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Borders as Membranes: Metaphors and Models for Improved Policy in Border Regions

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With important contributions from:
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Abstract

Political borders are controversial and contested spaces. In an attempt to better understand movement along and through political borders, this project applied the metaphor of a membrane to look at how people, ideas, and things "move" through a border. More specifically, the research team employed this metaphor in a system dynamics framework to construct a computer model to assess legal and illegal migration on the US-Mexico border. Employing a metaphor can be helpful, as it was in this project, to gain different perspectives on a complex system. In addition to the metaphor, the multidisciplinary team utilized an array of methods to gather data including traditional literature searches, an experts workshop, a focus group, interviews, and culling expertise from the individuals on the research team. Results from the qualitative efforts revealed strong social as well as economic drivers that motivate individuals to cross the border legally. Based on the information gathered, the team concluded that legal migration dynamics were of a scope we did not want to consider hence, available demographic models sufficiently capture migration at the local level. Results from both the quantitative and qualitative data searches were used to modify a 1977 border model to demonstrate the dynamic nature of illegal migration. Model runs reveal that current US-policies based on neo-classic economic theory have proven ineffective in curbing illegal migration, and that proposed enforcement policies are also likely to be ineffective. We suggest, based on model results, that improvement in economic conditions within Mexico may have the biggest impact on illegal migration to the U.S. The modeling also supports the views expressed in the current literature suggesting that demographic and economic changes within Mexico are likely to slow illegal migration by 2060 with no special interventions made by either government.

Acknowledgements

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I Introduction

Throughout history humans have dedicated intense energy to identifying, expanding, and protecting borders — those places that delineate where one territory ends and another begins. While a border is how we define the political boundary between two countries, the word also has more conceptual definitions including to “extend along the edge of” or to “almost be”, such as *to border on madness* (Neufeldt 1988). The similarities between a conceptual border and a physical border are numerous and political borders are unique subjects for studying these similarities. This project approaches a political border conceptually as a membrane with gradient and permeability characteristics that affect the dynamics of who crosses a border and why. The research team applied the membrane metaphor within a system dynamics framework. As efforts throughout the world to draw and/or enforce existing boundaries between political entities remain conflicted and controversial, it is relevant to develop tools to try to better understand the dynamics in a border region and to better understand what we mean when we say a border exists. Using a system dynamics model to apply the metaphor of a membrane with concentration gradients on either side is one approach for looking at how people, ideas, and things move through a border. Borders and their concomitant tension are a global issue, but in the interest of time and resources, this project focused on the political boundary between the United States and Mexico. Further, this project looked more specifically at a sister city locale in Columbus, New Mexico and Palomas, Chihuahua. Because both the concept of a border is large and the variables at play on a physical border are numerous, the research team narrowed their focus to looking at people crossing the political border, both legally and illegally.

The timing for this effort is propitious as President Bush is emphasizing immigration as a key policy issue for his second term and has made strong statements in State of the Union addresses about immigration reform (Bush 2005; Fix et al. 2005; Storrs 2005; Bush 2004). News stories from Idaho to New Hampshire to New Mexico reveal mounting pressure for local, state, and federal agencies to address Mexican migration (Carrier 2005; Egan 2005; Gorman 2005; Marks 2005). Immigrant benefits, work visas, and border patrols are topics debated in the halls of Congress as well as in city halls. The US government is running advertisements in Mexico discouraging illegal crossing attempts (Fox News 2005). The governors of Arizona and New Mexico have declared “states of emergency” to address increasingly negative conditions along their borders (Blumenthal 2005).

Relevant data shed some light on the increasing attention to these issues. Since the 1970 census, there has been a 13-fold increase in the number of people living in the US who were born in Mexico and currently about 9% of the Mexican population resides in the US (Passel 2005). Estimates suggest that by 2050 there will be 22 million Mexicans in the US (Passel 2005). Historically, immigrants settled into the border states or in large cities with existing immigrant populations (e.g. Chicago). This has changed, with unauthorized immigrants becoming more geographically dispersed. In fact, North Carolina is classified as a “major destination” and states as diverse as Georgia and Washington are seeing increased immigration (Passel 2005). Since 1995 unauthorized immigration has outpaced legal entries and about 85% of immigrants from Mexico enter the US unauthorized. Many of these individuals eventually obtain legal status (Passel 2005).

The terrorist attacks in 2001 have had a significant impact on how the US perceives and protects its borders. Both the US and Mexico governments want to avoid adversely affecting the billions of dollars in trade between the two countries each year. Both, however, have taken measures designed to reduce potential terrorist attacks and this has affected border crossing dynamics (Smith 2005).

Researchers well understand the complexity inherent in studying border regions. There are cultural, economic, historical and political variables intertwined with immigration and this complicates our ability to comprehend drivers and incentives for migration. As Fix et al. (2005) note, “Immigration issues are complex, with wide ranging consequences that span individual rights, the rule of law, the way our cities and labor markets operate, American competitiveness, national security, and the unique character of the United States in the world. Immigration issues are also controversial and little consensus exists on key policy questions. Part of the explanation for this controversy and political division owes to the fact that immigration policy debates are often poorly informed, polarized and narrow.”

This project was designed to help broaden the debate and thus reduce the level of polarization. There is evidence that traditional beliefs about what drives migration may be flawed and subsequently policies designed to manage migration have perhaps not been as effective as they might be (see Reyes and Mameesh 2002; Zahniser 1999; Massey and Espinosa 1997). System dynamics modeling is an appropriate tool for highlighting where assumed relationships among variables may be erroneous. Using system dynamics enables people to “see” the complexity and the relationships among the diverse and often un-quantified variables. Ultimately, such models can be useful in better understanding border dynamics and designing improved policies for addressing border control and immigration.

This project is not the first to apply a system dynamics modeling approach to explore the US-Mexico border. Several simple system dynamics models of transborder human migration have been created as tools for teaching fundamental systems thinking concepts (see Charles & Kolvoord, undated; isee Systems, undated). More complicated models include that of Dabiri and Low (1977) and Peach (2005). This project relied on the Dabiri and Low (1977) work to create the illegal migration model reported here. The research team also reviewed the demographic model that the Border + 20 (B+20) team of the Southwest Consortium of Environmental Policy and Research (SCERP) developed as a module within their system dynamics model of human-environment interactions in the Paso del Norte trans-border region (Peach 2005; Sadalla 2005).

This report documents the year-long effort focused on understanding the dynamics in the US-Mexico border region and the process for developing system dynamics models using the membrane metaphor as a unique way of looking at border dynamics. The following pages present a brief history of migration in the US-Mexico border; a summary of the research team efforts to apply the membrane metaphor to a “real” border; a summary of the methods used to gather data and to construct the models; and results from the entire project, including lessons in interdisciplinarity, data collected, model output and conclusions from these results.

II US-Mexico Border and Migration History

Following is a brief history of immigration policy and activities on the US-Mexico border. Unless otherwise noted, information was drawn from a Public Broadcasting Service (2005) timeline about the border.

The 1848 Treaty of Guadalupe-Hidalgo marked the end of the US-Mexican War and established the political boundary between the United States and Mexico. This agreement cost Mexico almost half of its territory, at which time, about 80,000 Mexicans were living in the territory that became part of the United States. Most of these individuals opted to become US citizens and this set the stage for continuing strong ties between Mexican Americans and their families and ancestors in Mexico.

National attention granted to the border region has ebbed and flowed over the years, but Mexican workers have consistently entered the US. Between 1850 and 1880, 55,000 crossed the new border. A confluence of events including the Chinese Exclusion Act of 1882, which stopped immigration from China, and the

Mexican Revolution in 1910 increased Mexican migration into the US. Between 1910 and 1920 890,000 legal immigrants entered the US to work on the railroad and to escape strife within Mexico.

In 1917 Congress required a literacy test for all immigrants and the Immigration Act of 1924 established permanent border stations to formally admit workers who had to pay a tax to enter. Although this Act was designed to decrease immigration from southern and eastern Europe, it created the concept of the "illegal alien" which increased suspicion of Mexican workers throughout the US.

Immigration once again boomed during WWII when the US Government established the Bracero Program, which brought millions of Mexican workers into the US between 1942 and 1964. This program "altered the social and economic environments of many border towns" as people flocked to the border seeking work in the US.

Illegal immigration increased over this time period as well. Border Patrol seized 280,000 unauthorized persons in 1949 and 865,000 in 1953. This prompted Operation Wetback in 1954, in which police raided southwestern barrios and stopped Mexican-looking citizens to request identification. The operation discovered more than one million illegal immigrants, but legal immigrants and US citizens expressed outrage, bringing the program to a halt.

In the latter half of the 20th century, immigration legislation continued to reflect prevailing social and cultural mores. The Immigration and Naturalization Act of 1965 changed US immigration policy from a quota system to an emphasis on reuniting families and bringing needed skills into the US. Under the Reagan Administration, criminal and civil penalties for employers who hired unauthorized workers were a key part of the 1986 Immigration Reform Act (Storrs 2005). In 1996 President Clinton signed immigration legislation restricting benefits to legal immigrants and increasing border control to reduce illegal entry (Storrs 2005).

Most recently, the 2001 terrorist attacks generated increased attention to US borders. A key change has been in consolidating federal roles for customs, border patrol and immigration under the Department of Homeland Security. Numerous policies and practices were implemented to increase security at US borders. Policy changes included revising visa requirements. For example, student visas were no longer issued for the duration of study, but had to be renewed annually (From the Hill 2004). As tensions relaxed, visa requirements have been altered and revised as debate over immigration has continued (The US Citizenship and Immigration Services provide information on various visa categories). Despite more stringent crossing policies, there is still significant traffic crossing into the US legally every day as well as continued illegal crossing. Current estimates are that as many as 10 million unauthorized people (from Mexico and elsewhere) reside in the US (Passel 2005; Cornelius 2005).

III Border as Membrane: Applying Metaphor

Philosophers and scholars from time immemorial have used and debated metaphor as a tool and a way of seeing the world. Robert Frost is attributed with writing that, "All thinking is metaphorical" and this project has been an attempt to treat a political border metaphorically as a membrane in order to think about the border from a different perspective. Ramsey (1972) noted that metaphors are "tangential meetings of two diverse contexts" and that the meeting often generates insight and inspiration.

The language of science is metaphorical because metaphors help us understand what is often complex and/or incompletely defined (see Brown 2003; Dunbar 1995; Kuhn 1979). We are a visual species, yet many phenomena are not truly visible and are often not completely understood, so we describe them using a metaphor for something we can see and do understand. Metaphor is not simply a literary device;

its choice frames and shapes how we think and subsequently what we learn about a process or system. For example the success of applying the metaphor of earth as machine significantly influenced the development of western science (see Brown 2003; Hesse 1972).

Brown (2003) provides the following ideas related to using metaphor:

- Metaphors can be thought of as mappings from a source domain of literal, everyday experience to a target domain, with the aim of enlarging and enhancing understanding of that target domain. We use understandings from the domain of direct physical and social experiences to structure our understanding of a more abstract domain.
- A given metaphor highlights certain features of the source domain and hides others, depending on the intent of the author. Often, however, some of the hidden elements are implied by the author or are inferred by the recipient, depending on context. It is just these implications that make metaphor a powerfully creative force in scientific reasoning.
- Although metaphors invite comparisons of two disparate things, the more interesting metaphors do more than this. They stimulate creation of similarities between the source and target domains, such that the target domain is seen in an entirely new light.
- Metaphors in science serve an explanatory role and are a stimulus to new experiments. They may be very simple and evocative initially, then grow more detailed as research findings support or disconfirm inferences drawn from the initial metaphor.
- Models, which are extended metaphors, give rise to metaphorical entailments, which influence the ways in which the model is understood and applied. Models commonly form the basis for theory formation.

This project began with considering a membrane, characterized by gradients and permeabilities as a way to think about dynamic relationships at international political borders. In proposing this effort, the principal investigator prepared the following abstract:

> Understanding and managing border dynamics is critical to U.S. regional and international security. *Border dynamics* include legal and illegal immigration and the exchange of raw materials, manufactured goods, water, pollution, disease, and drugs across international borders. These exchanges affect the physical security of the U.S and are moderated by cross-border gradients and permeabilities. *Border gradients* characterize the difference in concentrations of goods, jobs, wealth, etc., across a border. *Border permeability* refers to the ease with which goods, people, wealth, etc., move across the border. Physical and geographic barriers, security regulations, immigration policies, etc. control permeability. Together gradients and permeability control border dynamics and physical security. For example, a gradient in wealth across an international border may create higher concentrations of laborers on one side, and higher concentrations of jobs on the other. Permeability controls the rate at which laborers can cross the border. Better understanding of interactions among permeability and gradients across multiple interacting systems (i.e., immigration, goods, drugs, etc.) can lead to better border control and less border conflict.

Throughout the project, the team repeatedly returned to the metaphor and progressed through levels of "literalness" in thinking about borders as membranes. The following provides a narrative of this metaphor in its various incarnations.

The semi-permeable membrane has often been used as a metaphor to represent the interface between a wide range of adjacent entities such as business organizations (Gander et al. 2005) and nations (Slatta 1997). In biological and industrial applications, membranes permit selective transfer of different molecules or ions between two regions. Similarly, international borders permit selective transfer of different types of people (citizens, visa-holders, illegal migrants) between two countries. It is this similarity in selectively limiting movement across an interface that makes the membrane metaphor useful in explaining, and modeling, movement of people between countries. In biology, the cell membrane is a physical barrier between two fluids, one inside and one outside the cell. A national border is a physical and imaginary boundary between two cultures, two countries, or between other political entities.

Applying the membrane metaphor requires some care when moving beyond the analogy of the border as a membrane to consider the factors that cause people (e.g. workers, tourists, shoppers) to cross a border in response to the analogs of concentration gradients that cause chemical species to move through a membrane. The gradient that drives diffusion transport is expressed in terms of the concentration of the chemical species that moves down the concentration gradient. For the diffusion analogy to exactly match the border crossing process, we require a direct analog to the concentration gradient. Although we have considered several possibilities we have yet to identify an exact match. For example, if the number of unemployed Mexicans willing to take low paying jobs in the US is analogous to concentration, then having a greater number of such people in Mexico would cause a diffusive type flow from Mexico to the US until the number of formerly unemployed Mexicans residing in the US equals the number of currently unemployed Mexicans in Mexico. This view of the system does not make sense, however, because the movement of unemployed Mexicans is largely in response to job availability in the US rather than the different numbers of unemployed people in each country. Although very useful as a general analogy, difficulties in finding an exact analog in the diffusion process led us to consider more complex metaphors where people moving across the border are being carried in a flow that is, in turn, caused by a gradient related to the number of available jobs and the number of unemployed people on each side of the border.

From a high-level perspective people move across border in response to a gradient that reflects the various factors that affect their personal decision-making. At this level, Fick's First Law of diffusion provides a way to more carefully review the applicability of the membrane metaphor. Fick's Law states:

$$J_A = -D(dC_A/dX)$$

where D is the diffusion coefficient (Length^2/Time)

J_A is the flux of molecule type A across the interface (moles/L^2/T)
C_A is the number of moles of the molecule of interest (moles)
X is membrane thickness (L)

where the dimensions of each parameter are given in terms of length (L), time (T) and moles. In this case, the rate of transfer across the interface is controlled by the diffusion coefficient of the molecule within the membrane D, the membrane thickness X, and the gradient in concentration of the molecule across the membrane (dC_A/dX).

Under Fick's First Law a potential gradient (e.g., chemical concentration gradient or fluid pressure gradient) causes the specified constituent (e.g., specific molecule or specified fluid) to move down gradient (from high to low potential) through a region (e.g., a membrane) that restricts free movement. For example, applying Fick's First Law to the movement of unemployed workers between countries leads to the idea that unemployed workers move across a border from the region with a greater number of unemployed workers to the region with fewer unemployed workers. The passive diffusion model represented by Fick's First Law predicts that molecule concentrations (numbers of unemployed workers) on each side of the membrane (Figure 1) will eventually equalize (Figure 2) as long as molecules (unemployed workers) are neither added to, nor subtracted from, the two-region system. In Figure 1 the upstream volume has high concentration before the process begins while the downstream volume has low concentration. After a time controlled by the diffusion rate of the diffusing species, both volumes ultimately contain an equal concentration of the species. In Figure 2 note that concentrations in both volumes equilibrate at a normalized concentration of 0.5 because the volumes are equal in size and mass is neither added nor subtracted during this process of passive diffusion. This equalization behavior is unlikely to occur in the US-Mexico system because, in the absence of job creation in Mexico or massive unemployment in the US, population growth in Mexico will provide a continuing supply of unemployed workers. This observation, however, does not negate the applicability of the Fickian diffusion model.

Applying Fick's Law also requires that the unemployed Mexican workers would only return to Mexico when there is a higher 'concentration' (greater number) of unemployed workers in the US than there is in Mexico. Although likely true in an aggregate sense, more factors affect the two-way movement of unemployed workers (and other people) across a border than just the number of unemployed workers on each side of the border. Jobs must also be available in sufficient numbers to induce the workers to make the step of dealing with the various factors that promote, or inhibit, their crossing the border. The decision to cross the border is also affected by the strength of social networks that extend between countries and provide support for those considering crossing, non-economic (social unrest) factors in the home country, and perceptions of the risks associated with illegal crossing (see Zahniser 1999; Massey and Espinosa 1997). Although the net effect of these factors can be embodied in a 'potential' that causes unemployed Mexican workers to travel to the US, the detailed 2-way movement of people in various categories (unemployed workers, tourists, shoppers, etc.) across a border is poorly represented by Fick's First Law.

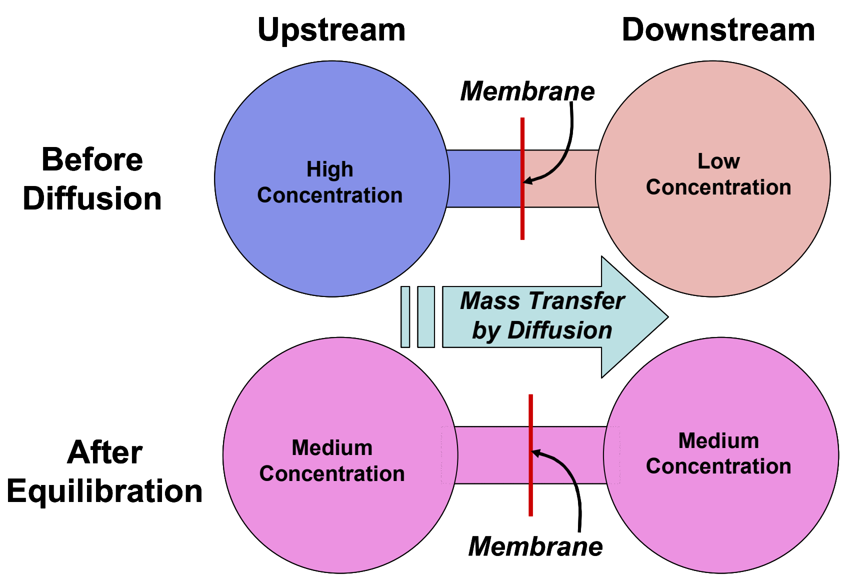


Figure 1. Schematic of the diffusion process that transports mass (molecules or ions) between two closed volumes separated by a semi-permeable membrane.

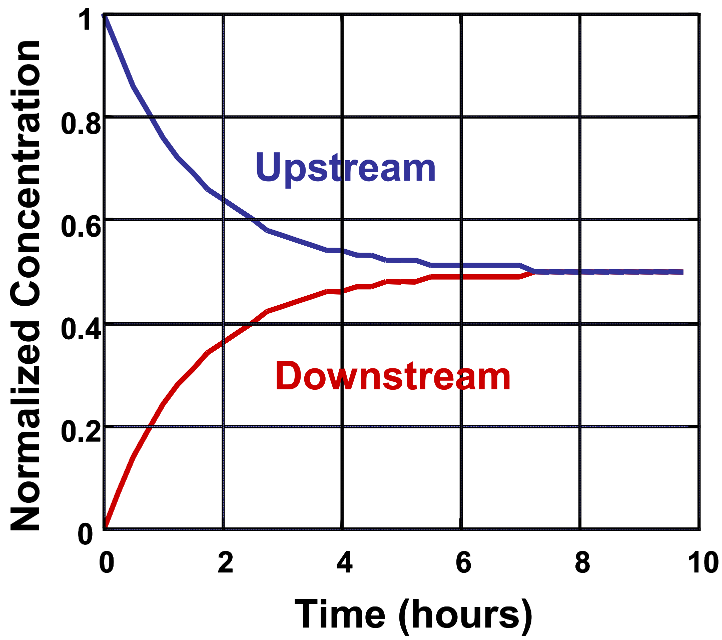


Figure 2. Growth in concentration (normalized to range from 0 to 1) of a hypothetical molecule in a downstream volume as molecules are transferred through a membrane from an initially higher concentration upstream volume.

The process of membrane filtration used in industrial processes provides a more appropriate metaphor for the forces driving movement of people across an international border. Here, a fluid pressure gradient generated using external energy drives a carrier fluid (e.g., water) through the holes in the membrane. Any molecules or suspended solids small enough to pass through the holes are transferred across the interface by the fluid. Molecules, or solid particles, too large to pass through the holes remain on the up-gradient side of the membrane. Although both filtration and diffusion processes require a gradient to cause flow across a membrane, two very different gradient types are needed. In the diffusion case, the gradient is defined in terms of the constituent traveling through the membrane. In the filtration case, the gradient causes the fluid flow that, in turn, carries the constituent through the membrane.

Given the imperfect analogy provided by the diffusion process, we looked more closely at the membrane filtration process. This metaphor represents more clearly the way that illegal migrants without proper documentation are turned away by immigration officials at national borders while legal migrants are allowed to cross. In this case, the legal migrants correspond to the smallest particles that can pass through a membrane. The factors cause people to want to travel between nations correspond to the pressure gradient that drives the carrier fluid through the membrane while filtering out particles larger than a desired size (illegal migrants). Factors that can pull people to a destination across a national border include: tourism, business, attractive jobs, family visits, shopping, access to personal services, and education. Factors in the home country that can enhance the pull by the destination country include: social strife, poverty, lack of jobs, family breakup, and unhealthy conditions.

