POPULATION DYNAMICS IN HISTORY:

Balancing Endogenous Structure And Exogenous Variables In History Education

By Jeff Potash, Jennifer Andersen and Lees Stuntz

Creative Learning Exchange

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Abstract

This paper describes a project to develop a four-part high school curriculum using system dynamics modeling to show the effect of demographic change on society through four different epochs in U.S. history. Following in the path of such demographic models as Dr. Jay Forrester's Urban and World models, this curriculum is designed to help high school students and their teachers experience the power of using system dynamics to look at historical events. The four simulations of the Population Dynamics series supplement existing high school history curricula while elucidating Dr. Forrester's characteristics of complex systems. They are intended to introduce students to a variety of systems tools along with primary and secondary historical resources. This unique combination of tools offers students opportunities to actively reconstruct patterns of change in the past based on structural relationships that continue to exist and influence the present and future. This curriculum generates an interesting discussion about the use of exogenous variables within an endogenous structure to create meaningful learning within the context of K-12 education.

Introduction

Most of us are familiar with Santayana's famous quote that "Those who do not remember the past are condemned to repeat it."(Santayana, 1905) But what does this mean, in practical terms, for how we teach history? Are there opportunities to help our students better recognize and apply lessons from the past to understand the present and what may happen in the future?

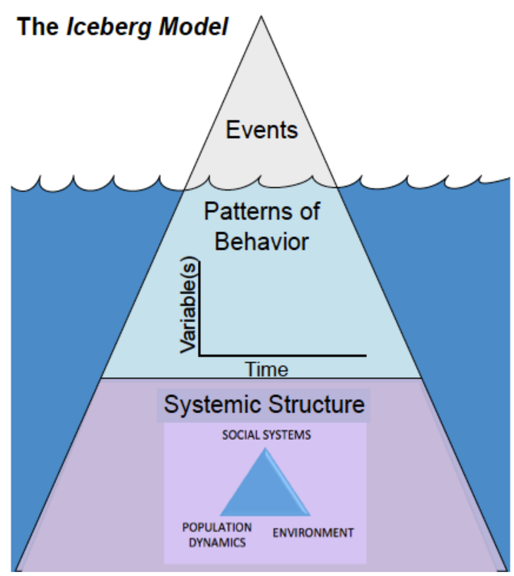

Figure 1: The Iceberg Model

As systems thinkers and dynamic modelers, we have unique tools and perspectives with which to foster deep learning. Consider our "Iceberg" (Figure 1). Some may apply Santayana's warning to particular *Events* (e.g., Neville Chamberlin's 1938 appeasement policy granting Adolph Hitler's demands, or the failure of the U.S. to anticipate the Japanese attack on Pearl Harbor). As systems thinkers, we look at longer-term behaviors over time to find recurring *Patterns* (e.g., exponential growth, oscillations, overshot and collapse). These generic patterns appear as periods of economic boom and bust, war and peace, social and political upheaval. We recognize that underlying these patterns are closed networks of structured relationships or *Systems*. Finally, we know that these systems continue to function in the present, informing patterns that impact today's world and future events.

Professor Jay Forrester, in his paper, *Counterintuitive Behavior of Social Systems,*[1] observes that repeated public policy failures in U.S. history reflect an inadequate understanding of "complex and highly interacting systems," and in particular the non-linear and hence non-intuitive dynamics of social change (Forrester, 1995). Complex systems exhibit general and recurring behaviors that include: (1) large distances both in time and space between cause and effect; and (2) short-term solutions that only exacerbate problems and make them worse over the long term (Forrester, 2009).

What is needed, Forrester asserts, are systems tools, including models and simulations, to help citizens and policymakers better understand how structures of relationships (complex systems) have produced past patterns of behaviors while also informing future possibilities. Actively reconstructing and simulating the past offers better possibilities for managing in the future (Forrester, 2009).

As a first step in addressing Dr. Forrester's concerns, the four simulations of the *Population Dynamics in History* series have been designed to supplement existing high school history curricula and be largely self-directed by students outside of class time. They are intended to introduce students to a variety of systems tools (behavior-over-time graphs, stock/flow maps, models/simulations) alongside primary and secondary historical resources. This unique combination of tools offers students opportunities to actively reconstruct patterns of change in the past based on structural relationships that continue to exist and influence the present and future. Each of the four simulations examines an important period of development within American history. Topics include:

A. Settlement of New England (1630)
B. New England's Colonial History (1630-1776)
C. U.S. Urbanization (1820-1920)
D. America's Baby Boom and Global Youth Bulges (1945 – present)

How Do the Simulations Work?

Each simulation begins with a conceptual frame to help students organize ideas across three broad sectors (Figure 2). Students learn that changes occurring within each sector are likely to be connected, through cause and effect, to changes in the other two sectors.

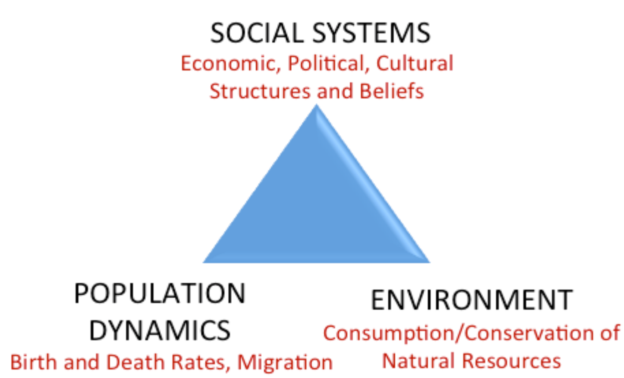

Figure 2: Conceptual Framework

The underlying models are variations of small population models such as the one shown in Figure 3. Models for Parts C and

[1] Prof. Forrester's paper can be found at http://clexchange.org/ftp/documents/system-dynamics/SD1993-01CounterintuitiveBe.pdf.

D contain additional structure to allow for richer behavior, yet the focus remains on population dynamics – births, deaths, immigration and emigration.

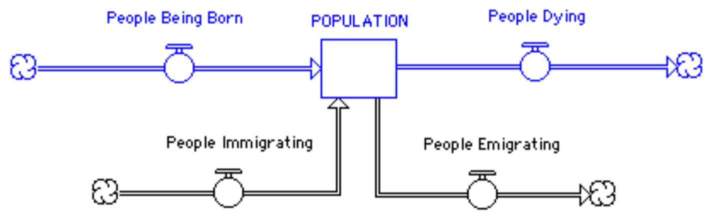

Figure 3: The Basic Population Model

The models are used to investigate historical patterns of population change, for example, Part B of the curriculum, the simulation on New England's Colonial History (http://clexchange.org/curriculum/complexsystems/populationdynamics/popdynB.asp). There were many important events that happened in New England from 1620 – 1770 while its population grew dramatically (Figure 4). This project was designed to use system dynamics simulations and models to clarify the relationships of these events to a pattern of population growth.

