AN ALGORITHMIC FRAMEWORK FOR MODELING INSTITUTIONAL PROCESSES

by

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DEDICATION

I dedicate this work to the many people who made me the person I am today. I can never fully repay their gifts, but I promise to follow their examples.

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Throughout the writing of this dissertation, numerous people have contributed to this process in a variety of ways deserving of attention.

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ABSTRACT

AN ALGORITHMIC FRAMEWORK FOR MODELING INSTITUTIONAL PROCESSES

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Human behavior in a given moment is simultaneously influenced by a variety entangled institutional structures. Economic, political, legal, cultural rules and norms all contribute to this process in explicit and implicit ways. This dissertation details a framework to model institutions as a set of computational algorithms with the goal of isolating and determining the impact of particular methods of interaction. This formal analysis allows for a better understanding of the mechanisms agents require to properly engage with one another and the types of economic outcomes made possible by the presence of certain institutions. To demonstrate the utility of this approach, I apply this toolset to a variety of contexts, including O-Ring production, HOA governance, and macroeconomic policy.

In the first chapter, I program an agent-based version of the O-Ring theory of development, allowing workers to endogenously match and select which countries or

firms to inhabit within the model. Through this process, I demonstrate that in a world with heterogenous technology, a previously unknown Nash equilibrium exists as agents sort in the opposite manner prescribed by the original model. Further, I determine that the predicted equilibrium cannot be recovered through the adjustment of any parameters within the original piece. In other words, a market institution cannot in isolation sort workers in the predicted manner, showcasing the need for complementary mechanisms.

In the second chapter, I argue that government and market institutions, when interacting with one another, lead to the generation of a network effect with respect to property value. Using data on all home values in 17 counties from the Florida Department of Revenue, I demonstrate that living within a basic governing structure, an HOA, increases the market value of an average home by nearly 20%. I then estimate the size of the network effect and demonstrate using an agent-based model that the only way to take advantage of this value increase is through interaction between market and political institutional structures as these arrangements in isolation cannot generate the desired impact.

In the third chapter, I propose the initiation of a new economic cybernetics and apply this approach to the traditional problem of determining monetary policy and pursuing macroeconomic stability. Using a New Keynesian macroeconomic model as the initial framework, I remove the Taylor rule equation and give an artificial intelligence control of interest rate policy. I then outline three distinct institutional approaches to central banking as alternate reward functions in a reinforcement learning algorithm. Under this approach, the AI, with no knowledge of the underlying model and access to only a subset of the data generated by the economy, can capably achieve near optimal monetary policy under a variety of parameter values due to the algorithmic institutional structure. Further, I find that different types of central banks generate superior policy outcomes dependent upon the behavior of agents in the macroeconomy.

CHAPTER ONE

Kremer's O-Ring Theory of Development (1993) represents an important effort to explain a collection of stylized facts from the economic development literature, most critically the large skill disparities between countries. This paper tests the theory by utilizing an agent-based model to add endogenous choice to workers' behavior and examines the robustness of its results, determining if a collection of agents can sort themselves into the predicted equilibrium under a variety of circumstances. The agent-based approach reveals that in a world where countries or firms possess a heterogenous number of tasks in their respective production functions, the skill matching in Kremer's model cannot be reached via market allocation alone. Instead, workers sort into a previously unknown Nash equilibrium rather than the efficient outcome. Further, this result is shown to be robust to changes in productivity and worker density.

Section One: Introduction

The economic development literature wrestles with understanding the role of skill matching among workers in generating widespread disparities. One such theory meant to illuminate the importance of skill matching is the O-Ring Theory of Development from Michael Kremer. In this piece, Kremer argues that due to new technological innovations there now exist increasing returns for workers who match with those of similar skill levels and this alteration to the production function explains the vast skill disparities observed in the data. Further, others have taken this alteration and used it to examine the rise of super-firms in industrial organization (Autor et al 2021) or skill matching and inequality in labor markets (Dalmazzo et al 2007, Jones 2013). The article represents a critical contribution to our understanding of labor movements and productivity outcomes.

This piece examines the conclusions of the O-Ring model and attempts to replicate the findings in an alternative setting, an agent-based model. The main focus of this approach is to determine if the skill matching driving the model's findings can be endogenously reached by a collection of agents acting individually to maximize their welfare. Through this procedure, I find that the predicted outcome cannot be reached in a market setting and in fact, agents match in the reverse capacity predicted. High skill agents choose the lowest task firms in an effort to minimize the impact of low skill workers on their wages. To recover the original result, a secondary coordination mechanism beyond market allocation is required. The piece proceeds as follows. I begin with a brief review of the original paper and its applications in a variety of literatures outside development. I then outline the agent-based approach and explain the translation of this mathematical model into a computational one, clearly addressing any key areas of difference. Finally, I review the results of the model and address the implications of its output for the variety of literatures the O-Ring insight has been utilized for before concluding the piece.

Section Two: Literature Review

The O-Ring Theory of Development

Kremer begins by outlining a unique production function. It alters the traditional Cobb-Douglas function in one important way, labor substitutability (Kremer, 1993). In traditional Cobb-Douglas form, one high skill laborer can be substituted for multiple low skill workers. Such a possibility creates tradeoffs for a firm choosing between the two in production. Kremer rejects this notion. Instead, the O-Ring production function is structured such that differing labor skill level no longer provides a substitute (Kremer, 1993). This complimentary nature means substituting a low skill worker into a production process lowers the value of the entire output.

Mathematically, each worker possesses some skill level q, representing the probability of successfully completing a task such that a product retains full value or the fraction of value the product retains after the worker completes the task. Further, to produce a non-descript good, there are some n number of tasks to be completed. This number is determined in the simple version of the model by the technology present in the industry and can functionally be treated as exogenous. A firm cannot produce without each task filled. Once again, the role, or lack thereof, for substitutability in the production function now changes. As the skill level of workers increases, a low q worker imposes more costs on the higher skilled workers as well as the firm's output. Therefore, the firm possesses an interest in spreading high q workers throughout the production process. These assumptions generate the following production function where k is capital, $(\prod_{i=1}^{n} q_i)$ is the product of worker skills, n is the number tasks, and B is output per worker with a single unit of capital if production were done flawlessly (Kremer, 1993).

$$\boldsymbol{y = k^{\alpha}\left(\prod_{i=1}^{n} q_i\right) nB}$$

$$0 \leq q \leq 1$$

Equation 1

Workers of skill level q are exogenously distributed and face no choice between labor and leisure. The main difference between the traditional and O-Ring production function are the implied returns. While capital remains constant or diminishing as with Cobb-Douglas, labor now possesses increasing returns with respect to skill (Kremer, 1993). For the cost function, each firm faces a labor schedule and pays some wage w which increases with q. Capital remains paid its rental rate r. These generate the profit function below (Kremer, 1993). The firm selects an amount of capital to employ based upon the skill level of workers present in the firm.

$$\boldsymbol{\max_{k_i|q_i|} k^{\alpha}\left(\prod_{i=1}^{n} q_i\right) nB - \sum_{i=1}^{n} w(q_i) - rk}$$

Equation 2

Wages in this model adjust dependent upon the skill level, revealing the following first order condition.

$$\boldsymbol{\frac{dw_i}{dq_i} = q_i^{n-1} nBk_i^{\alpha}}$$

Equation 3

The following capital function then converges to an equilibrium value dependent upon the density of workers at a given skill level. Upon reaching this level of capital, a wage schedule emerges that the firm pays.

$$\boldsymbol{k^* = \int_0^1 (\frac{\alpha q^n n B}{r})^{1/(1-\alpha)} \frac{1}{n} \partial\phi(q)}$$

Equation 4

$$\boldsymbol{w(q) = (1-\alpha) q^n B k^\alpha + c}$$

Equation 5

In concert with a few other assumptions such as complete rationality and perfect information, total matching among a firm's labor occurs.

Kremer relaxes the assumptions mentioned above, such as a fixed level of n, exogenously determined worker skill q, and perfect information, resulting in imperfect matching. Functionally, the difference is twofold. First, general geographic, political, and national specialization in skill occurs, meaning there will exist pockets of high and low q firms and countries (Kremer, 1993). Second, workers are incentivized to invest in their human capital (Kremer, 1993). Kremer argues these realizations align with a collection of stylized facts pertaining to development which validate the theory outlined in the paper. These facts are provided in the table below.

Table 1: O-Ring Stylized Facts to be Replicated

Number	Stylized Fact
1	Wage and productivity differentials between rich and poor countries are enormous.
2	Firms hire workers of different skill and produce different quality products.
3	There is a positive correlation among the wages of workers in different occupations within enterprises.
4	Firms only offer jobs to some workers rather than paying all workers their estimated marginal product.
5	Income distribution is skewed to the right.
6	Poor countries have higher shares of primary production in GNP.
7	Workers are paid more in industries with high value inputs.