Many, but not all, of these factors also motivate illegal migrants to cross at locations other than official border crossings (and, to a lesser degree, at official border crossings). Consider a membrane with two hole sizes; small holes represent ports of entry that permit legal migrants to cross while larger holes represent the border between official crossing points where illegal migrants attempt to cross. As border security is tightened, illegal migration is reduced in the same way that the larger hole size might be reduced in a new batch of membranes. The movement of legal migrants through the official border crossings, however, is little affected by increased border security; except when some trips are eliminated because delays at the border become intolerable. Only a portion of the illegal migrants making the attempt successfully reach their destination after crossing the border. Thus, it seems reasonable to assume that the wide variability in factors that inhibit the success of individual illegal migrants (e.g., poor health, lack of funds, apprehension by border guards, dangerous environmental conditions, and risk aversion) is mimicked by a range of suspended particle sizes that might be carried to a membrane in a carrier fluid. Only a portion of the suspended particles will pass through the largest hole size of the membrane; the rest will remain on the up-gradient side of the membrane.

Adopting the membrane filtration metaphor indicates that reducing the flow of people across an international border would require one or more of the following:

1) reduce the overall motivation to cross the border (reduce the fluid flow rate by reducing the fluid pressure gradient)
2) reduce the number of people willing to act on that motivation to cross the border (reduce the number of particles in the fluid stream)
3) increase border security to reduce the number of people able to cross the border (reduce the size of the membrane holes)

One approach to reducing the number of people crossing an international border would involve reducing the underlying factors that attract people to cross the border by improving social, economic, public health and educational conditions in the country of origin and restricting access to jobs in the destination country. It is likely that declining birth rates accompanying the improved living conditions would lead to slower growth in the numbers of people that might become motivated to migrate. In fact, Dowd (2005) has predicted that changing demographic patterns in Mexico will result in fewer unauthorized migrants entering the US. This approach is similar to reducing the pressure gradient driving flow of the transporting fluid while also decreasing the number of particles flowing in the upstream region (points (1) and (2) above). Another approach is to increase border security and divert illegal migrants into increasingly dangerous border territory. Knowledge of the increased risk of apprehension, or death, may dissuade some migrants from attempting to cross. Some of those that remain highly motivated to cross the border, however, will contribute to the migrant apprehension and death rate statistics. This approach is similar to reducing the size of the membrane holes to reduce the number of particles passing through the membrane (point (3) above).

With the previous discussion in mind, a simpler approach to the metaphor was identified that may be more accessible to those unfamiliar with the dynamics of flows across semi-permeable membranes. Brown (2003) outlines how the biological processes of flow across a semi-permeable membrane can be explained using flows through a channel as a metaphor. Thus, rather than using the membrane metaphor for the details of border crossing dynamics, we can revert to the channel metaphor that is conceptually more accessible to the average person. In taking this tack we return to the higher-level view where a gradient in 'something' either directly (diffusion analogy) or indirectly (membrane filtration analogy) causes people to cross international borders.

A channel is a narrow waterway connecting two water bodies. Ships move in one direction or another through the channel under their own power, depending upon the various factors that dictate the ultimate destination of the ship. By analogy, people crossing the border travel along the roads, air routes, railroads and trails that provide legal and illegal routes (channels) for crossing the border in ways that depend upon the factors that motivate them to travel. New border crossings (analogous to increasing the number of channels) can be constructed to enable more efficient movement between nations. Laws, regulations, border entry characteristics and border climate/terrain exert constraints on people wanting to enter a nation (analogous to constraints imposed by channel width, depth, locks or gates). Just as ships travel between water bodies under their own power in response to economic, and other factors, people travel across borders between adjacent nations after weighing economic, social and logistical factors/risks. The factors involved in decision-making lead to a 'potential' gradient that induces unemployed workers to cross the border. However, the 'potential' is only partly related to the number (concentration) of unemployed workers in each country.

The channel metaphor is readily applied to the movement of particles through a semi-permeable membrane where some particles are carried by a flow of water across the membrane while others are filtered out to remain on the upstream side of the membrane. In this case, ships moving in the channel by drifting in the water flow, or traveling under their own power, are analogous to the particles carried through the membrane pores by the flowing water; or to ions driven by electrical gradients. Similarly, the channel metaphor can be applied to describe a variety of cross-border flows from one country to the other with adjustments made to match the metaphor to each type of flow. Types of flows to consider might include, but is not restricted to: (1) unemployed workers moving to find jobs, (2) people returning home after working in another country, and (3) tourists and shoppers making short visits.

The description of the process that the research team applied to utilizing the membrane metaphor to model border dynamics well demonstrates philosopher Max Black's (1962) critical discussion of using metaphor in a comparative sense. He states, "Metaphorical statement is not a substitute for a formal comparison or any other kind of literal statement, but has its own distinctive capacities and achievements" (p. 37). While it may be *possible* to find analogs for the gradient requirements in Fick's Law (or other physical characterization of a membrane) the benefit in terms of more clearly elucidating border dynamics is likely negligible. Black goes on to state that, "It would be more illuminating in some of these cases to say that the metaphor creates similarity than to say that it formulates some similarity antecedently existing" (p. 37). Kuhn (1979) contributes the idea that, "However metaphor functions, it neither presupposes nor supplies a list of the respects in which the subjects juxtaposed by metaphor are similar" (p. 409). The power in metaphor is not found in its ability to "fit" literally the source of the metaphor (in this case a mathematical formula such as Fick's Law), but to provide a more generalized image that can help people better understand some process or system (in this case seeing the border as a channel).

IV Methods

The first, and perhaps most crucial, methodological decision was to convene a multidisciplinary team including practitioners in economics, ecology, hydrology, policy, and anthropology. The principal investigator and team members had experience working with multidisciplinary teams and hence were well positioned to develop an interdisciplinary approach (i.e. actually moving beyond individual disciplinary input to a synthesis of all the disciplines represented).

This team met approximately monthly and thoroughly discussed the metaphor and generated numerous questions that a system dynamics model of the border might address. Team members utilized an array of methods to gather data and knowledge and to employ system dynamics principles. Data collecting techniques included traditional literature searches, an experts workshop, a focus group, interviews, and culling expertise from the individuals on the research team. The modeling method used was system dynamics and the team utilized the computer software Studio Expert 2005, produced by Powersim, Inc.

To help with integration, to broaden applicability, and to build on preceding work, the Sandia research team linked with researchers from the Southwest Center for Environmental Research and Policy and to the extent possible tried to avoid "reinventing the wheel" and build instead on previous efforts by SCERP researchers and others.

The original project proposal explained why a multidisciplinary approach and system dynamics modeling were appropriate methods:

> The primary technical requirement for this effort is modeling capability allowing simulation of interactions among multiple complex, multi-disciplinary systems (i.e., security, economics, etc.). Our modeling team has a unique capability to meet this requirement because of success with smaller, simpler projects of similar nature. Through these similar projects we developed multi-disciplinary approaches and techniques for collecting and integrating data on interacting physical and non-physical systems. Our system dynamics modeling approach is uniquely suited to this project because of its ability to accommodate multiple spatially and temporally dynamic systems, allow real-time user input, provide real-time graphical output, and provide user-friendly interfaces facilitating model implementation by security professionals, policy makers, and planners. These modeling approaches enhance SNL's ability to address future missions associated with threat and risk reduction along borders.

1. Data Collection

Concurrent with thinking about model construction, the research team identified and collected data necessary to understand the dynamics in the border and to populate the models. Team members identified the data needs for various aspects of the project, including:

- Total population over time and demographic breakouts for gender, age
- Visa types and numbers issued
- Business inventory for those businesses hiring illegal immigrants
- Law enforcement (Border Patrol, etc.) expenses
- Duration of stay of legal migrants
- Remittances to Mexico from illegal and legal migrants
- Business investment in rural Mexico
- Mexican demographic statistics
- Average illegal and legal migrant wage
- Crossing by visa type and estimates of illegal crossings

The data collection effort consisted largely of web-based searches and in some cases follow up with phone calls to specific sources. See Appendix A for a list of web sources identified. The first data collected were demographics for the border region. The New Mexico Bureau of Business and Economic Research provided many starting points and useful websites. The US Census Bureau provided demographic data from 1970-2000 and projections out to 2030 for the US as a whole and for border states specifically. State government websites provided births and deaths for those years for the same demographic categories.

A second data category was the numbers of legal and illegal border crossings. Much of these data came from the Department of Homeland Security. Other data came from the Department of Labor; the Department of State; the New Mexico Border Authority; the Center for Comparative Immigration Statistics, as well as the body of literature on border issues. While the research team made every effort to obtain the most accurate and reliable data, there is significant uncertainty associated with any information concerning illegal activity.

2. Experts Workshop

With funding from both Sandia and SCERP, the research team was able to convene a one-day workshop to glean information from individuals with extensive experience studying the border region. The experts invited to participate had several years of experience in building system dynamics models of borderland human-environment interactions via SCERP's B+20 research program (Sadalla 2005). This group came together in Albuquerque on 11 February 2005 and shared their insights with the Sandia research team.

3. Case Study: Focus Group and Interviews

As a "case study" of sorts, the research team conducted a focus group in Columbus, New Mexico to obtain first hand information about border crossing behavior in a small border town. Nine individuals participated in the 6 May 2005 focus group. Cockerill and Passell also interviewed the Port Director at the Columbus Port of Entry and talked with other port employees. Additionally, Cockerill completed phone interviews with four additional individuals who live on or near the border.

4. System Dynamics Modeling

Like the power in a good metaphor, system dynamics modeling provides a means for re-viewing a complex system and "seeing" in potentially new ways. Also like a metaphor, model structure—variables selected, data utilized—all frame and shape the outcome from the model. System dynamics utilizes a stock and flow metaphor to help visualize the interaction among variables in a complex system.

In Industrial Dynamics[1], Jay Forrester (1961) presents a type of model structure that is "amenable to the objectives and principles outlined." He indicates that a model should have the following characteristics:

- Be able to describe any statement of cause-effect relationships that we may wish to include.
- Be simple in mathematical nature.
- Be closely synonymous in nomenclature to industrial, economic and social terminology.
- Be extendable to large numbers of variables (thousands) without exceeding the practical limits of digital computers, and
- Be able to handle "continuous" interactions in the sense that any artificial discontinuities introduced by solution-time intervals will not affect the results. It should, however, be able to generate discontinuous changes in decisions when these are needed.

He concludes that those requirements can be met by "an alternating structure of reservoirs or levels interconnected by controlled flows." These are made operational by stocks, flow rates, decision functions and information channels, the building blocks of a system dynamics model. Forrester's proposal has often been metaphorically described as "bathtub dynamics." Stocks are the bathtubs themselves, decision functions are the automated or humanly controlled valves on the flows to and from bathtubs, and the information channels serve as pipes between stocks. It is a small and enlightening step from stocks and flows to membranes and borders as shown in Table 1.

[1] Now commonly termed system dynamics.

Table 1. Knowledge representation scheme mapping the properties of channels in the macroscopic domain onto biological channels and biological channels on to a port of entry between two countries.

The concepts are further annotated by a comparison to Forrester's modeling paradigm. Adapted and enhanced from Brown (2003) Figure 2.2

Source Domain		Target Domain		New Domain		System Dynamics Domain
Channel		*Cells*		*Border*		*Stocks and Flows*
Narrow passage between two larger bodies of water	Maps to →	Rapid transfer of ions between inside and outside of cell	Maps to →	Movement of persons across a point of entry	Maps to ←	Information channel between stocks
Channel walls may be constructed	Maps to →	Formed from substance embedded in cell wall	Maps to →	Formed by paths, roadways	Maps to ←	Decision function and existence of flow
Channel width and depth constrain sizes of vessels that may pass	Maps to →	Selective for ionic size or charge	Maps to →	Physical characteristics of port of entry permit different kinds of traffic	Maps to ←	Decision function resulting in controlled flow rates
Channel may have locks or gates	Maps to →	Ion passage can be blocked by chemical agents	Maps to →	Laws or regulations	Maps to ←	Decision function resulting in controlled flow rate

The applicability of the stock and flow or system dynamics paradigm is powerful in helping to explain relationships among numerous variables. Sterman (2000) states, "Stocks and flows are familiar to all of us" and this makes them useful in model building. Sterman (2000) cautions, however, that it is imperative to understand the distinctions between stocks and flows. He notes that, "Failure to understand the difference between stocks and flows often leads to underestimation of time delays, a short-term focus, and policy resistance."

The non-trivial aspect of the modeling is to ask the right questions in order to map the correct real world objects to the system dynamics metaphor. A typical attempt to model a problem using the system dynamics approach starts with listing variables of interest, creating reference modes or time graphs, building causal loop diagrams, developing dynamic hypothesis and then, if required, building a computer model (Sterman 2000).

In developing causal loops and models, the team utilized information, data and models from other sources. Early in the project, the team reviewed the model developed by SCERP's B+20 group and used that model to think about the legal migration component of the project (Sadalla 2005). Much of this work was examined via the insight gained from our membrane metaphor, especially as developed into the generic membrane model (Figure 4). The team also used information provided by Zahniser (1999) to populate a system dynamics model in Powersim Studio 2005. This model includes variables about demographic characteristics of people who choose to migrate to the US, why they migrate, and what prompts them to return to Mexico. Finally, this project relied heavily on a model developed by Dabiri and Low in 1977 as a modeling assignment at the MIT Sloan School of Management.

V Results

1. Lessons in Interdisciplinarity, Model Building, and Metaphor

For at least two decades researchers have promoted interdisciplinary approaches as one path toward better decision-making (see Klein 1990). In more recent years, using computer models in concert with a multi- or interdisciplinary research team has gained popularity (Cockerill et al. 2005 (in press); van den Belt 2004; Nicolson et al. 2002; Rouwette et al. 2002; Moxey and White 1998). Lessons learned from these projects reflect the "growing pains" that any new approach must suffer. Multidisciplinary modeling teams report similar group dynamic issues and make similar suggestions to help advance this method. The project described here is no exception. Because these modeling efforts are a relatively new approach, documenting the process is as important as the final product. The discussions, debates, misturns, and decisions that ultimately lead to a model are part of the learning process and help delineate the complexity in studying any system. Ideally, future teams will be able to glean information from this project's experience and continue to find ways to improve how multidisciplinary modeling teams are organized and operate.

Unlike some multidisciplinary projects, team members on the border dynamic modeling project did not waste energy trying to "protect their turf." All individuals were dedicated to finding synthesis across the disciplines (hence were truly attempting to be interdisciplinary) and were not concerned with ensuring that a particular discipline held sway. Related to this, the team actively sought input from those with more expertise about the US-Mexico border, which served the project well.

Like projects that have come before and reflecting the difficulties in moving from multidisciplinary to interdisciplinary work, this team did struggle with communicating across disciplines. This was epitomized, perhaps, in how information was reported in meetings and used in the project. The team did not spend much time discussing how meetings should function, what information was expected from each member or how the team would decide what information to use. Moxey and White (1998) raise an example of this in noting that data from different disciplines differs in spatial and temporal aggregation and reconciling differing ideas about data is important. Early in their formation, teams should consider establishing protocols for how meetings will function, what information is to be presented and in what format. The team should dedicate time to discussing how information from the diverse disciplines will be evaluated and incorporated into the modeling project. This will contribute to learning across disciplines and may ease some frustration in data collection efforts.

Specific to this project, there were recurring discussions about the membrane as metaphor. As would be expected, each discipline brought their own perspective on how to define "membrane" and how best to utilize the metaphor. The role of metaphor generally as it is used in various disciplines was not delineated as well as it might have been early in the project. It is not clear that there was ever consensus on how membrane was to be used in describing the border, but rather it was defined by default in final model construction.

Additionally, like many multidisciplinary teams, it was difficult to come to consensus on methodology and a philosophical approach to conducting research. For example, there were many discussions concerning the relative importance of data type and availability as well as the timing for completing various aspects of the project. The team repeatedly debated the need to know whether there was solid data available before selecting a site to study. There were discussions about how much modeling should be accomplished without knowing the status of data. Much of this debate centered on distinctions between "hard" and "soft" science methodologies—do you review diverse data and identify patterns, or do you frame a hypothesis and test it with more focused data? The team did eventually strike a balance by simultaneously seeking data for particular border locations and framing the story of border dynamics via causal loops and proto-models.

Another lesson from this effort was that it is never too early to actually create a model. Very early in the project timeline, teams should create a rudimentary model (or examine an existing model). This early model can be built with very little data. Instead, it can represent the early understanding of the system to be modeled, and it can use data gathered casually. This model can become a kind of hypothesis, to be tested and disproved as better data are collected and as system understanding improves. This approach also serves the purpose of placing the model as the focal point of the project, and can help prevent collective efforts from wandering. Our team had a generic model ready to show at the experts workshop and this did help generate and focus the discussion.

The group also discussed the value of working as a single body or in subgroups. The team reached consensus that splitting up would impede efforts to synthesize across the disciplines. This decision, intuitive at the time, is supported by research on cognition in interdisciplinary teamwork. Derry et al. (1998) report that interdisciplinary groups are not effective under executive style management approaches, where the group leader delegates tasks to individuals.

There is, however, a need to have a strong leadership in these types of projects. Ideally, a team leader would have (or strive to develop) a deep understanding of the various disciplines reflected in the system to be modeled because his or her role is to help synthesize and cross the disciplinary boundaries. Leadership based only on an effort to facilitate or coordinate can fail, due to the same kind of difficulties associated with "herding cats," which one might assume must occur with determination, resolve, and single-mindedness.

Echoing Nicolson et al. (2002), this team noted that it is important to quickly focus on developing a research question (defining the problem) so that each discipline can then contribute their specialized skills and insight. The team also recognized, however, that it must be flexible enough to change the question later in the process, if warranted. One issue that seems to have been unique to this project is that there was no client. Hence, there was not a problem defined exogenously to the team and therefore, the options were infinite. The team did change focus several times throughout the year. There were discussions in meetings and via e-mail exchanges concerning the value of focusing on a "generic" border versus a specific location as well as on focusing on various subsystems versus selecting a single subsystem. While there was not a client *per se*, this project did have reporting requirements to the funding office. Problems with focus were exacerbated when a mid-project review by the funding office resulted in a request to broaden the focus that the research team had created.

One conclusion from the team was that a first step in any modeling project should be to actually observe the system to be modeled. Simple as this sounds, the tendency among experts may be to believe that they know enough about the system to sufficiently comprehend it in their minds, without the inconvenience of actually examining it. This project should have begun with a trip to two or three different border communities, with project participants given the task of fanning out, making observations and gathering information from as many sources as possible. Then, project participants could reconvene, sort information, and draw early conclusions that would be very helpful in setting early directions for the modeling project.

2. Experts Workshop

One of the first results from this effort was the knowledge gleaned from convening a group of experts who have studied the US-Mexico border region. Appendix C provides the meeting agenda, attendee list, and full notes.

The meeting began with an overview of the membrane metaphor and an example of applying a membrane to a migration model. The group then participated in a facilitated discussion. Key ideas resulting from the discussion included:

- Understanding the power of a metaphor.
  - Lacking a shared metaphor often means failure for interdisciplinary teams because each person/discipline is using a different frame to approach the problem. This connects to ideas related to applying values. The question that the team asks will frame the model and the very act of identifying variables includes implicit value assumptions. For example, ideas about allowing the "good" elements to cross while keeping "bad" elements out are rife with value judgments that change over time and across space.

- The reality of a physical border and its history.
  - The US-Mexico border as it is understood today is a relatively new concept. There was no "membrane" 100 years ago: restrictions have created the membrane. There are few tensions at the physical border and attempts to "manage" the border are short-sighted – especially attempts to "manage" from national capitals in Washington DC or Mexico City. The idea of a gradient is not new and the key gradient is the difference in GDP. Additionally, within Mexico there is a gradient with the border being "rich" relative to the interior.

- Using system dynamics as the method.
  - Modeling gradients may not show directly what to do: it will show consequences of actions. This project has the flavor of a demonstration—we get to see if system dynamics is useful, because it has not been applied to the idea of gradients. We try to model what we can control because it is comfortable, but we should try to see where things are not clear. System dynamic models let us see how "levers" connect to things. A system dynamics model can show that some variables are irrelevant and can prompt discussion to help address questions like what is "healthy" as well as help deal with uncertainty. Constraints affect stocks and flows and may help the membrane metaphor "fit."

Following this discussion, the group brainstormed ideas for specific "flows" to begin to model in scheduled breakout sessions. The group generated the following list:

money	ideas
vehicles	water (waste, ground, treated)
oil	natural gas
scrap cars	financial capital
disease	social change
terrorists	political systems/influence
education	demographics
people (jobs)	materials (goods, hazmat)
air pollution	ecosystem
electricity	tires
infrastructure (physical, institutional)	services

guns	implements of terror
ideology	energy
culture	flora/fauna

After much discussion and no consensus about how to prioritize from this list, the group opted to let Howard Passell, the principal investigator, select three topics to tackle in smaller groups.

He selected:

- Air pollution
- Students (education)
- Water supply

Over lunch and continuing after, three sub-groups discussed the variables for their topic and created causal loop diagrams for their subsystem. Then each group presented their diagram and rationale to the plenary.

<u>Air Pollution</u>—This group, driven largely by the knowledge level of one participant, scaled up this topic to "pollution" then condensed it back down to "tires." The group agreed this is an interesting subject because tire disposal is not really an important environmental issue, but it is perceived to be a problem. The group's goal statement was reported to be "reduce inappropriate disposal rate" and their causal loop included options for disposal, stocks of tires, actors in tire use and disposal and policy issues.

<u>Student/ Education</u>—This group reported a key question as, "What is the *gradient* that drives movement of students?" Key drivers for students to cross into the US to attend school include cost, quality, prestige, access. There are also students from the US who cross into Mexico to attend school. Another reason for students to cross into Mexico is social, and includes things like alcohol and entertainment.

<u>Water Quality</u>—The water quality group created causal loop diagrams for both surface and ground water linking economics, social issues, and physical realities. The group reported that they tried to apply the membrane concept, but concluded that the issue is just one of flow, although they did need to consider flow on both sides of the border.

Following the group presentations, all attendees joined in a brief discussion on how we could link the three disparate topics. As the group discovered, there are unique and potentially infinite ways to link them, thus stressing the interrelatedness of any topic we might assess related to the border.