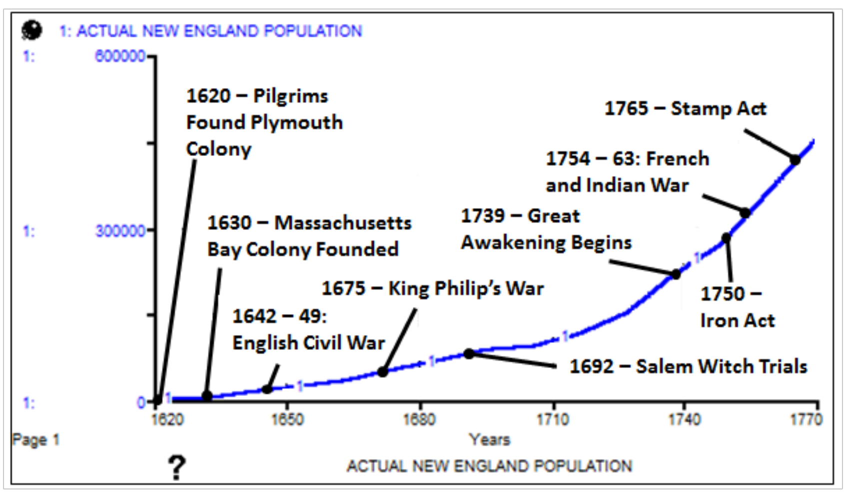

Figure 4: New England's Population, 1620 - 1770

The simulations encourage students to think in terms of systems or structured relationships. At the simplest level, populations change as a result of people being born and people dying. Within a particular setting or population, there are the added factors of movement, comprising immigration and emigration. A growing population, in the simplest terms, suggests the combination of people being added to the population (through births and immigration) exceed the number dying and emigrating.

New England's population did not operate in a vacuum. The factors of the environment and social systems of New England played important roles in allowing the population to grow exponentially. In broad terms, "environment" spans a variety of factors – water, soil, trees, and so on. During the time period of interest, arable land was an essential ingredient for generating food. Similarly, "social systems" is a broad concept, but we surmise that small farm communities within which residents could both feed and govern themselves shaped both the numbers of people (impacting births and deaths) and their environmental needs (land). A systems approach thus adds perspective to what can be a confusing presentation of historical names, dates and facts.

The exercise of asking students to use a simulation to reconstruct population growth, within the context of known local and regional environmental and social systems, illuminates a wide array of events, including the Salem Witch trials, King Philips War, and even the American Revolution. Environmental conditions and resources, plus the social structures created by New England's founders, shaped the dynamics of New England growth. As populations changed, spreading from initial settlement to more distant land, pressures grew to change the New England environment and its social systems.

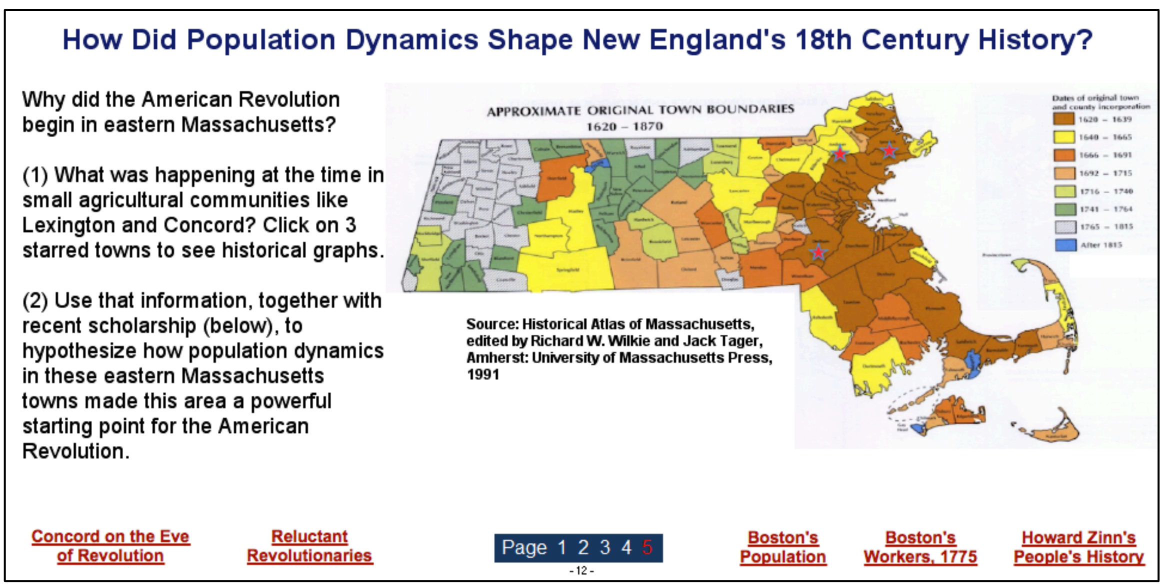

Figure 5: A page from the simulation (red buttons contain primary and secondary historical sources)

In addition to illuminating the past, this curriculum was designed to illustrate the dynamics of changing populations that can be transferred to consider future prospects. Across the globe there are a variety of patterns. In some cases, countries and regions are subject to accelerating rates of population growth, with accompanying issues of environmental sustainability and social instability (including, as Part D simulations illustrate, "youth bulges"). In other countries, social pressures involve net population decline generated by rapidly falling birth rates. In still others, the issue of aging populations, due to healthcare advances that extend life spans and reduce death rates, worries governments and citizens alike.

The Project

This curriculum is part of the Characteristics of Complex Systems Project (CCSP)[2] instigated by Dr. Jay Forrester. The CCSP has been designed to create student-friendly curricula with the long-term goal to help students understand the nature of complex social systems: Why do such systems resist policy changes? Why are short-term and long-term responses to corrective action often at odds with each other? How can leverage points be applied to bring about desirable change in social systems? An abstract level of understanding about social systems will help prepare future citizens to actively shape their society.

The lessons in CSSP are developed in conjunction with model-based simulations that permit students to explore different scenarios. Part C of Population Dynamics is used here to illustrate the type of models that were utilized in Parts C and D of the curriculum. While all the models were based on the Basic Population Model (Figure 3), Parts A and B used less complex models. All the models are posted and available on the CLE website (clexchange.org).

