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Empires of Halcyon: An Online Nation Simulator with Macroeconomic Modeling

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EMPIRES OF HALCYON:

AN ONLINE NATION SIMULATOR WITH MACROECONOMIC MODELING

By

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My immense gratitude goes out to my professors, especially John Hamman and John Lightle, who so patiently allowed for my company, and to my friend Wickus Nienaber, who first inspired this project and provided such invaluable assistance in its execution.

Our task as I see it…is to write a FORTRAN program that will accept specific economic policy rules as "input" and will generate as "output" statistics describing the operating characteristics of the time series we care about, which are predicted to result from these policies.

-Robert Lucas (1980)

1. Introduction

The goal of this creative project thesis has been to construct an online, text-based nation simulator which incorporates several important models and concepts from macroeconomic theory. The simulator, named "Empires of Halcyon" and abbreviated "Halcyon", operates as an eternal massively-multiplayer online role playing game in which players are able to create and manage their own digital nations, playing the role of government. Within the game players are able to pass laws, wage war, invest in their economy, join and form alliances with other players, and send aid to other nations. Crucial to this project is a computer simulation model of macroeconomic growth involving Malthusian and Solow growth models. The game may function as an educational tool for players and may present the possibility of a future avenue for experimental research.

Text-based online nation simulation games are not a concept original to this project. NationStates was one of the first multiplayer games of this type and has existed for over a decade (established in November of 2002 [Barry, 2011]). The gameplay is extremely simple – a player simply responds to daily "issues," and their country's description reflects their style of governing in different categories. Most of the interaction between players occurs through lengthy role-playing discussions on web forums with very little in-game consequence.

A more advanced vision of online nation simulators came with the release of Cyber Nations, which offered actual in-game accounting for money, military units, infrastructure, technology, and land. Cyber Nations escalated the political side of gameplay by offering players the chance to war, aid, and trade with one another (Cyber Nations). With time, these increased incentives for cooperation (and increased opportunities for antisocial behavior) led to the development of large alliances of players and a complicated political environment arose in which alliances formed blocs and engaged in warfare with one another under a set of endogenously developed political norms. The political blocs came to rule the game, with style-of-play ideology being the main differentiating factor between the sides. "Roleplay" alliances are ones which tend to take the game more seriously as a nation simulator, with members writing out lengthy fictional histories and political manifestos for their virtual nations and alliances. "lulz" alliances generally form as invasions from outside internet communities, often with the malicious intention of ruining the gameplay experience for serious players, and these types of players tend to view the game as an opportunity to antagonize enemies and socialize with similar players.

While the introduction of actual game mechanics to a nation simulator provided a boom in popularity, players have complained that the game is still not nearly complex enough to provide a convincing simulation of actual nations. Indeed, Cyber Nations operates on an extremely simplistic basis – money comes from taxes, which comes from citizens, which automatically appear when the player purchases infrastructure (Cyber

Nations, 2013). Therefore, the goal of the game is to buy infrastructure. Certain additional game features can increase tax collections dramatically, including technology, improvements, national wonders, and other features – but the operation of these adjusters is extremely static with one dimensional affects which are public information. The game is so formulaic that alliances generally provide their members with simple guides which explain to new players exactly what to do, knowing full well how much money players will have at each stage of the building process and what the optimal next step is. The stochastic variations and opaque inter-connected causalities facing real-world policy makers do not exist in this virtual reality.

Other simulators have been released with the intent of capitalizing on the success of Cyber Nations. A notable example is Project Terra, which aims to increase the complexity of the simulation experience with more specific developments in industry, resource management, and legislative options (Project Terra, 2012). However, even Project Terra still falls short of the next logical extension of increasingly complex online nation simulators: formal macroeconomic modeling. In order to truly capture the complex causalities and unintended consequences inherent to policy making, rich underlying models are required that simulate economic behavior and growth. Such models have existed in the macroeconomic literature for decades and will serve as the basis for this creative project.

The existence of a simulator based off of macroeconomic models would offer many potential benefits to those interested in macroeconomics (or nation simulator games, for that matter). Such a simulator would be able to easily and conveniently test policy hypotheses according to the encoded models. Finding equilibriums for a large number of markets covering potentially hundreds of variables has long been a problem, and computer simulations have been employed before to provide an easy way to compare policy alternatives (Frigg, 2009).

The project at hand is unique, however, in its accessibility to those who are not professional economists. Economic simulation software is generally expensive and confusing for laypeople (Woltjer, 2005). A free text-based online nation simulator which employs macroeconomic models could be an important teaching tool for professors trying to convey the ideas behind macroeconomic models to undergraduate students. These text-based nation simulation games are generally thought to be popular with college-age players[1], and the added complexity of dynamic economic systems which must be reckoned with by the digital government may help maintain the interest of the player. Furthermore, this project features a social aspect between a potentially massive number of simulation users that is unique to rigorous economic simulators. The marriage of accessibility and social interaction may even present the potential for virtual experiments to see how changes in game mechanics affect player behavior.

Another advantage to developing an explicit model-based game is to facilitate my own personal research into macroeconomic modeling. Constructing games which employ social models as a means of helping the game developer to develop more complete and advanced models is not a new idea. Sociologist James Coleman famously used his game *Democracy* to aid in the development of his mathematical theory of collective action (Feld, 1997) and advocated the general use of simulation as a means of developing social theory (Coleman, 1989).