The key issue with this outline is that the matching of the model is implicitly assumed via the market allocation process. One certainly cannot debate that by this formulation the arrangement which maximizes the wages of workers is in fact the one described by this approach. However, actions and outcomes which require broad degrees of simultaneous, endogenous coordination among agents should not be assumed to transpire. It is this specific component the agent-based model attempts to illuminate.

O-Ring Applications and Critiques

The applications of the O-Ring theory and in particular the production function remain broad as time has passed. Some authors have utilized the skill matching phenomenon to explain "brain drain" with workers of higher skill departing low q countries (Docquier & Rapoport, 2012). Another set of scholars build from the O-Ring style technology framework and incorporate efficiency wages in an effort to analyze wage inequality (Dalmazzo, Pekkarinen, & Scaramozzino, 2007). Others describe upgrade mechanisms that derive in part from O-Ring production (Verhoogen, 2008) as well as analyze skill stratification in an economy (Garicano and Rossi-Hansberg, 2006). Skill complementarity is also applied in the trade literature to examine productivity and skill dispersion (Bombardini, Gallipoli, & Pupato, 2012). Additionally, some apply the theory to explain wage differentials for individuals with the same basic skillset, in this case programming, in two locations to empirically show skill clustering (Clemens, 2013). The role of entrepreneurship stands as another concept to which the basic O-Ring theory has been applied (Fabel, 2004). Lastly, the approach contributes to studies of technological complexity (Dittmar, 2011) and its ability to change wages (Dalmazzo, 2002). However, while these studies utilize the O-Ring concept to promote their theory, others express skepticism citing simpler networks as the reason the stylized facts above emerge (Hausmann & Hidalgo, 2011).

In total, most traditional economists embrace the O-Ring production function and its implications for productivity, wages, and growth as well as its view on technology. However, others also consider the potential issues with endogenous matching in particular organizational contexts (Garciano and Rossi-Hansberg, 2006) and some studying complexity, emergent phenomena, network effects, and power law distributions remain unconvinced, but any agentization of the O-Ring theory has yet to manifest until now.

Agent-based Modeling

Sorting and matching stand as two phenomena profoundly important to agent-based models and emergent concepts. The first considerations of micro-level behavior manifesting in a manner alternative to the macro-level outcomes began with Thomas Schelling and housing segregation (1978). Schelling found, and others reiterated, that even with inclusive racial preferences in a society, outcomes resembling those of segregation naturally can emerge (1978). In other words, a highly matched collection of people can emerge from a set of circumstances suggesting no matching would transpire. Given this fact, the concept of matching along some similar margins seems entirely feasible within an emergent framework.

Further, recent work in agent-based modeling focuses on reexamining the validity of traditional economic models. While still rather new compared to other components of agent-based modeling, it offers a unique lens and potential to understand economic blind spots that traditional approaches fail to observe or consider. Perhaps the most notable approach comes from Axtell and Guerrero (2011) which applied the concept to firm dynamics. This methodology remains underdeveloped relative to other tests. However, the potential advantages it affords for examining the robustness of classical models is significant.

Section Three: An Agent Based O-Ring

Model Description

The agent-based model possesses two main objects: agents and firms, although firms functionally stand equivalent to countries producing measured aggregates. The agents are heterogenous on the skill level margin within a range of possible values. This range begins at .01, implying a product retains one percent of its original value, and ends at 1 such that a product retains its whole value. The global population of agents' respective skill levels will be normally distributed. An agent's primary goal during the model is to find the highest conceivable wage possible, given a firm chooses to employ them. As in the O-Ring model, there is no labor/leisure choice and employees only spend their time working. For now, agents will know exactly the wage they will receive from joining a specific firm, eliminating themselves from contention if a wage less than their present payment is offered. This specification will be relaxed later. The agent simply receives some skill level between .01 and 1 and attempts to locate a higher wage.

$$p(q_i) = P\{s \in S | a \leq Q(s) \leq b\}$$

$$a = .01,\ b = 1$$

$$max\ (w_i)$$

Firms in the model each possess a production and profit function equivalent to the O-Ring theory. Their goal, as in the traditional model, is to maximize this value. However, some slight differences are required. First, capital selections occur at the start of each period based upon the average skill level of the firm. In the original piece, such a selection occurs after the matching among workers has transpired but here as the process occurs endogenously, it is calculated for all periods, converging to the optimal as workers match. The amount of capital selected is determined by the following equation. The rental rate is exogenously determined, an adjustment Kremer allows in his model as well.

$$\boldsymbol{k_i = \left(\frac{\alpha q_{mean}^{n} nB}{r}\right)^{1/(1-\alpha)}}$$

Equation 6

Firms will generally attempt to pay workers their marginal product. However, this goal will not always be possible due to the poor initial matching. At the outset, workers are randomly distributed among the firms meaning that low skill individuals restrict firms' output and therefore the resources required to pay workers their full marginal product will not be met. To overcome this issue, firms construct a second-best wage schedule by multiplying every worker's marginal product-based wage by the ratio of achieved output, y_i, to the output necessary for paying all workers their marginal product, Y. It is assumed capital is always paid its full rental rate first before workers.

$$\boldsymbol{y_i - rk \geq \sum_{i=1}^{n} \left(\frac{y_i}{Y}\right) w(q_i)}$$

Equation 7

When determining if a worker i should be hired, the firm examines what that worker's contribution to output given the altered wage bill relative to its present standing with some current worker j. If the output increase is greater than that of the associated increase in the wage bill, the firm considers the agent a viable option for employment. Such calculations are made for all agents who apply to the firm with the agent who maximizes this difference being hired.

$$\boldsymbol{\max\left(y_{Q_i} - y_{Q_j}\right) s.t. \sum_{i,j=1}^{n} w_i - w_j}$$

Equation 8

A number of factors are determined exogenous to the firm in this model. First, the share to capital α is exogenously determined and homogenous for all firms. Second, n will be determined at the outset as well. Both homogenous and heterogenous specifications for firm tasks will be tested. In all periods, every task in the economy is filled. In other words, the economy always rests at full employment. Finally, to meet this assertion, the worker fired after a new hiring is sent to the old firm who previously employed the now newly hired worker.

Information and Rationality

The initial framework Kremer develops begins with total rationality and perfect information, over time relaxing such assumptions. This model will also introduce these adjustments in a particular form. At first, workers and firms will know each other's exact wage and skill level respectively. Errors and uncertainty will be introduced in two main ways. First, instead of knowing the wage they will receive upon joining a new firm, a worker only observes the average wage paid out in the firm. Second, a firm will observe the skill level of an applied worker but can make a small error in either the positive or negative direction. This error ε is uniformly distributed over the range of -.05 to .05, or one twentieth of the total possible skill level.

$$p(\varepsilon) = P\{s \in S | a \leq E(s) \leq b\}, a = -.05,\ b = .05$$

These errors can be increased in size or distributed in an alternative capacity, but for now these adjustments to the information present in the system will be sufficient.

Dynamics of the Model

At the outset of the model, agents and firms are generated. The agents each possess a skill level in the range described in the prior sections. Initially, firms all possess the same parameters for B, n, r, and α. This specification means the heterogeneity lies only on the employee skill level margin. After their generation, agents are randomly distributed among the firms. From this point, the model follows a simple sequence. All firms produce their output and collect profit. After this procedure, agents examine all firms in the economy, calculate their alternative wages, and apply to any with wages higher than their current. Next, firms will evaluate all agents who applied according to the hiring criteria mentioned in the prior section. The worker who offers the maximum possible gain relative to their wage bill is hired and the rest are removed from the applicant pool. In this framework, only one worker can be hired at a time. This assumption does not compromise the analysis in any way. Tests can be run for mass worker hiring, and have been, but the results remain the same. Therefore, in the interest of computational simplicity only single worker adjustments are allowed. This assertion is also based on the empirical fact that entire populations en masse do not cycle through countries. Production and payment of workers occurs, and the period ends. At the end of a period, the order firms hire workers is shuffled. This action ensures no single firm receives a systemic advantage.

The remaining parameters for the model are provided in the table below. To test the model, I employ a Monte Carlo method. The only change between model runs is the order firms activate in each period. This specification allows for a determination of the sensitivity of the equilibrium.