Population Dynamics: Part C: U.S. Urbanization from 1820-1920

This section of the curriculum addresses America's transition from an almost entirely rural society in 1820 (93% of its people living in communities of 2500 or less) to one in 1920, where a majority resided in cities, marking a major turning point in American history. Similar dynamics of dramatic urban growth are happening across the globe today, raising important implications for the future. The lesson introduces students to the dynamics of "relative attractiveness" in both rural and urban settings that contribute to "Push" and "Pull" movements of people either into or out of a particular setting.

Part C is composed of three simulations based on underlying system dynamics models:

- **Simulation 1**: How Do Population Dynamics Create Push and Pull Forces in a Rural Setting?
  Students examine how births and deaths (population dynamics), rural land (environment), and farm labor productivity (social systems) combine to affect overall rural jobs. Depending upon the relationship between the size of the labor force and available farm jobs, residents may be pushed out or pulled into rural communities.

- **Simulation 2:** How Do Population Dynamics Create Push and Pull Forces in an Urban Setting?
  Students investigate how births, deaths, and migration combine to influence numbers of urban jobs. Depending upon the relationship between the size of the

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[2] http://www.clexchange.org/curriculum/complexsystems/complexsystems_project.asp

urban labor force and available factory jobs, residents may be pushed out of rural communities or pulled into urban communities.

- **Simulation 3:** How Did Push and Pull Dynamics Affect American History From 1820-1920?
  Students learn about the specific conditions underlying America's changing (1820-1920) population dynamics (both rural and urban), environment (farmland and urban factories), and social systems (both rural and urban jobs and technology). In addition to reconstructing the specific push and pull dynamics operating during this period, students will use the simulation to recreate alternative historical scenarios ("What ifs") based on the presence of one or more constraints on urban growth.

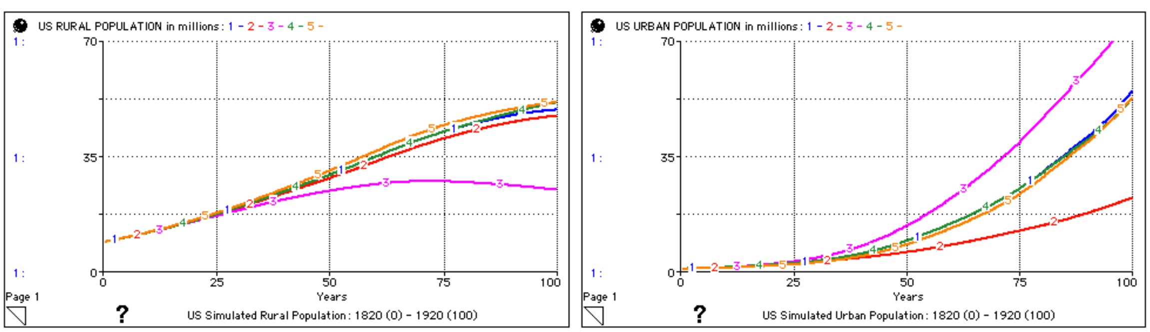
Creating the Simulations: What Are The Pedagogical Benefits Of Exogenous Variables In Models To Teach History?

- **Adding "Value" By Modeling Historical "What if's".** As an example:

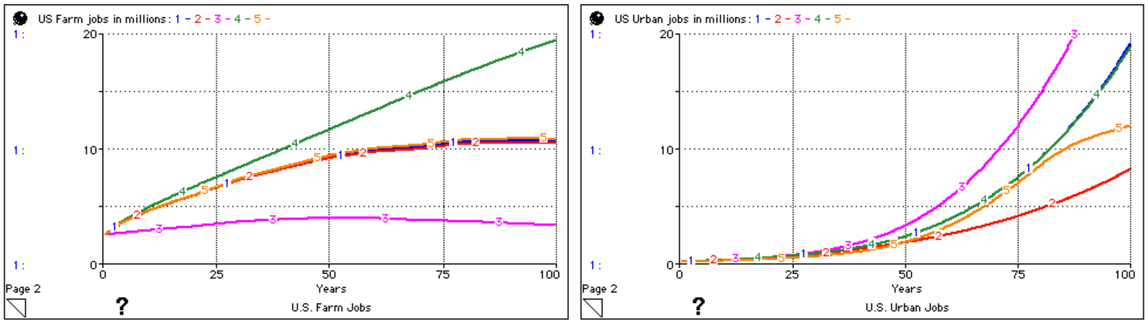
  The output below accurately projects (line 1 – in blue) what happened between 1820 (Year 0) and 1920 (Year 100).

  But what if:

  - There had been NO foreign immigration (line 2 – red)
  - America had NOT expanded beyond its 1820 territorial boundaries (line 3 – purple)
  - Farm productivity had NOT occurred through new invention (line 4 – green)
  - Factories had NOT grown in size/average number of employees (line 5 – gold)



Rural/ Urban Population



Rural/Urban Jobs

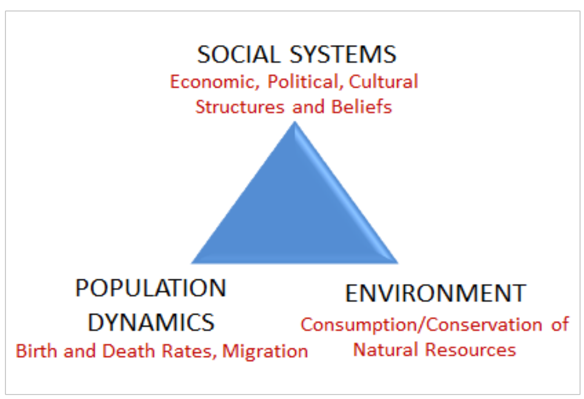
- **Striving Toward a Larger Purpose: Reframing What Students Learn From History**

  Ultimately, the value of history rests in its ability to inform patterns that have relevance in the present and future (re Santayana and Forrester).

  Beyond reconstructing the particulars of the American past, these simulations offer teachers and students *a broad 3-sector conceptual frame within which to explore how changes occurring within each sector are likely to be connected, through cause and effect, to changes in the other two sectors*.

  "Better Questions" naturally emerge: How do changing population dynamics effect either resource dynamics and/or social systems? And how might a change in resources in turn impact on populations and/or social systems? And how might a social or political development have implications on environment or population dynamics?

  These core questions are as relevant in the present and possible futures as they are in seeing the manner in which the past unfolded.



Model for Simulation 3*

*Depiction represented in the paper is a simplification of the formal model, which is included with the materials.

To illustrate for high school teachers and their students how "Push" and "Pull" dynamics transformed the United States between 1820 and 1920 from a small, agrarian society to a much larger and more populous urban and industrial-based culture, it is necessary to create a working relationship between the goal of endogenity and the practicality of using system dynamics to teach in the K-12 system. System dynamics models strive to endogenize all of the relevant driving factors underlying general behaviors. However, for purposes of replicating what happened and affording students opportunities to explore historical counterfactuals, a limited number of exogenous variables are necessary to capture and accurately represent the past.