The discussion then shifted to the membrane concept and lessons in applying it from the three specific topics broken out in the meeting. As to whether the metaphor "works", the group agreed that it may be topic dependent. Additionally, individual perspective may determine where it is working or not and the metaphor may "work" in multiple ways, as it can change views on a specific topic. The group agreed that identifying "classes" of problems where the membrane metaphor is most useful would be good. Other key conclusions were that the membrane may work better for social issues and that it may be less useful for topics where knowledge is abundant or where there is no polarity to the issue.

There was also an extended discussion about what a physical membrane "is" and how definitions may differ across disciplines and applications. Some key ideas raised included the idea that gradients can change permeability; that something does not have to cross the membrane in order to change it; flow is always through a medium; there are few natural membranes above the cell level; and that it is the social/political/human aspects of a problem that create the membrane. Membranes were juxtaposed to "pipe works" as an approach to looking at issues and that membranes are only one alternative to pipe works, a magnet concept could work as well.

As is often true in interdisciplinary efforts, the vocabulary was at times problematic, but the group concluded that the following terms are key to this metaphor:

Medium
Membrane
Change
Flow/diffusion

This discussion evolved to focus on the metaphor itself, rather than the border as a focal point. Participants raised questions regarding the "edge" of the membrane and how literal we should be in applying the metaphor.

The group also returned to the idea of applying values in trying to understand border gradients and who determines what is "good". As an example, for many, the value of the border IS the border, the asymmetry is a value that the border region provides.

To wrap up the meeting, Passell asked the group if they would suggest a generic model versus a specific location. The group recommended taking a specific approach where it may be easier to get a customer for the model. Suggested paired cities included Ambos/Nogales and Palomas/Columbus.

3. Case Study: Focus Group and Interviews

Based partially on recommendations from the experts workshop, the research team completed a "case study" of the Columbus/Palomas city pair at the New Mexico/Chihuahua border. This included documenting the history of the two municipalities, interviewing Port personnel, interviewing border residents and conducting a focus group in Columbus. Appendix D provides the full report from this case study.

The village of Columbus, New Mexico was initially established in 1891 and its fate has historically been linked with the railroad, which ceased running in Columbus in 1981. While once a large town with a 12-grade school and three hotels, by 1990 the population had fallen to 641. In recent years, Columbus, like much of the southwest has experienced growth and the town's population was 1765 in the 2000 census. The town is populated largely with mobile homes. The elementary school and the post office are prominent structures. Among other facilities, there is a museum, a bed and breakfast, a theatre (plays, not movies), a health center, an RV park, and a café. On the edge of town are signs in Spanish warning people not to dump their trash.

Situated south of town, just at the border on the US side is a dirt parking lot, a liquor store, a check cashing/money transfer station and a Family Dollar store. There are also signs advertising a pharmacy and a dental clinic in Palomas. At the Columbus Port of Entry there are two lanes for cars to enter and pass through the x-ray machine and radiation detectors. Pedestrians enter the Port building and pass through a turn-style manned by two border officers.

On the Mexico side, what is now known as Puerto Palomas originated in the mid-1800s as a community of 120 migrant families of Mexican origin coming from the United States. It is one of 209 communities that belong to the municipality of Ascension and in 2000 it had a population of 4980 (Enciclopedia, INAFED). The town includes a large pharmacy and a dental clinic as well as The Pink Store, a local landmark. At the crossing, there are no guards, no check stations, a single lane for vehicles and a narrow pathway for pedestrians to enter Mexico.

The region's primary claim to fame is as the site of 'Pancho' Villa's raid in 1916. Several hundred guerrillas of the Mexican Revolution under General Francisco Villa crossed into the US and attacked Columbus, leaving 10 civilians, eight US soldiers, and 100 guerrillas dead. The US military had previously established a military outpost in Columbus because of the ongoing friction between the two countries. In retaliation, General 'Black Jack' Pershing, later the commander of the Allied forces during World War I, led 10,000 troops some 400 miles into Mexico. Over the next 11 months they searched for the Mexican forces, eventually dispersing them, but never finding Villa (Public Broadcasting Service 2005).

According to Port personnel interviewed as part of this project, in the early 1900s the official border crossing station was in Deming. There was little enforcement as to who crossed. After the Pancho Villa raid, the port moved to Columbus. In 1994 the Columbus Port of Entry had two managers, one Port Director and 25 officers. There was little of today's technology and rarely a dog on duty. In 2005 there are about 60 officers, each has a pager that is also a radiation detector, there are X-ray machines, and data systems. There is always a dog on duty. Terrorism is key to the Port's mission. Immigration, customs, and border patrol are all now under Homeland Security and are working together at all entries.

Crossing the Border—Among interview and focus group respondents, their individual crossing frequency ranges from several times a day to a less than once a month. The Port reports about 800 pedestrians crossing into the US daily, although this number swells during chili picking season and holidays. Border personnel report that near holidays (e.g. Christmas, Easter) crossings increase to 2-3000 cars and 1500 pedestrians per day.

Economics (employment as well as goods and services) and social reasons are the key drivers to local, legal migration in both directions. Cheaper products and services in Palomas provide an incentive to cross into Mexico while product and service availability in Columbus and Deming provide a reason to enter the US. Additionally, strong family ties and the recreational aspects of crossing were cited as strong incentives for people going either direction.

Various participants reported that it is cheaper to live and operate a business in Mexico. Additionally, prices in Mexico are cheaper for different commodities and services, such as cigarettes, car repair, dental and eye care. As an example, respondents reported that a carton of Marlboros is $14 in Palomas, $30-35 in the US. Respondents did say, however, that prices on the Mexican side have increased in recent years because of the value of the dollar. They also noted that for some commodities, it is no longer cheaper to go to Mexico because of Wal-Mart and K-Mart in Deming.

Also related to the economics of the region are the seasonal workers who cross from Mexico into the US to pick green chile. Employees at the Port of Entry told us, "You know the chile pickers – can smell them from the door." The crossing is packed every morning from 2 – 5 am during the chile season. Buses wait at the crossing to take them to the fields. Port personnel said that most cross back and forth everyday and most are resident aliens.

For crossers from Mexico to the US, the issue is product and service availability. There are no stores in Palomas to provide the goods available at Wal-Mart or K-Mart located in Deming. According to respondents, the Family Dollar Store in Columbus provides the town $5000 in gross receipts taxes.

Additionally, students cross from Palomas into Columbus and Deming to attend school. In the late 1990s there was a push to keep Palomas students from attending US schools. One respondent said that it was "mean, ugly Anglos" who tried to stop kids from coming across for school and that "they all died or moved away." Students now have to be US citizens to attend the schools and the Port of Entry reports that about 120 students cross everyday to go to Columbus Elementary or on to the junior high and high school in Deming. The buses wait at the crossing for them.

Another group of "service" crossers are those seeking medical care in the US. The Port Director told us that they frequently do get women claiming a "medical emergency" so that they can be taken to the Deming hospital. The policy at the port is first to protect health and safety of the individuals. The Port Director said they do follow up on those who come in and do paperwork while waiting for the ambulance. They check the hospital for releases and returns to the border.

Changes in crossing habits—According to respondents, the terrorist attacks of 9/11 changed things "but that's really loosened up" since shortly after the attack. People said that they used to feel comfortable driving a car over, but now there are X-ray machines and delays. One respondent said, "You just never know when you're going to get stuck, it's faster to walk."

There was general agreement that at the Columbus port there is not a long wait, maybe 10 minutes. All said, however, that this is longer than it used to be and is a negative change. Focus group participants joked about the fact that they were saying the wait had gotten "long" when it is only 10 minutes. Port of Entry personnel said that 9/11 had little impact on their numbers crossing, but that in the immediate aftermath, there were long waits. They have since streamlined their process and improved traffic management. Respondents attributed any reduced crossing frequency to one of three reasons: rude border agents; difficulty in getting visas; waiting time to cross.

Crossing policies/comments—Among focus group participants there was strong opposition to requiring passports to cross. Participants noted that passports are expensive and will only succeed in making it more difficult for legal crossing. There was general agreement that the "bad guys" will get across regardless.

There was consensus (and the researchers observed) that people are allowed to cross into the US without showing any identification. Several people said that they believe the Port should be checking IDs, but the passport is too much. One participant noted that as a transplant, she knows if she were living in another part of the country and knew that the border agents didn't check IDs, she'd be upset. Several people agreed that because they live on the border and in a small town where everybody knows everybody, they have a different attitude about these security issues.

One participant said that when coming back to the US with big groups, they've had people try to "join" the party as they come through the crossing. She noted, however, that the agents always identify the interlopers and pick them out to show IDs.

There was general consensus among all respondents that what you look and sound like affects whether you will be stopped as you cross into the US. Respondents reported variations on a theme that young, Hispanic males with fancy cars will be stopped and that blue-eyed people will not be stopped.

There was consensus that Columbus and Palomas get along fine. A Columbus resident stated, "We're an extension of each other, we're much closer to Palomas than we are to Deming."

Unauthorized entry—Respondents raised the issue of unauthorized border crossing. Several participants said that we need more border patrol because they had experience with "illegals" entering their property, sleeping in their cars etc. "The other night I had six of them who came into my house, they wanted me to feed them," said one respondent. This participant said she told them to leave because she would get in trouble for helping them.

Respondents said that this is something that has changed in the past 5 years. Previously, residents on the border were not afraid of the people crossing illegally and would give them water or food. Now, participants report that they are afraid, because “you don’t know if there’s a bad one in the bunch.” One respondent said that the “wetback” population has changed from “family types to marauding groups.” Additionally, one participant noted that if you help the illegal crossers, then your house is marked as a safe house and they keep coming. There was a sense among respondents that harboring illegals has become a serious issue.

A couple of respondents discussed the poverty in central and southern Mexico that drives people to try to cross into the US. One individual plainly stated that efforts to stop illegal migration by tightening the border or increasing enforcement will not stop desperate people from trying to cross.

4. Model Construction

The system dynamics paradigm was applied to border issues as early as 1977. However, if we include Forrester's urban dynamics work (1969), especially his attraction theory of migration we can go back to the late 1960s. Criticism of Forrester’s work included the belief that simple gravity models could adequately describe migration and that Forrester’s formulation was incorrect. However, Laird (1971) showed that gravity models only work over short periods of time, from one to five years. “The standard gravity formulation does not include variables which describe factors creating differential attractiveness or the factors which change the attractiveness differential between starting and ending points” (Laird 1971).

Employing the membrane/channel metaphor, the team developed a causal loop diagram and a generic membrane transfer process model (Figures 3 and 4). Our generic membrane model alludes to the multi-dimensioned measure of attractiveness in the arrows that indicate that ‘An entire model may determine this stock’s value.’

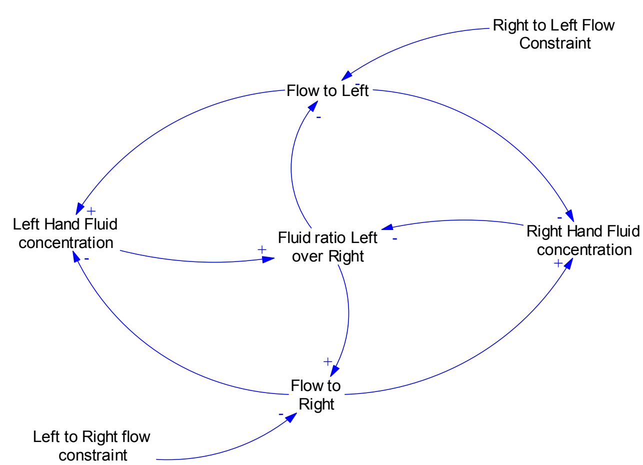


Figure 3. Causal loop diagram for a generic membrane transfer process.

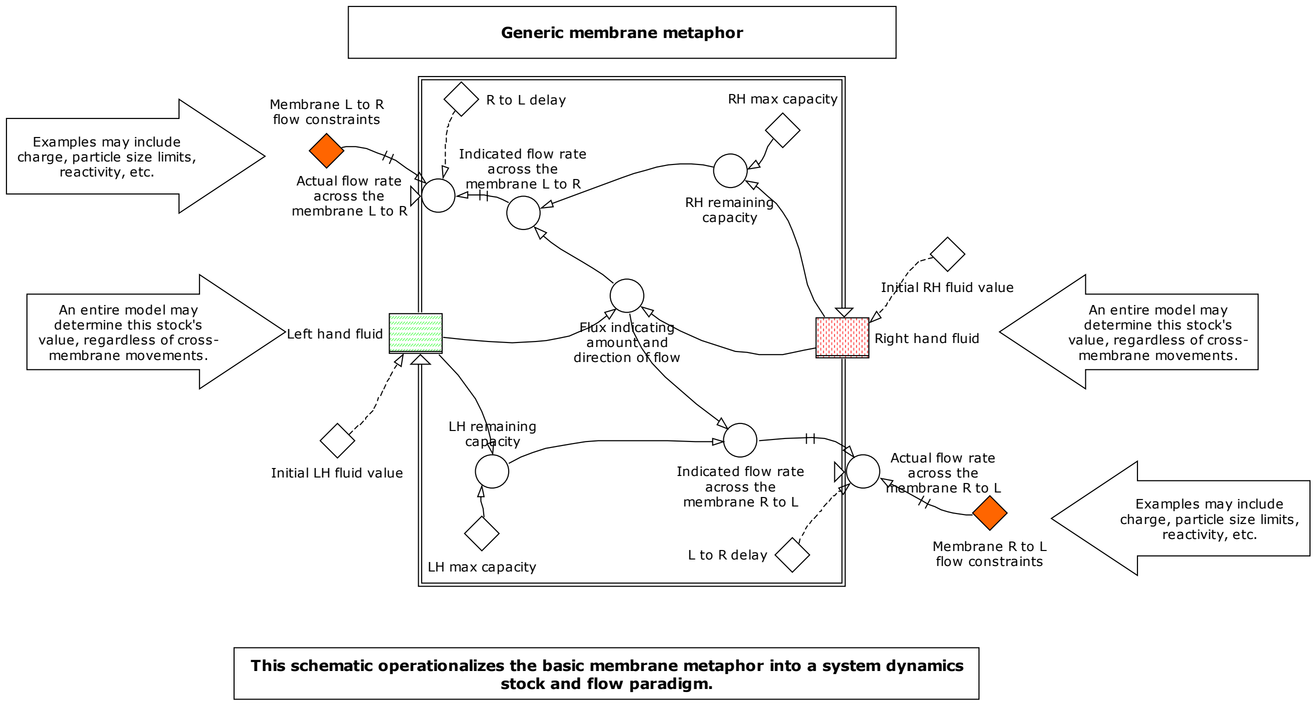


Figure 4. Generic membrane metaphor as a Powersim Studio model.

i. Legal Migration Model

Evidence from the literature, from the experts workshop as well as the focus group and interviews reveal that there are both economic and social drivers that determine why people cross the border legally in either direction. The research team did not find quantitative data on the numbers or frequency of people who cross from the US to Mexico. In our small sample, there is evidence that people who live near a border do cross on a regular basis and that there are people who come from further away to cross for a variety of reasons, such as to buy pharmaceuticals and seek medial care.

The B+20 research project did develop a demographic sector model of legal migration from Mexico to the US as part of a larger effort assessing dynamics of human-environment interaction (Peach 2005; Sadalla 2005). As part of this project we reviewed that effort and collected some data on legal migration. Other than causal loop diagramming, we did not attempt to model legal migration. Tables 2 and 3 show the data for legal migration from Mexico to the US.

Table 2: Legal migration from Mexico to the US 1994-2003.

Source: US Department of Transportation

Border Crossings (Total)	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Commercial	2763120	2860625	3254084	3689665	3946543	4358121	4525579	4304959	4426593	4238045
Private Vehicles	66409554	61785071	62429373	80052978	83854491	98469745	91156796	89526957	89849415	88068391
Pedestrians	34947744	32835972	34109364	43911311	44461554	48213234	47089642	51501321	50278281	48663773

Table 3: Legal migration at the Columbus, NM Port of Entry 1999-2002.

Source: New Mexico Border Authority

Columbus Port of Entry	1999	2000	2001	2002
Commercial	5241	4536	4396	737
Private vehicles	382856	382269	367100	123633
Pedestrians	194672	187111	181469	78276

ii. Illegal Migration Model

The sense from the focus groups and interviews concerning unauthorized entry corresponds to what we found in published reports concerning illegal migration research and to model results. Despite the tightening controls on the US side and sharply increased budgets dedicated to halting the flow, illegal crossing attempts continue apace. Estimates suggest that there may be as many as 10 million unauthorized persons in the US. This is an increase from estimates ranging from 7 million to 8.4 million in 2000. The majority of these individuals are Mexicans (Passel 2005; Cornelius 2005). Apprehension levels have increased and crossers do report that they believe crossing has gotten more difficult. The evidence, however, does not indicate that this new reality is leading to a decrease in crossing attempts. Newspaper accounts and survey research feature individuals who have crossed as many as 20 times and have been caught many times, but say they will continue to cross to earn money (Associated Press 2005, Carrier 2005, Cornelius 2005; Hoffman 2004). Several hundred deaths are attributed each year to attempts at unauthorized border crossing (Cornelius 2005). Cornelius (2005) concludes that, “Enhanced border enforcement has no statistically significant effect on intention to migrate” and that “only ‘demand-reduction’ (= fewer jobs) on the U.S. side is likely to be an effective deterrent.”

Fix et al. (2005) draw a similar conclusion stating that, “Strengthened border enforcement has not been equal to the task of curbing unauthorized immigration. Although getting into the country has become increasingly difficult and dangerous, once here, jobs are plentiful and there is little likelihood that prohibitions on hiring unauthorized workers will be enforced with great enough vigor to change behavior. Our enforcement policies, then, essentially invite people to take great personal risk to defeat border controls in return for the payoff of ready access to the labor market. As long as this situation persists, border enforcement will be unable to override the economic laws of supply and demand that fuel unauthorized immigration.”

In 1997 Massey and Espinosa concluded that policy efforts geared toward discouraging and decreasing illegal migration may actually have exacerbated the problem. They found that contrary to many of the neoclassical economic-based rationales for illegal migration, more powerful drivers were access to social and human capital. Therefore, economic-based policy initiatives have not only failed to stem the flow of undocumented workers, but in some cases have contributed to increasing the flow.

As far as we can determine, the first complex efforts to use system dynamics for cross border migration modeling is Dabiri and Low's 1977 MIT modeling assignment specific to illegal Mexican migration into the United States. The original model was written in DYNAMO and was converted to Powersim Studio 2005 as a part of this project. We have also reverse engineered a causal loop diagram from the original DYNAMO model (Figure 5). Read this diagram by picking one variable and asking yourself, “If this variable were to increase in value?” then follow any arrow from it to the next variable. A + indicates that the variable at the arrow head will increase, a – indicates it will decrease. The opposite applies if you ask, “If this were to decrease?” The + and – signs indicate movement in the same or opposite direction as the change in the base (where the arrow starts) variable The model works at a national level and focuses on issues including economic aid to the Mexican government for labor-intensive industries, introducing added control at the border to reduce the flow of illegal Mexicans across the U.S./Mexico border, allowing temporary-worker migration visas to reduce the institutional barriers for Mexican workers in the U.S., and programs to address the birth rate in rural Mexico. Figure 6 shows simplified version of the CLD indicating selected loops.

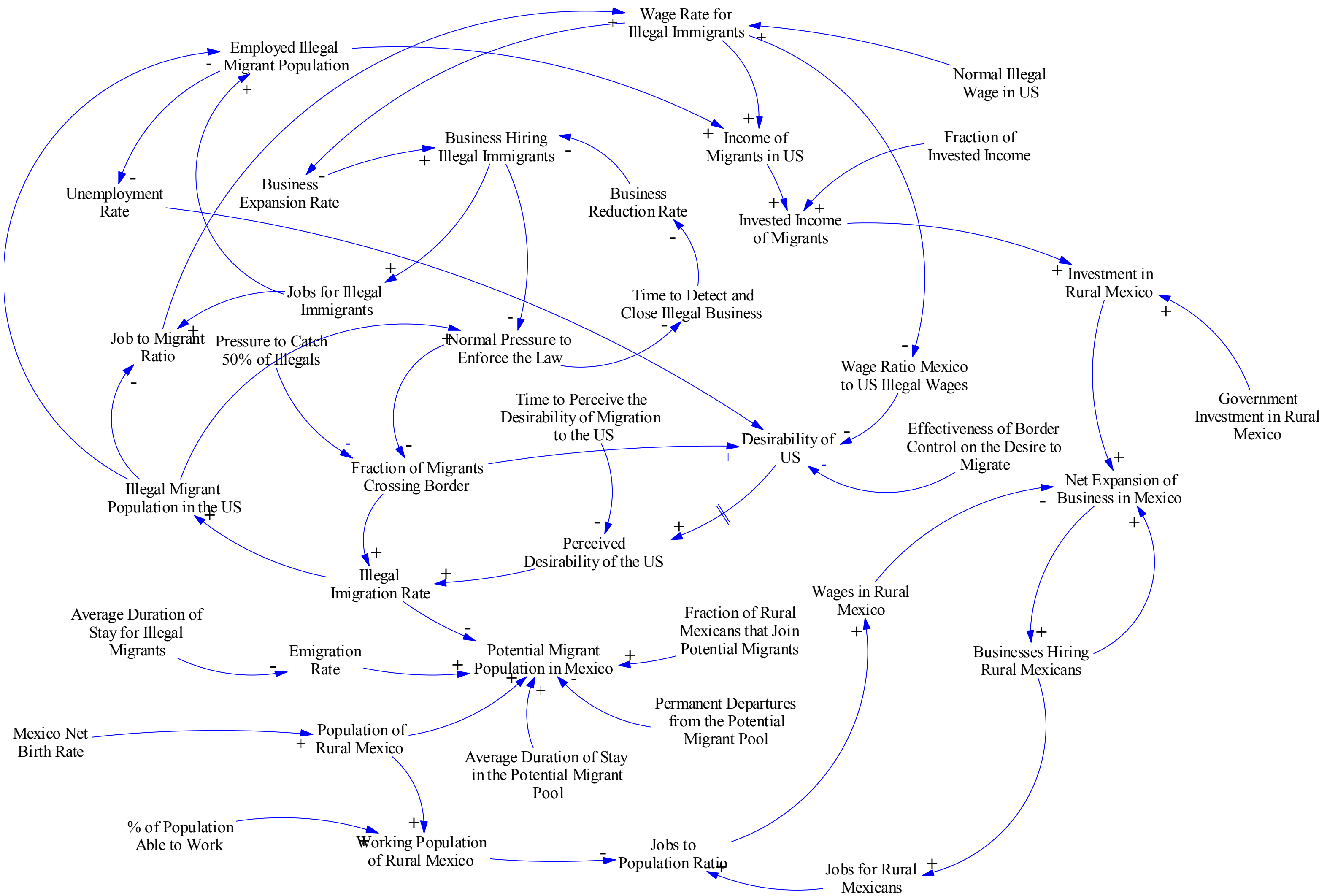


Figure 5. A causal loop diagram created based on the Dabiri and low system dynamics model of illegal migration.