[1] Unfortunately, the relatively small player base for text-based multiplayer games means this is a casual observation instead of a citable fact.

Choosing economic models on which to base the simulation engine proved a more complex task than I had originally estimated. During the course of the project it became clear that the original goal of implementing a complete real business cycle model in the game was unfeasible at this time, so a Solow growth model was chosen instead. While the Solow growth model lacks the fascinating short run dynamics inherent to a business cycle model, it does provide both a beginning point for working with programmed macroeconomic models and a foundation off of which a real business cycle model may later be implemented. It should be noted that non-monetary models are necessitated by the nature of the project. While monetary policy is undoubtedly important to macroeconomics, the existence of monetary policies unique to each nation would make exchange between nations extremely difficult as a foreign exchange market with potentially thousands of participants would be unfeasible. This compelled my original line of research into the real business cycle model and, later, the neoclassical growth model. The strength of the neoclassical growth model is that it is highly compatible with a large array of different theories, including real business cycle theory. The current build of the game involves only the neoclassical growth model, but development of a business cycle simulator promises to be a fruitful and logical extension of the game in the future.

The rest of this paper will serve as developer documentation and academic justification for the nation simulator which I have designed. A prior literature section will document the research that has been done into the varying macroeconomic models I have researched without bias against those models which have been excluded from the final project. This will be followed by documentation of the simulator's implementation, including brief overviews of non-economic components of the game, and then some concluding notes.

2. Prior Literature

It is important to note that this simulator's economic content is necessarily focused on *growth theory*. To varying degrees of formality, growth theory has been the defining research agenda in economics since Adam Smith's *An Inquiry Into the Nature and Causes of the Wealth of Nations*. Ostensibly, much of economics can be said to be related to the quest to improve the living standards of economic agents, and growth theory is the direct and obvious attempt at this end. Smith's answer to the question of growth was given on the first page of his magnum opus: the division of labor increases productivity, increasing material wealth for individuals (Smith, 2003). Smith's analysis looked beyond the obvious short-term labor reductions that came through productivity increases and instead told a richer story of advances in real material wealth that would come through this increased efficiency. The Smithian view was one of ever-expanding economic growth and prosperity, if only markets were left free and open so that gains from trade and cooperation could be realized. For his time this was a fairly baffling viewpoint – living standards in 1776 were roughly the same as they had been throughout all of human history, which was hardly a story of uncontrollable economic growth (Clark, p. 1) – but this did not stop his fame from becoming immediate. With the benefit of historical perspective, Smith's ability to look beyond the persistent poverty around him to realize the underlying mechanics of growth has made him a kind of patron saint of economics.

While Smith's views on economic growth have permanently informed macroeconomics, the first explicit growth model usually taught to undergraduate students is one inspired by Thomas Malthus. Malthus was an English Anglican minister, trained in mathematics, who became a professor in political economy following the publishing of his controversial *Essay on the Principle of Population* (Peterson, 1979). His prognosis of humanity's future is well known: standards of living (per-capita income) can never permanently increase as each technological advance that creates more wealth for society simply allows for more people to survive in that society. The resulting boom in population will again stretch resources thin until humanity has returned to its previous state of subsistence living. Malthus proposed that the population's tendency to increase exponentially would constantly be checked by the finite and linearly-expanding resource base, forever leaving humanity in a state of destitution, war, and famine.

Fortunately for humanity, the Malthusian assertion of permanent and inescapable poverty seems to be wrong, and his model has been replaced by more empirically accurate narratives. In addition to the Malthusian model, I will review early Keynesian growth models, the Solow growth models that replaced them, and derivatives of the Solow growth model. These later neoclassical models provide a more complete vision of modern wealthy economies, and it is for this reason that the neoclassical model has been chosen as the basis for this project.

2.1 Malthusian Model

The Malthusian growth model paints a notoriously dreary picture of economic growth. It is often incorrectly stated that the nickname for economics, "the dismal science", was originally coined to describe Malthus's work. While this is untrue (Thomas Carlyle described the field this way while arguing for reinstating slavery in the West Indies, not while criticizing Malthus [Levy, 2001]), it has become a popular misconception for good reason. Malthus proposed that humanity was doomed to subsistence-level conditions, with wars and starvation constantly pruning the population to a sustainable number.

While his views may seem absurd by today's experience, Malthus was actually quite accurate in describing the world around him at the time. The lot of the average individual had not improved for hundreds of years by the late 18th century. Indeed, the Malthusian model remains an extremely reasonable descriptor of life in many poverty-stricken countries to this day. For this reason, the Malthusian model has a place in my project and is worth discussing in detail (Williamson, 2011).

While Malthus did not explicitly model his ideas in the sense of a formal mathematical economic model, his descriptions are easily implemented into just such a framework. The following descriptions are inspired by Stephen Williamson's 2010 textbook *Macroeconomics*. Consider a two part model, in which a production function of the Cobb-Douglas (Douglas et al., 1928) form describes output:

$$Y_t = z_t * f(N, L) \qquad [1]$$

In which Y_t represents output, z_t represents technology, N represents labor input, and L represents available land, which is assumed to be held constant. This creates a production function in which labor input is the only independent variable. This function should be constantly increasing and yet concave, such that $lim_{N\to\infty} f'(N,L) = 0$, while $lim_{N\to 0} f'(N,L) = \infty$.

