifically, we assert that essential human behaviors can be computationally modeled based on well-vetted psychological, social (psychosocial), political, and economic theories. These models can capture cultural differences and individual uniqueness. They can include the collective knowledge of domain experts and incorporate all available information about individuals and their environment.

The feedback-rich quality of Cognitive, Social, Political, and Economic (CSPE) systems makes these systems an ideal case for system dynamics modeling in combination with psychosocial modeling techniques. The psychosocial element of our framework, which is consistent with system dynamics principles, simulates the key cognitive processes underlying how people make decisions and express behaviors. These behaviors affect other decision-makers, creating complex feedback loops within and between individuals and groups. Confidence management practices can then be incorporated throughout the model building process to ensure that the model is as useful as possible in understanding potential CSPE dynamics within a society.

Our framework is intended to model fundamental characteristics described in established CSPE models of attitude, motivation, intent formation and change, social learning, qualitative choice, and volitional behaviors (both rational and irrational from our vantage point). The objective of the framework is to represent the processes described and predicted in the established CSPE models, as scientifically rigorously as possible, as a theoretically consistent and plausible meta-model of decision making. It is asserted here that emergent CSPE processes that are consistent with, and potentially overlap with, multiple theoretical models can serve to strengthen the theoretical underpinnings of these models, as well as help theoretically strengthen and validate the overall framework. The CSPE models that are expressed in the BIA framework are considered to be highly robust, explaining a relatively large percentage of the variance associated with the specific human behaviors that are represented in this system. The CSPE models have also been specifically cited by the defense and intelligence community as useful to their respective domains (Larson et al., 2009).

This framework is designed to comprehensively represent the significant processes of human behavior and encompass any number of alternative decisions being made by any number of different entities, which can include both individuals and groups of people. By embedding this framework within a system dynamics model, we can also include relationships between entities and the feedback structures that these create.

The cognitive framework is based on a unique set of elements from psychosocial theories that are consistent with economic theory, experimental data, and historical data on human behavior. The theories are consistent with one another, and are easily translated into mathematical equations. All of the theories included in the framework can also be instantiated, tested, and verified using accessible data. The theories incorporated into the cognitive framework include the theory of planned behavior (Ajzen 1985), expectancy value (Fishbein 1963), elaboration likelihood (Petty and Cacioppo 1986), cognitive dissonance (Festinger 1957), bounded rationality (Simon 1957), qualitative choice (McFadden 1984), imperfect information (Stiglitz 1985), risk asymmetry (Tversky and Kahneman 1974), and stock and flow cointegration (Engle and Granger 1987). An overview of the cognitive framework is shown in figure 1.