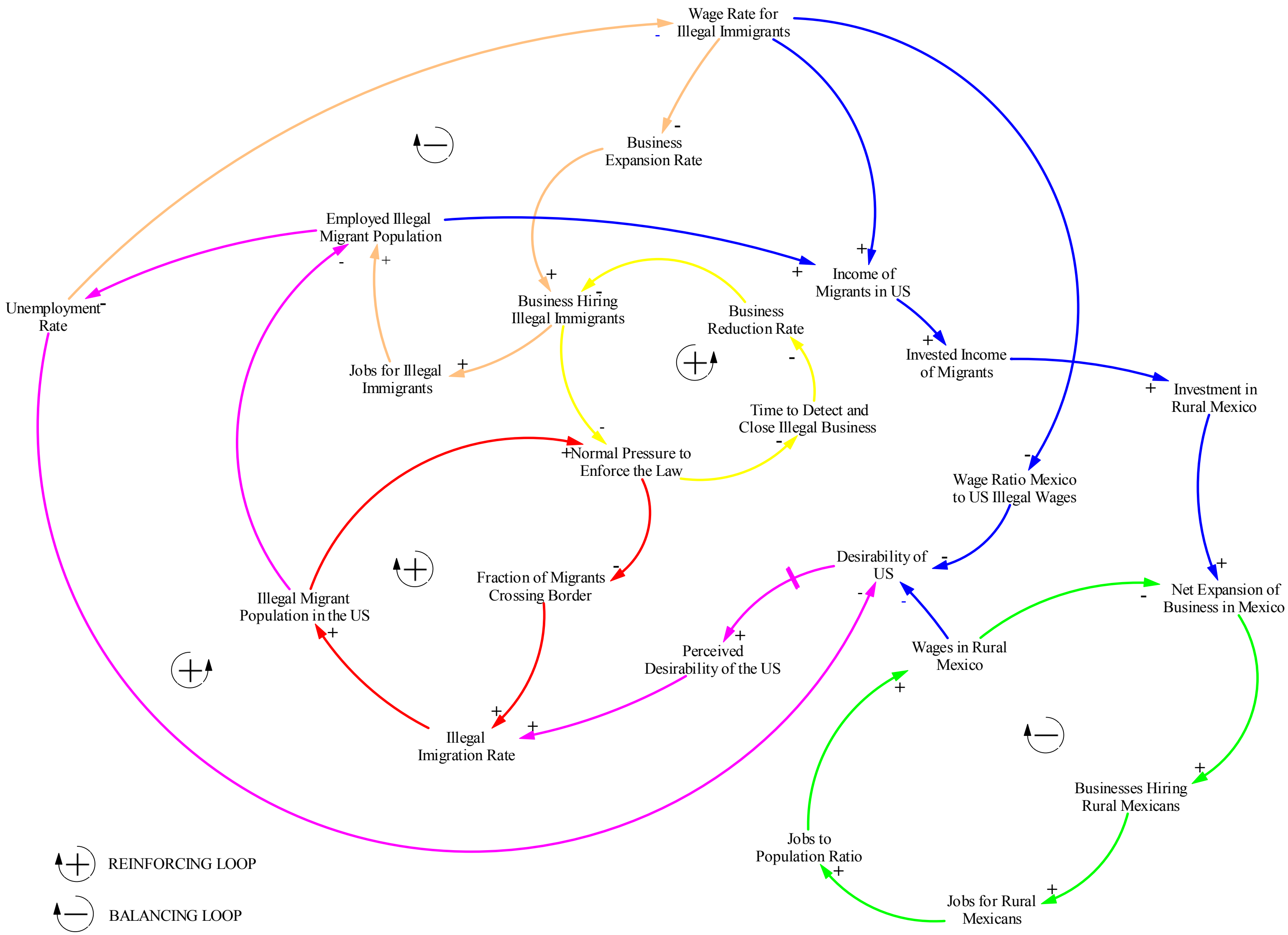


Figure 6. A simplified causal loop diagram created based on the Dabiri and low system dynamics model of illegal migration.

The model develops five main levels to address illegal migration from Mexico to the U.S., and the subsequent drivers of these levels. The levels include the number of U.S. businesses hiring illegal migrants, the illegal migrant population in the U.S., the population of rural Mexico, the potential migrant population in Mexico, and the number of business hiring rural Mexicans. The central thesis of the model is to examine how the business climate in rural Mexico affects the drive for illegal migrants to seek work in the United States. Population growth, local and national economic conditions, political border rigidity (difficulty of crossing) and a multitude of other variables drive the model's insights for illegal Mexican migration.

Dabiri (1977) and Dabiri and Low's (1977) main findings included an ever-growing population of potential illegal migrant labor from Mexico to the U.S. (from 500,000 in 1960 to an expected 2.5 million by 1995, to a stabilizing 3.5 million by 2050), an increasing number of U.S. businesses that hire illegal Mexican migrants (4.5 thousand U.S. businesses in 1960 to an expected 40 thousand by 1995). A few of the key drivers for this change include increasingly "inadequate wages in rural Mexico," and a high birth rate in rural Mexico that adds to the potential pool of illegal Mexicans seeking work in the U.S. (Dabiri 1977, pp. 25). Additionally, as the illegal Mexican population increases (by way of the model's calculations) the pressure on border patrol increases – leading to questions regarding border security resources necessary to address the growth in potential attempted illegal border crossings. As the illegal migrant population fills the demand for illegal labor in the U.S., along with border control measures, the desirability of Mexicans to illegally cross the border may decrease until an equilibrium of sorts develops that, "is characterized by high wages in the U.S. and in Mexico, low desirability of U.S. for potential migrants, low domestic law enforcement pressures, and a high presence of illegal Mexican migrants in this country" (Dabiri 1997, pp. 33).

Finally, the model tests policies that address tighter border control, increasing economic aid to Mexico, instituting a system of temporary worker visas, and how family planning could achieve a reduced birth rate in rural Mexico. The model finds no discernable impact to increasing border efficiency; rather, reinforcing the border control may only postpone an illegal migration problem. Providing aid to Mexico could increase the local and national conditions to a point where the perceived benefit of migrating to the U.S. illegally diminishes to an extent (e.g., reducing the desirability to migrate), thereby reducing the potential population of illegal Mexicans in the U.S. Establishing a temporary worker visa program leads to a higher total illegal Mexican population in the U.S. This is due to the fact that illegal migration does not change after the legal visa program develops (up to 5 million illegal migrants in the U.S. and stabilizing at 4 million vs. 3.5 million under the base case assumption). Finally, addressing rural birth rates in Mexico would eventually lead to a smaller illegal migrant population in the U.S. using the model's assumed decline in the birth rate from 3% in the base case in 1980 to 1.5% by the year 2000. Illegal migrant population would reach a peak of 4 million by 2010, and decline to 1 million by 2060.

Table 4 shows the variables used for a sensitivity analysis in the illegal migration model.

Table 4. Illegal migration model variables.

Variable Abbreviation	Variable Description	Years of Data Located	Source
JPB	JPB Jobs per Business that Hire illegals	---	---
IBHM	IBHM Initial Businesses Hiring Immigrants	---	---
NPEL	NPEL Normal Pressure for Law Enforcement	---	---
IMPUS	Illegal Migrant Population in the US	1990-1999	INS, 2003
ADS	Average Duration of Stay for Temporary Illegal Migrants		
IPRM	Initial Population in Rural Mexico (Persons)	1995 (Total Pop.)	WRI, 1999
JPBM	Jobs per Business in Mexico	---	---
IBHRM	Initial Number of Businesses Hiring Rural Mexicans (Business Units)	---	---
NWRM	Normal Wage in Rural Mexico	1990-1997	Economic Policy Institute, 2001
NINV	Normal Investment Necessary for Maintenance of Existing Industries ($/year)	---	---
NGIRA	Normal Investment in Labor Intensive Industry	---	---
FIGI	Fractional Increase in Government Investment	---	---
ADSPMP	Average Duration of Stay in the Potential Migrant Pool	1990	Reyes and Mameesh, 2002
WHPY	Work Hours per Year	---	---
NIWUS	Normal Illegal Wages in US	---	---

iii. Comparing Dabiri's Model DYNAMO Output to Powersim Studio 2005 Output

In order to gain a rapid understanding of the dynamics of illegal Mexican migration, this research team attempted to duplicate the results of Dabiri's DYNAMO model by converting that model to Powersim Studio 2005. DYNAMO was the original digital computer software that permitted the modeling of system dynamics problems. Although DYNAMO is still available, its use has been superseded by other system dynamics modeling software. Studio has a graphical interactive development environment (IDE), which greatly eases the programming of models.

The Powersim Studio model of illegal migration developed in this project (Appendix C) has at its core the generic membrane metaphor shown as a causal loop diagram in Figure 5 and as a Powersim Studio model in Appendix C. Two central stocks represent the cumulative outcome of movement of chemical species (illegal migrants to the US from Mexico) from one side of the membrane (US-Mexico border) to the other: (1) 'left hand fluid' or 'illegal migrant population in the US - IMPUS', and (2) 'right hand fluid' or 'potential migrant population in Mexico - PMPM'. The stocks are connected by flows ('actual flow rate across the membrane', or 'immigration rate - IMR' and 'emigration rate - EMR') that represent the flux of chemical species (migrants) across the membrane (US-Mexico border). The model of illegal migration differs from that of the generic membrane metaphor in two principal ways. First, the stock of potential migrant population in Mexico is affected by two additional flows: gains through a growing population (‘new additions to the potential migrant population’) and losses through disinterest on the part of prospective migrants (‘permanent departures from the potential migrant pool’). Second, the flows between stocks at the core of the model of illegal migration are influenced by a variety of factors and relationships captured in the much larger model that reflect the complexity of border crossing dynamics. Flows between stocks in the generic membrane metaphor model comprise very simple relationships. We find that starting with the metaphor and building the simple generic model were valuable preliminary steps to getting the team more deeply involved and knowledgeable while modifying and exercising the illegal migration model of Dabiri and Low (1977).

The equations that make up the original DYNAMO code take up approximately two pages of printed text. The model converted to Powersim Studio 2005 is composed of 76 variables, five of which are levels. The conversion process was relatively straightforward. Dabiri’s (1977) suggested solution included a schematic of the model (similar to Appendix C) and an equation listing. There were some language syntax translation difficulties but we are confident that the Powersim Studio version calibrates to the DYNAMO model.

In order to increase our confidence in the calibration we present five sets of graphics, each includes a graph from Dabiri’s memorandum and a similarly designed graph from the Powersim Studio 2005 model. Table 5 shows the five sets.

Table 5. Comparing Dabiri (1977) to the Sandia Powersim Studio conversion.

Dabiri’s original graph	Parameters changed in Powersim Studio
Figure 14 Base Run	None
Figure 19 Border Control Policy	Decrease PNC50 Law Enforcement Pressure to Catch 50% at Border to 0.7 from 1 resulting in 66% success rate in crossing into the US.
Figure 20 Economic Aid to Mexico	Increasing FIGI Fractional Increase in Government Investment by 100% in 1980 to 2 billion USD.
Figure 21 Temporary Migrant Visa	Through the addition of several variables permitting 2 million migrants to enter the US with temporary visas.
Figure 22 Family Planning	Executing a 3% to 1.5% decline in NFBR Net Fractional Birth Rate in Mexico between 1980 and 2000.

We have not attempted to duplicate the numerical output from both models, in part because we are not yet proficient in the current version of DYNAMO. We believe that the graphs show a very strong correspondence between the two model formulations. Of course this effort was undertaken due to our confidence that the Dabiri model is a useful representation of the causal issues concerning illegal Mexican migration to the US. After all, “All models are wrong, some are useful” (Box 1979).

The Dabiri model makes use of table functions. Table functions create an explicit relationship between two variables, typically in the form of a logistic or ‘S’ shaped curve. These functions are common when empirical data is unavailable. Many of the variables are constant, exogenously determined and useful as parameters to test model validity (See Sterman 2000 for a complete discussion of system dynamics model validity and verification). Ideally, a system dynamics model is causally closed, such that “…the closed boundary separates the dynamically significant inner workings of the system from the dynamically insignificant external environment” (Richardson 1991). There are upwards of 20 exogenous variables in the model that make excellent parameters to test policy changes. Recent work has indicated that one of Dabiri’s exogenous variables may be causally closed. That variable is Average Duration of Stay (ADS) in the US. Work by Cornelius (2005) suggests that ADS may be dependent upon the effectiveness of border control. ADS is expected to increase with border control success.

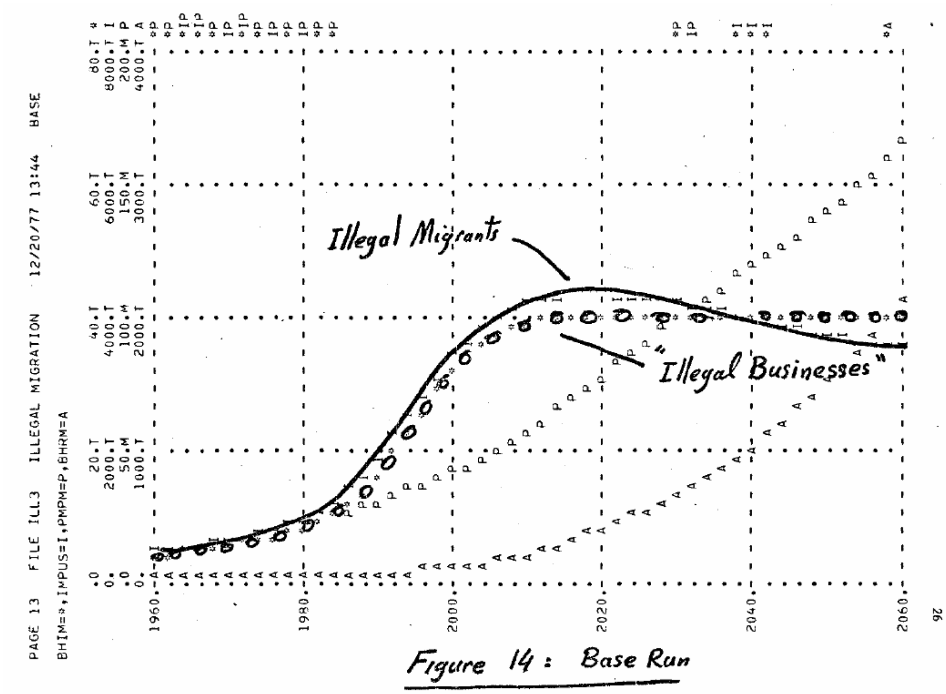


Figure 7. Dabiri model Base Case Scenario.

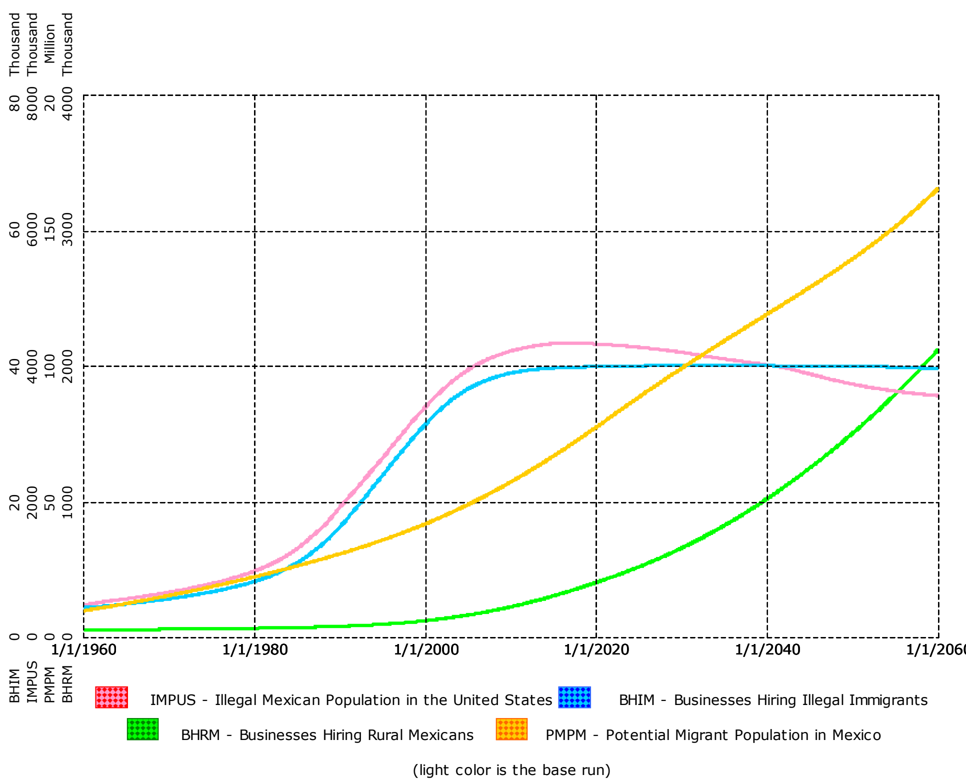


Figure 8. Powersim Studio version of Dabiri Base Case Scenario.

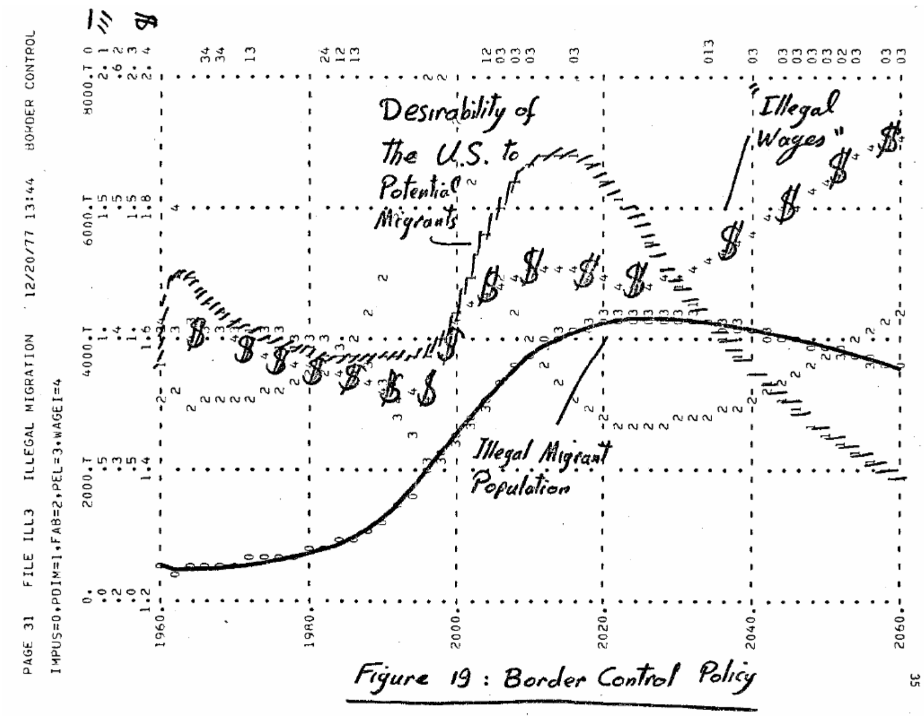


Figure 9. Dabiri model Border Control Policy Scenario.

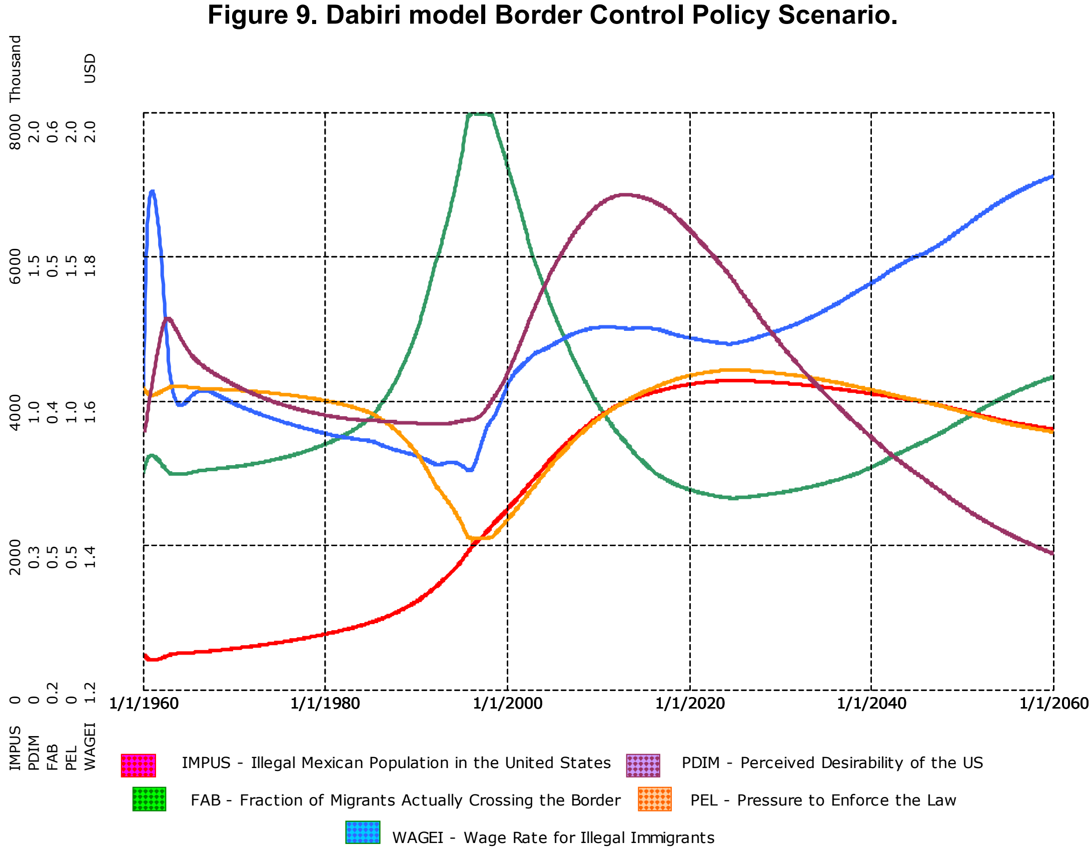


Figure 10. Powersim Studio version of Border Control Policy Scenario.
NOTE: PCN%) law enforcement pressure to catch 50% at border set to 1.5.