Table 2: O-Ring Model Parameters

Parameter	Value
Firm Population	10
Agent Population	$\sum_{i=1}^{Firms} n_i$
B	$n^{.5}$
α	$.2$
t	500

Section Four: Testing the Model

Homogenous Task Count

The first framework to test is if the number of tasks in the production process, n, is equal for all firms in the economy. The parameter will be set to a value of 10. While unrealistic, this formulation offers a chance to test if the simulation can replicate the core matching of the mathematical model in a highly simplified setting. Worker skill level is assumed to be approximated by a global normal distribution. The results are provided in the chart below where the colored lines represent the output of the economy, and the dashed line represents the predicted output if the highest degree of matching possible occurred.

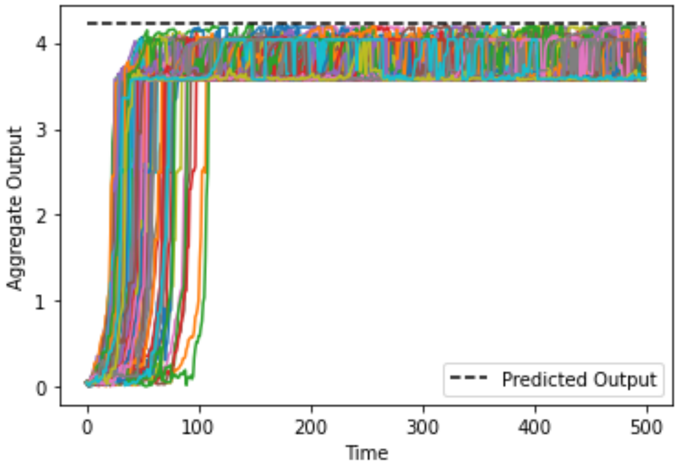

Figure 1:Homogenous Tasks and Perfect Information Output

Observed here, Kremer's prediction is mostly recovered in the computational model. On average, the agents achieved nearly 90% of the predicted output, with some small errors in matching at lower skill level firms. However, one can obviously see that the order of movements plays a role in the time of convergence. There seems to exist a sort of critical point that once reached leads to a rapid transition to the predicted equilibrium. Further, the model also replicates the type of wage distribution theorized. While this small setting leads to a peculiar looking distribution, if expanded the needed pattern would emerge.

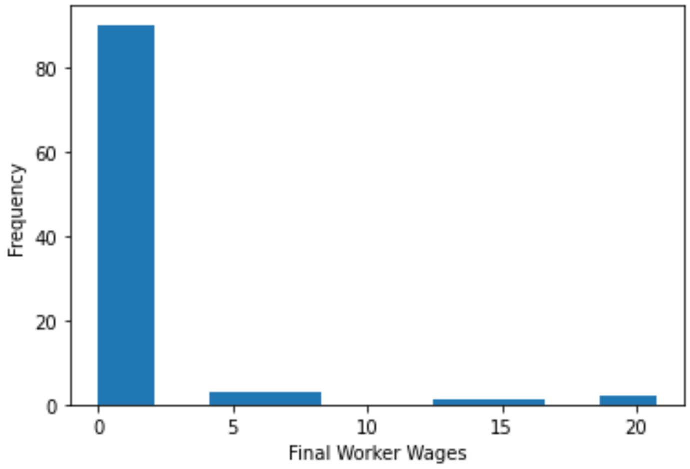

Figure 2: Homogenous Task and Perfect Information Wages

Introducing errors does not alter the results of this framework in a significant manner. The key difference is the average achieved output falls from 90% to 65%. However, this does not occur due to a lack of matching. Those simulations which do match still reach approximately 90% of the predicted output. However, by introducing these small errors, the possibility for catastrophe expands. Instead of only a single faulty simulation, 30% of simulations failed to transition to the matched equilibrium. In other words, errors in skill level evaluation by firms or wage calculation by workers can prevent convergence to the matching outcome, and at the very least significantly delay the transition.

The homogenous framework, while not particularly interesting in and of itself, demonstrates that the computational translation is capable of replicating the predicted equilibrium to a satisfactory degree.

Heterogenous Task Count

The second framework allows for a heterogenous number of tasks among firms. The parameter value is normally distributed around an average value of 10 with a standard deviation of 3. Every other facet is the same as the previous framework. The output is presented below.

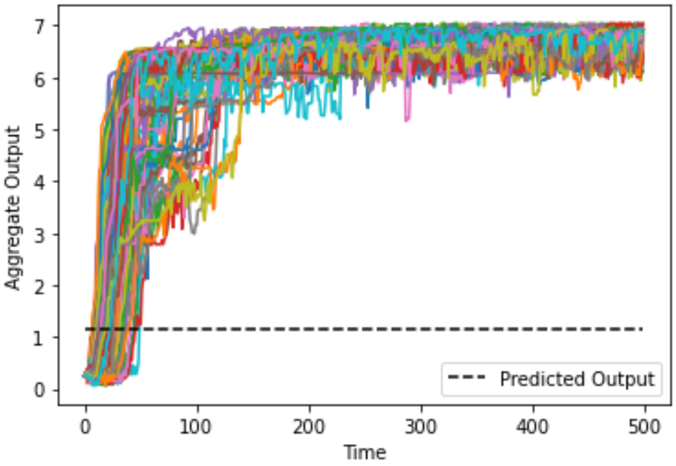

Figure 3: Heterogenous Task and Perfect Information Output

Here the model seems to outperform the predicted equilibrium. While this overperformance is simply a computational artefact given the size of the firm objects, the underlying phenomena driving this result does not dissipate with size increases. Transitioning to a heterogenous number of tasks between firms, matching indeed occurs. However, it is in the exact opposite capacity predicted in the model. Whereas in the original framework, the highest skill individuals arrived at the highest task firms or countries, the output of this model shows them coming to rest in the very lowest task firms. Additionally, the wage distribution closely approximates the predicted pattern as in the homogenous task world.

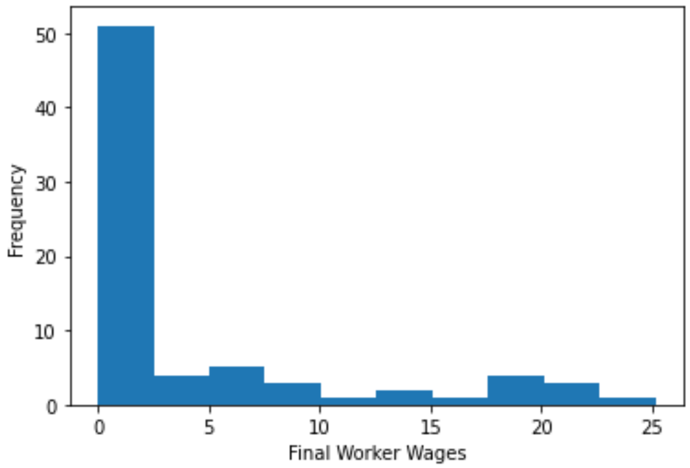

Figure 4: Heterogenous Task and Perfect Information Wages

Under this framework, the agent-based model reveals an outcome not previously thought to be possible. The highest skill agents intentionally seem to seek out these lower task firms. The reason is rather simple. Because of the complementarity present in an O-Ring production function, as the number of tasks in a process increases towards some infinity, the impact of a worker's own selection on her wage converges to zero. Therefore, as production becomes more technically complex there will emerge a dominant strategy for high skill individuals to isolate themselves. A high skill worker, seeking to minimize their coworkers' impact on her wage, chooses to sort herself into these low n firms. To be clear, this outcome is inefficient in the aggregate. Larger simulation sizes demonstrate this fact. Therefore, the implication of this alternative equilibrium is that implicit within the O-Ring framework there exists a Nash equilibrium of sorts. The individually dominant strategy leads to Pareto inefficient matches. Further, the addition of errors generates similar results.

Recovering the Predication: Productivity and Skill Density

The framework above proves the existence of a Nash equilibrium via simulation in worlds which there exist heterogenous task numbers across firms. The question then becomes if the original prediction can be recovered through the adjustment of parameters and considerations in the mathematical formulation. Two particular strategies are possible. First, the only exogenous factor in the original production function B, effectively a total factor productivity substitute, can be increased, potentially breaking the agents free of this alternative steady state. To test this possibility, I run another Monte Carlo simulation in which the rate of increase of output per worker for each additional task rises. Beginning within the established bounds Kremer specifies, $n^{.1}$, adding .1 to this exponent for each framework before ending at n^{2}, well beyond the original assumptions. Each simulation is run 100 times. The output below shows this Nash equilibrium is resilient to these TFP alterations.