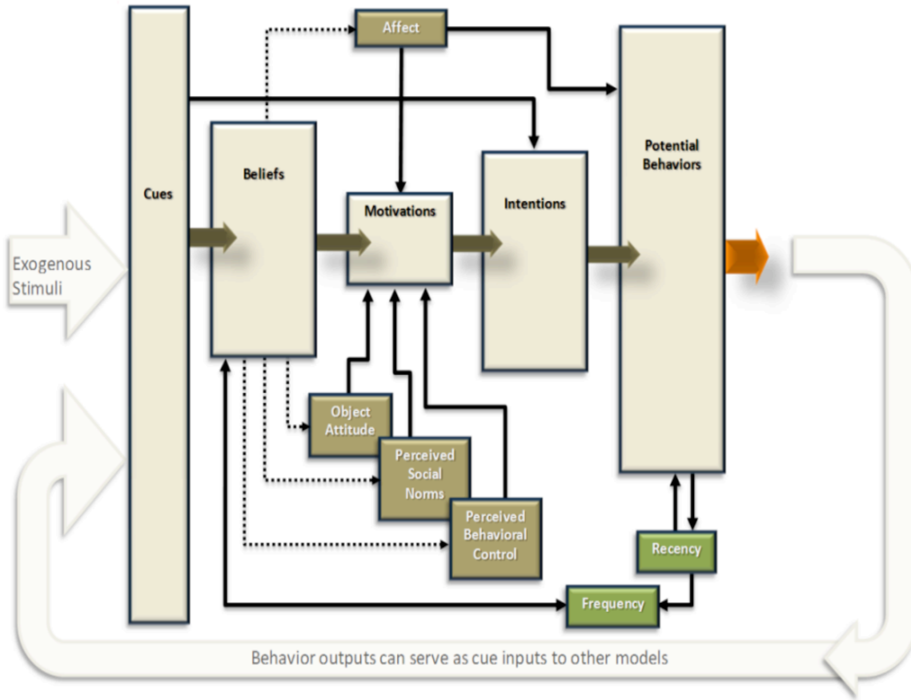

Figure 1: Overview of the cognitive framework

Precisely as laid out by Lewin (1951), the model's behavior is a function of individuals' cognitive characteristics (described below) along with environmental and group dynamics factors. In the framework, individuals and the environment emit signals that propagate outward. These signals can be received by cognitive entities as stimuli, and if relevant, be perceived as cues that can stimulate a particular belief. However, because of differences in individuals' cognitive structures, the same stimuli may be interpreted differently by different people or groups, stimulating different beliefs. These beliefs may stimulate pre-existing attitudes and associated norms and perceptions of behavioral control. They may also stimulate affect (positive and/or negative) associated with the belief. This may motivate the cognitive entity to perform some behavior. If this motivation is high enough it can lead to an intention or set of intentions to perform a specific behavior. The specific intention to perform a behavior is a function of what is actionable. Thus, upon assessing the environment, intentions that are not realizable will lose strength while intentions that are realizable will gain strength. Moreover, the valence associated with affect (low to high positive, low to high negative) will mediate the selection of a behavior. The chosen behavior is a function of the intent, associated affect, and external stimuli that indicate that behavior is indeed actionable. Additional factors that affect the likelihood of a behavior being realized include how often and how recently that behavior has occurred in the past. In other words, previous behaviors are a good predictor of future behaviors. This cognitive process is simulated in our model as shown in Figure 1. The final result of this cognitive process is the entity's actions, which can go on to affect the political system.

The System Dynamics Model

To model the consequences of internal and external influences on a society, it is necessary to model not only the behaviors of affected individuals, but also their interactions with other individuals and the physical world over time. The feedback processes among individuals and the physical world unfold dynamically and can cause unexpected or counterintuitive results. For example, an intervention may cause the system to begin moving in the desired direction, but long-term counter-responses could generate new concerns. The delay between behaviors and impacts can make it extremely difficult to know whether the ups and downs of behavioral responses and counter-responses will ultimately lead to the desired outcome.

Computational modeling of national security interventions needs to address the dynamic evolution of the integrated socioeconomic and geopolitical system. Such systems are most readily modeled using differential equations. Differential equations not only simulate the dynamics, but also causally describe why the dynamics occur. The System Dynamics (SD) methodology developed at MIT is commonly used to model social systems whose interactions are expressible with differential equations (Sterman 1994, 2000).

The process for developing a psychological model using the system dynamics methodology starts with a description of the psychological theories the model must simulate. These theories need to encompass all the salient considerations needed to make a comprehensive systems model describing the problems of interest. Note that there is no attempt to model the entire system, but only those aspects of the system relevant to the problems to be addressed/analyzed. The next step is to develop a causal-loop diagram. This causality relates all the interactions embodied in the theories. The casual loop diagram is next mapped to a stock-and-flow diagram that explicitly details the flow of information and physical quantities through the system.

The exact mathematical expression of the theory is anchored in the accumulation of flows into and out of the stocks. The mathematical expression of the flows comes from a causal interpretation of the theory into the language of mathematics. Only those theories that have a measurable meaning, supportable, at least in principle, by historical or experimental data, are included in this model. The data determine the parameters that control the progression of the simulated values through time. Rigorous statistical techniques determine the appropriate parameters and the uncertainty associated with their use. This uncertainty can later define the confidence in the results of an intervention analysis.