Population growth makes up the other half of the model, and it is modeled as follows:

$$\frac{N_{t+1}}{N_t} = g(c) \qquad [2]$$

So that:

$$N_{t+1} = g(c) * N_t \qquad [3]$$

This implies a growth rate dependent on the level of consumption c where $g(c)$ represents an increasing function whose value in the steady-state is equal to one.

These two equations, together with the equilibrium condition $Y = C$, represent a solvable system. An increase in productivity is imputed by an increase in z, and occurs exogenously. Such an increase causes output per capita to rise. Since output is equal to consumption, this causes $g(c)$ to become greater than one, spurring an increase in the population growth rate. The per-capita income of individuals in this economy is then driven down until population levels return to a steady state. This reflects the impossibility of permanent improvement in the average individual's standard of living.

The Malthusian model is generally viewed as having done remarkably poorly in describing modern industrialized economies (Williamson, p. 191). While many thirdworld countries persist in a Malthusian trap, Malthus's view that all humans are forever doomed to a life of poverty clearly seems to have been disproven. While transitioning an economy from a Malthusian state to a more neoclassical path has proven challenging, countries such as China and India are showing that it is still very possible to make the change. For this reason the Malthusian model may have a role in this project. Simulated nations are established without an effective government and until a constitution is passed they exist in a state of anarchy. A Malthusian model describes this level of subsistence gracefully.

2.2 Early Keynesian Growth Models

A brief note will be given here to the Keynesian growth model advanced by Roy Harrod and Evsey Domar in the late 1930's (Harrod, 1939; Domar, 1946). The model itself is not included in my project but is instead mentioned for contextualization of the neoclassical model which followed it. The goal of the Harrod-Domar model was to apply Keynesian thinking to the problem of economic growth. It should be noted that Harrod and Domar never actually built a model together but instead developed similar models at nearly the same time. Growth theorists who are interested in historical models will be quick to point out that there are some critical differences between the Harrod and Domar models, and they would be correct. However, for the purpose of providing a contextual background for the Solow model, considering the models together is a reasonable simplification (Punzo, 2009).

As Solow himself pointed out in his paper, the Harrod-Domar model's defining conclusion is that "even for the long run the economic system is at best balanced on a knife-edge of equilibrium growth," (Solow, 1956). The implication of the Harrod-Domar model is indeed that deviation from the "warranted" rate of growth produces drawn-out and persistent period of either massive underemployment or massive labor shortage. The very Keynesian flavor of the model comes from the fact that such incredible disequilibria are not only possible but seemingly inevitable and serves as a rejection of the classical macrodynamics vision of economies as being stable at their core while only suffering marginal fluctuations (Punzo, 2009). While it does seem unlikely that economies tend towards massive disequilibria which are taken out on labor, one must remember that the idea may have seemed more intuitively appealing when it was first published near the end of the Great Depression.

Solow's assertion is that such empirically unrealistic results come from the Harrod-Domar model because of its assumption of fixed proportions for factors of production. The Harrod-Domar model takes a top-down approach to macroeconomic modeling and as such it lacks a production function component that would allow for such input flexibility. The model aims to describe in specific terms the necessary conditions for full employment without necessarily providing a path towards equilibrium or a realistic description of an economy that has come off the equilibrium path (Hagemann, 2009). This means that off-equilibrium paths do not easily resolve themselves and instead lead to wild swings in employment and output. This carries Keynes's interest in short term disequilibria in labor markets into the long run, applying technology meant to describe a fixed-input static state to long run economies which are actually capable of shifting inputs. The resulting model produces results which are not backed up by the facts of economic growth.

Technically speaking, the failing of the Harrod-Domar model was the importance of the $s = vn$ equation[2], in which s is the savings rate, v is the capital/output ratio, and n is the growth rate of the population. These exogenous parameters defined equilibrium in the model despite there being no imaginable reason why this particular equation should be true in reality. No correction mechanism existed, as the parameters were considered to be fixed. A situation in which $s > vn$ meant a savings rate which was higher than equilibrium, which meant a stock of capital which spiraled out of control leading to a massive labor shortage problem. Likewise, $s < vn$ implies a savings rate which is insufficient to support the growing population, meaning a massive unemployment problem (Solow, 1973). This resulted in a model which performed differently than what we think of when considering formal economic models today; instead of presenting testable hypotheses of an economy's path, the Harrod-Domar model simply tried to capture the conditions under which an economy would experience steady-state growth. If a variable within the $s = vn$ equation were actually malleable by the model itself, a path towards equilibrium could exist and the model could become self-correcting.

The fundamental inflexibility of Harrod-Domar (and resulting lack of empirical realism) provided the impetus for Solow's research into a better growth model (Solow, 1956; Boianovsky, 2009).

2.3 Neoclassical Growth Model

The neoclassical growth model (or Solow growth model, as it is also known) has revolutionized economic growth theory and, in many respects, founded the field as a

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[2] A full technical description of the Harrod-Domar model is not necessary here, as the model itself does not enter into the game. My description only serves as preliminary exposition for the importance of the neoclassical growth model.

discipline which produces formal mathematical models with testable hypotheses. Starting with Robert Solow's 1956 *A Contribution to the Theory of Economic Growth*, the neoclassical model has provided not only its own explanation for so much of modern economic growth but also a platform for more endogenized growth models and for an extremely influential series of business cycle models (Prescott, 1988). The conclusion of the neoclassical model is that the Harrod-Domar "knife-edge" of growth does not exist under general neoclassical conditions of variable production factors and constant returns to scale. Indeed, given any initial conditions for an economy, the neoclassical model will return to an equilibrium level of capital and investment (Sato, 1964). This technical sturdiness combined with the empirical validation of many of the model's implications (Prescott, 1988) is the reason that the neoclassical model plays a leading role in this project.