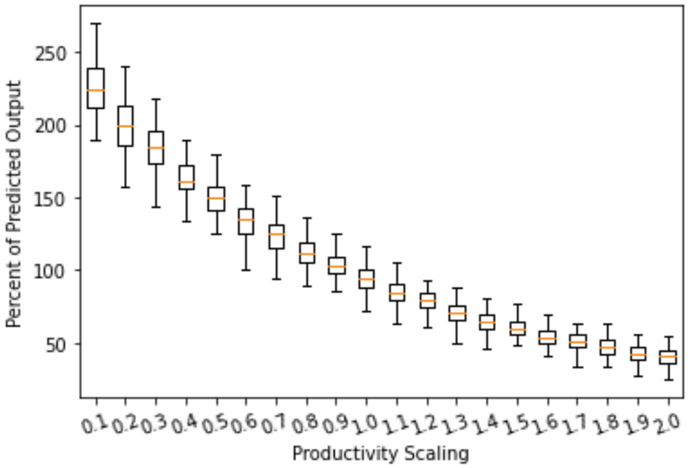

Figure 5: Percent of Realized Prediction by Rate of Productivity

The chart above graphs the percent of realized predicted output against the associated rate of productivity growth. As productivity growth increases with each additional task, no change is observed as the agents sort into the same steady state. In other words, the Nash equilibrium is stable and immune to changes in productivity.

The final test necessary to determine the robustness of this Nash equilibrium is to examine the impact of skill level density. This key input for the equilibrium of the original formulation was largely set aside for a more realistic distribution. To this end, two alternative distributions are now tested. First, a uniformly probable but random distribution for worker skill draws is used. Second, a "true" uniform distribution in which I artificially impose higher density on worker skill levels by allowing only a set number of workers to possess a given level. Once this number is met, I create a gap of 10% between these skill levels. For example, I might create 10 workers of .01 skill and next create 10 more of .11, repeating until the needed number of agents to satisfy the full employment requirement are generated. The results for both the randomly uniform and true uniform respectively are provided below.

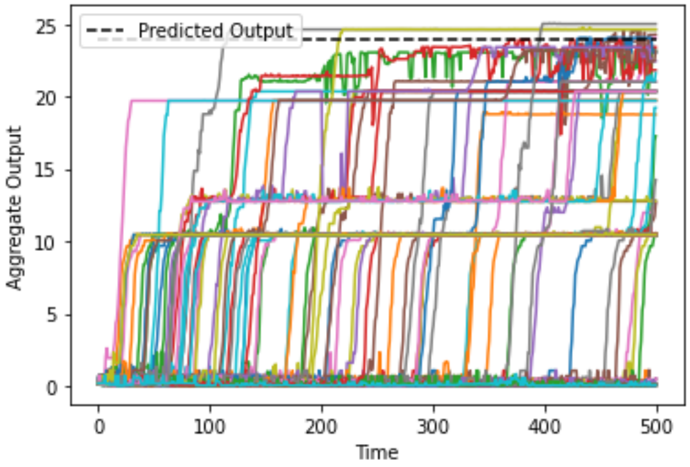

Figure 6: Random Uniform Output

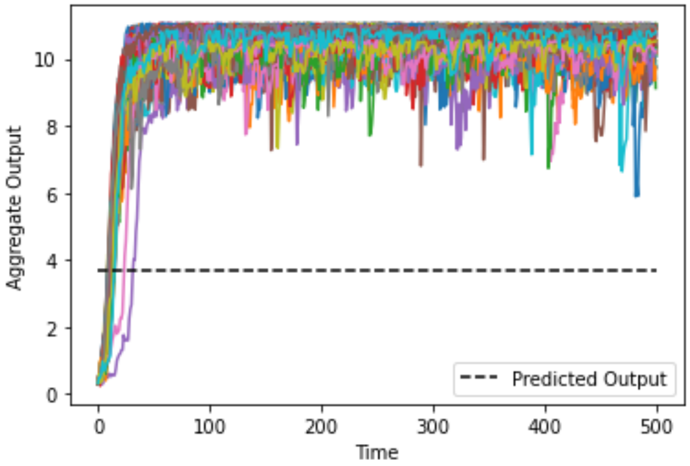

Figure 7: True Uniform Output

Both outcomes show again the stability of the Nash equilibrium. While the random uniform distribution might seem to indicate the necessary matching transpires, the sorting occurs according to the Nash equilibrium instead. It simply takes an exceptional amount of time for any coordination to happen. The same outcome holds for the true uniform distribution. With skill density examined the implication is twofold. The Nash equilibrium presented by the O-Ring is stable and immune to all internal factors in the mathematical formulation. Adjustments to these parameters cannot break the agents free and lead them to the efficient equilibrium. Second, a market mechanism acting in isolation cannot inspire the necessary coordination to seize the advantages of complementarity presented by an O-Ring. To that end, another institutional mechanism to facilitate coordination must be added to work in concert.

Recovering the Predication: A Subsidy Function

Though there are a variety of potential mechanisms one might introduce to free the agents from Nash's grasp, this project will consider a simple subsidy function. In this framework, each firm receives some subsidy, S_i, in each period specified by the following equation.

$$S_i = n_i^{\delta}$$

Equation 9

This subsidy is freely given and does not impact the wage bill of the firm. By increasing the subsidy with the number of tasks, the most technical firms receive the greatest additional benefit. A worker evaluating whether she wishes to join this firm will expect the following wage.

$$E(w_i) = w_i + \frac{1}{n_i} S_i$$

Equation 10

All workers receive an equal fraction of the subsidy. The key accomplishment of this mechanism is that firms now pay above the marginal returns. The result reveals that by paying above marginal product, the matching strategy reemerges as a profitable one. Once again using the same Monte Carlo method with identical parameters to the heterogenous task initial test, the following output is created.

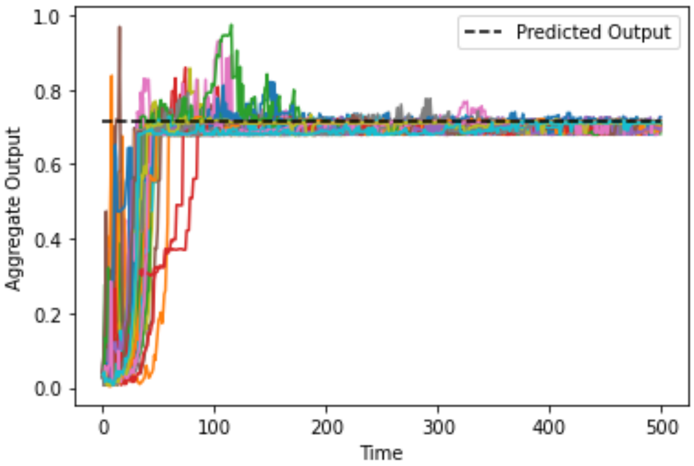

Figure 8: Subsidy Function Mechanism

Once again, the brief periods of over performance are an artefact of size not to be read into. Here we see the predicted output is recovered and the agents freed from the Nash equilibrium. The workers match and arrive at the Pareto efficient outcome. However, the wage distribution now resembles a normal distribution with some slight rightward skew, unlike the initial models.

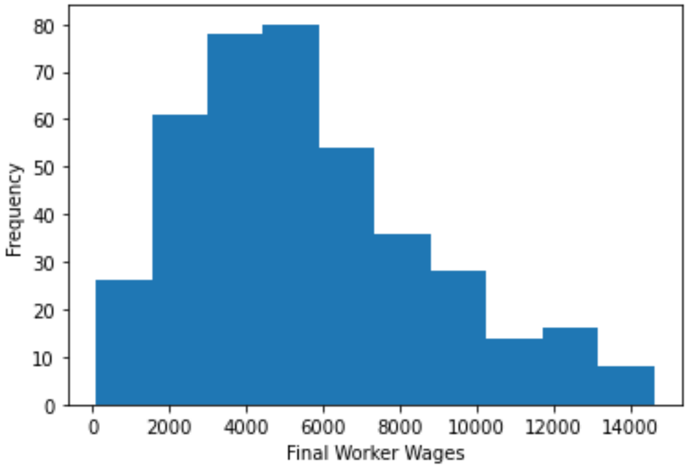

Figure 9: Subsidy Function Mechanism Wage Distribution

The key result demonstrated here is with an additional mechanism incorporated, the predicted matching from the model is recovered but the alternative predictions along other margins are invalidated.

Implications

Given these findings, there are a number of implications for the various applications of this original model. In particular, I focus on three aspects, development, industrial organization, and labor economics. The presence of this Nash equilibrium presents a challenge for economic development and the O-Ring. Because agents will naturally sort into the inefficient matches, a global O-Ring mechanism, as presently described, likely does not motivate the widespread skill sorting observed in the data. The level of coordination required to endogenously generate this result will not emerge within purely market exchange. This outcome does not mean a O-Ring does not exist per se. It is entirely possible and in fact likely the returns to skill matching described do exist.