The cognitive framework (figure 1) is embedded within a system dynamics model to determine the behavior of the people and groups that the model simulates. The framework is instantiated four times within this model, for the government, opposition, high-income population, and low-income population. Each of these entities has a separate cognitive framework. The basic structure of each is as described above, but each is parameterized specifically for its associated entity. The general structure of the system dynamics model is shown in figure 2.

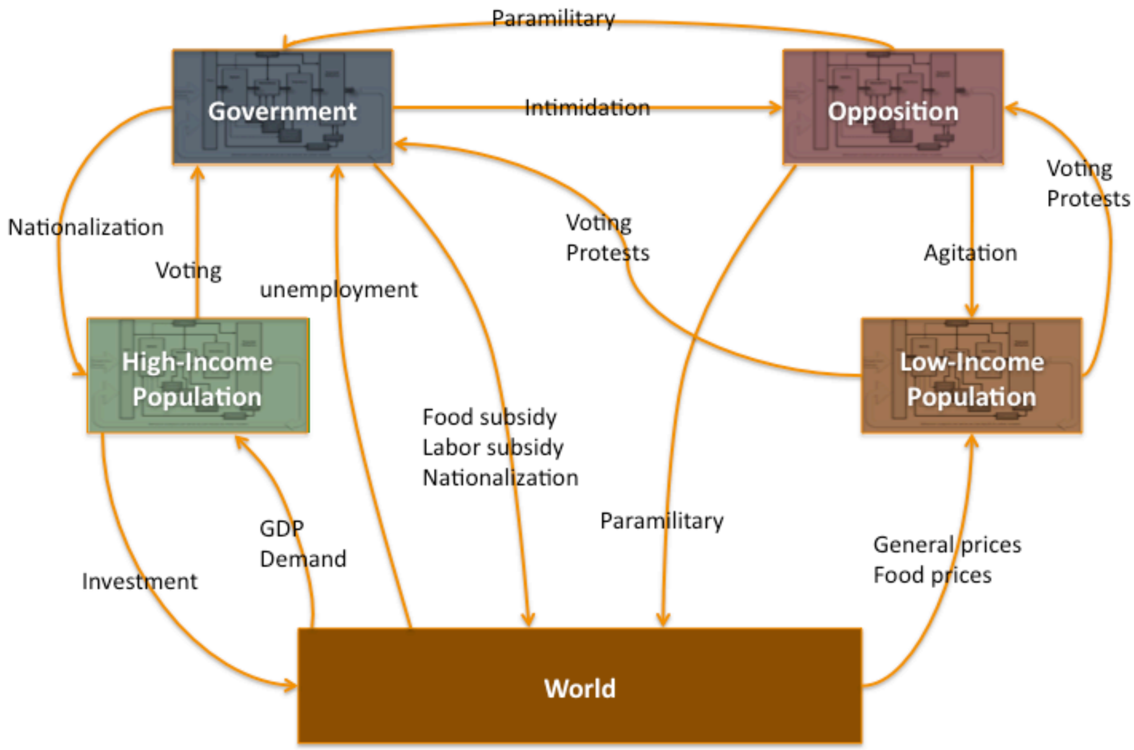

Figure 2: Overview of the model structure

The low-income population in this society makes its political decisions primarily based on prices of food and general goods. This population can take political action through voting and protesting, and might be encouraged to protest by the opposition. The high-income population is more interested in macroeconomic indicators like GDP and demand, and also pays attention when the government nationalizes industry. This population affects the political system through voting, but can also indirectly affect the system by investing in the society's economy.

The government pays close attention to voting preferences, protesting, and unemployment. In order to keep voters happy, the government may implement subsidies for food or labor. It may also nationalize industry. Finally, if the government feels threatened, it might try to intimidate the opposition. The opposition determines its behavior based on this intimidation, as well as on voting and protests. The opposition may encourage protesting by agitating the low-income population. Finally, the opposition has the option of initiating paramilitary operations against the government.

Results

This model has been used to gain an understanding of the consequences of different internal and external influences on a society. Results from the base case scenario, in which only internal influences affect the society, are shown in figure 3. The top graph shows low-income support for the government over the two-year time horizon simulated in the model. The middle graph shows protesting behavior, and the bottom graph shows the subsidies implemented by the government (for food in red and labor in green).