The simple Solow growth model as described by Edward Prescott (1988) serves as the basis for the game's economic modeling engine. The model is expressed as follows:

$$c_t + i_t = z_t f(k_t, n_t) = y \quad [4]$$

$$k_{t+1} = (1 - \delta)k_t + i_t \quad [5]$$

$$i_t = s_t * z_t f(k_t, n_t) \quad [6]$$

Where c_t represents consumption, i_t investment, k_t capital, n_t labor, s_t the savings rate, δ depreciation, and z_t represents technology. It is assumed that the production function exhibits constant returns to scale, is constantly increasing, and is concave such that

$lim_{N \to \infty} f'(N, L) = 0$, while $lim_{N \to 0} f'(N, L) = \infty$. For these reasons a Cobb-Douglas production function is generally employed in the model (Solow, 2007) and I have followed this precedence in the project. As these equations are in per-capita terms they should involve the gross growth rate, but I have assumed zero population growth for simplicity. As these equations describe a steady state there is no loss in generalizability.

Even this simplistic model displays consistent equilibrium-finding behavior, constantly returning the level of capital to its steady-state level such that $k_t = k_{t-1}$. The key to this is the variability, in terms of the Harrod-Domar model described above, of the capital/output ratio v in the equation $s = vn$. A fixed savings rate defines investment and an exogenous net growth rate defines changes in the population level. However, where Harrod-Domar used a fixed capital/output coefficient, Solow employed a neoclassical production function implicitly capable of factor substitution. To keep with the comparison to Harrod-Domar, v actually changes in the Solow model to reflect the change in the ratio of capital to output that comes with a below-equilibrium or above-equilibrium savings rate; instead of acting as a fixed-coefficient of capital to output, the actual ratio resulting from the return of last period's investments redefines output.

A more intuitive way to think of the Solow model is in per-capita terms, as we did above, instead of in per-capital terms. The following derivations describe a steady state using the equations from above:

$$k_{t+1} = (1 - \delta)k_t + i_t \qquad [7]$$

$$i_t = s_t * z_t f(k_t) \qquad [8]$$

$$\therefore\ k_{t+1} = (1 - \delta)k_t + s_t * z_t f(k_t) \qquad [9]$$

This delivers a steady-state level of capital which is self-correcting; if we were to impose a starting capital that is higher than equilibrium, than depreciation would eat up the excess stock faster than savings could replenish it. If, on the other hand, we were to start with an extremely low level of capital, then the losses from depreciation would be negligible to the excess investment coming from the savings rate, assuming the savings rate was parameterized at a reasonably high enough level to produce such a result. In this way capital always returns to steady-state equilibrium and the model produces stability instead of careening out of control in the way Harrod-Domar tends to.

Growth in the Solow growth model does not come from higher rates of investment. Indeed, while a higher savings rate will prompt an economy to move to a higher-capital position, it will not affect the *rate of change* of that capital stock. Technology shocks, exogenous to the model, serve to increase growth rates. It was Solow's contention that much of the growth we see in first-world economies comes from advances in technology. While his original estimates may have been high, it is believed that over 50% of growth in wealthy nations is due to technological advance (Prescott, 1988). In this project this crucial technological development equation has been made somewhat endogenous to the model. While typically growth models employ an independent semi-stochastic equation to generate technological shocks, this project's technological generator incorporates investment levels to ensure that technology growth is somewhat reflective of investment, reflecting a line of thought which lead to a more complete derivative of the Solow growth model. This "New Growth Theory", along with the Ramsey and Diamond growth models, are covered in the next section.

2.4 Neoclassical Growth Model Derivatives

As mentioned before, the Solow growth model has spurred the development of a wide body of theories pertaining to economic growth. Many of these neoclassical models aim to endogenize particular variables which may have been left as exogenously-imposed parameters in the original model (Romer, p. 47). These deeper models present future paths of development for my project. Some effort was made in development to at least make certain variables (such as labor hours) responsive to the choices of players in the game, making these parameters somewhat endogenous in a larger sense. However, these particular models provide potential extensions to the economic modeling behind the growth engine that remain self-contained within the growth model itself. This section provides short descriptions of a few of these models.

The Ramsey model is a neoclassical growth model that endogenizes the saving rate decision (Cass, 1965; Ramsey, 1928). Recall that the Solow model takes the savings rate as an exogenous parameter and allows it to remain static, despite probable changes in the interest rate which would occur with varying rates of investment. The Ramsey model removes this artificiality by building off of microeconomic foundations of market analysis. By using the concept of model firms and households which interact according to certain rules, markets for goods, labor, and debt can be simulated and an optimal supply and price for these three homogeneous commodities can be discovered.

A further extension of the neoclassical model comes with the Diamond model, which takes into account the continuous creation of new households and destruction of old households (Diamond, 1965; Romer, p. 75). This presents optimization problems which are unique for households attempting to maximize utility with savings, labor, and consumption choices. Households are split into “new” and “old” households, with new households working and saving, then becoming old households which consume the previous period savings. After each period the old households die, the new labor-providing households become old capital-providing households, and new "new" households are generated. This new heterogeneity of households allows researchers to model demographic changes and hypotheses such as the life-cycle savings hypothesis.