However, the mechanism outlined in the initial piece would not induce this matching unless another institution beyond the market is present. For a market to achieve this outcome, the sorting must have already transpired prior to the adoption of the technology which shifts the production function into an O-Ring function. In industrial organization, the existence of the Nash equilibrium actually assists in generating patterns observed in the data. With the rise of micro-level data on individual firms, productivity differentials between small and large firms have been observed to follow the type of pattern generated here (Decker et al 2016). Just as in the superstar firm hypothesis (Autor et al 2019), those firms which are the most productive possess the lowest share of labor and are responsible for the majority of output in the simulated "industry." Future work may focus on applying this concept to production networks as well (Demir et al. 2021). However, the simulation also indicates that in a world with superstar firms, significant efficiency gains exist if workers sorted in the predicted capacity. Finally in labor economics, the model indicates that optimal skill matching at large scale is particularly challenging to successfully coordinate purely with market prices. In this case, the presence of other mechanisms become critical for arranging this efficient sorting and increasing workers' wages in a highly technological economy.

Section Five: Conclusion

This piece has demonstrated that the matching necessary in the O-Ring model is not possible within a pure market context. Instead, agents converge to a Nash equilibrium which appears to replicate some of the stylized facts originally sought after in the classic piece. Workers sort in the exact reverse capacity predicted. Because of this previously undetected potential outcome, new grounds for analysis emerge. First, the O-Ring in development, as originally described, cannot be a causal mechanism to create skill disparities observed and in fact indicates that if a decentralized process is responsible for the present global skill distribution, then significant efficiency gains exist. Second, the super firm hypothesis in the industrial organization literature endogenously emerges but is not efficient when taken at the aggregate level. Finally, large-scale efficient matching and the implicit coordination necessary to maximize wages in labor markets are difficult to endogenously generate. Therefore, it is likely that in an O-Ring world, a worker's network matters significantly for achieving the highest possible wage.

CHAPTER TWO

This paper argues that government and market institutions when interacting with one another lead to the generation of a network effect in property value. Using data from the Florida Department of Revenue on market value assessments of homes in 17 counties, I find that living in a basic governing institution, an HOA, increases the market value of an average home by nearly 20% and creates larger neighborhoods. From this result, I estimate the size of the network effect as well as demonstrate through an agent-based model that given the size of this effect, the only way to exploit these gains is through market and political interaction. Using this model, I then show that the algorithmic framework necessary to maximize the welfare of those in the neighborhood is in fact the one present for both non-HOA and HOA situations given their average size.

Section One: Introduction

This paper argues that a key role of the government in an economic system is to assist in aligning the uses of property rights such that they complement one another, effectively generating a network of property. This network effect created through the assistance of certain market and political interaction mechanisms leads to a greater degree of wealth than previously possible had either institution operated of its own accord. Prior to now, the classical theory of property has understood the capability of environmental traits in incentivizing the creation of property rights (Demsetz 1967). Overtime, more robust incorporations for the role of politics (Besey and Persson 2009, Cai et al 2020), and the impact of regulations (Scheiber 1981) enhanced this initial path laid out by

Demsetz. Further work on the provision and mechanisms of property rights have also been established. The value of informal enforcement and definition seems the more relevant component to successful formation (Williamson and Kerekes 2011), but the legal provision of property through a state seems important for increased investment (De Soto 2000). This piece charts a somewhat different path, arguing that as these network gains become possible, agents will transition to alternative institutional processes in an effort to capture the higher level of welfare.

This theory of a property system describes a world in which a multitude of institutions will necessarily engage with one another to solve a collection of coordination problems resulting in the formation of networks of property rights which maximize the wealth in the system. In other words, property becomes a network good. This paper represents the first application of network theory to the area of property rights and shows that such networks which positively enhance the value of the total system can only exist in a world of cross institutional interaction. This paper proceeds as follows beginning with an initial outline of the theory of property systems and its theoretical core. Second, I outline the model developed and explain the empirical ties to HOA governance and home values. Third, I review the results of the agent-based model as well as its implications for future policy before concluding the piece.

Section Two: The Foundations of a Property System

The core of the theory of property systems can effectively be reduced to three simple claims about the economy. First, the value of a person's property in a society is determined, at least in part, by the property arrangements of the individuals around her.

Second, in a society with both political and market spheres of interaction, property rights and their uses will necessarily involve both sets of institutions. Finally, and most importantly, these interactions generate connections, resulting in networks of property creating wealth above the previously possible level should their coordination be absent. These three tenets construct the fundamental viewpoint of the theory of property systems. Interaction among institutions, motivated by interest in others' choices, cultivates networks which result in welfare improvements.

Property Systems and Complementarity

Complementarity of value among goods is relatively common and work has been done to expand this concept into other areas such as labor skill (Kremer 1993) and movement to countries or cities (Bombardini et al 2012). However, the theory of property systems attempts to explain complementarity ingrained within the existence of property through its incorporation into the broader economy via the collection of potential uses contained within the property right. Arguing that not only is such incorporation between pieces of property highly beneficial, it drives a number of positive effects in an economy after all, but also the explicit result of the interaction of market and political actors via legal mechanisms. An example of such emerging complementarity is seen in cities and urban environments. Urbanization has empirically been observed as a highly relevant factor in cultivating economic development (Goetz and Kayser 1993; Johnson 2008), improving industrialization (Henderson et al 1995), and all around contributing to the transition from agriculture to more modern economic sectors (Moomaw and Shatter 1996). Such gains are highly relevant and at least anecdotal evidence for the system of property concept. However, in an effort to dive deeper into the mechanisms which make cities unique, further engagement is required.

This complementarity can be observed in a number of areas but perhaps the simplest example is housing prices. A variety of methods have been utilized to increase the value of homes or property in a neighborhood, the most basic being the role of a Homeowner's Association (HOA) in regulating the appearance or construction of homes. At its core, an HOA is effectively a political government for a neighborhood. Individuals elect members who make selections about certain rules and policies. In essence, the role of the HOA can be distilled to restricting or regulating the opportunity set of a homeowner such that she does not engage in any undesired uses of property. This outcome occurs because the use of a property right can influence the value of adjacent property rights. This complementarity is an important economic force in optimization at the micro-level. An individual may opt out of or into a particular neighborhood given the regulations of an HOA. Though not the main driver necessarily, it does influence purchasing choices (Clarke and Freedman 2019).

Two traits would need to be met for this type of bargaining to occur in a market environment. First, all individuals would need to possess a primary focus on maximizing the value of their home. Given the treatment of housing as a primary form of investment by many, such an assumption may be accurate. Second, there would need to be agreement among the neighbors what uses of a property right lead to the increase of value of all other property rights in the neighborhood. This specification presents a potential issue for the decentralized market mechanism. The informational advantages of a market are well noted (Hayek 1945), but its ability to fully internalize the externalities of behavior can be more challenging in particular given the presence of complementarity. Now such an externality's existence is not direct evidence of inefficiency (Demsetz 1964), but it at least signals the potential demand for some new institution which may be capable of navigating such disagreements[1].

Property Systems and Actor Interaction

If there exists demand for some institutional solution to the potential complementarity of property rights, individuals will seek out and devise it. This type of creativity is observed in a number of other areas with respect to the classic tragedy of the commons (Ostrom 1990). Property rights, like all other aspects of society, do not exist in a vacuum relegated purely to the whims of market institutions. Politics will necessarily play a role. As Wagner (2016) argues, the real world entails a multitude of interactions between the political and market actors. Due to this fact, these institutions cannot be isolated from one another and the insights for the actual operation of society remain the same.

Returning to the evidence afforded by the city, the interaction of the market and political is commonplace. Various approvals must be acquired to build new businesses or homes which influences the various prices and value of property rights in the region (Noam 1982). Zoning laws outright regulate the ways certain portions of a city can be used, creating a number of economic outcomes (Noam 1982). Further, the cultivation of a variety of secondary services (roads, ports, marinas, bridges, etc.) also generate real

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[1] The ability of people to endogenously develop such institutions is well documented (Ostrom 1990)

impacts on the value of property rights even if the calculation may present some challenges (Lipscomb 2003). These activities require cooperation between city officials and market individuals to successfully reach an ideal outcome. Traditional theorists often allege significant negative impacts to such interactions (Tullock 1967; Krueger 1974; Tullock 1975). However, recognition that such interaction is not only likely to occur, but also demanded by the market to address the potential complementarity benefit leads to a different conclusion. The interaction of market and political actors can actually improve the value of the present property right distribution in a real capacity. This conclusion does not imply all types of interactions are positive. Such a claim would certainly be empirically incorrect. Instead, it formally acknowledges that in certain instances the interaction acts to unlock complementarity between property rights and therefore overcomes inefficiencies normally present from rent-seeking. The mechanism for this outcome to occur will be discussed within the formal outline of the property system theory.