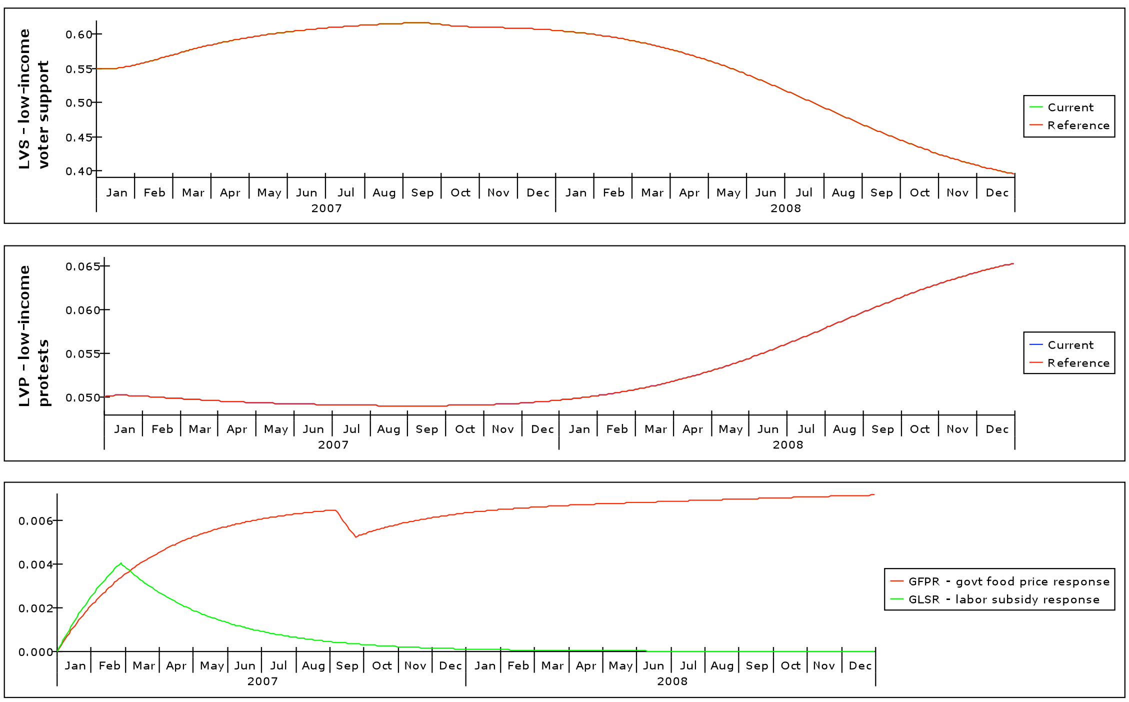

Figure 3: Results from the base case scenario

At the start of the simulation, the government has not enacted subsidies for either food or labor. Low-income protesting and support for the government are both relatively stable, but the government would like to see voter support increase. To encourage support, the government implements subsidies for both food and labor. The labor subsidy causes unemployment to decrease quickly, so the government soon begins to reduce the labor subsidy. In September of the first year, the government sees that low-income voter support has increased, and begins to decrease the food subsidy. Low-income voters are unhappy with the resulting price increases and begin to protest more and support the government less. The government slowly increases the food subsidy to satisfy the low-income voters.

Unlike early in the simulation, these subsidies are not enough to keep voters happy. Although food prices are suppressed by the subsidies, inflation causes the price of general goods to increase. The food subsidy required the government to print money, leading to higher prices for goods. This inflationary effect is gradual, but by the end of the time horizon inflation has a very significant effect on low-income voter support and levels of protesting.

The next scenario (figure 4) begins similarly to the base case, but after four weeks an outside government begins to actively support the opposition, through monetary support, encouragement, or other means. Figure 4 shows the base case (labeled reference) along with the opposition support case (labeled current). The bottom graph shows the subsidies in the current scenario. When the opposition receives outside support, it increases its agitation of low-income protests. Protests increase, which decreases the low-income population's support for the government.