Endogenization of technology change came with New Growth Theory (Aghion, 1992; Romer, p. 99). Previously a stochastic exogenous equation defined technology change in neoclassical growth models and this crudely modeled aspect of growth was pinpointed as being responsible for most economic growth in the real world. The goal of New Growth Theory is to open the black box of technological change and makes it endogenous to the model. My project actually takes a cue from this line of thinking; while a stochastic equation defines technology growth, it is weighted by a research and development investment variable, which is taken from capital investment.

2.5 Business Cycle Models

Perhaps a more surprising development to come from the Solow growth model is a revolution in business cycle modeling. The lineage makes for an interesting story – Keynes originally set out to describe disequilibria that caused business cycles. His theory on short-run disequilibria was applied to the long-run by Harrod-Domar in an ill-fitting growth model. This growth model inspired a more equilibrium-centric Solow growth model, which was then adapted by Finn Kydland and Edward Prescott into a new business cycle theory to challenge Keynes' original vision of the business cycle (Kydland, 1982). This new set of business cycle theories came to be known as *real business cycle* theory for its focus on the real factors that produce business cycles, as opposed to monetary influences.

Real business cycle models will be a natural extension of the simulator for multiple reasons. Being based off of the Solow model makes RBC easy to implement into the game without an undesirable alteration to the gameplay and strategies that players will be accustomed to, as the model simply describes deviations from the overall Solow growth trend. The model also represents a Pareto-optimal economy without disequilibria, so model-solving tools such as the social planner's problem may be employed to provide simpler solutions. It is also worth noting that the real business cycle model is, naturally, a *real* model that does not feature a monetary component. As mentioned before, thousands of nations with individual monetary policies produces a nightmare scenario for exchange between nations, making a non-monetary model especially attractive.

Originally the intent of this project was to incorporate a functioning real business cycle model into the finished project. While my research into the topic served as a highly educational diversion, the warnings of my advisors turned out to be right: the project was simply too complex. While the Solow model serves to give the game the economic rigor that I desired to see in an online nation simulator, the addition of a business cycle model would make this simulator especially unique and rich. The nature of this project is its longevity and constant development and with that in mind I plan to someday bring a real business cycle generator into the game.

3. Complete Game Design

The goal of this project has been to build a nation simulator which provides a far richer simulation experience than what is currently available to casual players. This is what separates this nation simulation project from a macroeconomic simulation project: the point is to provide a simulation of all the decisions a national leader must make instead of just a simulation of an economy. This includes the management of warfare, foreign aid, legislation, law enforcement, education, infrastructure, and more. Many of these pieces interact with each other in complex ways to provide a richer set of strategies with less obvious optimal solutions.

The game design follows, at least in the beginning, the story of a new and struggling nation. Players decide their leader name and the name of their nation. This nation is then established on the foreign planet *Halcyon*, a world which is still being explored geographically. The player's nation is born small and in a state of anarchy, but they have become the de-facto leader of the region. Economic production is extremely depressed and will remain so until institutional stability arises with the implementation of a constitution and certain economic reforms. After this, the economic modeling engine begins producing natural growth and players are able to directly invest in capital, technology, and infrastructure. They are also able to pass laws and build government-funded institutions such as police and fire services, sanitation plants, stadiums, and more.

The following is a description of some of the major components of the simulator. This describes a project which is constantly in development, but the basic ideas of each section are stable.

3.1 Economic Simulator

One of the core features of the game is the economic simulation engine. The simulation script runs discretely without user input and executes a Solow growth model with a semi-endogenous, semi-stochastic technological innovation model. This simulator calculates new levels of capital, technology, output, consumption, and investment in per-capita terms. It also calculates available tax collection for the period and bills owed by the government.

The Solow model provided a clearly optimal basis for the simulator for several reasons. It is fairly simple to implement while still producing results which match Kaldor's stylized facts of economic growth. It also provides ample room for future expansion; the real business cycle model, which is the basis of most business cycle models studied today, is based off of the Solow growth model. As mentioned before, implementing a real business cycle model means that the apparent gameplay for the user does not change significantly.

The simulator operates on an hourly schedule, running a script which updates figures according to the following set of equations:

$$k = (1 - \delta) * k + i \quad [10]$$

$$y = z * k^{\alpha} * n^{1-\alpha} \quad [11]$$

$$w = \frac{y}{n} \quad [12]$$

$$c = y * \tau \quad [13]$$

$$i = y * (1 - \tau) \quad [14]$$

Here k is capital, δ is depreciation, i is investment, y is output, n is labor hours, w is wage rate, c is consumption, and τ is the share of income dedicated to consumption. All variables are considered to be in per-capita form where applicable.

Capital is calculated as a function of previously existing capital, depreciation, and investment, all of which can be exogenously imposed for the first period's calculations. The assumption of exogenously imposed labor hours – this is somewhat endogenized as a function of the user's chosen tax rate, as seen below – allows us to then calculate output using last-period technology levels. It is assumed that domestic households capture all wages and profits, which are lumped together as hourly wages for simplification. Consumption is an exogenously defined portion of total output (0.8 by default, subject to change in response to legislation and population happiness), and investment is simply the output left over after consumption.