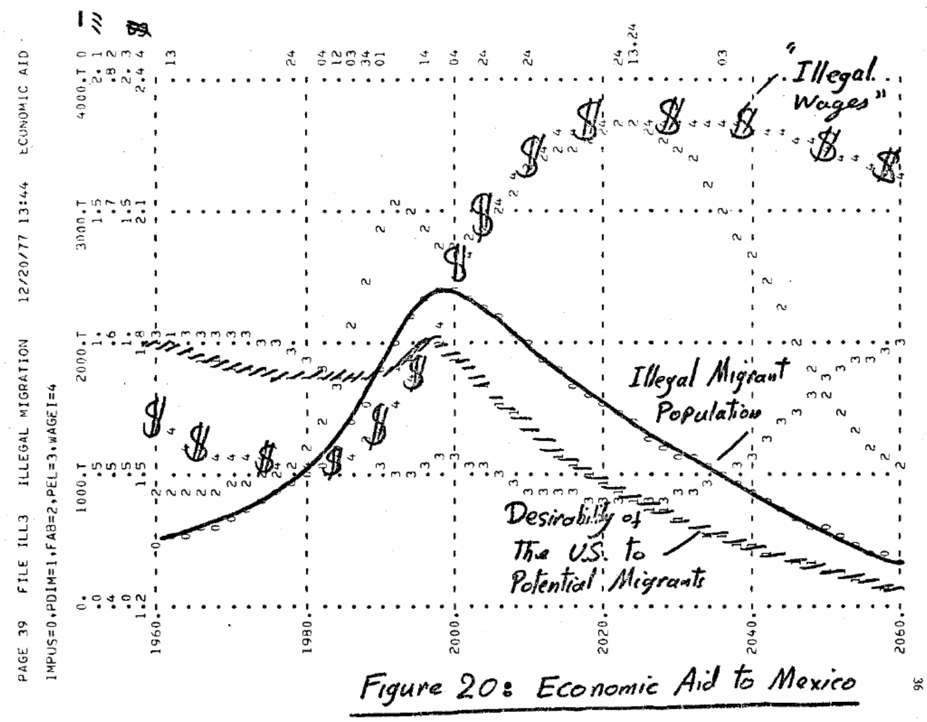


Figure 11. Dabiri model Economic Aid to Mexico Scenario.

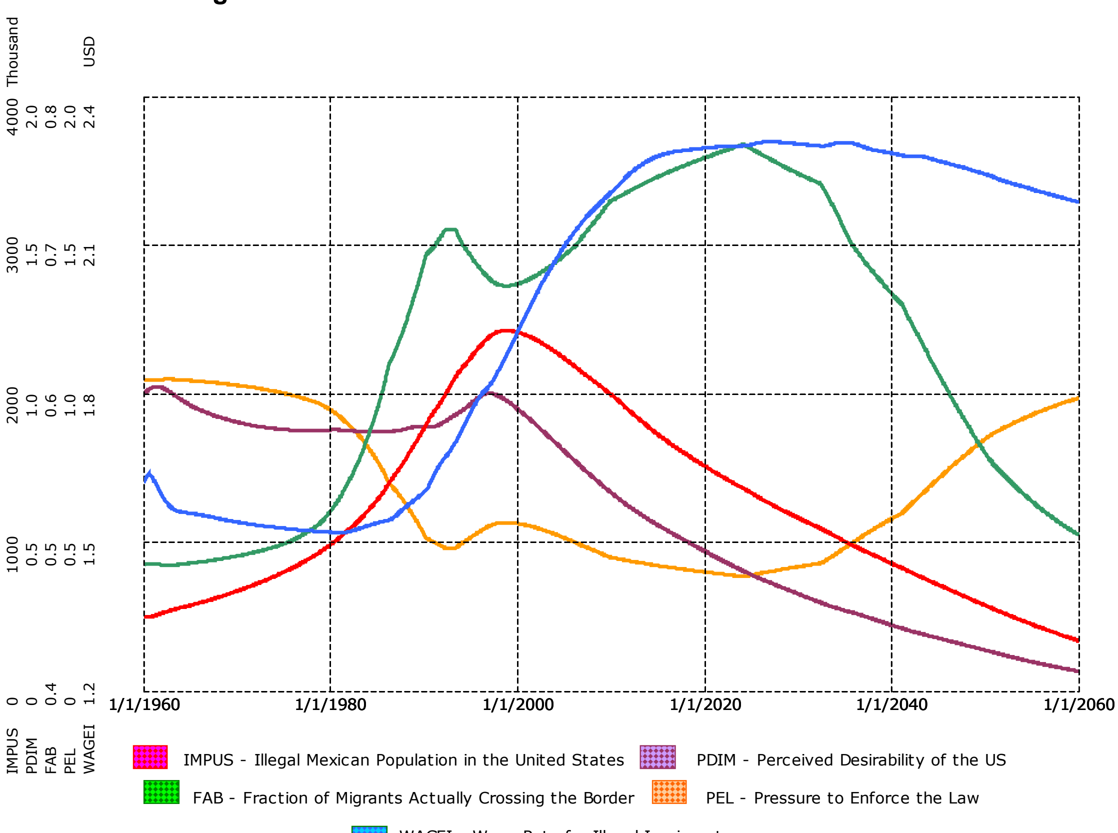


Figure 12. Powersim Studio version of Economic Aid to Mexico.
NOTE: FIGI fractional increase in government investment set to 100% in 1980.

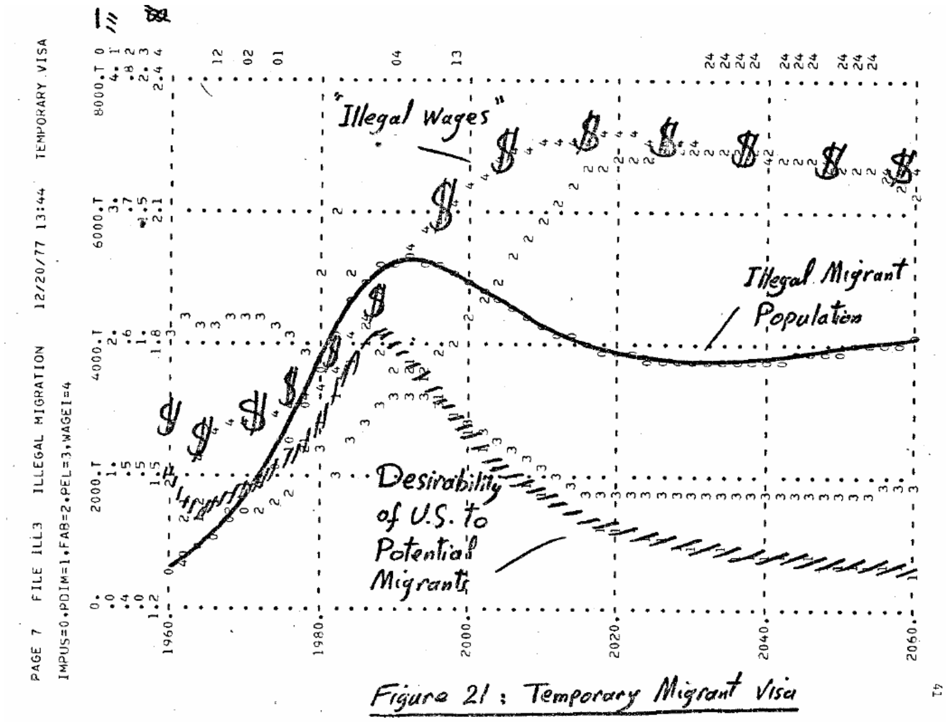


Figure 13. Dabiri model Temporary Migrant Visa Scenario.

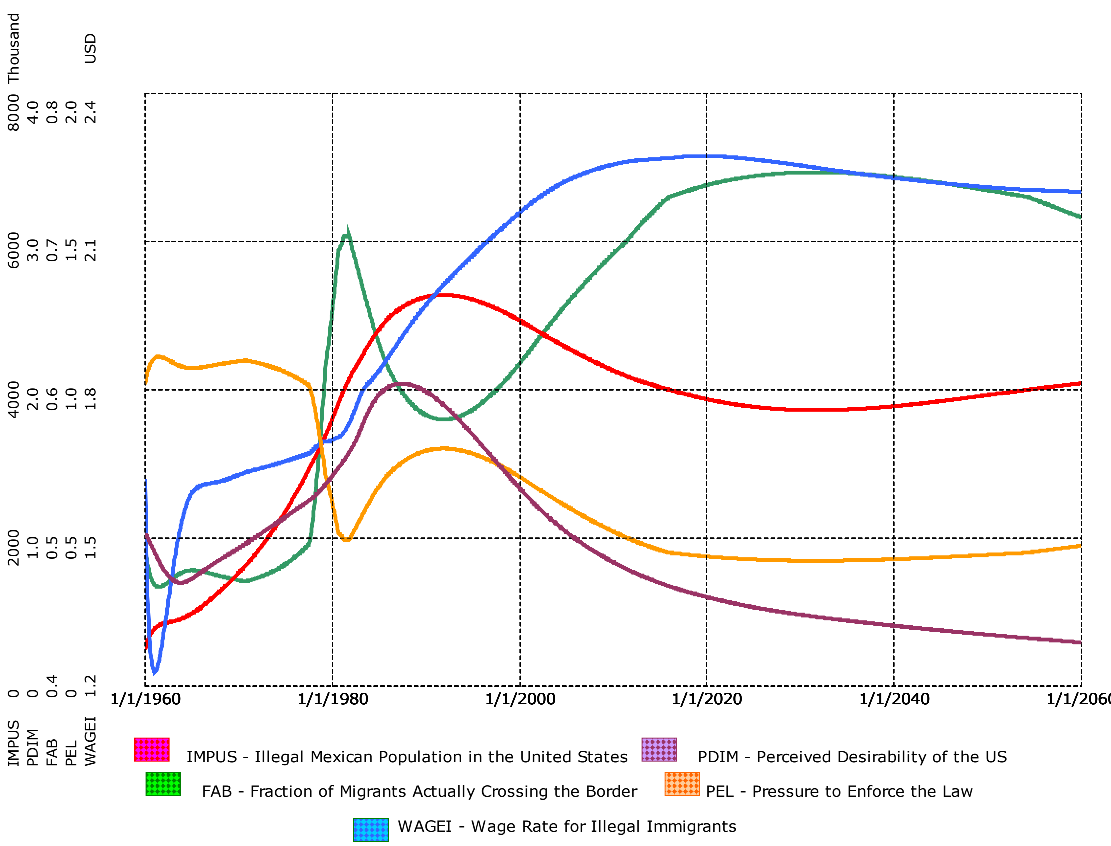


Figure 14. Powersim Studio version of Temporary Migrant Visa.
NOTE: MNMTV maximum desired number of migrants with temporary visas set to 2,000,000.

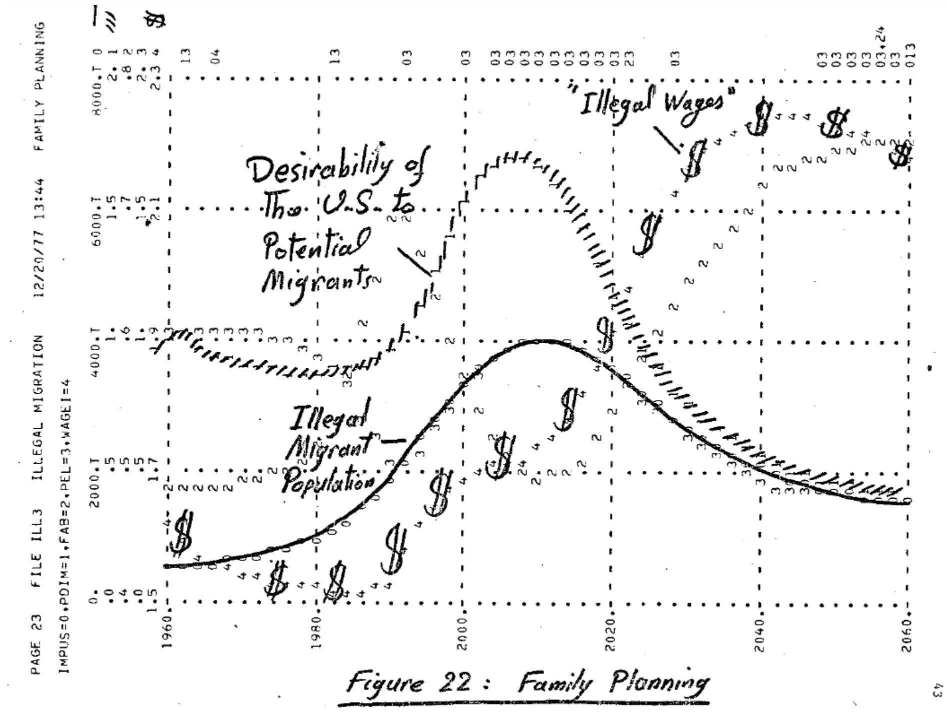


Figure 15. Dabiri model Family Planning Scenario.

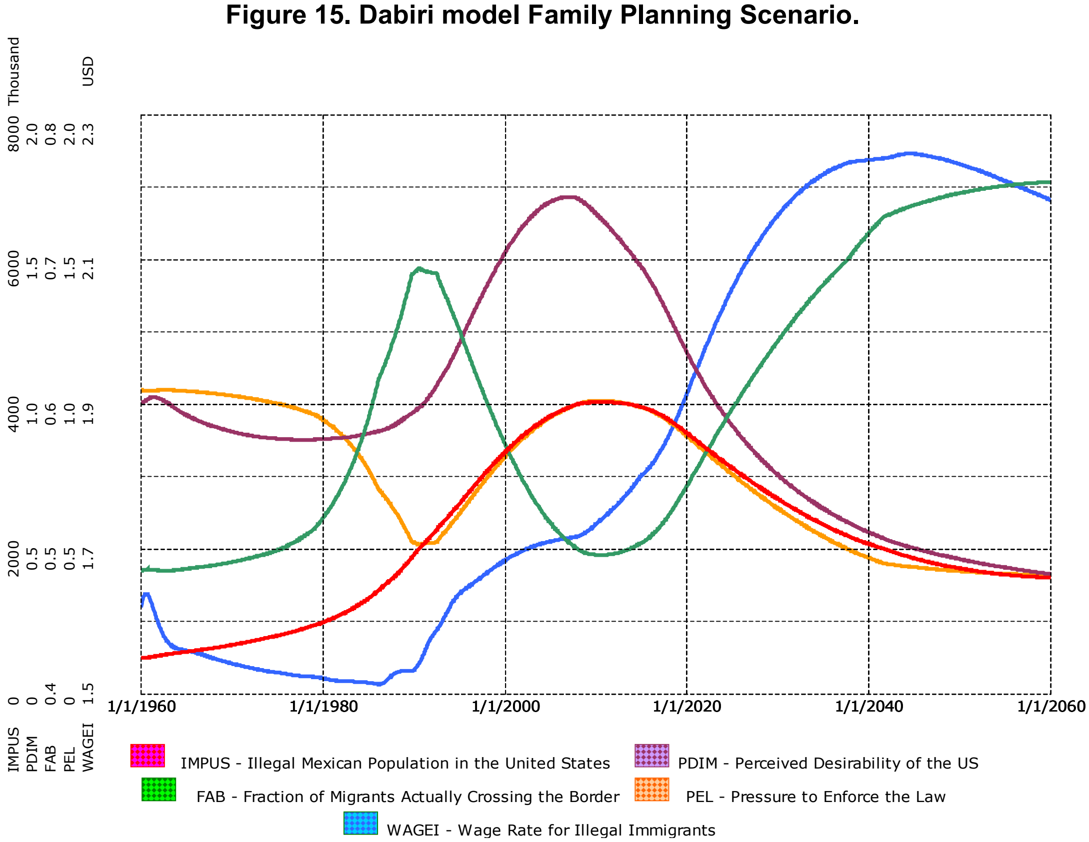


Figure 16. Powersim Studio version of Family Planning Scenario.

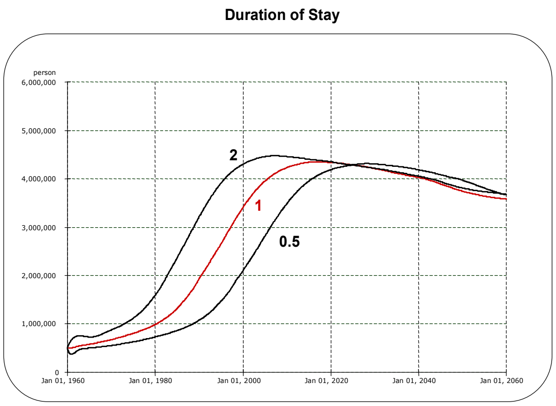
NOTE: NFBR net fractional birth rate set to decline from 3% to 1.5% over the period 1980-2000.

iv. Results of Sensitivity Runs of Change in Parameter Values on the US Illegal Mexican Migrant Population

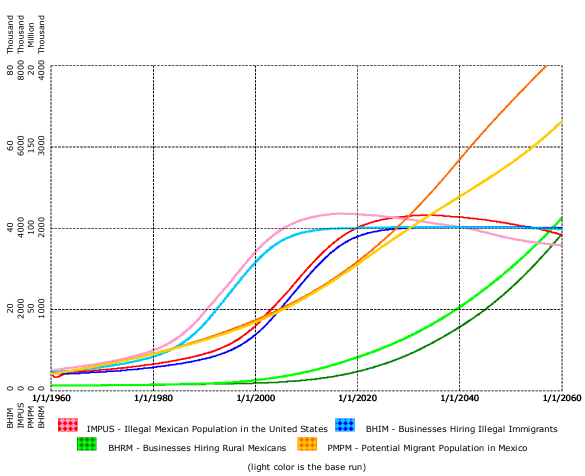
As discussed above, illegal migration issues are currently widely discussed in the media. In the following pages, each graph on the top left represents a halving and doubling of the indicated parameter and shows its affect on the illegal migrant population in the US. The two graphs below illustrate the results of having applied a halving (left) and doubling (right) of the indicated parameter on Dabiri's four original base case variables, also from 1960 on.

Although it is implausible to retroactively impose the various policy options at the 1960 starting year for the simulations, the following graphs provide a sound basis for learning how the policies might affect the pattern of illegal immigrant growth, and other variables in the dynamic system that underlie illegal migration. With this insight in hand, we can then move forward to more clearly understand the outcomes of simulations that explore the more plausible possibility that the same policy options might be enacted in 2010, after 50 years of growth in the illegal immigrant population. As is often the case, reviewing the simulation results underscores the importance of making early policy interventions, rather than waiting until the issue of concern - in this case the size of the illegal immigrant population - has grown to a size that is now much less manageable than that of the 1960s.

Table 6. Sensitivity runs on ADS average duration of stay for temporary illegal migrants.



Parameter: ADS Average Duration of Stay for Temporary Illegal Migrants
Discussion: As the average duration of stay in years increases the emigration rate to Mexico declines. Therefore there are more migrants in the US. Wayne Cornelius (2005) has shown an increase in stay from 40 to 70 weeks from 1993 to 2002.



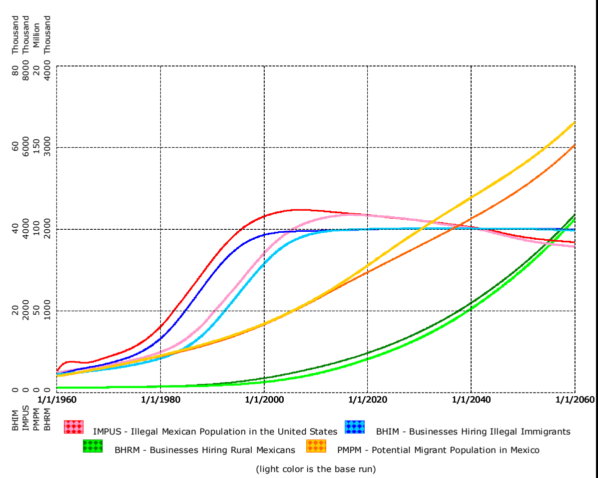
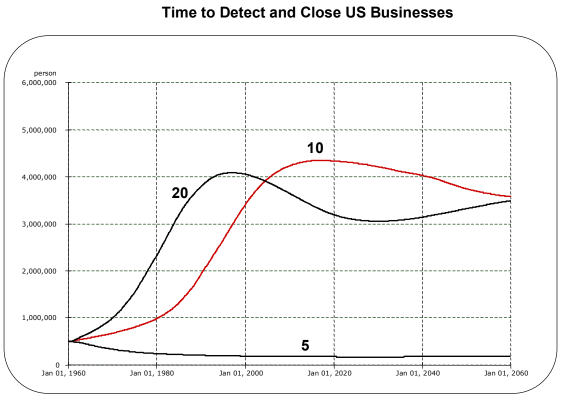
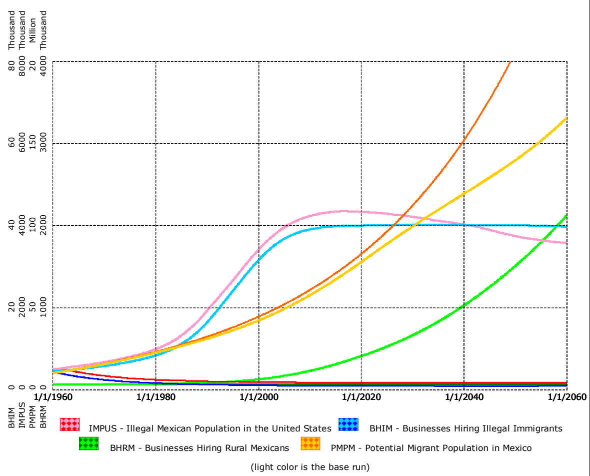


Table 7. Sensitivity runs for TDCIB time to detect and close illegal business.