The model we developed borrows from Forrester's *World Dynamics* model to represent core systemic structures. The model contains three broad sectors: (1) total population, disaggregated into rural and urban; (2) a rural sector (involving land and jobs) and an (3) urban sector (incorporating factories and jobs). The interplay between these three dynamic sectors frames the broad progression of U.S. history through (1) continual and rapid population growth, (2) expanding territorial frontiers, and – most important to system dynamicists – (3) rural and urban job dynamics that shape comparative "attractiveness" over time.

The population sector is relatively straightforward, incorporating births, deaths, and net immigration. Consistent with demographic practice, births and deaths are defined per 1000 population.

Figure 6: Population Dynamics

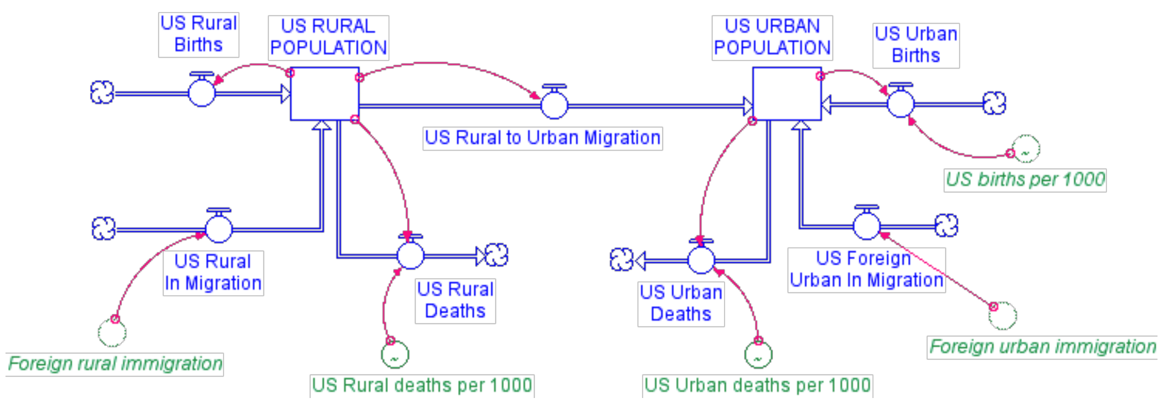
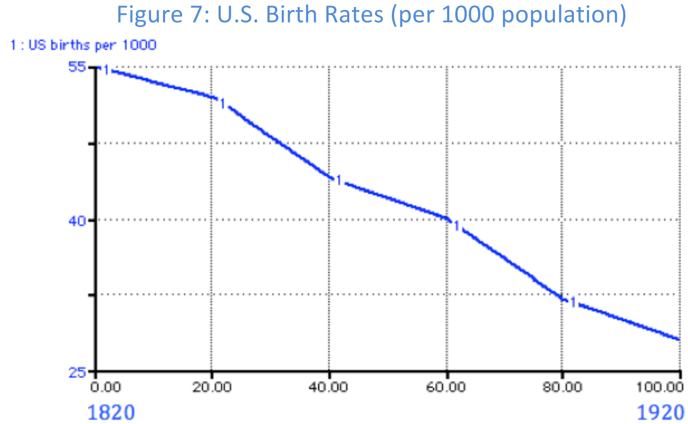
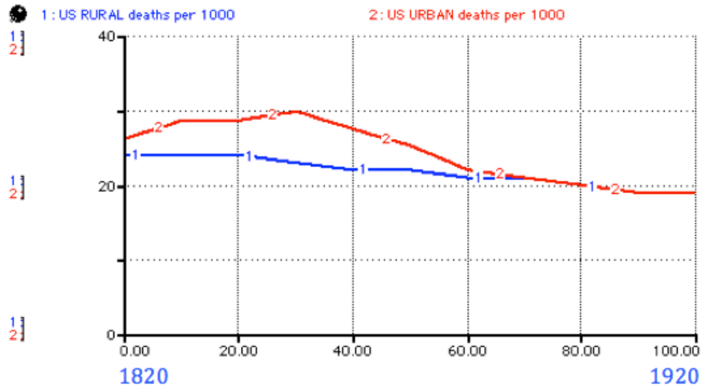


Figure 7: U.S. Birth Rates (per 1000 population)



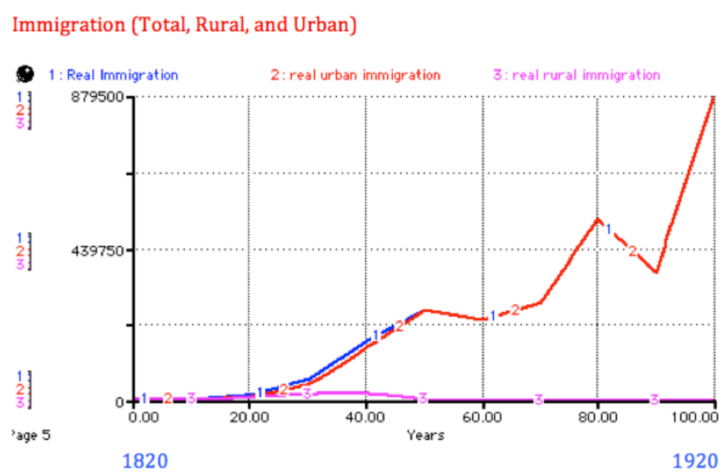
Note that the variables shown in green represent exogenous variables, necessary to capture what actually transpired. U.S. births per 1000 (shown to left) fell during the period from 55 per 1000 (in 1820) to slightly more than 26 per 1000 (in 1920). This pattern, operating in both rural and urban America, reflects numerous factors outside the boundaries of our simple model, involving what demographers refer to as a "demographic transition." The graph provides a launching point for history teachers and students to explore and qualitatively discuss these factors and the process of demographic change.

Figure 8: U.S. Rural and Urban Death Rates (per 1000)



Death rates offer a similar opportunity for broader historical exploration. As the graph used in the model illustrates (on left), while death rates overall declined during the period (albeit at a smaller rate than births), death rates were initially much higher in American cities than within its rural environs, a phenomenon that holds true throughout much of human history, due to such factors as sanitary conditions, population density and disease spread, and other quality of life issues.

Figure 9: Total Foreign Immigration into the U.S.



A final and critically important factor shaping America's population between 1820 and 1920 involved foreign immigration. Beginning in the 1840s, but in steadily growing numbers in the years following the American Civil War, immigration into the United States played a major role in reshaping and growing the American population. Once again, as illustrated in the graph (left), the dynamics of immigration were shaped by a number of factors, including political and economic events unfolding across Europe and Asia at the time, as well as American economic and political cycles. How, when, and why immigrants chose to come to America is fundamental for understanding American history, and this exogenous graph strives to facilitate that understanding.