Technology generates as part of the same script that generates the economic model. A percentage of investment goes into research and development, which in turn is taken into account in the technological growth equation. The equation is as follows:

$$z_t = z_{t-1} + \omega + (\mu * \omega_{t-1}) + (\sigma * \ln(1 + \theta * i_z)) \quad [15]$$

$$\omega = \tau * rand(j_1, j_2) \quad [16]$$

Where z is technology, i_z is investment in research and development, ω is a random-shock variable as defined in the following equation, μ represents shock persistence between periods, and σ and θ are adjustment parameters as explained in Section 3.1.1. To clarify, $rand(j_1, j_2)$ indicates a random integer inclusively between integers j_1 and j_2, chosen with a flat distribution, and τ serves as an adjustment parameter. The parameters are somewhat arbitrarily designated below, but the functional form of this equation was designed with two specific points in mind. First, there should be a degree of memory to the system, so a random burst in technology should not be followed by a period of flat technological gain. This is why this function features a historical-trend component. Second, the level of investment should affect the degree of technological innovation, which is the purpose served by the i_z variable. It is assumed that there is a declining marginal benefit to single-period technological research. The top reason this assumption is made is to keep older nations from slipping onto a track of runaway growth, although the intuition behind the assumption is not controversial.

Population growth is also calculated by the economic model update process. As a simple model, population growth follows this equation:

$$p_t = p_{t-1} + \varphi * \ln({p_{t-1}}^{\alpha}) \qquad [17]$$

Where p is the population level, φ is the adjustment variable for the growth rate, and α is a growth parameter defined below. The φ adjustment variable's value is exogenous to this equation and is determined by factors such as legislation or public works. This growth rate model is implicitly the sum of the death rate, birth rate, and immigration rate, and responds to legislation and public works that would affect these statistics in an obvious fashion.

The model also calculates tax collection for the period, but the user is not credited with the collection until going to their nation page and clicking the link to collect taxes. Taxes are set by the user and have an adverse effect on the willingness of the population to work. This function is normalized so that 30% tax rate returns a willingness-to-work of roughly 8 hours and a 100% tax rate returns a willingness-to-work of 0 hours, reflecting casual Laffer-curve assumptions concerning tax collection elasticities. The base work-hours function that satisfies this is as following:

$$n = -\vartheta e^{\beta t} + \varepsilon \qquad [18]$$

Where n is the hours the representative household will work per-day, t is the user-determined tax rate, and ϑ, β, and ε are gameplay parameters described in Section 3.1.1, normally calibrated to achieve the aforementioned effects.

Taxes and government bills are accumulated at the end of every simulated "day", with each day being seven hours long. Tax accumulation means that back taxes can be collected at a later point in time, with fifteen days of taxes being the maximum backlog before older tax collections become "forgiven" and cannot be collected. Bills accumulate in a similar fashion, with government functions stopping after fifteen days of nonpayment and the government's chances of being overthrown increasing (as outlined in section 3.2).

3.1.1 Economic Parameters

The following table provides parameter values for the above equations. Despite the difficulty of empirically capturing such intangibles such as population happiness or technology, these concepts are important to Halcyon as a game and must be accounted for. Similarly, and somewhat as a result, a plethora of parameters enter into the above equations which either must be arbitrarily defined for lack of better data or must be defined in such a way so as to shape gameplay into something that is enjoyable and intuitive. Parameters that help gameplay in this way are denoted so in the "Use" column, and parameters which are defined and assigned in an effort to facilitate the actual functioning of the models are denoted "function".

Symbol	Equation	Value	Use
μ	15	0.5	Adjusting persistence of last-period technology shock (function).
σ	15	0.1	Tempers effect of investment – outside logarithm (gameplay).
θ	15	0.1	Tempers effect of investment – inside equation (gameplay).
τ	16	0.01	Adjusts integer to decimal value relative to game scale (function).
(j_1, j_2)	16	(-1,8)	Random technology generation range (function).
φ	17	18 (varies)	Adjusts population growth for law/public works (function).
α	17	0.8	Tempers effect of previous population (gameplay).
ϑ	18	5	Adjustment parameter for tax elasticity (gameplay).
β	18	1.09861	Adjustment parameter for tax elasticity (gameplay).
ε	18	15	Adjustment parameter for working hours (gameplay).

3.2 Political Simulator

Text-based nation simulators thus far have generally failed to clearly characterize the role the player assumes in the nation they are running. Cyber Nations ostensibly places the player as the government, but the fact that the player directly "purchases" technology which does not accumulate otherwise and engages in resource trade with other nations stretches this characterization. Project Terra's option set for players involves an even more detailed resource trade market with floating prices where players directly buy and sell quantities of resources harvested in their nation, an activity few governments engage in exclusively on behalf of their nations in reality. However, Project Terra does succeed in expanding the nation simulation experience internally in the form of a democratic government with which a player must cope in order to pass desired legislation. The simple system offered in Project Terra served as inspiration for a more complex system in my project. What follows is an explanatory description of the political system; attached in Political Appendix are details from the development notes for this aspect of the game.

As opposed to other games which assume varying degrees of omnipotence for the player, my project requires players to cope with a simulation of political activity. The political will to pass laws is accounted for by *political capital*, which accrues on an hourly basis in a manner similar to the economic model. Players can then "spend" their political capital on passing predefined laws with listed political capital costs and real effects on economic and population variables.

When a nation is first created it assumes a state of anarchy with the player as the ostensible leader of the nation. The player is imbued with a large amount of political capital but will find a nearly empty list of laws to spend it on. At this stage in the game there is only one type of legislation available: a constitution. Players can choose from a democratic or dictatorial constitution, a choice which will shape the way their political simulator operates.