Parameter: TDCIB Time to Detect and Close Illegal Business
Discussion: Illegal businesses provide employment to illegal migrants. Shortening this time decreases the number of businesses which in turn decreases the number of jobs for migrants. Decreasing employment opportunities also decreases the desirability of migrating to the US.



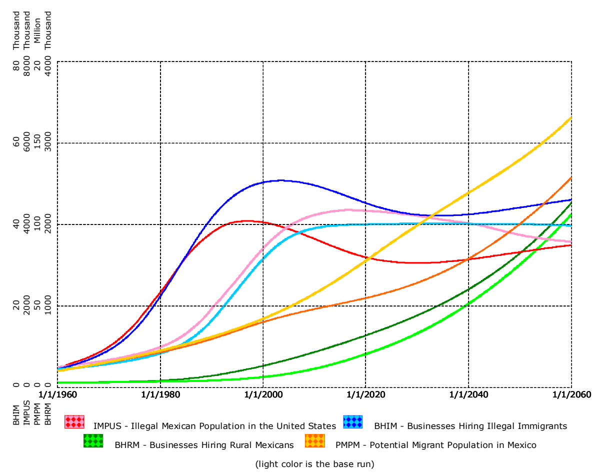


Table 8. Sensitivity runs for PNC50 law enforcement pressure to catch 50% at border.

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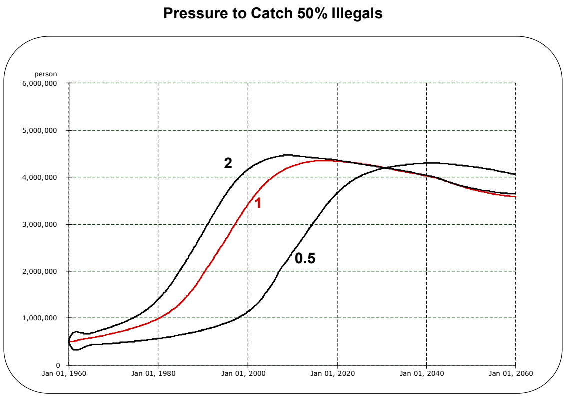

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Parameter: PNC50 Law Enforcement Pressure to Catch 50 % at Border

Discussion: Increasing the pressure to catch illegal migrants is coupled with the pressure to enforce the law. Unless law enforcement also increases changes in PCN50 just delay the arrival of migrants.

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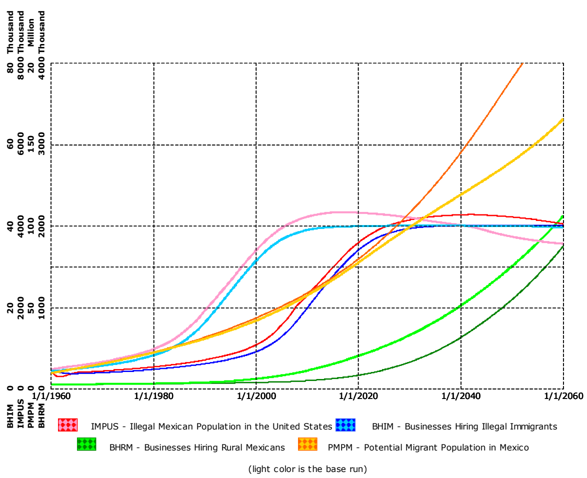

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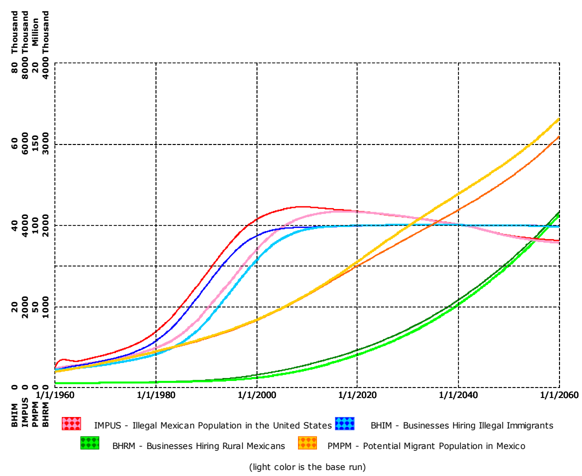

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Table 9. Sensitivity runs for NPEL normal pressure for law enforcement.

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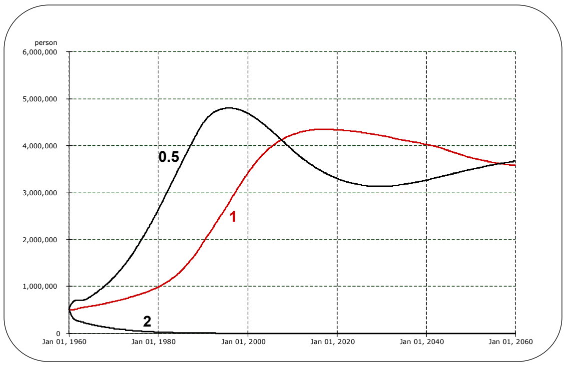
Normal Pressure for Law Enforcement



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Parameter: NPEL Normal Pressure for Law Enforcement

Discussion: The pressure for law enforcement increases as the number of illegal migrants increases. It decreases as businesses that hire illegal migrants increase. It affects both border crossing success and the shutdown of illegal businesses.

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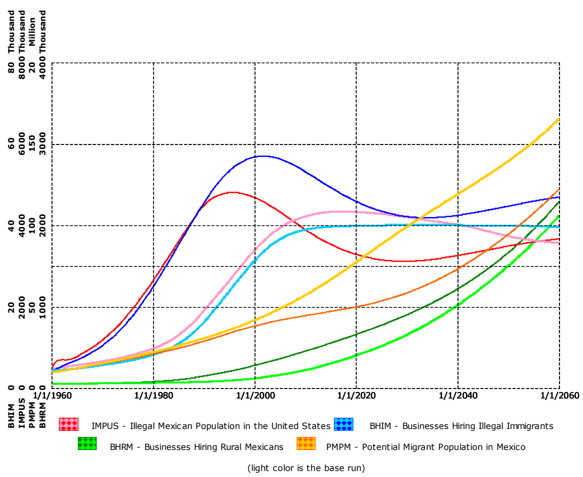

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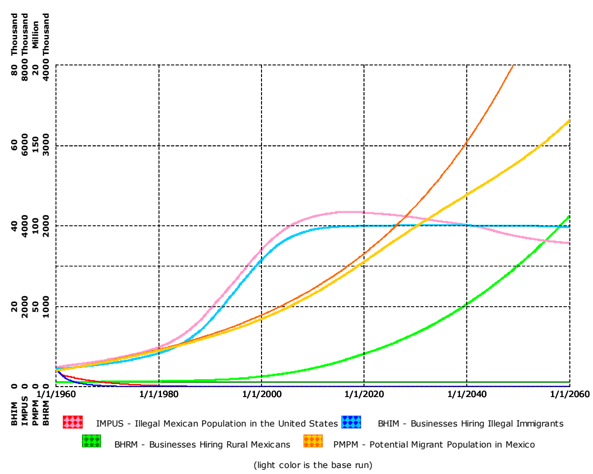

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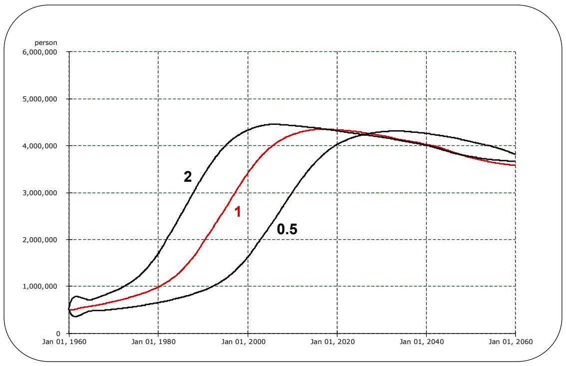
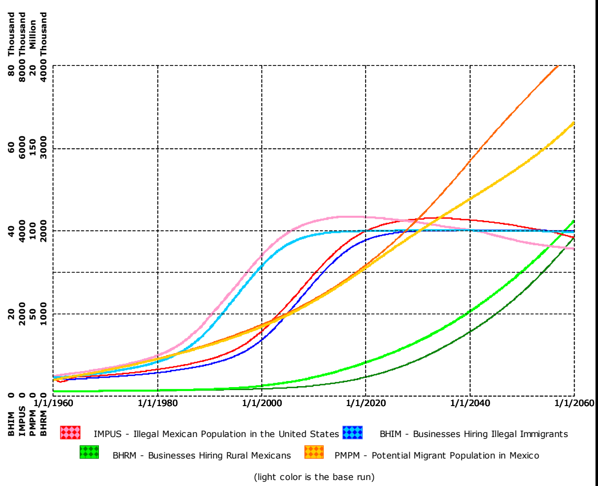
Table 10. Sensitivity runs for effectiveness of border control on desirability to migrate.

Effectiveness of Border Control on Desire to Migrate



Parameter: Effectiveness of Border Control on Desirability to Migrate
Discussion: In the model increasing this variable increases the desirability of the US. This increase causes an earlier peak in the illegal immigrant population.



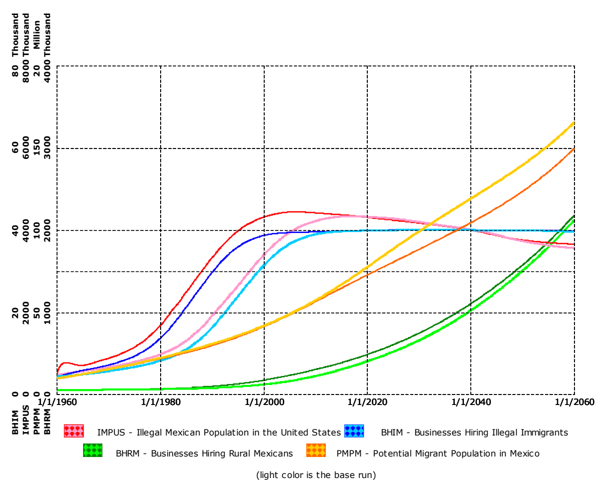


Table 11. Sensitivity runs for NFEB net fractional expansion of business in Mexico.

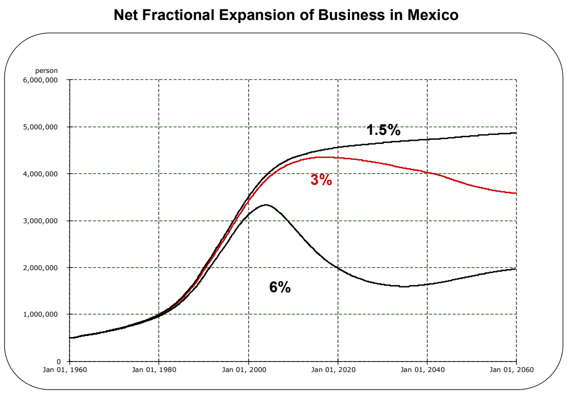
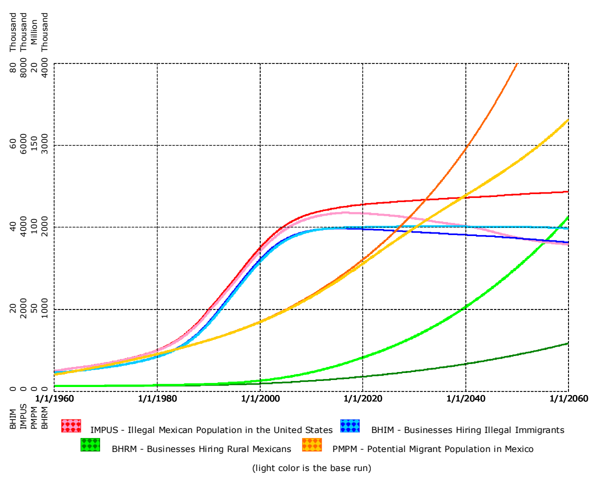
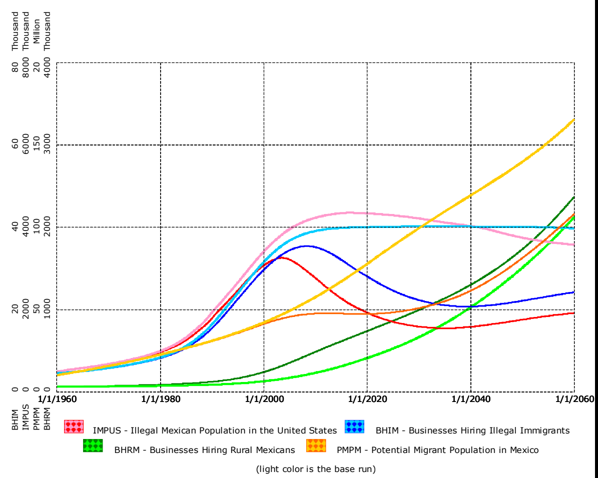
	**Parameter**: NFEB Net Fractional Expansion of Business in Mexico. **Discussion**: Expansion of business in rural Mexico changes the relative attractiveness of the US. This decreases the number of potential and actual migrants.
	

Table 12. Sensitivity runs for FII fraction of invested income.

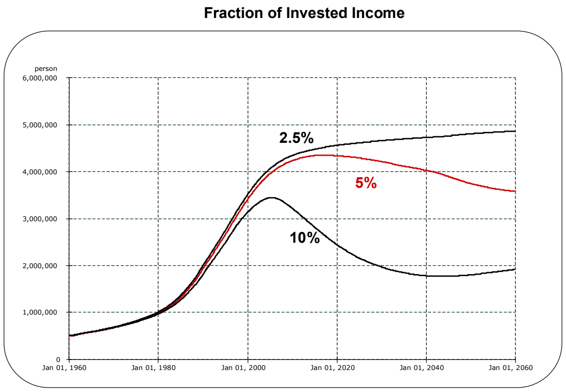
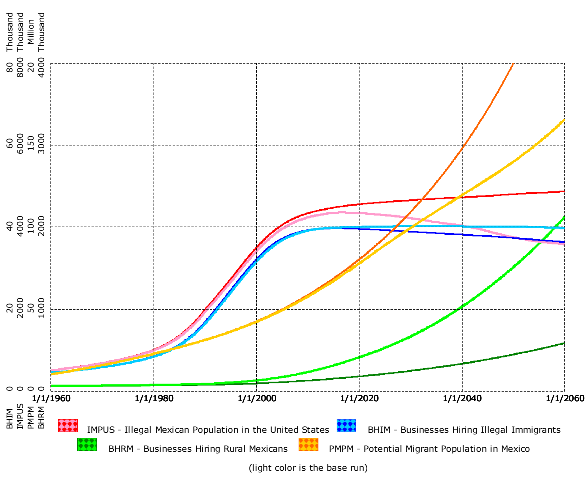
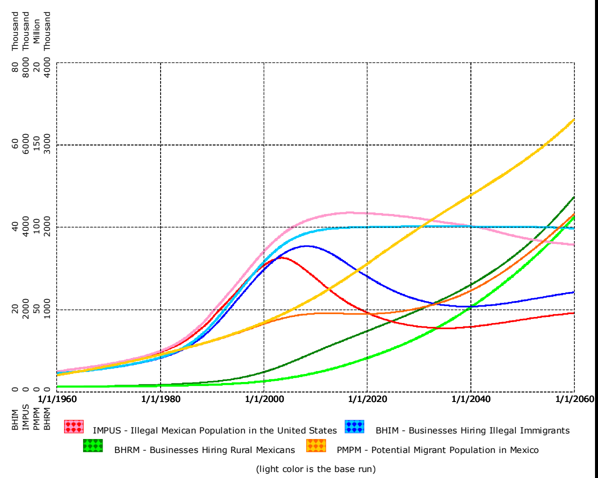
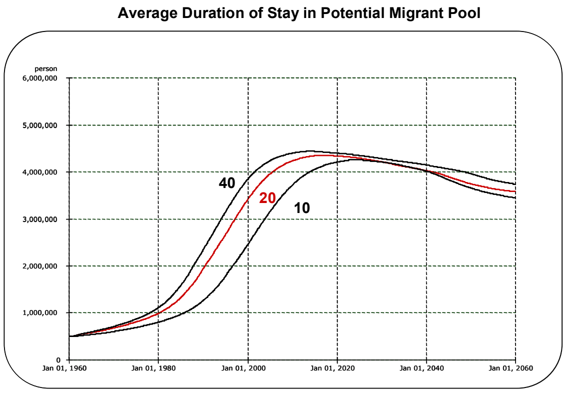
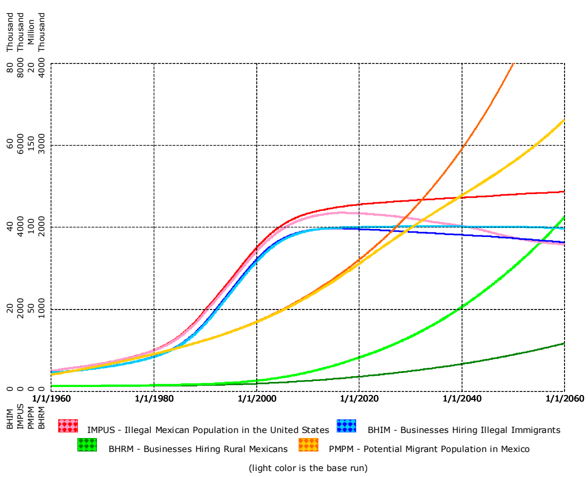
	**Parameter**: FII Fraction of Invested Income. **Discussion**: This fraction in the amount of a migrant's wage returned to Mexico. As this percent increases more opportunities for employment exist in Mexico thus lowering the migrant population. Note that decreasing this is equivalent to taxing illegal migrants regardless of their social service burden in the US.
	

Table 13. Sensitivity runs for ADSPMP average duration of stay in the potential migrant pool.



Parameter: ADSPMP Average Duration of Stay in the Potential Migrant Pool.
Discussion: Over time potential migrants lose interest in migration. Lowering this value just shifts the migrant population in the US out over time.



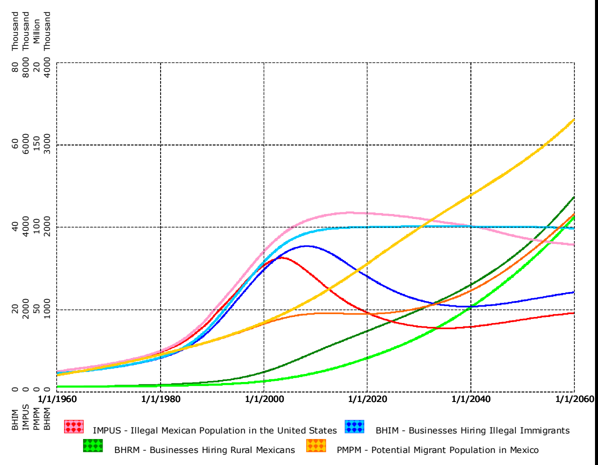
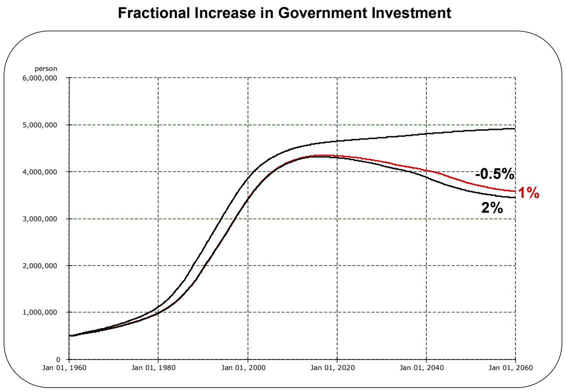
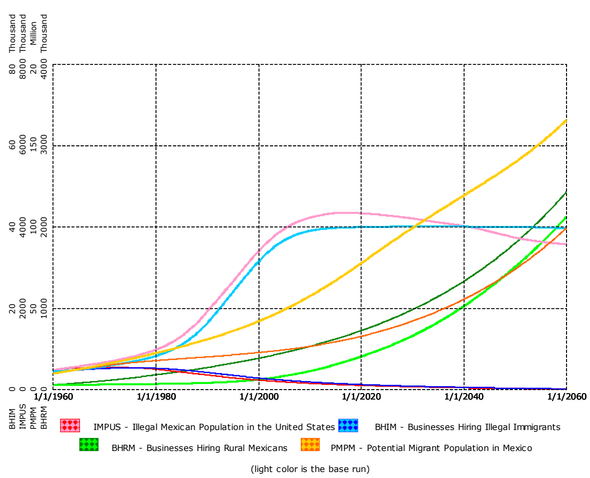


Table 14. Sensitivity runs for FIGI fractional increase in government investment.



Parameter: FIGI Fractional Increase in Government Investment.
Discussion: It takes large (100%) increase in government investment to have substantial effects on the expansion of rural business in Mexico. Amounts less than 2 billion USD are ineffective, 2 billion is estimated as the base investment to maintain the status quo.