The second sector (borrowing on selected concepts from Forrester's *World Dynamics* model, Forrester, 1979) explores rural dynamics through relationships involving changing rural populations, available farmland, and farm labor productivity. The size of a rural population and its rate of farm participation define a labor force. Assuming some level of productivity (e.g., acres an individual worker can productively oversee), the workforce requires a certain amount of land with which to satisfy the needs of the resident workforce. Potential farmland offers an opportunity for growing populations to be accommodated; growing labor productivity and/or land constraints (including land overuse and loss of productivity) generate possibilities for a rural workforce to exceed land resource capacities. These dynamics presumably would lead to rural emigration.

Figure 10: Rural Dynamics in the U.S.

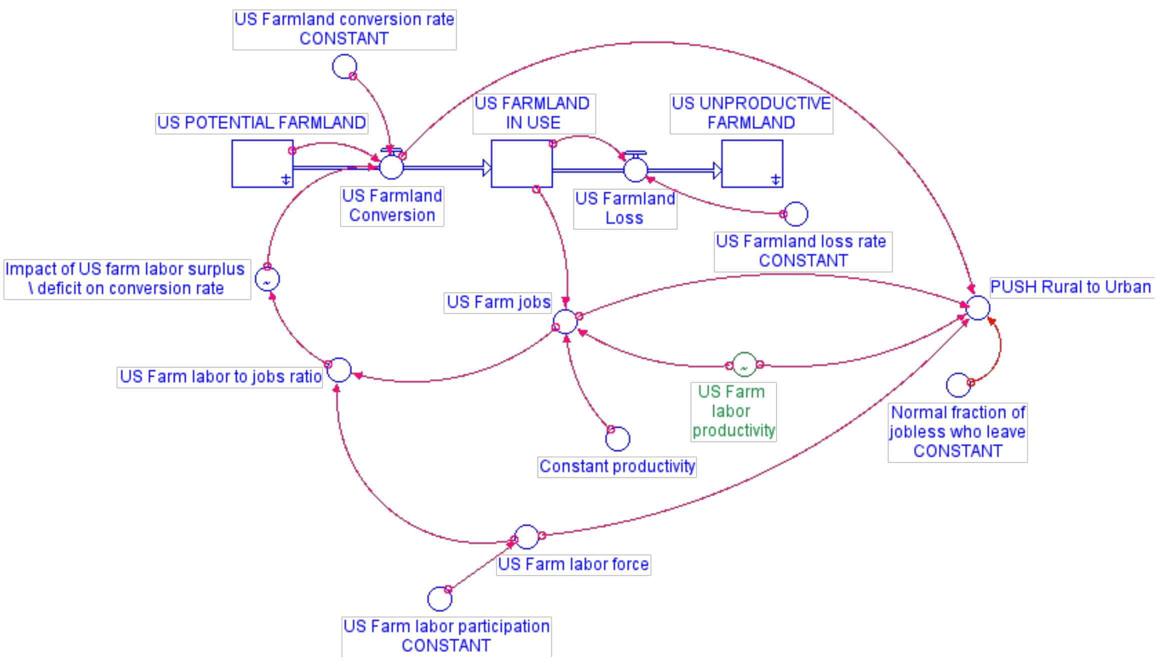
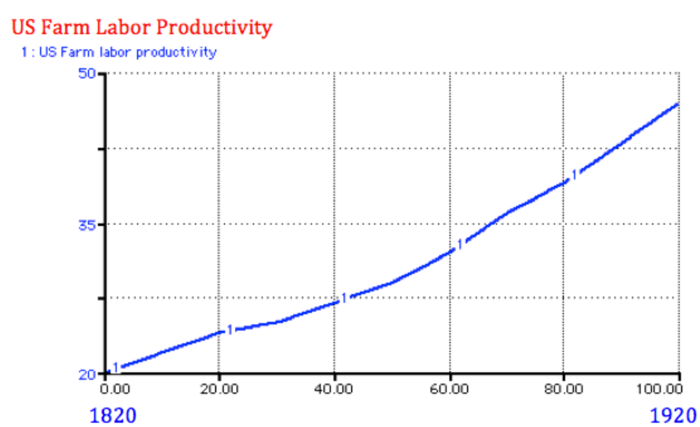


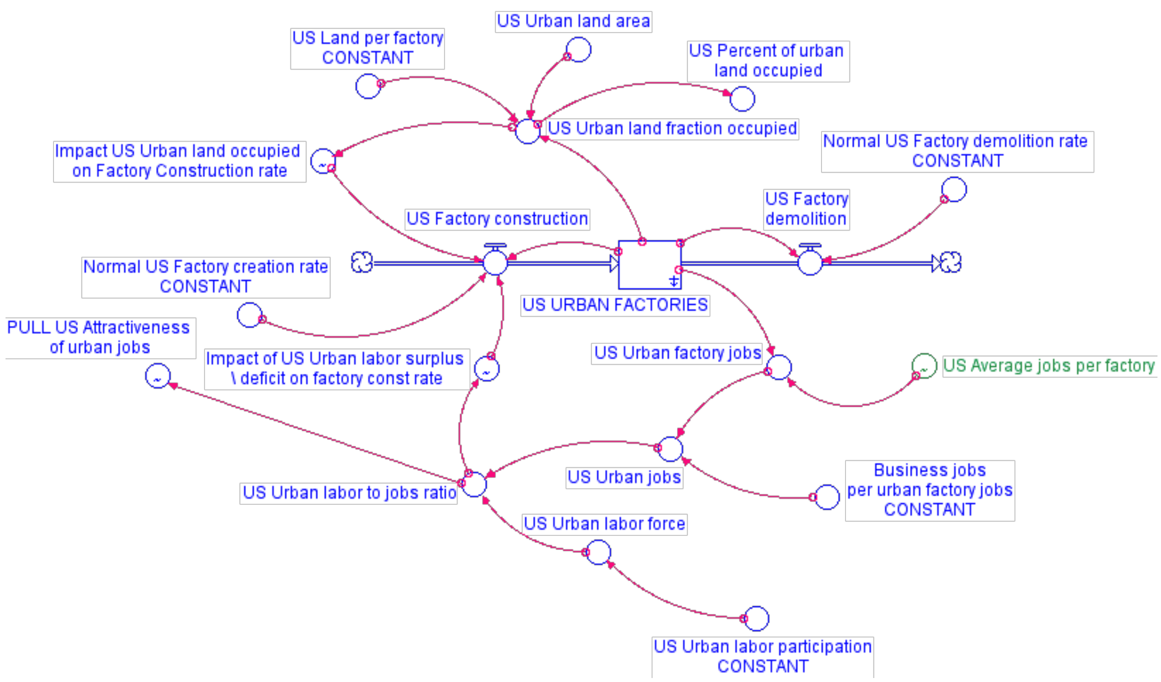
Figure 11: Changing Farm Labor Productivity (acres per farm worker)



Note the use of a single green exogenous variable representing U.S. Farm labor productivity in this model. As indicated in the graph (to left), productivity rose steadily throughout the period. The causes for this rise in productivity can be traced to an explosion of new agricultural inventions (beginning with steel plows, horse-drawn reapers and threshers and progressing into motorized equipment), together with agricultural practices. The particulars surrounding this unique set of developments, outside the model boundaries, is very much grist for meaningful history class conversation.