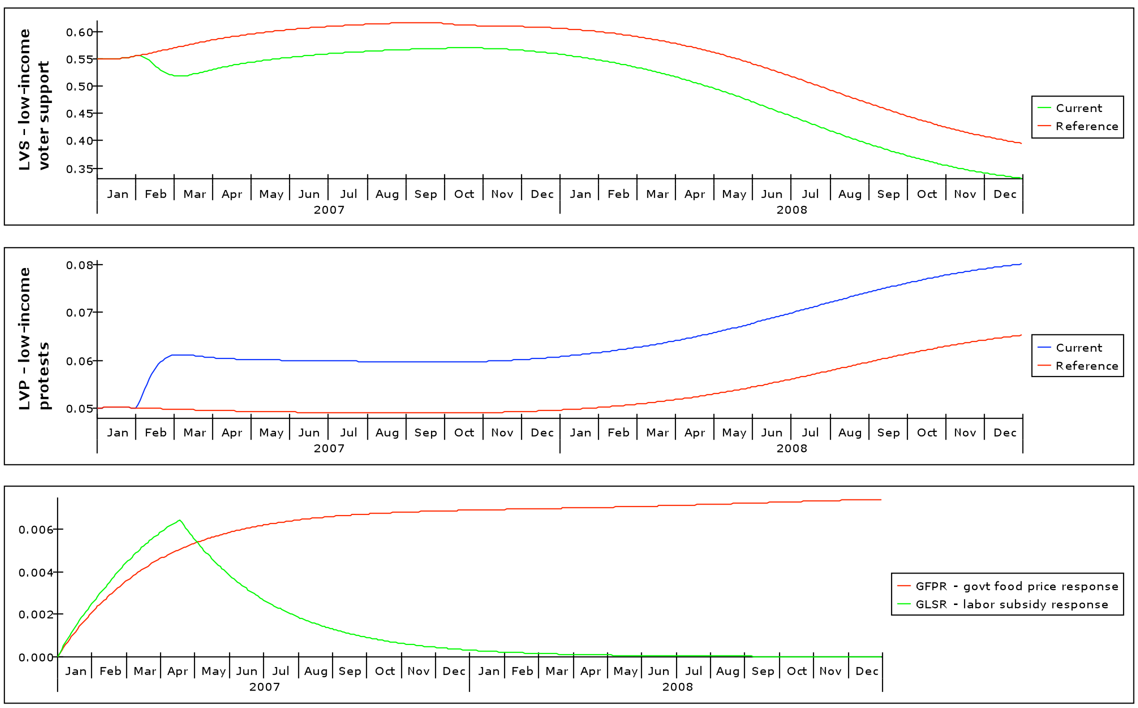

Figure 4: Results from the opposition support case

Figure 5 shows the results of a simulation in which voter information operations are carried out in the society. This is intended to discourage voters from supporting the government. This strategy has a small direct effect on voter support, but alarms the high-income population. They decrease investment in their society's economy, which affects GDP and the general price index. Protesting increases slightly, which causes voter support to decrease somewhat.