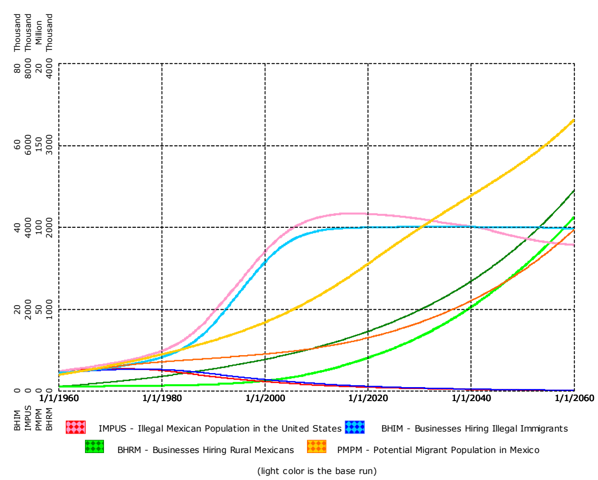
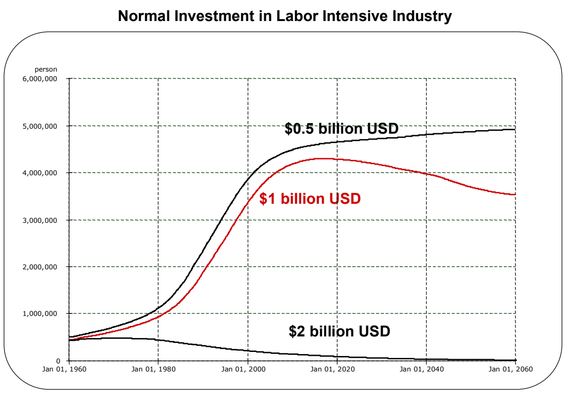
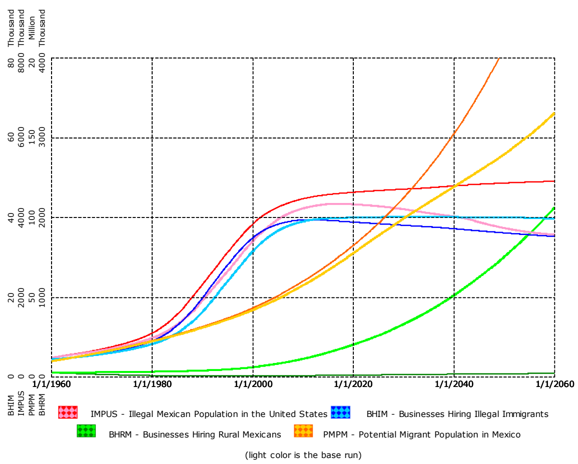
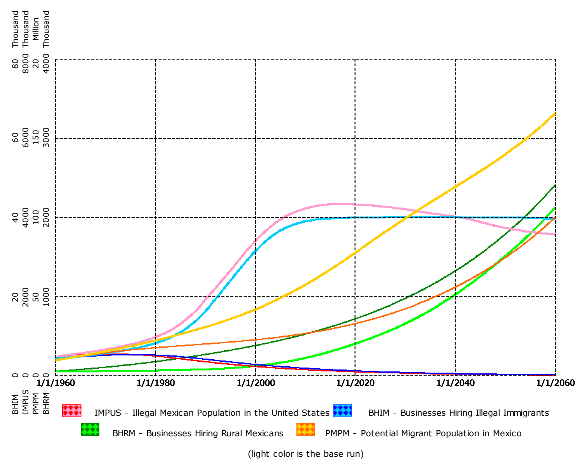


Table 15. Sensitivity runs for NGIRA normal investment in labor intensive industry.

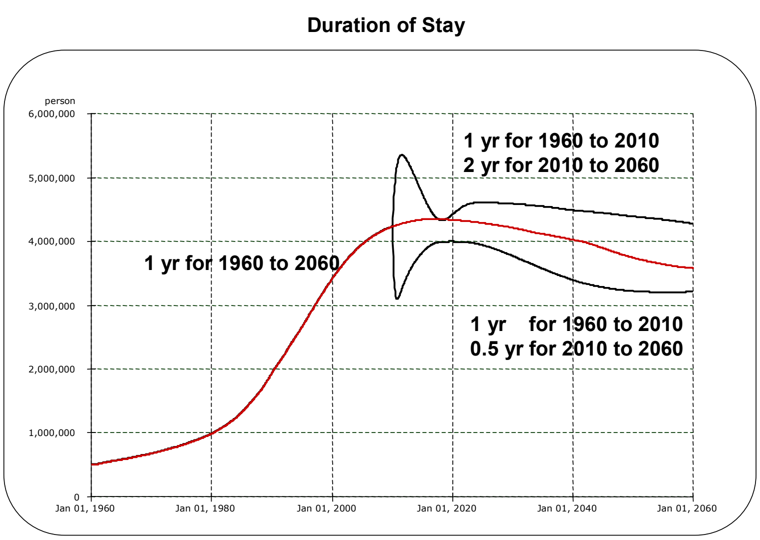
<table>
<tr>
<td>
</td>
<td>Parameter: NGIRA Normal Investment in Labor Intensive Industry.
Discussion: This variable is the base investment in rural business in Mexico. Increasing this amount provides more job opportunities in Mexico and therefore decreases migration to the US.</td>
</tr>
<tr>
<td>
</td>
<td>
</td>
</tr>
</table>

vi. Results of Policy Runs of Changes in Parameter Values on US Illegal Mexican Migrant Population

In the section below we have used the Dabiri model to test parameter changes that take affect in 2010. Each graph in the tables below represents a doubling and halving the indicated parameter, along with the base case value of the parameter. The text below the graph explains the behavior.

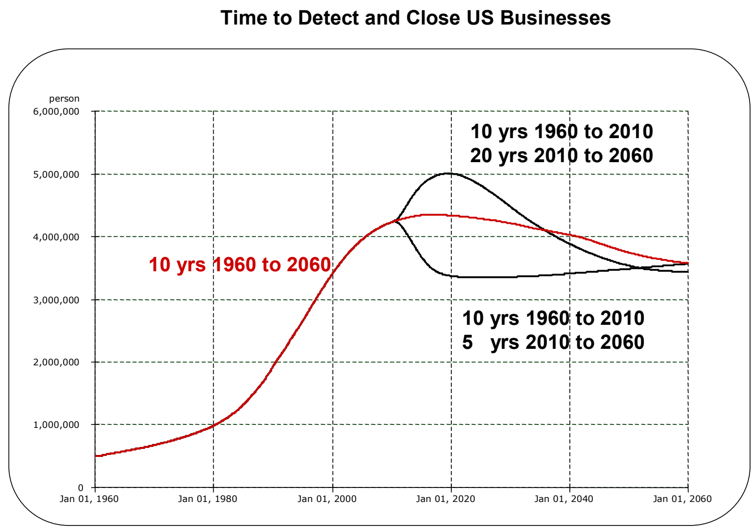
We selected the 2010 implementation year because it is unlikely that significant policy changes can be fully implemented and operational prior to that time. It is more likely that, if implemented, the policies would only become fully effective some number of years after 2010. It is interesting to note that 2010 is about 5 to 10 years prior to the projected peak, and gradual decline, in illegal immigrant population if we assume 'business-as-usual' conditions through to 2060. Because the "business-as-usual" decline in illegal migrant population is gradual, delaying the implementation of proposed policies will cause us to miss the window of opportunity for maximizing the effect of the policies; particularly those that yield a rapid decline in the illegal migrant population.

Table 16. Policy test on average duration of stay post 2010.



Increases in the average duration of stay cause a temporary increase or decrease in the immigrant population in the US. Similarly, the immigrant population curve moves back to equilibrium after an increase. In the case of a decrease there are effects upon the job force equilibrium that causes a delayed temporary increase in the immigrant population until the migrant to job equilibrium is reached.

Table 17. Policy test on average time to detect and close illegal businesses post 2010.



The Time to Detect and Close US Businesses hiring illegal migrants has a direct impact on the number of those businesses and therefore the job opportunities for migrants. Increasing the detection time causes a rapid increase in the illegal migrant population which eventually reaches equilibrium over time, primarily due to the wage effect. The decrease in detection time produces the opposite result. More businesses are shut down, unemployment increases, and the desirability of the US decreases in the short run. Later effects include a decrease in pressure to enforce the law resulting in a slow climb to equilibrium.

Table 18. Policy test on pressure to catch 50% of illegal immigrants post 2010.

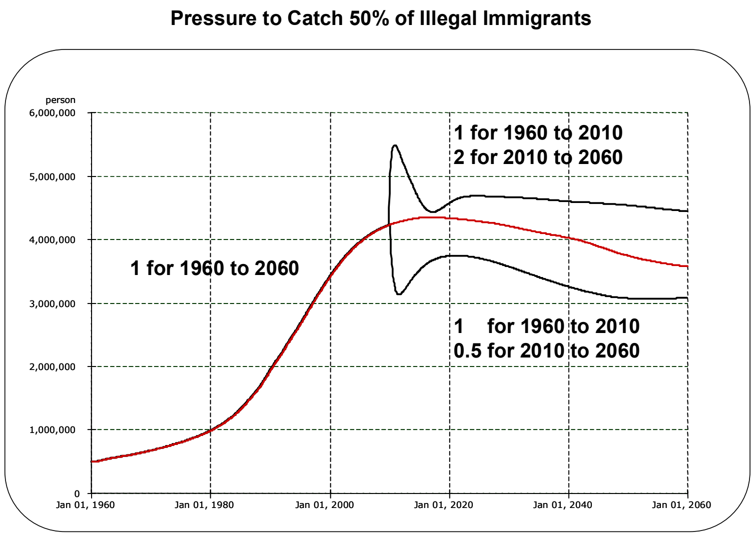
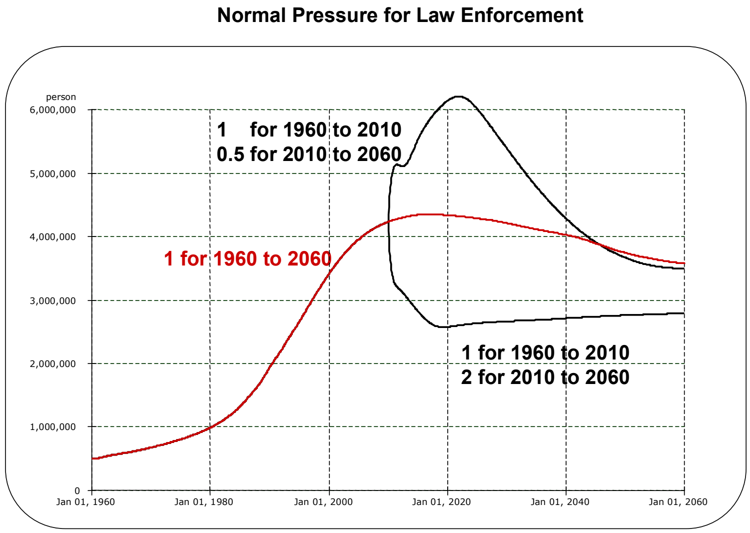

Change in the pressure to catch illegal immigrants has immediate effects on the illegal immigrant population. The number of illegal immigrants crossing the border is reduced. Once again, in the long run, equilibrium is achieved.

Table 19. Policy test on normal pressure for law enforcement post 2010.

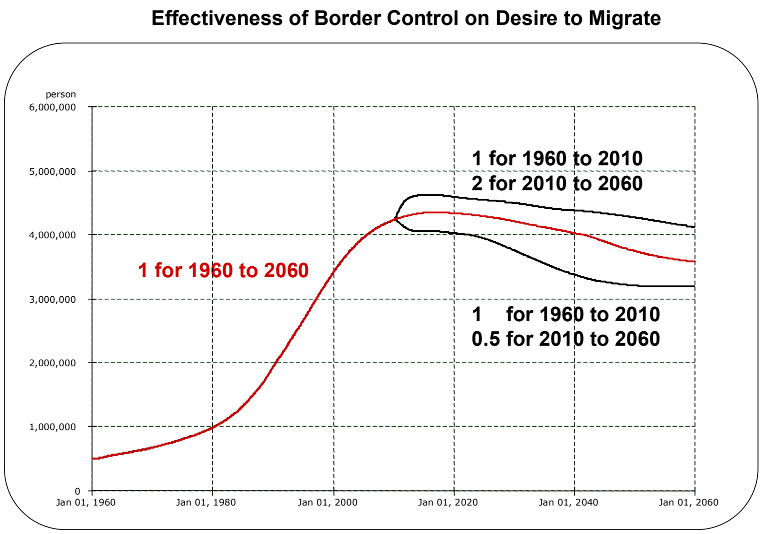


The pressure to enforce the law is constructed as an index. Initially set the value 1, changes are multiples of 1. A change to 2 means that the pressure has doubled, a 0.5 means a halving of pressure. As expected, halving the pressure leads to a rapid increase in illegal migrants. This is mediated in the long run by employment effects. This same holds true for increases in the pressure for law enforcement. Please see Figure 7 below for a better understanding of the complex causal relationships between these two variables.

Figure 17 is a screen capture of the dependency link between PEL Pressure to Enforce the Law and the IMPUS Illegal Migrant Population in the US as provided by the Powersim Studio 2005 'Search for Dependency' tool. Note the long list of causally linked variables that can be followed by hand in Appendix C Diagram of the Powersim Studio Version of the Dabiri Model. The causal path passes through 4 stocks causing a 4 time step delay of changes in PEL Pressure to Enforce the Law on IMPUS Illegal Migrant Population in the US.

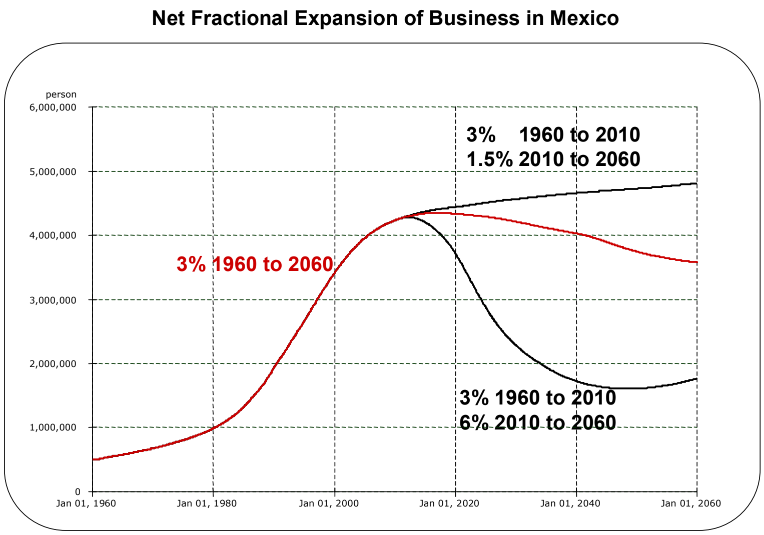
Figure 17. Powersim Studio search for dependency output.

Table 20. Policy test on effectiveness of border control on the desire to migrate post 2010.



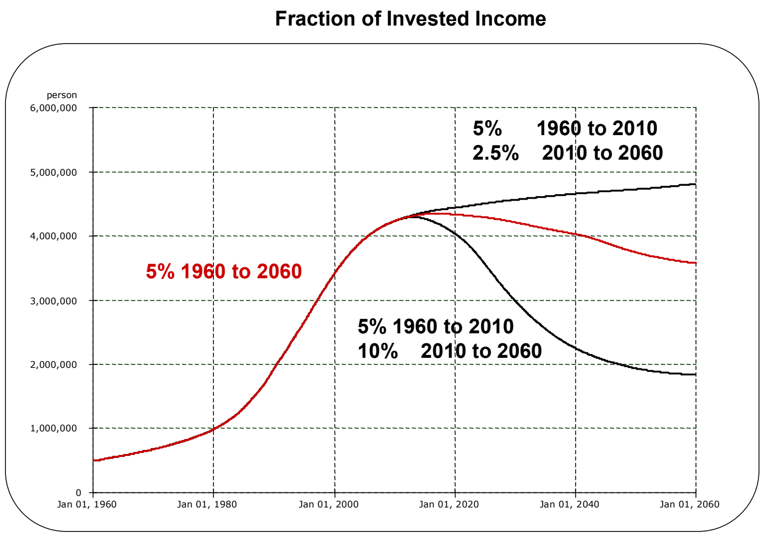
Simply, as the effectiveness changes so does the number of illegal migrants in the US. In this case Border Control effectiveness is somewhat of a misnomer as higher values indicate a weaker effect on border control.

Table 21. Policy test on net fractional expansion of business in Mexico post 2010.



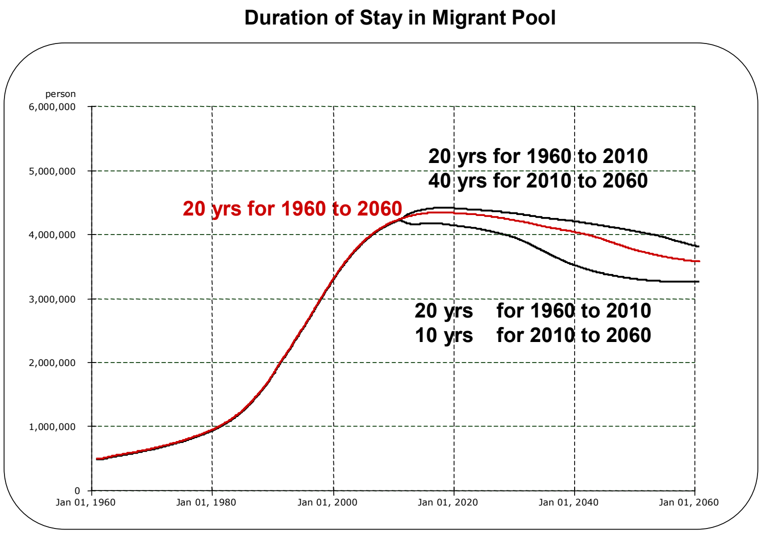
These changes highlight one of the major conclusions in the model as well a numerous references in the press and academic journals. Expansion of business in rural Mexico provides additional opportunities for rural Mexicans to find employment in rural Mexico and diminishes the desirability of migration to the US. A simple halving of the investment rate from 3%/yr to 1.5%/yr causes an ever increasing number of illegal migrants within this time period.

Table 22. Policy test on fraction of invested income post 2010.



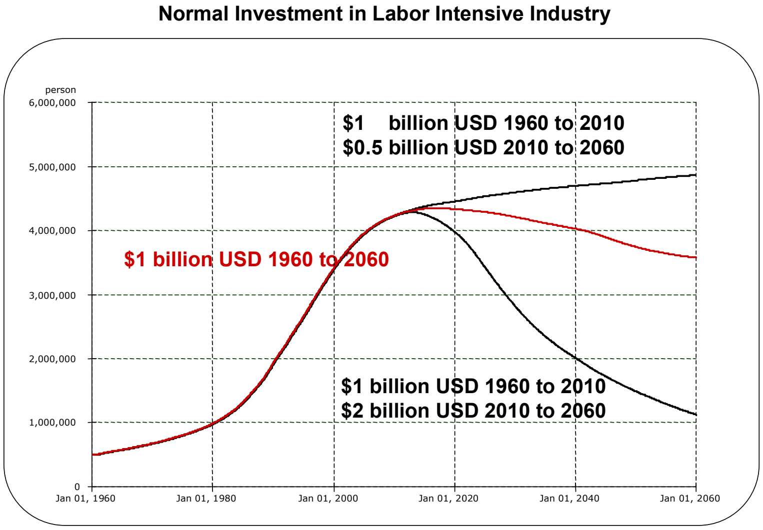
Similar to Net Fractional Expansion of Business in Mexico, the Fraction of Invested Income fuels business expansion in Mexico. One might consider a decrease of 2.5% in this percentage to be equivalent to a 2.5% tax placed on illegal migrants in the US. Recently a tax on migrants has been proposed by numerous politicians to account for the cost of services they consume in the US. This graphic shows how that would actually have the effect of increasing the number of illegal migrants in the US.

Table 23. Policy test on duration of stay in migrant pool post 2010.



Changes in the Duration of Stay in the Migrant Pool have little effect on the number of illegal migrants in the US. This is primarily due to the large number of potential migrants. This is a parameter that needs more elaboration in future models.

Table 24. Policy test on normal investment in labor intensive industry post 2010.



Changes in the Normal Investment in Labor Intensive Industry in Mexico create the expected behavior. Increase precipitate a rapid decline in illegal migration as rural Mexicans are employed in Mexico. The effects of decreases in this parameter are muted by business conditions in the US that for this test, have not been changed.

VI Discussion

Overall, the modeling exercise described above supports the idea that increasing controls on the border itself may not be the strongest measures for reducing illegal migration, contrary to most policy-level measures currently being taken. The modeling supports the idea that changing economic conditions on either side of the border may in fact be the strongest measures for changing the rates of illegal migration, and ultimately reducing the population of illegal immigrants in the U.S. This view is also widely reflected in the literature (Amador 2005; Angelucci 2005; Cornelius 2005; Dowd 2005; Fix et al. 2005; Zahniser 1999; Massey and Espinosa 1997).

Evidence for this view comes most clearly from the sensitivity analyses shown above. The variables that showed the greatest reduction in overall number of illegal immigrants to the U.S. with model runs beginning in 1960 and running with default values through 2060 were:

Time to detect and close illegal businesses, Table 7
Normal pressure for law enforcement, Table 9
Net fractional expansion of business in Mexico, Table 11
Fraction of invested income in Mexico, Table 12
Normal investment in labor intensive industry, Table 15

It is worth noting that "Normal pressure for law enforcement (Table 9)" includes law enforcement pressure at the border as well as pressure on businesses hiring illegal immigrants. "Law enforcement pressure to catch 50% at border (table 8)" does not make a big a difference in ultimate immigrant numbers, and it focuses on law enforcement pressure only at the border.

Similar results are found in the model runs that included a step change made away from default values, representing simulated policy changes, in 2010. Those most noteworthy are:

Net fractional expansion of business in Mexico, Table 21
Fraction of Invested Income in Mexico, Table 22
Normal investment in labor intensive industry, Table 24

Model test results illustrate how different policies enacted in 2010 might lead to a wide range in projected illegal Mexican migrant population in the US (1 to 5 million). Although our updated results project a spread in possible illegal migrant population similar to that of Dabiri and Low (1977), our 2060 estimates are about 0.5 million larger. The patterns in future migrant population trends, however, are similar. Important lessons learned build on the conclusions of Dabiri and Low (1977) and include the following:

- we appear to be approaching a future of stable or declining illegal migrant population – particularly when compared to the pattern of the past 20 years
- increasing investment in Mexico through Mexican and US government actions, Mexico business expansion and investment of migrant remittance funds has the potential to help cut the future illegal migrant population to about half of the current population.
- it will be difficult, if not impossible, to eliminate the presence of illegal Mexican migrants in the US

- achieving a 50% decline in illegal migrant population requires that the pressure for border law enforcement be maintained at current or higher levels so that border security is not relaxed

- while attempts to reduce northward migrant flow by improving the ability to rapidly detect and close US businesses employing illegal migrants should be maintained, the necessary investment might be used to better advantage in rural Mexico

This project has successfully contributed to several knowledge bases. First, it provided lessons learned from working in a multidisciplinary team trying to develop an interdisciplinary tool while applying a metaphor to help explain complex phenomena. The research team faced difficulties that are common to integrated teams including communication and methodological issues. There were also some unique conditions, such as not having a client to frame project requirements and struggles employing a metaphor across disciplines. The team did, however, coalesce sufficiently to generate a model that is based on the metaphor and to prepare this paper, which both cross disciplinary boundaries.