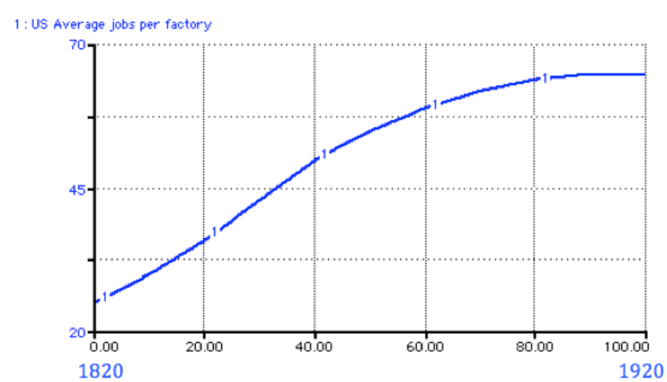
The third and final sub-model, examining the dynamics of urban growth, draws directly on elements developed in Forrester's *Urban Dynamics* model (Forrester, 1969). Here, the size of an urban workforce is defined both by natural growth and in-migration. Factory jobs are determined by the number of factories operating within an urban area and the relative size of each factory. For purposes of simplicity, total factory jobs are used to calculate total urban jobs.

Figure 12: Urban Dynamics



While the model calculates urban growth based on the capacity of growing labor forces to reinforce factory growth, it acknowledges several balancing feedbacks that can also be triggered. One involves a limit to growth based on depleting supplies of available urban land; another involves the potential for an insufficient workforce to stunt factory growth; still another raises issues involving the impact of adequate diminishing the city's "attractiveness" to future immigrants.

Figure 13: Average Number of Jobs per U.S. Factory



Here, as in the rural model, we've used a single green exogenous variable representing Average Number of Jobs per U.S. factory in this model. Unlike the other exogenous variables that are grounded directly in specific data, the data shown in the graph (to left) reflect have been developed in part with data and in part through extrapolating overall urban labor figures for the period. What emerges from this is our understanding that industrial productivity combined with broader urban diversification (industrial and commercial) to generate growing job opportunities throughout the period.

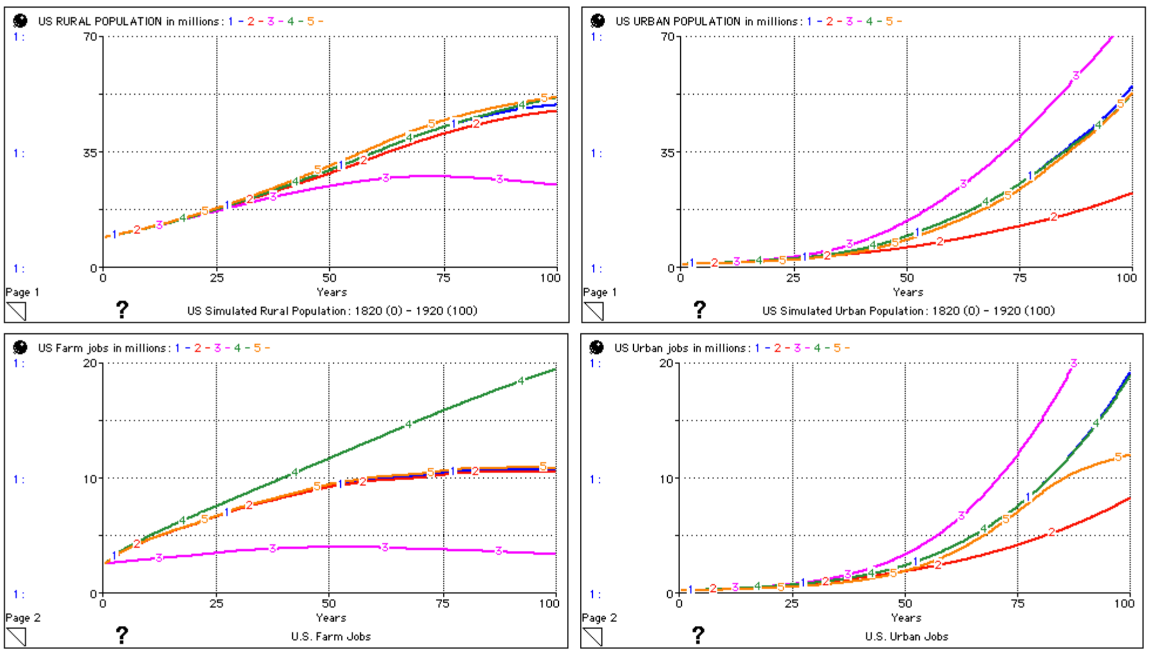
This relatively simple model offers students a chance to see where, when, and how different patterns of rural versus urban growth were directly related to jobs, population dynamics, resource availability and labor productivity.

The output below accurately projects (line 1 – in blue) what happened between 1820 (Year 0) and 1920 (Year 100). Graphical output allows students to explore what if"

- There had been NO foreign immigration (line 2 – red)
- America had NOT expanded beyond its 1820 territorial boundaries (line 3 – purple)
- Farm productivity had NOT occurred through new invention (line 4 – green)
- Factories had NOT grown in size/average number of employees (line 5 – gold)

Rural/Urban Populations

Rural/Urban Jobs



In its entirety, the U.S. model provides a platform for examining how the interrelationships between the three broad sectors, dynamic populations (involving both natural growth and migration), natural resources (here, land), and Social Systems (here, technology and jobs) shape the relative "attractiveness" of different environments; and, in turn, how that attractiveness feeds back over time in reshaping elements within each of these three broad sectors.

By allowing students' to ask "what ifs," they see history not merely as a set of facts but as a dynamic set of systemic processes. By fostering a deeper understanding that these processes apply beyond the particulars of a distant and particular past, students are further encouraged to explore the broader implications of these processes and the dynamic implications on the present and possible future.