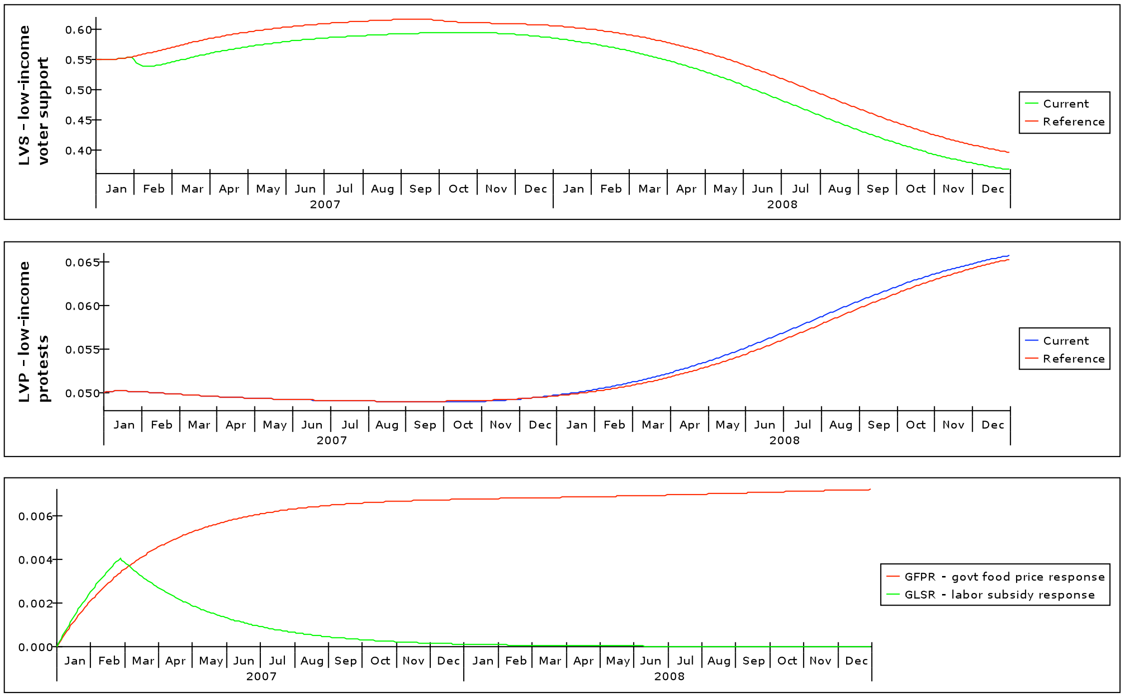

Figure 5: Results from the information operations case

The final influence operation considered is a show of force by an outside government (figure 6). When this show of force occurs, the society's population becomes very patriotic. Low-income voter support for the government increases substantially, and protesting drops to zero. The government is satisfied with levels of protesting and support, so it decreases the food subsidy.