Property Systems and Networks

An outcome of the actor interaction outlined above given that certain uses or types of property will enhance value is the emergence of a network of property rights. Traditional network theory establishes two main components, nodes, referring to a point within a network in which things flow into or out of, and edges, the connections which exist between nodes. Further, tapping into network theory unlocks analysis of certain peculiar statistical properties such as scale-free phenomena or power law distributions, unique but important empirical findings. Networks are relatively recent additions to economic theory with some of the more prominent applications including macroeconomic networks (Acemoglu et al 2016), trade and supplier networks (Guilmi and Fukiwara 2020) and originating with social networks (Montgomery 1991). The initial application in economic contexts stems from work on the impact of social interaction on economic outcomes (Jackson 2010, Jackson and Watts 2002). However, property rights remain an area functionally untouched by the tool. There have been some attempts to examine intellectual property rights and the impact of networks (Haunss and Kohlmorgen 2010), but the broader concepts explored here are unique.

The property right itself and its collective uses, regulated through this mechanism, shall therefore influence the value, optimality choices, and general connectivity of the economic system more broadly. Property examined through this structural lens outlines more unique insights. First, as with traditional networks, additional rights will augment the value of those already present in the system. Property rights, in effect, become a network good. Second, the centrality of certain rights in a network can explain the greater volatility for a given economic shock as removing or altering specific nodes can impact the survival of the system. Finally, a network in property rights unlocks the traditional exponential relationships often observed in a network. This network approach to property rights offers new potential analytical ground relative to the previous theories of passive, market generation.

Section Three: A Theory of Property Systems – A Simplified Form

Suppose there exists some set of n property rights referred to in aggregation as PR. The key component of a property right, PR_i, in this approach is the set of uses which an agent j can select.[2] These uses represent what an agent can utilize her property for in the economy. For example, an individual might use a piece of land to build residential housing or an industrial factory. These uses of property are regulated, taxed, or subsidized in a legal and political system altering the value of that property. As another example, if someone offered to sell a hamburger yet the legal system outlawed the consumption of hamburgers, a use of that property, the value of owning that property declines due to its regulation in this manner. Returning to the model, each agent holds a single property right thereby resulting in the population of agents equaling the number of property rights. The goal of the agent is to select uses in each period which maximize her stream of payments from ownership of the property right and use of the property. For now, let us assume only two uses from which an agent, Ag_j, selects for the property accordingly.

$$PR_i \epsilon PR$$

$$PR_i = \{a, b\}$$

$$Ag_j \begin{cases} if\ a, PR_i = PR_{i,a} \\ if\ b, PR_i = PR_{i,b} \end{cases}$$

When an agent selects a particular use a, she receives the gain, P_a, associated with it. The right and property are not consumed and persist into the next period where the agent then makes another use selection. She makes these choices until selling the property in some future period T. In this period T, the agent chooses to sell the property right and receives

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[2] This model does not focus on issues of enforcement or defining rights relative to other individuals. For work discussing these matters see (Murtazashvili and Murtazashvili 2016).

the present market value, MV_i. This value is determined by the use the agent selects in the final period. For example, if selecting use a, she receives the following.

$$MV_i = MV_a$$

The goal of the agent is to maximize the stream of payments over the time she holds the right as well as the market value before sale. In other words, she selects a productive use for periods prior to T as a supplier and then the use most valued by the market in period T when she sells the right off[3]. Some agent j holding property right i maximizes by selecting uses each period.

$$\max_{PR_i} \pi_j = \sum_{t=1}^{T-1} P_i + MV_i$$

Equation 11

Now, suppose that use a affords the higher gain of the two options available to the agent during the non-selling periods. In the final period, if an agent selects use b in isolation they earn less market value than use a.

$$P_a > P_b$$

$$MV_a > MV_b$$

However, also suppose that if all agents with property rights in PR select use b and under these conditions $MV_b > MV_a$. In other words, there exists a network effect should multiple agents select this particular use in the final period. The market value of this use then is some fraction γ of the alternative use's market value plus the gain of the network

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[3] As an aside, this gain could also be interpreted as utility from selecting a particular use of a property right. The analysis does not change.

effect, u_{PR_i} which equals the number of connected property rights $k_{PR_{i,b}}$ raised to the power δ. Allow the maximum number of connections be equivalent to a complete network.

$$u_{PR_i,b} = {k_{PR_{i,b}}}^{\delta}$$

Equation 12

$$MV_b = \gamma MV_a + u_{PR_i}$$

Equation 13

$$MV_b = \gamma MV_a + {k_{PR_{i,b}}}^{\delta}$$

$$0 < \gamma \leq 1$$

$$k_{PR_{i,b}} = n - 1$$

If all agents sell at the same time T, coordination occurs and the wealth maximizing, W_{max} result is endogenously reached.

$$W_{max,j} = (T - 1)P_a + MV_b$$

Equation 14

$$W_{max,j} = (T - 1)P_a + \gamma MV_a + {k_{PR_{i,b}}}^{\delta}$$

However, more realistically allow, T to vary across agents. In this case, the blessing of coordination is not manifest and requires a mechanism to generate.

The Market Mechanism

A market mechanism cannot take advantage of this network effect except under very specific circumstances. First, consider a world where all agents know the network effect exists and the use which generates it. Assume agent j is the only individual selling her holding at time T. The agent then is willing to pay all other agents some amount in the sell period to have them switch to the network use. The other agents, seeking to extract the full potential surplus, request not only the lost revenue from the period for changing uses, but also the full network effect. The $n-1$ agents do not coordinate in their negotiations, they each request the network effect payment, rendering the transition to network use entirely unprofitable. For simplicity, assume $\gamma = 1$ and $P_a - P_b = 0$.

$$MV_b - MV_a = \sum_{j=1}^{n-1} (P_a - P_b) + (n-1){k_{PR_{i,b}}}^{\delta}$$

Equation 15

$${k_{PR_{i,b}}}^{\delta} = (n-1){k_{PR_{i,b}}}^{\delta}$$

$$(n-1) = 1$$

$$n = 2$$

Under perfect information, the market mechanism cannot achieve the wealth maximizing network outcome unless there is no revenue loss, and the number of total parties is two. Even if all non-selling agents coordinate such that they each receive an equal $\frac{1}{n-1}$ fraction of the network effect, unless the revenue loss equals zero, the network use selection remains unprofitable for the selling agent. A market mechanism under perfect information cannot reach the wealth maximizing outcome unless there are no costs associated with not only creating the bargain but coordinating all agents in the neighborhood as well as no lost revenue from switching uses. By the basic assertions of market behavior, no bargain can be reached which exploits the full network effect. If the selling agent opts to bargain with some subset of the total population, then smaller network effects are indeed possible. However, it becomes very difficult as that subset increases in size. Some portion of the wealth increase created by the coordination of uses cannot be generated. Under imperfect information, the non-selling agents do not learn of the network effect until their own sell date. Therefore, there are now two conditions which must be met. First, the network effect must be larger than the loss in revenue for other agents. Second, the remaining surplus must be larger in size than the market value of the alternative use. For $\gamma = 1$, this condition reduces to the following below.

$$k_{PR_{i,b}}{}^{\delta} \geq \sum_{j=1}^{n-1} (P_a - P_b)$$

Equation 16

$$(n-1)^{\delta} \geq (n-1)(P_a - P_b)$$

$$(n-1)^{\delta-1} \geq (P_a - P_b)$$

$$(\delta - 1)\log{(n-1)} \geq \log{(P_a - P_b)}$$

$$\delta \geq \frac{\log(P_a - P_b)}{\log(n-1)} + 1$$

In other words, the magnitude of the network effect's growth must be greater than the ratio of the logarithms of lost revenue and maximum network size plus one. As long as this condition holds, there are sufficient resources for a bargain to occur. However, the contract is created only so long as the remaining gain after paying non-selling agents to change uses exceeds the market value of the alternative use. For $\gamma = 1$, this value needs to be greater than zero.

$$k_{PR_{i,b}}{}^{\delta} \geq 0$$

This arrangement also implicitly assumes that once the network effect is revealed in the first sale, all agents who choose to sell later are naïve to its existence in their bargains. In other words, unless agents are completely naïve, the imperfect information outcome collapses into the perfect information system after the first sale. These are a remarkably narrow or limited set of conditions, and such sensitivity is present even before introducing concerns about costs of switching uses or non-zero transaction costs.