Conclusion

The four Population Dynamics simulations are designed to illustrate how systems thinking and dynamic modeling could support and supplement deeper and more meaningful student learning. While we chose to focus first on demographic patterns in U.S. history, it would be equally valuable to start in one of the other sectors. What happens, for instance, when there is a sudden or dramatic environmental change or a social or political development? What questions might students surface to better understand how the other sectors fit in structural relationships of cause and effect? And how might models and simulations help reconstruct past patterns or hypothesize future possibilities?

The possibilities are truly exciting. As teachers and systems thinkers, we recognize the potential for engaging and empowering our students to actively reconstruct the world around them. Searching for and then identifying patterns is every bit as important as learning civics or acknowledging the important role of particular individuals and events in shaping a particular past.

The power of past experience rests in its capacity to provide lessons and insights for managing the future. This small curricular experiment provides an illustration or prototype for how students can connect their study of the past with an understanding of science, math, and systems thinking, to harness the genius of Santayana or Forrester, and, in so doing, confidently contemplate and manage the future.

Our hope is that this illustration inspires more Population-Resource-Social Systems Models that help inform better ways to inspire systems citizens to more effectively address meaningful problems.

Acknowledgements:

This curriculum benefited from the excellent critiquing of Anne LaVigne, Alan Ticotsky and Marcy Kenah.

Supporting Materials:

CC2015_PopDynPartC.pdf
Models:
Generic PopDynC.STMX
US Model PopDynC.STMX
US Model Map.STMX

The entire curriculum is available on the CLE website at http://clexchange.org/curriculum/complexsystems/populationdynamics/.

Appendix 1: Equations for US Model PopDynC.STMX

US_POTENTIAL_FARMLAND(t) = US_POTENTIAL_FARMLAND(t - dt) + (-US_Farmland_conversion) * dt

INIT US_POTENTIAL_FARMLAND = US__Potential__Farmland

OUTFLOWS:

US_Farmland_conversion = (US_POTENTIAL_FARMLAND * (US_Farmland_conversion_rate / 100)) * US_Farm_labor_multiplier

US_UNPRODUCTIVE_FARMLAND(t) = US_UNPRODUCTIVE_FARMLAND(t - dt) + (US_Farmland_loss) * dt

INIT US_UNPRODUCTIVE_FARMLAND = 0

INFLOWS:

US_Farmland_loss = US_FARMLAND_IN_USE *(US_Farmland_loss_rate / 100)

US_URBAN_FACTORIES(t) = US_URBAN_FACTORIES(t - dt) + (US_Factory_construction - US_Factory_demolition) * dt

INIT US_URBAN_FACTORIES = US_Initial_urban_factories

INFLOWS:

US_Factory_construction = US_URBAN_FACTORIES *(US_Factory_creation_rate / 100) * US_Urban_labor_multiplier * US_Urban_land_multiplier

OUTFLOWS:

US_Factory_demolition = US_URBAN_FACTORIES * US_Factory_demolition_rate

US_FARMLAND_IN_USE(t) = US_FARMLAND_IN_USE(t - dt) + (US_Farmland_conversion - US_Farmland_loss) * dt

INIT US_FARMLAND_IN_USE = US_Initial__farmland_used

INFLOWS:

US_Farmland_conversion = (US_POTENTIAL_FARMLAND * (US_Farmland_conversion_rate / 100)) * US_Farm_labor_multiplier

OUTFLOWS:

US_Farmland_loss = US_FARMLAND_IN_USE *(US_Farmland_loss_rate / 100)

US_RURAL_POPULATION(t) = US_RURAL_POPULATION(t - dt) + (US_Rural_Births + US_Rural_in_Migration - US_Rural_Deaths - US_Rural_to_urban_migration) * dt

INIT US_RURAL_POPULATION = Initial_US_Rural_Population

INFLOWS:

US_Rural_Births = US_RURAL_POPULATION * (US_births_per_1000 / 1000)

US_Rural_in_Migration = real_rural_immigration

OUTFLOWS:

US_Rural_Deaths = US_RURAL_POPULATION * (US_deaths_per_1000 / 1000)

US_Rural_to_urban_migration = (US_RURAL_POPULATION * (US_Rural_out_migration_per_1000 / 1000) * PULL_US_Attractiveness_of_urban_jobs) + PUSH_Rural_to_Urban

US_Rural_to_Urban_Migration_in_millions(t) = US_Rural_to_Urban_Migration_in_millions(t - dt) + (Flow_1) * dt

INIT US_Rural_to_Urban_Migration_in_millions = 0

INFLOWS:

Flow_1 = US_Rural_to_urban_migration/1000000

US_URBAN_POPULATION(t) = US_URBAN_POPULATION(t - dt) + (US_Urban_Births + US_Urban_in_migration + US_Rural_to_urban_migration - US_Urban_Deaths) * dt

INIT US_URBAN_POPULATION = Initial_US_Urban_Population

INFLOWS:

US_Urban_Births = US_URBAN_POPULATION * (US_births_per_1000 / 1000)

US_Urban_in_migration = real_urban_immigration

US_Rural_to_urban_migration = (US_RURAL_POPULATION * (US_Rural_out_migration_per_1000 / 1000) * PULL_US_Attractiveness_of_urban_jobs) + PUSH_Rural_to_Urban

OUTFLOWS:

US_Urban_Deaths = US_URBAN_POPULATION * (US_deaths_per_1000 / 1000)*US_Urban_Death_Multiplier

Business_jobs_per_urban_factory_jobs = 1.75

Constant_productivity = 0

fraction_of_jobless_who_leave = 0.1

Growth = 1

Immigration_off = 0

Immigration_on = 1

Increase_productivity = 1

Initial_US_Rural_Population = 8945000

Initial_US_Urban_Population = 694000

No_growth = 0

per_cent_immigrants_settle_rural = GRAPH(time)

(0.00, 50.0), (10.0, 50.0), (20.0, 40.0), (30.0, 25.0), (40.0, 10.0), (50.0, 0.00), (60.0, 0.00), (70.0, 0.00), (80.0, 0.00), (90.0, 0.00), (100, 0.00)

PULL_US_Attractiveness_of_urban_jobs = GRAPH(US_Urban_labor_to_jobs_ratio)

(0.00, 2.00), (0.2, 1.95), (0.4, 1.80), (0.6, 1.60), (0.8, 1.35), (1.00, 1.00), (1.20, 0.5), (1.40, 0.3), (1.60, 0.2), (1.80, 0.15), (2.00, 0.1)

PUSH_Rural_to_Urban = MAX(US_Farm_labor_force-US_Farm_jobs - (US_Farmland_conversion/US_Farm_labor_productivity),0)*fraction_of_jobless_who_leave

Real_Immigration = GRAPH(time)