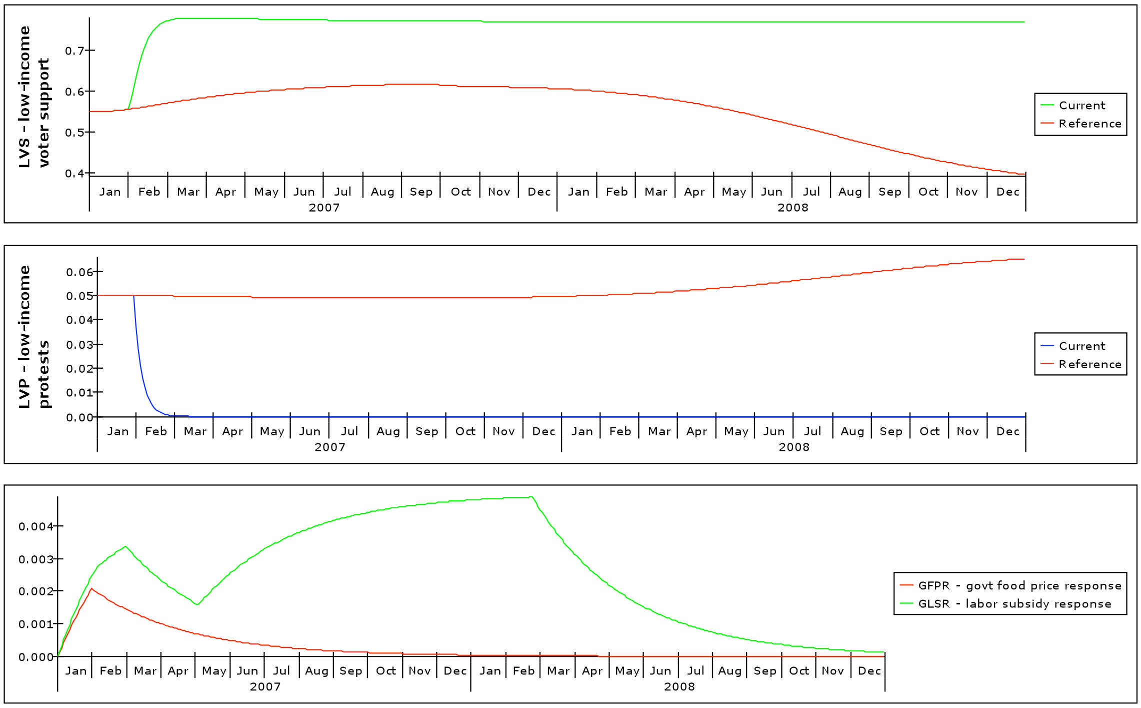

Figure 6: Results from the show of force case

The high-income population, however, is worried by the show of force. Investment in the society's economy drops, and the resulting weakened economy causes unemployment to increases dramatically. The government increases the labor subsidy to account for unemployment rates, and then decreases the subsidy when the unemployment rate improves. The poor economy pushes unemployment up again, causing the government to increase the labor subsidy. Eventually the high-income population regains confidence in the economy and begins to invest more, which reduces unemployment and once again allows the government to decrease the labor subsidy.

Conclusions

Using a cognitive model to simulate decision-making in a system dynamics model has proved to be both effective and descriptive of real decision-making processes. In using this method, we allow exploration not only of behaviors, but also of the thought processes behind them. This can be very useful in situations where thoughts and beliefs are important, such as in political systems. For instance, we might use this type of model to understand which emotions are likely to cause a volatile political situation, or whether a different outcome is likely to be reached if the beliefs held by a population change.

Our exploration of political dynamics shows that there is a potential for significant effects resulting from both internal and external influences. There is also a potential for indirect, and possibly unintended, consequences. Some of the largest effects of these influences were due to changes in inflation and investment behavior, rather than direct effects on voting and protesting levels. An understanding of political structures and dynamics thus seems to be valuable in assessing and managing the risks that may occur under different scenarios.

Embedding a cognitive model within a system dynamics model proved extremely useful in simulating the political system described here. We plan to further this work in various ways. Modeling larger numbers of individuals with this cognitive framework might involve either system dynamics or agent-based models. Verification and validation of the cognitive framework could be conducted, both in the psychological and mathematical sense. The cognitive framework can be enhanced to allow individuals to evolve and learn. Finally, this framework can be applied to many different types of projects in which the behavior and cognitive processes of individuals is important in a dynamic and feedback-rich system.

Works Cited

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In J. Kuhl & J. Beckmann (Eds.), Action control: From cognition to behavior. Berlin, Heidelber, New York: Springer-Verlag.

Engle RF, and Granger, CWJ. (1987). Co-integration and error correction: Representation, estimation and testing. Econometrica 55(2): 251-276.

Festinger, L. (1957). A theory of cognitive dissonance. Stanford, CA: Stanford University Press.

Fishbein, M. (1963). An investigation of the relationships between beliefs about an object and the attitude toward that object. Human Relations 16, pp. 233–240.

Larson, EV, Darilek, RE, Gibran, D, Nichiporuk, B, Richardson, A, Schwartz, LH, and Thurston, CQ. (2009). Foundations of effective influence operations: A framework for enhancing army capabilities. RAND Corporation, Santa Monica, CA.

Lewin, K. (1951). Field theory in social science. New York, NY: Harper.

McFadden, DL. (1984). Econometric analysis of qualitative response models. Handbook of Econometrics, Volume II. Chapter 24. Elsevier Science Publishers BV.

Petty, RE, and Cacioppo, JT. (1986). Communication and Persuasion: Central and Peripheral Routes to Attitude Change. New York: Springer-Verlag.

Simon, H. (1957). A Behavioral Model of Rational Choice. In Models of Man, Social and Rational: Mathematical Essays on Rational Human Behavior in a Social Setting. New York: Wiley.

Sterman, JD. (1994). Learning in and about complex systems. System Dynamics Review 10(2-3): 291-330.

Sterman, JD. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World. Boston, MA: Irwin/McGraw-Hill.

Stiglitz JE. (1985). Information and Economic Analysis: A Perspective, The Economic Journal, Vol. 95, Supplement: Conference Papers, pp. 21-41.

Tversky, A., and Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. Science, 185, 1124–1131. Science Mag Link.

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