The Failings of a Political Mechanism

A simple method to get all agents to coordinate might be to enact a law or rule requiring the network use and punishing those who do not select it. Legal mechanisms selected by an "outside" individual that offer only one viable option, compliance, have an advantage in that they will necessarily coordinate individuals as other options are effectively removed from the opportunity set. However, the coordination centers around the use which maximizes the payment stream, taxes, to the politician in a manner akin to a stationary bandit (Olson 1974). Here two tax schemas are considered possible.

The first is an income-based schema. A politician operating within this framework seeks to enact laws and regulations which maximize the income generated by the system. In the framework we have outlined here, the politician chooses use a and bans b. Over the time interval, the politician then receives some rate λ of revenue as tax income TI from each agent.

$$TI = \sum_{j=1}^{n} \lambda P_a$$

Equation 17

The agent is willing to bear the cost of the tax unless the revenue loss $(1 - \lambda)P_a$ results in the "illegal" option P_b offering greater gain. If this condition is not met, the agent and their property right exit the model. The key point being that in this schema given our parameters, the network effect is not politically possible.[4]

$$(1-\lambda)P_a \leq P_b$$

The second potential framework will be called a value schema in which the politician extracts some fixed percentage of the market value of the property right. In this framework, the politician chooses use b and bans a.

$$TI = \sum_{j=1}^{n} \lambda MV_b$$

Equation 18

The agent j is willing to bear the cost of the tax so long as the increased gain from the networked market value expected at the agent's respective sell date T exceeds the revenue loss over all prior periods. Again assume $\gamma = 1$. Each agent evaluates the following condition.

$$MV_b - MV_a \geq \sum_{t=1}^{T-1} (P_a - P_b)$$

Equation 19

$${k_{PR_{i,b}}}^{\delta} \geq \sum_{t=1}^{T-1} (P_a - P_b)$$

This mechanism does select for the network effect. However, its stability is dependent upon the distribution of sell dates over the time interval.

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[4] It should be noted that an income-based schema could lead to a networked system if the effect fed into revenue generation of the individual agents for periods prior to their selling date. The framework established here prevents that by its very nature but should not be read as impossible. It only depends upon the context.

The key issue with the political mechanism is if the information necessary to select the proper use is endogenously generated via the incentive created through taxation. Because the politician does not themselves own the right, the potential for them to possess the same level of knowledge as the agent who holds the property is low. There must be some process for them to gain this information to act in the coordinating capacity.

Rent-seeking and Democratic Mechanisms

The mechanism which reveals this information to the politician is rent-seeking. Remaining in the world where $\gamma = 1$, the agent selling her property right is willing to spend up to the network effect to have uses coordinated. However, unlike the negotiation using the market mechanism, there will always exist a successful bargain as the politician is incentivized to enact the policy so long as the revenue gathered from the new network use plus the selling agent's payment is greater than the revenue stream from the previous use.

$$TI_a \leq TI_b + {k_{PR_{i,b}}}^{\delta}$$

Equation 20

$$TI_a - TI_b \leq {k_{PR_{i,b}}}^{\delta}$$

It should be noted that this rent-seeking allows mechanisms such as an income tax schema, which if utilized in isolation prevents this framework from maximizing wealth, to select for the network effect so long as its benefit is large enough. In other words, rent-seeking can be a welfare enhancing prospect if utilized in the proper circumstances.

However, such circumstances may not arise and if the rent-seeking mechanism exists, it requires a check to ensure it is not welfare harming. A democratic mechanism is one possible check. Prior to this point, if an agent was dissatisfied with a policy her only option is to depart the model and cease participation. Such an action reduces the number of property rights in the set PR and overall harms the system. However, the conditions described above can easily translate to a voting system. Suppose that a politician enacts the policy described which alters the legal uses of the agents. Given the conditions are met among a majority, agents express dissatisfaction, and the policy is overruled or a new politician supporting the desired policy is elected. This type of check could not be done through negotiation and contracting. It is easy show that the gain received by both the politician and selling agent will exceed the total revenue loss from the rest of the agent population. Instead, by using voting, the bargaining capabilities of agents become entirely homogenous and properly check the rent-seeking mechanism.

Final Notes and Generalization

The framework discussed above can be expanded to possess greater uses for property rights, different network effects, and heterogeneity among agents. However, the core logic remains the same. One can use interaction between market and political institutional settings to reach Pareto improving and welfare maximizing network effects that are impossible to reach otherwise. A political office is necessary to enact coordination, but to properly generate the information necessary one needs rent-seeking. To protect the populace from potential rent generation which does not enhance social welfare, a democratic mechanism can check such activities. This institutional web unlocks greater wealth generation than possible in anarchic or purely political systems.

Section Four: Modeling the Property System

To examine the role of government and market interaction in coordinating these uses to generate the network effect, I will use the example of an HOA governing a neighborhood. The data to facilitate this analysis comes from the Florida Department of Revenue and their property appraisements. In addition, I web scrape data on neighborhood HOA's from the Florida Community Network. The focus here is on residential homes and the impact of the HOA on the neighborhood's market value, denoted here on as just value. Using 2018 data from 17 counties across the state of Florida comprising nearly 2.5 million individual properties and over 8,000 different neighborhoods, I will estimate the impact of possessing an HOA and demonstrate via an agent-based model that the only way to unlock this benefit is through the interaction of the governing and market institutions.

The Impact of an HOA: OLS

The theory above makes two main testable predictions. First, a neighborhood with an HOA should possesses a higher average home value than one which does not due to the addition of the network effect. Second, neighborhoods with HOA governments should be larger than those without as there is an incentive to add more property rights to it while those without the coordinating mechanism of governance are harmed by the additional competition other property rights create, resulting in lower sizes. Given their rising prevalence, HOAs are largely understudied (Hopkins 2016). Previous work estimated the impact of being in an HOA on selling price finding an impact of only 5% (Meltzer and Cheung 2014). The data used here examines property assessments of just value from the state, an annual measure gathered far more frequently which then directly impacts taxation. From this data, the impact on wealth is more directly observed.

The simplest method to examine the impact of an HOA is on the difference between the average HOA governed neighborhood versus its non-HOA counterpart. Controlling for location and therefore keeping comparisons in the same county, I find living in HOA increases just value of a property relative to its non-HOA neighbors by an average of approximately 68%[5]. The distribution of the increase for all 17 counties examined is provided below.

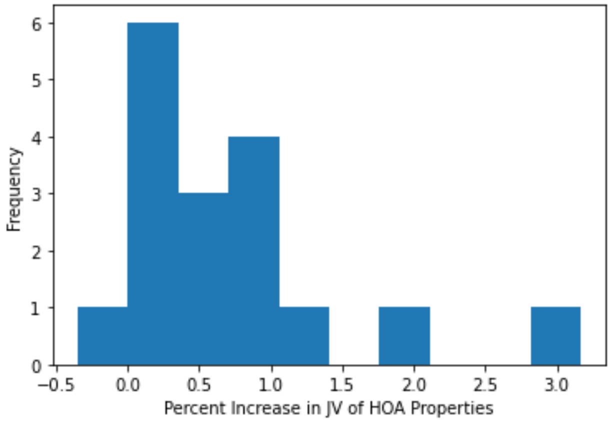

Figure 10: HOA Impact Controlling for County

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[5] The median increase in value is 43%

A similar increase is found for median home value to check against the impact of outliers. Obviously, this rather crude method does not establish any causal connection, but it demonstrates that homes in HOAs tend to be more valuable relative to their ungoverned counterparts. However, a number of factors might incentivize the creation of an HOA so simply inter-county comparisons might be invalid. To that end, I estimate a basic regression model using 2018 data. Instead of examining the value of all pieces of property, I collapse all properties into a single neighborhood average. These neighborhoods are already classified within the Florida data. I create a neighborhood average just value, land value, and square footage measures. An HOA is represented as a binary treatment variable. The model estimated is provided below.

$$\overline{JV}_i = \beta_0 + \beta_1 HOA_i + \beta_1 \overline{LND}_i + \beta_2 \overline{SQ}_i + \beta_3 \mathrm{X} + u_i$$

Equation 21

All non-dummy variables are log values. Controlling for the value of land, square footage of the home, and a collection of county-based fixed effects, I find HOA's maintain a significant, large effect, increasing home value by 22%. Coefficients for county fixed effects are not reported but are provided in the appendix.

Table 3: HOA OLS Results

VARIABLES	(1) HOA Impact 2018	(2) HOA Impact 2018 Land	(3) HOA Impact 2018 Land and Size
HOA	0.565***	0.303***	0.216***
	(0.0252)	(0.0152)	(0.0130)
NBRHD Mean Land Value		0.928***	0.707***
		(0.0142)	(0.0179)
NBRHD Mean Square Footage			0.496***
			(0.0314)
Constant	11.37***	1.838***	0.472***
	(0.0370)	(0.149)	(0.126)
Observations	8,228	7,975	7,494
R-squared	0.174	0.766	0.764

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

If instead examining only single-family homes, the result remains both an economically and statistically significant 16% increase.