Democracies generate lower amounts of political capital and must hold elections or deal with an increasingly unhappy electorate which may eventually revolt. The result of the election is determined by population happiness, which is a function of factors such as income and technology growth. Elections can be called every five simulator days and if an election is not held for fifteen simulator days then population happiness begins to fall, increasing the probability of the electorate forcing a recall election. Losing an election means that the player cannot accumulate nor spend political capital, declare war, or send aid for five days. During this time the player is still able to control other functions of government, including fighting wars which are in progress. After the five days, the player is restored as leader.

Dictatorships give higher value political capital payouts and are not required to hold elections. However, a dictator can be overthrown if population happiness becomes too low or if police power is not sufficient. In this case, a player is up for exile and another player must be willing to host the deposed leader. Exile lasts for three days, during which time the nation is thrown into anarchy and large sums of capital and infrastructure are destroyed. The player has no control over their nation during anarchy, making them particularly vulnerable in wartime. A player who has found political exile with another nation will be restored as leader after the three days.

Both democracies and dictatorships must be mindful of population happiness. Happiness is determined by the following equation:

$$p = 1 + 3l + 6\theta + 2\gamma + 2\beta - 2\vartheta + 2\rho + 0.1y + 0.5z \qquad [19]$$

This is a kitchen-sink equation that serves as a catch-all for many improvement effects. l represents population literacy, θ represents the percentage of the population with a college degree, γ represents law and order, β represents sanitation, ϑ represents the fire risk in the nation, ρ represents stadiums per capita, y represents per-capita output, and z represents technology. This function will expand as new improvements for players to develop are added to the game.

The choices of happiness coefficients here is somewhat arbitrary in part because of the generally shaky ground of happiness research (Johns, 2007) and partially because the nature of happiness research does not tend to assign utility coefficients to particular public works, but instead tends towards general relative satisfaction ratings or happiness with particular government policy changes. The coefficients here are instead drawn from the prices of the improvements, which are meant to be realistically ranked in terms of real-world costs for public works. The idea behind this choice is that the displayed preferences of voters can act as a proxy for their satisfaction with particular public works projects. While this mechanism is certainly imperfect for drawing out happiness ratings, it will satisfy the needs of this project as a rough estimation.

3.3 Military Simulator

An important aspect of multiplayer nation simulators is the ability to declare war. This social (or perhaps anti-social) aspect of a game is the driving force behind the player development of incredibly rich and complex alliance politics. The existence of the military option has transformed basic-functionality nation simulation games into deep strategic political simulation games. Common defense is often the ostensible reason for the formation of alliances, but generally the reason that players remain with a game becomes the alliance culture and political intrigue that comes with it. My goal for this aspect of the project was to develop a more realistic and complex military engine, but a longwinded technical exposition is unsuited for a prose-form essay. See attached War Appendix for a detailed description of the war system mechanics.

Nations are not endowed or simply assumed to have military assets; they instead must be purchased. The foundation of military force in my project is the *military base*, of which three types exist: ground bases, air bases, and navy bases. These bases serve as prerequisites for the purchase of their related military buildings, and these buildings are in turn prerequisites for the purchase of their related military units. For instance, an important building for a ground base is a barrack. Obtaining barracks allows a player to hire a certain number of soldiers, which are recruited from the civilian population. Similar chains of dependencies exist for all twenty-six types of military units, and each base, building, and unit imposes both acquisition and upkeep costs on the player's virtual government.

The set of rules that govern war declarations has been a contentious point among the communities surrounding nation simulator games[3]. Nearly all games of this type restrict the number of wars a player can have by implementing a "war slot" system in which players only have a certain number of war slots (generally between three and five) to stop them from attacking an absurd number of nations or to protect controversial players from being attacked by a large number of nations. The deliberately unrealistic concept of "war slots" is excused as being necessary to make simulator games which are playable for everybody.

This project takes a different tact by favoring *implicit limits* over *explicit limits*. The realities of waging war allow for some reasonable variations in interpretation for the convenience of achieving game design goals. For wars this means that the resource demands of waging wars can be prohibitive to a degree that it would be impossible to declare effective war on an absurd number of nations. By employing the philosophy of implicit controls, the war system in this project can be dramatically more laissez-faire

[3] While giving exact reference to this fact is out of the realm of academic sources, the "Suggestion Box" message board at forums.cybernations.net offers the brave researcher ample evidence of this claim.

than the war systems of other nation simulator games, and countries are explicitly allowed to have an unlimited number of wars.

A nation declaring war on another nation does not itself do damage to either party; declaring war simply opens up the channel for attacks. Once war is declared a leader must deploy military units to that "theater," and this deployment takes time: three simulated days for ground forces, two days for navy forces, and one day for air forces. The time cost of deployment is an important implicit limit on war-seeking nations which retains a sense of realism. Because units deployed to one theater cannot simultaneously be deployed in another theater, fighting foreign wars is subject to a budget constraint of military forces.

When deployed units reach the front lines, attacks can begin. Attacks are launched as any combination of deployed forces and take one simulated day to complete. They are launched at either a particular base or as a general civilian-area attack. Each military unit comes with a infrastructure attack strength, a personal attack strength, and a personal defense strength. Battles between countries pit the attacking nation's deployed forces against the defending nation's defending forces by stages; first an air and sea battle is simulated which pits the personal attack and defense strengths of the two sides' navy and air forces with some stochastic variation. Following this a ground battle is simulated, and if the attacking forces air and navy were victorious in their pre-battle then their remaining forces add to the strength of the ground attackers. The ground battle is handled in a similar manner as the pre-battle. A modest mathematical advantage is provided to the defender on the assumed principle that it is easier to defend a base than to take it.