(0.00, 200), (10.0, 800), (20.0, 14300), (30.0, 59900), (40.0, 171300), (50.0, 259800), (60.0, 231500), (70.0, 281200), (80.0, 524700), (90.0, 368800), (100, 879500)

real_rural_immigration = (1 - Immigration_off) * (per_cent_immigrants_settle_rural*.01*Real_Immigration)

real_rural_pop = REAL_US_RURAL_POPULATION_in_millions*1000000

real_total_pop = real_rural_pop+real_urban_pop

real_urban_immigration = (1 - Immigration_off) * (Real_Immigration - real_rural_immigration)

real_urban_pop = REAL_US_URBAN_POPULATION_in_millions*1000000

REAL_US_RURAL_POPULATION_in_millions = GRAPH(TIME)

(0.00, 8.90), (10.0, 11.7), (20.0, 15.2), (30.0, 19.6), (40.0, 25.2), (50.0, 28.7), (60.0, 36.1), (70.0, 40.9), (80.0, 45.9), (90.0, 50.2), (100, 51.8)

REAL_US_URBAN_POPULATION_in_millions = GRAPH(TIME)

(0.00, 0.7), (10.0, 1.20), (20.0, 1.90), (30.0, 3.60), (40.0, 6.20), (50.0, 9.90), (60.0, 14.1), (70.0, 22.1), (80.0, 30.2), (90.0, 42.1), (100, 54.3)

US_Average_jobs_per_factory = GRAPH(time)

(0.00, 25.0), (10.0, 30.0), (20.0, 36.0), (30.0, 43.0), (40.0, 50.0), (50.0, 55.0), (60.0, 59.0), (70.0, 62.0), (80.0, 64.0), (90.0, 65.0), (100, 65.0)

US_births_per_1000 = GRAPH(time)

(0.00, 55.0), (10.0, 53.5), (20.0, 52.0), (30.0, 48.0), (40.0, 44.0), (50.0, 42.0), (60.0, 40.0), (70.0, 36.0), (80.0, 32.0), (90.0, 30.0), (100, 28.0)

US_deaths_per_1000 = GRAPH(time)

(0.00, 24.0), (10.0, 24.0), (20.0, 24.0), (30.0, 23.0), (40.0, 22.0), (50.0, 22.0), (60.0, 21.0), (70.0, 21.0), (80.0, 20.0), (90.0, 19.0), (100, 19.0)

US_Factory_creation_rate = 5

US_Factory_demolition_rate = 0.01

US_Farmland_conversion_rate = 1

US_FARMLAND_IN_USE__in_millions_of_acres = US_FARMLAND_IN_USE/1000000

US_Farmland_loss_rate = 0.05

US_Farm_jobs = if Constant_productivity = 1 then US_FARMLAND_IN_USE/20 else US_FARMLAND_IN_USE / US_Farm_labor_productivity

US_Farm_jobs_in_millions = US_Farm_jobs/1000000

US_Farm_labor_force = US_RURAL_POPULATION * (US_Farm_labor_participation / 100)

US_Farm_labor_multiplier = GRAPH(US_Farm_labor_to_jobs_ratio)

(0.00, 0.00), (0.2, 0.114), (0.4, 0.26), (0.6, 0.483), (0.8, 0.756), (1.00, 1.00), (1.20, 1.19), (1.40, 1.33), (1.60, 1.43), (1.80, 1.52), (2.00, 1.61)

US_Farm_labor_participation = 25

US_Farm_labor_productivity = GRAPH(time)

(0.00, 20.0), (10.0, 22.0), (20.0, 24.0), (30.0, 25.0), (40.0, 27.0), (50.0, 29.0), (60.0, 32.0), (70.0, 36.0), (80.0, 39.0), (90.0, 43.0), (100, 47.0)

US_Farm_labor_to_jobs_ratio = US_Farm_labor_force / US_Farm_jobs

US_Initial_urban_factories = 2000

US_Initial_urban_population = 2500

US_Initial__farmland_used = 50000000

US_Land_per_factory = 0.2

US_Percent_of_urban_land_occupied = US_Urban_land_fraction_occupied*100

US_Rural_out_migration_per_1000 = 2.5

US_RURAL_POPULATION_in_millions = US_RURAL_POPULATION/1000000

US_Total_farmland = US_POTENTIAL_FARMLAND + US_FARMLAND_IN_USE + US_UNPRODUCTIVE_FARMLAND

US_Total_Population = US_RURAL_POPULATION + US_URBAN_POPULATION

US_Total_potential_farmland = 900

US_Urban_Death_Multiplier = GRAPH(time)

(0.00, 1.10), (10.0, 1.20), (20.0, 1.20), (30.0, 1.30), (40.0, 1.25), (50.0, 1.15), (60.0, 1.05), (70.0, 1.00), (80.0, 1.00), (90.0, 1.00), (100, 1.00)

US_Urban_factory_jobs = if No_growth = 1 then US_URBAN_FACTORIES*20 else US_URBAN_FACTORIES * US_Average_jobs_per_factory

US_Urban_immigrants_per_1000 = 0

US_Urban_jobs = US_Urban_Factory_jobs + (business_jobs_per_urban_factory_jobs*US_Urban_Factory_jobs)

US_Urban_jobs_in_millions = US_urban_jobs/1000000

US_Urban_labor_force = US_URBAN_POPULATION * US_urban_labor_participation

US_Urban_labor_multiplier = GRAPH(US_Urban_labor_to_jobs_ratio)

(0.00, 0.2), (0.2, 0.25), (0.4, 0.35), (0.6, 0.5), (0.8, 0.7), (1.00, 1.00), (1.20, 1.35), (1.40, 1.60), (1.60, 1.80), (1.80, 1.95), (2.00, 2.00)

US_Urban_labor_participation = 0.25

US_Urban_labor_to_jobs_ratio = US_urban_labor_force /US_urban_jobs

US_Urban_land_area = 50000

US_Urban_land_fraction_occupied = (US_URBAN_FACTORIES * US_Land_per_factory) / US_Urban_land_area

US_Urban_land_multiplier = GRAPH(US_Urban_land_fraction_occupied)

(0.00, 1.00), (0.1, 1.15), (0.2, 1.30), (0.3, 1.40), (0.4, 1.45), (0.5, 1.40), (0.6, 1.30), (0.7, 0.9), (0.8, 0.5), (0.9, 0.25), (1.00, 0.00)

US_URBAN_POPULATION_in_millions = US_URBAN_POPULATION/1000000

US__Potential__Farmland = (US_total_Potential_Farmland*1000000) - US_Initial__farmland_used

Sim_Total_Pop = US_RURAL_POPULATION + US_URBAN_POPULATION

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