The illegal migration model developed contributes to the growing body of work on using system dynamics models to help decipher complex systems and potentially contribute to improved policy-making. The model's output provides input to the cacophonous voices calling for various policy measures to address illegal migration. This effort also shows the value in building on existing models to save time and resources, as well as to strengthen the value of the new model. This project's model is based on work done by Dabiri and Low, whose results have well-matched illegal migration reality since 1977.

Dabiri and Low (1977) developed their system dynamics model to represent the process of illegal migration from Mexico to the United States by accounting for feedback and interactions within and between: (1) the US and Mexico economies, (2) US border security strategies, (3) US and Mexico investment policies in rural Mexico, and (4) population growth in Mexico. At that time, they estimated that illegal Mexican workers in the US numbered less than 1 million. Twenty-five years later, a number of writers estimate that illegal Mexican workers in the US number about 4 million; about half of the total illegal migrants in the US (see Leiken 2002). Interestingly, this is about the number of illegal Mexican workers Dabiri and Low (1977) estimated for the early 21st century (4 to 4.5 million) when applying their model across a range of policies and scenarios. Over subsequent decades (2010 to 2060) they project a range of possible outcomes from 0.5 to 3.5 million illegal Mexican workers in the US at 2060. Thus, the Dabiri and Low (1977) model appears to capture the now historic, steep increase in illegal migration between 1980 and 2000 and projects small to large declines in illegal migration over the coming decades. These projections are consistent with the expectation of the Mexican government, and others, who anticipate a significant decline in migration by 2015 in response to economic growth and declining birth rates in Mexico (Dowd 2005; Leiken 2002). If these projections are correct, then awareness of the fact that we have passed the period of steep growth in the illegal migrant population should help to identify preferred policy options for minimizing the flow of illegal Mexican migrants to the US in ways that improve economic conditions in rural Mexico. Accomplishing this goal will reduce criminal activity and migrant deaths in the borderland while enabling workers and their families to work locally towards improving conditions in their home communities; rather than by sending remittance checks.

Given the confidence we had in the model formulation and construction and regardless of the apparent success of their projections, we adopted the Dabiri and Low (1977) model to explore the possible outcomes of policies aimed at reducing illegal migration that might be enacted within the next decade. In doing so, we updated one aspect of their model by allowing for the possibility that illegal Mexican workers might stay longer than 1 year in the US. This change is important because border security has likely caused some migrants to postpone their return to Mexico due to concern that their chances of a subsequent return to the US might be reduced. Longer duration stays in the US lead to a net increase in the illegal migrant population because new migrants continue to arrive while previous migrants elect to stay.

In general, the results from this model reflect what the research team found in the literature concerning drivers and disincentives for illegal migration. Yet, the policies being promulgated do not reflect what appears to be growing consensus concerning immigration. There is little evidence that increasing border enforcement or increasing employer sanctions results in concomitant reduction in illegal migration and may well increase the resident illegal population as migrants remain in the US longer. Amnesty programs appear to increase illegal migration as the newly legal US residents provide the necessary social and human capital to encourage other illegal immigrants to enter the US. This project continues the body of work suggesting that perhaps the most effective approach to addressing illegal migration is to continue working to improve living conditions in Mexico and then to wait: as the birth rate in Mexico declines and economic conditions improve, the drivers to migrate will lessen.

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VIII Appendices

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Appendix A: Web Sources Consulted Thorughout this Project

URL	Description
http://uscis.gov/graphics/shared/statistics	Department of Homeland Security Office of Immigration Statistics
http://uscis.gov/graphics/shared/statistics/yearbook/index.htm	Department of Homeland Security Office of Immigration Statistics, Yearbook of Immigration Statistics
http://uscis.gov/graphics/shared/statistics/publications/index.htm	Department of Homeland Security Office of Immigration Statistics, Publications
http://www.ccis-ucsd.org/	Center for Comparative Immigration Statistics
http://www.census.gov	US Census
http://travel.state.gov/visa/about/report/report_1476.html	US Department of State, Bureau of Consular Affairs
http://mcdc2.missouri.edu/	Missouri Census Data Center
http://www.census.gov/sdc/www/	US Census State Data Center
http://ww1.edd.state.nm.us/index.php?/data/	New Mexico Economic Development Department Data Center
http://www.worldbank.org/	World Bank
http://www.absborderlands.org/2JBS.html	Journal of Borderlands Studies
http://www.scerp.org	Southwest Consortium for Environmental Research and Policy
http://tinet.ita.doc.gov/view/f-2000-99-001/index.html	Office of Travel and Tourism Industries
http://www.inami.gob.mx/	Instituto Nacional de Migracîon (Mexico)
http://www.inegi.gob.mx/inegi/default.asp	Instituto Nacional de Estadîstica Geografia e Informatica (Mexico)
http://www.doleta.gov/agworker/naws.cfm	US Department of Labor
http://www.dol.gov/asp/programs/agworker/report9/introduction.htm	US Department of Labor National Agricultural Workers Survey 2001-2002
http://www.migrationpolicy.org/	Migration Policy Institute
http://pewhispanic.org/	Pew Hispanic Center
http://www.bts.gov/programs/international/border_crossing_entry_data/us_mexico/	US Department of Transportation, Bureau of Transportation Statistics
http://www.ilo.org	International Labor Organization

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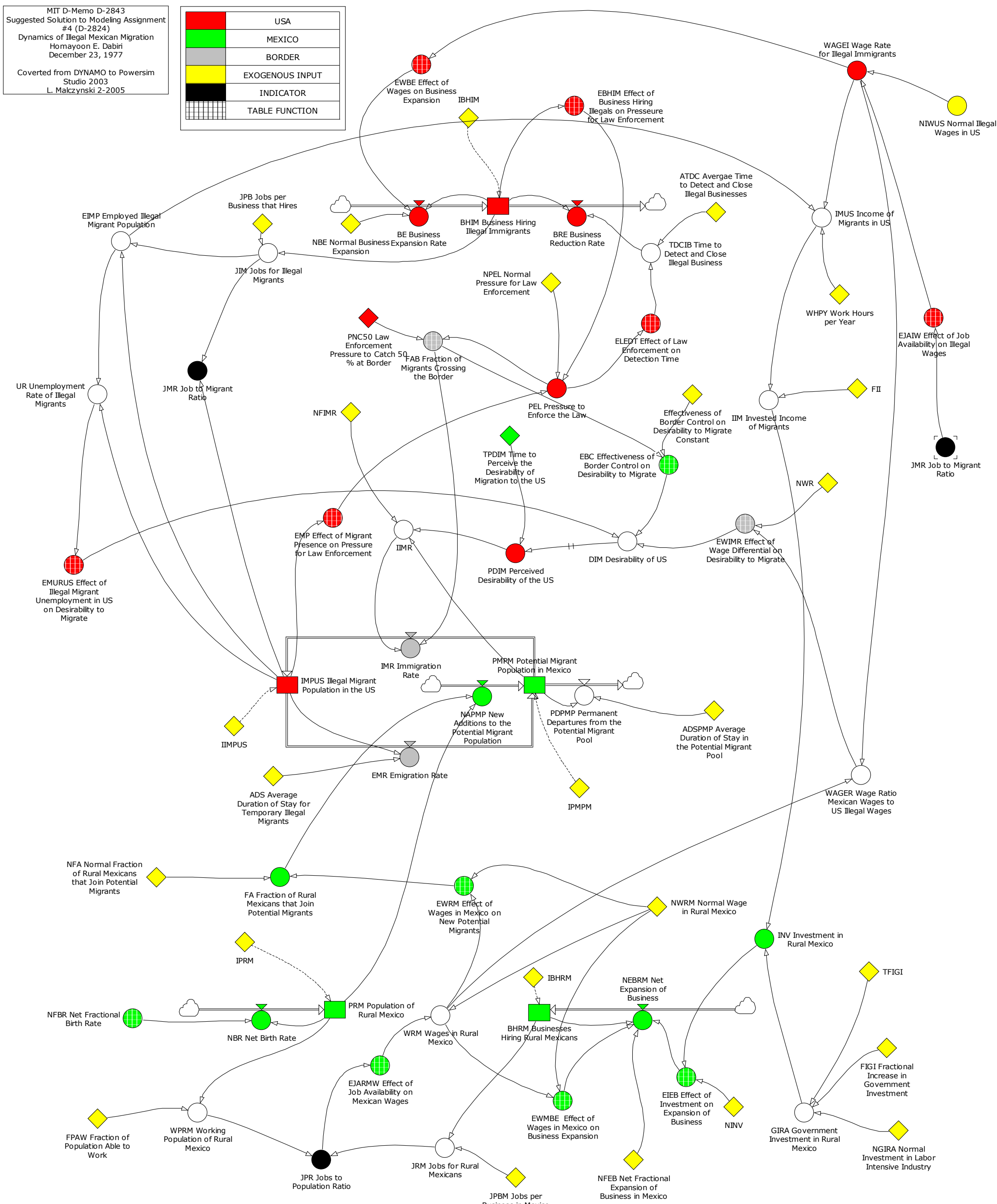
Appendix B: Listing of the Generic Membrane Model

Variable Number	Explanation
1	aux Actual flow rate across the membrane L to R def DELAYPPL(MIN('Indicated flow rate across the membrane L to R','Membrane L to R flow constraints'),'R to L delay')
2	aux Actual flow rate across the membrane R to L def DELAYPPL(MIN('Indicated flow rate across the membrane R to L', 'Membrane R to L flow constraints'),'L to R delay')
3	aux Flux indicating amount and direction of flow def 'Left hand fluid' - 'Right hand fluid'
4	aux Indicated flow rate across the membrane L to R def IF('RH remaining capacity' > 0, IF('Flux indicating amount and direction of flow' > 0, (MAX('Flux indicating amount and direction of flow','RH remaining (MAX('Flux indicating amount and direction of flow', 'RH remaining capacity',0)) / 1 <<yr>>, 0 / 1 <<yr>>), 0 / 1 <<yr>>)
5	aux Indicated flow rate across the membrane R to L def IF('LH remaining capacity' > 0, MIN('Flux indicating amount and direction of flow',0) * -1.0 / 1 <<yr>>, MIN('Flux indicating amount and direction of flow',0) * -1.0 / 1 <<yr>>, 0 / 1 <<yr>>)
6	const Initial LH fluid value init 300
7	const Initial RH fluid value init 150
8	const L to R delay init 0 <<yr>>
9	level Left hand fluid init 'Initial LH fluid value'
10	const LH max capacity init 300
11	aux LH remaining capacity def 'LH max capacity' - 'Left hand fluid'
12	const Membrane L to R flow constraints init 2.5 / 1 <<yr>>
13	const Membrane R to L flow constraints init 1 / 1 <<yr>>
14	const R to L delay init 0 <<yr>>
15	const RH max capacity init 300
16	aux RH remaining capacity def 'RH max capacity' - 'Right hand fluid'
17	level Right hand fluid init 'Initial RH fluid value'

75

Appendix C: Diagram of the Powersim Studio Version of the Dabiri Model



Appendix D: Equation Listing of the Powersim Studio Version of the Dabiri Model

Variable Number	Explanation
1	const ADS Average Duration of Stay for Temporary Illegal Migrants init 1 <<yr>>
2	const ADSPMP Average Duration of Stay in the Potential Migrant Pool init 20 <<yr>>
3	const ATDC Avergae Time to Detect and Close Illegal Businesses init 10 <<yr>>
4	aux BE Business Expansion Rate def 'NBE Normal Business Expansion' * 'BHIM Business Hiring Illegal Immigrants' * 'EWBE Effect of Wages on Business Expansion'
5	level BHIM Business Hiring Illegal Immigrants init IBHIM
6	level BHRM Businesses Hiring Rural Mexicans init IBHRM
7	aux BRE Business Reduction Rate def 'BHIM Business Hiring Illegal Immigrants' / 'TDCIB Time to Detect and Close Illegal Business'
8	aux DIM Desirability of US def 'EMURUS Effect of Illegal Migrant Unemployment in US on Desirability to Migrate' * 'EWIMR Effect of Wage Differential on Desirability to Migrate' * 'EBC Effectiveness of Border Control on Desirability to Migrate'
9	aux EBC Effectiveness of Border Control on Desirability to Migrate def 'Effectiveness of Border Control on Desirability to Migrate Constant' * GRAPH('FAB Fraction of Migrants Crossing the Border',0,0.25,{0.5,0.8,1,1.2,1.3//Min:0.5;Max:1.3//})
10	aux EBHIM Effect of Business Hiring Illegals on Presseure for Law Enforcement def GRAPH(NUMBER('BHIM Business Hiring Illegal Immigrants'),0,4E3,{1,0.9,0.7,0.45,0.3,0.25//Min:0.25;Max:1//})
11	const Effectiveness of Border Control on Desirability to Migrate Constant init 1
12	aux EIEB Effect of Investment on Expansion of Business def GRAPH(('INV Investment in Rural Mexico' / NINV), 0,0.5,{-1.5,0,1,1.5,1.8,2.1,2.3//Min:-1.5;Max:2.3//})
13	aux EIMP Employed Illegal Migrant Population def MIN(NUMBER('JIM Jobs for Illegal Migrants'), NUMBER('IMPUS Illegal Migrant Population in the US')) * 1 <<person>>
14	aux EJAIW Effect of Job Availability on Illegal Wages GRAPH('JMR Job to Migrant Ratio' * 1 <<person/job>>,0,0.5,{0.2,0.5,1,1.3,1.4//Min:0.2;Max:1.4//})
15	aux EJARMW Effect of Job Availability on Mexican Wages def GRAPH(NUMBER('JPR Jobs to Population Ratio'), 0, 0.5,{0.2,0.4,1,1.5,1.8//Min:0.2;Max:1.8//})
16	aux ELEDT Effect of Law Enforcement on Detection Time def GRAPH('PEL Pressure to Enforce the Law',0,0.5,{4,2,1,0.4,0.2//Min:0.2;Max:4//})
17	aux EMP Effect of Migrant Presence on Pressure for Law Enforcement def GRAPH(NUMBER('IMPUS Illegal Migrant Population in the US'),0,2000000,{1,1.8,4,7,9,10//Min:1;Max:10//})
18	aux EMR Emigration Rate def 'IMPUS Illegal Migrant Population in the US' / 'ADS Average Duration of Stay for

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Variable Number	Explanation
	Temporary Illegal Migrants'
19	aux EMURUS Effect of Illegal Migrant Unemployment in US on Desirability to Migrate def GRAPH('UR Unemployment Rate of Illegal Migrants',0,0.1,{2,1,0.5,0.2,0.1,0//Min:0;Max:2//})
20	aux EWBE Effect of Wages on Business Expansion def GRAPH(NUMBER('WAGEI Wage Rate for Illegal Immigrants'),0 ,0.6,{3,2.5,1.8,1,0,-0.5//Min:-0.5;Max:3//})
21	aux EWIMR Effect of Wage Differential on Desirability to Migrate def GRAPH(NUMBER('WAGER Wage Ratio Mexican Wages to US Illegal Wages')/NWR,0,0.5,{3,1.8,1,0.4,0//Min:0;Max:3//})
22	aux EWMBE Effect of Wages in Mexico on Business Expansion def GRAPH(NUMBER('WRM Wages in Rural Mexico'/'NWRM Normal Wage in Rural Mexico'),0,0.5,{4,2,1,0.5,0.3,0.2,0.15//Min:0.15;Max:4//})
23	aux EWRM Effect of Wages in Mexico on New Potential Migrants def GRAPH('WRM Wages in Rural Mexico'/'NWRM Normal Wage in Rural Mexico',0,0.5,{3,2.5,1,0.5,0.2//Min:0.2;Max:3//})
24	aux FA Fraction of Rural Mexicans that Join Potential Migrants def 'NFA Normal Fraction of Rural Mexicans that Join Potential Migrants' * 'EWRM Effect of Wages in Mexico on New Potential Migrants'
25	aux FAB Fraction of Migrants Crossing the Border def GRAPH('PEL Pressure to Enforce the Law'/'PNC50 Law Enforcement Pressure to Catch 50 % at Border',0,0.5,{1,0.7,0.5,0.35,0.25,0.17,0.1//Min:0.1;Max:1//})
26	const FIGI Fractional Increase in Government Investment init 0 <<%>>
27	const FII init 5 <<%>>
28	const FPAW Fraction of Population Able to Work init 60 <<%>>
29	aux GIRA Government Investment in Rural Mexico def 'NGIRA Normal Investment in Labor Intensive Industry' * (1 + STEP('FIGI Fractional Increase in Government Investment',TFIGI))
30	const IBHIM init 4500 <<business>>
31	const IBHRM init 60000 <<business>>
32	aux IIM Invested Income of Migrants def 'IMUS Income of Migrants in US' * FII
33	const IIMPUS init 500000 <<person>>
34	aux IIMR def NFIMR * 'PMPM Potential Migrant Population in Mexico' * 'PDIM Perceived Desirability of the US'
35	level IMPUS Illegal Migrant Population in the US init IIMPUS
36	aux IMR Immigration Rate def IIMR * 'FAB Fraction of Migrants Crossing the Border'
37	aux IMUS Income of Migrants in US def ('EIMP Employed Illegal Migrant Population'* 'WAGEI Wage Rate for Illegal Immigrants'* 'WHPY Work Hours per Year') / 1 <<yr>>
38	aux INV Investment in Rural Mexico

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Variable Number	Explanation
	def 'IIM Invested Income of Migrants' + 'GIRA Government Investment in Rural Mexico'
39	const IPMPM
	init 10000000 <<person>>
40	const IPRM
	init 20000000 <<person>>
41	aux JIM Jobs for Illegal Migrants
	def 'BHIM Business Hiring Illegal Immigrants' * 'JPB Jobs per Business that Hires'
42	aux JMR Job to Migrant Ratio
	def 'JIM Jobs for Illegal Migrants' / 'IMPUS Illegal Migrant Population in the US'
43	const JPB Jobs per Business that Hires
	init 100 <<job PER business>>
44	const JPBM Jobs per Business in Mexico
	init 100 <<job PER business>>
45	aux JPR Jobs to Population Ratio
	def 'JRM Jobs for Rural Mexicans' / 'WPRM Working Population of Rural Mexico'
46	aux JRM Jobs for Rural Mexicans
	def 'BHRM Businesses Hiring Rural Mexicans' * 'JPBM Jobs per Business in Mexico'
47	aux NAPMP New Additions to the Potential Migrant Population
	def 'FA Fraction of Rural Mexicans that Join Potential Migrants' * 'PRM Population of Rural Mexico'
48	const NBE Normal Business Expansion
	init 10 <<% PER yr>>
49	aux NBR Net Birth Rate
	def ('NFBR Net Fractional Birth Rate' * 'PRM Population of Rural Mexico') / 1 <<yr>>
50	aux NEBRM Net Expansion of Business
	def 'NFEB Net Fractional Expansion of Business in Mexico'
	* 'BHRM Businesses Hiring Rural Mexicans'
	* 'EWMBE Effect of Wages in Mexico on Business Expansion'
	* 'EIEB Effect of Investment on Expansion of Business'
51	const NFA Normal Fraction of Rural Mexicans that Join Potential Migrants
	init 2<<% PER yr>>
52	aux NFBR Net Fractional Birth Rate
	def GRAPH(NUMBER(TIME), 1980,20,{0.03,0.03//Min:0.3;Max:0.3//})
53	const NFEB Net Fractional Expansion of Business in Mexico
	init 3 <<% PER yr>>
54	const NFIMR
	init 10 <<% PER yr>>
55	const NGIRA Normal Investment in Labor Intensive Industry
	init 1000000000 <<USD PER yr>>
56	const NINV
	init 2000000000 <<USD PER yr>>
57	aux NIWUS Normal Illegal Wages in US
	def 1.8 <<USD/hr>>
58	const NPEL Normal Pressure for Law Enforcement
	init 1
59	const NWR
	init 0.2
60	const NWRM Normal Wage in Rural Mexico
	init 0.8 <<USD PER hr>>

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Variable Number	Explanation
61	aux PDIM Perceived Desirability of the US def DELAYINF('DIM Desirability of US', 'TPDIM Time to Perceive the Desirability of Migration to the US')
62	aux PDPMP Permanent Departures from the Potential Migrant Pool def 'PMPM Potential Migrant Population in Mexico' / 'ADSPMP Average Duration of Stay in the Potential Migrant Pool'
63	aux PEL Pressure to Enforce the Law def 'NPEL Normal Pressure for Law Enforcement' * 'EMP Effect of Migrant Presence on Pressure for Law Enforcement' * 'EBHIM Effect of Business Hiring Illegals on Presseure for Law Enforcement'
64	level PMPM Potential Migrant Population in Mexico init IPMPM
65	const PNC50 Law Enforcement Pressure to Catch 50 % at Border init 1
66	level PRM Population of Rural Mexico init IPRM
67	aux TDCIB Time to Detect and Close Illegal Business def 'ATDC Avergae Time to Detect and Close Illegal Businesses' * 'ELEDT Effect of Law Enforcement on Detection Time'
68	const TFIGI init DATE(1980)
69	const TPDIM Time to Perceive the Desirability of Migration to the US init 6 <<yr>>
70	aux UR Unemployment Rate of Illegal Migrants def ('IMPUS Illegal Migrant Population in the US' - 'EIMP Employed Illegal Migrant Population')/ 'IMPUS Illegal Migrant Population in the US'
71	aux WAGEI Wage Rate for Illegal Immigrants def 'EJAIW Effect of Job Availability on Illegal Wages' * 'NIWUS Normal Illegal Wages in US'
72	aux WAGER Wage Ratio Mexican Wages to US Illegal Wages def 'WRM Wages in Rural Mexico' / 'WAGEI Wage Rate for Illegal Immigrants'
73	const WHPY Work Hours per Year init 2500 <<hr PER person>>
74	aux WPRM Working Population of Rural Mexico def 'FPAW Fraction of Population Able to Work' * 'PRM Population of Rural Mexico'
75	aux WRM Wages in Rural Mexico def 'NWRM Normal Wage in Rural Mexico' * 'EJARMW Effect of Job Availability on Mexican Wages'

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Appendix E: A Diverse Array of Data and Information Identified and Consulted Throughout This Project.

Appendix F: Complete Report from the Experts Workshop

Appendix G: Complete Report from the Case Study: Focus Group and Interviews

NOTE Appendices E–G are included on the CD that accompanies this report

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