The sum of the infrastructure attack strengths of the remaining ships and planes (along with some types of ground units) will inflict damages on the infrastructure of the geographic target in the case of an attacker victory; in the case of a loss, no damage is assessed. Each military building is imbued with a certain amount of infrastructure strength which is known to the player before purchase and is adjusted in response to attacks. If a building falls below 30% of its potential infrastructure strength it is condemned; if it falls to 0% it is destroyed permanently. Infrastructure damage is spread evenly to buildings throughout the base and, in the case of more infrastructure damage being dealt than the base's buildings are cumulatively able to withstand, the damage is assessed against the base's infrastructure strength.

Alternative weaponry is also available for use. Nuclear weapons require a high technology level, the construction of a nuclear weapons facility, and nuclear weapons silo, and the use of nuclear weapons causes a temporary decrease in population happiness. Nuclear weapons deal a great amount of infrastructure and personal damage. Chemical weapons can be developed, although they come with a stiff happiness penalty for wealthier nations, reflecting their unpopularity amongst wealthier population in reality. Chemical weapons carry moderate technology requirements, require the construction of a chemical weapons factory and chemical weapons silo, and deal mostly personal damage with little effect on infrastructure.

Wars are concluded when both sides agree to peace or after three simulated days of no attacks, whichever comes first. Upon obtaining peace, deployed troops are returned home and the channel for attacks is closed.

3.4 Nation Management

Several terms have been used thus far which require expansion for a complete picture of the nature of my project. In the following paragraphs I will discuss public investment, public works, infrastructure, land, and a few meta-concepts such as time operation, alliances, and community forums. These descriptions are necessarily brief as the concepts are not complex, but this simplicity does not affect the importance in gameplay of these factors.

Every period the economic engine generates, among other figures, capital investment and technological investment. Capital investment diverts a certain percentage of output away from consumption and into the capital stock, which allows for future production of output. Technological investment diverts output away from capital investment and into technological research, and its effect is reflected in the technological growth equation. The simulator provides players with the option to directly invest in capital and technological investment. As of now this investment simply adds to the pool of investment funds for the next period; future revisions to the model will include a decreasing-marginal-returns effect for government investment, with initial investments assumed to be going towards correcting for the largest market failures in technology and capital investment.

Public works are commonly-public institutions which players can establish to provide services in their nation. The initial list includes schools, universities, police departments, fire departments, and stadiums. These improvements affect population happiness directly and provide a means for players to win favor with their populations.

Infrastructure is a more homogeneous concept which covers the road, bridges, and more that a government builds to facilitate commerce and leisure in a nation.

Infrastructure is purchased in "levels" and if the population-to-infrastructure ratio passes an arbitrarily high level then economic consequences are the result. The cost of infrastructure increases with each purchase, and infrastructure can be destroyed in warfare.

Land must be terraformed on the planet of Halcyon and as such there is an expense for nations wishing to expand their territory. If the population per square-mile of land becomes too high, it has a negative effect on the happiness of the population. Land can be stolen in warfare and population density will be incorporated into battle calculations in future updates.

As Halcyon is a foreign planet, I have elected for an arbitrary system to time. Days are eight hours long, weeks are considered twelve Halcyon days, seasons are six Halcyon weeks, and years are four Halcyon seasons. The effects of seasons will be nothing more than aesthetic at this point, but future updates should include productivity differences between seasons.

Alliances and forums are built-in features of the simulator which help keep user interest strong. As mentioned in section 3.3, complex alliance politics are an inherent part of social nation simulator games, and in-game recognition of alliances and the provision of community forums are crucial for supporting this aspect of gameplay. Currently alliances are "open access" – any nation can claim to be part of a particular alliance – but in future updates a closed system of alliance admission and administration will be implemented. Forums tie directly into the game by automatically creating an account for any player who registers, and logging that player into the forum system as they log into the game, seamlessly tying together the community and the simulator.

4.0 Conclusion

This project was first an individual initiative unrelated to academia which only later became a thesis project with the encouragement of my mentor, Dr. John Hamman. My initial goal was the incorporation of a business cycle generator into a nation simulation game. While the process of reading countless papers and graduate notes on the topic was certainly educational, the initial warnings of Dr. Schlagenhauf concerning the complexity turned out to be prophetic. My investigations into general equilibrium models resulted in a disappointing conclusion: the real business cycle model does not have analytic solutions, and numerical techniques beyond the grasp of an undergraduate would be necessary to estimate values with the needed efficiency. My time spent reading graduate macroeconomics note packets certainly were not without profit, but I was unable to find accessible solutions to the problem at hand.

The project's new status as an honors thesis forced me to continue development when I otherwise may have washed my hands of the idea, and the result is a nation simulator of which I am glad I finished. I now have a game established, removing many of the peripheral concerns initially surrounding the project and allowing me to focus on increasing the complexity of the economic modeling involved.

Taking the game to higher levels of intricacy is indeed now a persistent goal for me, and it is my hope that the update log of the game will act as a sort of proxy-diary for my further education in macroeconomics. A field so rich with beautiful models and concepts deserves a game which incorporates as many of these models as possible, and I hope to continue to build it with this in mind.

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