Table 4: HOA OLS Single Family Only Impact

VARIABLES	(1) SF HOA Impact 2018	(2) SF HOA Impact 2018 Land	(3) SF HOA Impact 2018 Land and Size
HOA	0.314***	0.229***	0.167***
	(0.0203)	(0.0117)	(0.0113)
NBRHD Mean Land Value		0.725***	0.540***
		(0.0120)	(0.0192)
NBRHD Mean Square Footage			0.687***
			(0.0344)
Constant	11.72***	4.146***	0.867***
	(0.0281)	(0.128)	(0.120)
Observations	5,834	5,581	5,581
R-squared	0.208	0.737	0.786

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

These effects are simply too large to be the result of any traditional alternative hypotheses. If negative externalities compromised nearly a fifth of home value and internalization could be accomplished with a simple organization structure, HOAs would be far more common. If the public goods offered by an HOA increased value of all homes by 16% than once again, the sheer pervasiveness of public pools would be self-evident. The network effect of property rights unlocked through interacting institutional algorithms offers the most plausible alternative. To be clear, these regression models are not meant to provide causal reasoning, such considerations are addressed with the computational model. However, by understanding the statistical associations present through introducing an HOA, the potential positive impact can be observed.

Briefly, before using these estimates to parameterize the agent-based model is to determine the average increase in size of a neighborhood with the presence of an HOA as this will be necessary to estimate the size of the network effect. To do so, the following regression model is estimated.

$$NBRHD_i = \beta_0 + \beta_1 HOA_i + \beta_1 \overline{LND}_i + \beta_2 \overline{SQ}_i + \beta_3 \mathrm{X} + u_i$$

Equation 22

The dependent variable is the number of properties in a neighborhood with the HOA treatment, mean logarithm of land value, and the county fixed effects. Once again, only the variables of interest are reported.

Table 5: HOA Neighborhood Count OLS Impact

VARIABLES	(1) HOA Count Impact 2018	(2) HOA Count Impact 2018 Land	(3) HOA Count Impact 2018 Land and Size
HOA	162.2***	188.0***	164.4***
	(17.94)	(18.48)	(19.05)
NBRHD Mean Land Value		-53.25***	-139.5***
		(8.119)	(17.66)
NBRHD Mean Square Footage			99.81***
			(26.39)
Observations	8,237	7,975	7,494
R-squared	0.140	0.157	0.179

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The model shows that neighborhoods with HOAs possess on average 164 more homes when considering all residential properties and 172 additional properties for only single-family neighborhoods. This result simply conveys that given an average neighborhood possesses an HOA, additional homes will be present due to the profitable addition via the network effect. Before applying this information to tune the agent-based model, further robustness checks are provided.

The Impact of an HOA: Propensity Score Matching

While useful, OLS provides only a simple interpretation of the effect of an HOA. For the network effect hypothesis to be correct, the key predictor of possessing an HOA must be the number of homes in the neighborhood. There must exist a point of clear transition. At this critical value, the dominant strategy employed by agents moves towards the governance rather than market algorithm. Now, not all neighborhoods meeting this critical value will transition as there are obviously confounders and costs. However, in aggregate, the strategy should become more prevalent. The figure below presents two histograms of the log-transformed count of homes in a neighborhood, separated only by the presence of HOA governance.

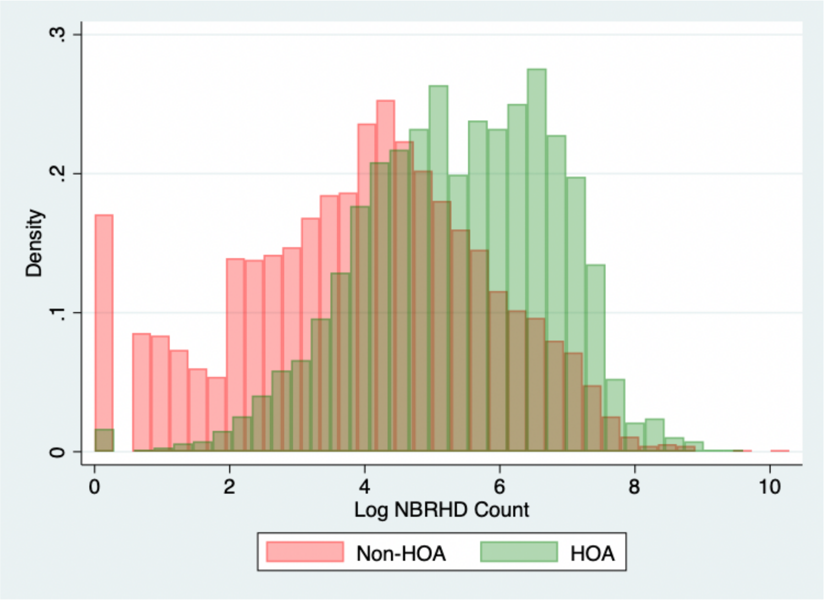

Figure 11: Neighborhood Size Histogram by HOA Status

As is evident in the figure, there does seem to exist a transition point at which the presence of HOA's become far more likely in a neighborhood. Other measures do not possess this type of critical value. With this value in mind, the size of the neighborhood inherently predicts the treatment status of a neighborhood. Because of this close tie, a propensity score model can be utilized to match like sized neighborhood to measure the impact of an HOA. I use a probit regression model to generate the estimate propensity scores.

$$pr(HOA_i) = \beta_0 + \beta_1 NBRHD_i + u_i$$

Equation 23

With the scores estimated, matching using the nearest neighbor method with 5 neighbors being selected leads to the following observed effect. The model is bootstrapped 500 times.

Table 6: HOA Propensity Score Matching Impact

VARIABLES	(1) Propensity Score Matching
HOA	0.503*** (0.0315)
Observations	8,238

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For single family homes, the effect is largely the same.

Table 7: HOA Single Family Only Propensity Score Matching Impact

VARIABLES	(1) Propensity Score Matching Single Family Homes
HOA	0.499*** (0.0329)
Observations	5,832

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

This effect, obviously much larger, indicates that for neighborhoods of similar size, the average just value of the HOA neighborhood is nearly 50% larger. However, in order to maintain balanced blocks, a number of other factors such as land value, square footage, and county fixed effects could not be used to generate the propensity scores. Further, the size of the network effect will be heterogenous across neighborhoods conditional on their size. Propensity score matching misses these broader contextual matters which greatly influence the size of the HOA premium.

The Impact of an HOA: Causal Forest Machine Learning

To capture the conditional average treatment effect and reincorporate these broader margins of heterogeneity which likely also influence the decision to utilize an HOA treatment, I employ a causal forest machine learning algorithm. Due to recent advances in causal machine learning (Wager and Athey 2018, Athey et al 2019), this type of generalized random forest using a doubly robust learning algorithms can lead to the inference of causal effects from large, mutltidimensional datasets. I utilize a weighted lasso regression to estimate the coefficients and incorporate all covariates from the OLS model in addition to a home's age and its "effective" age, accounting for any significant renovations. Finally, the number of homes in the property's neighborhood is used as a confounder due to its influence on receiving a treatment and the just value through added competition. From the causal forest, the constant marginal treatment effect is estimated as well as the ATT for the base treatments (those units actually treated) and the ATT for target treatments (previously untreated units). Using the covariates, the algorithm creates a proposed treatment effect. Further, the conditional average treatment effect for all observations is calculate using the causal forest method. 10,000 decision trees are grown.

Given the property system hypothesis, homes in the HOA should possess a positive premium and additionally units left untreated, when targeted for treatment, should possess a smaller or entirely insignificant effect.

Table 8: HOA Treatment Causal Forest Machine Learning Impact

Effect Estimated	(1) Doubly Robust Forest Training Data
ATE	0.149*** (0.028)
ATT (T=0)	.194*** (.028)
ATT (T=1)	.035 (.071)
Constant MTE	.184** (.085)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results align with the expectation, units already treated (T=0) possess a large, significant effect, whereas units previously untreated units (T=1) are much smaller and insignificant. Further, using the estimates from the training data, a constant marginal average treatment effect of 18.4% is estimated.

The final component is to examine the heterogeneity of the conditional average treatment effect. Per the property system theory, additional homes add to the effect. Due to this fact, there should be some degree of heterogeneity of the effect. To this end, the CATE for all observations is estimated and displayed in the chart below.

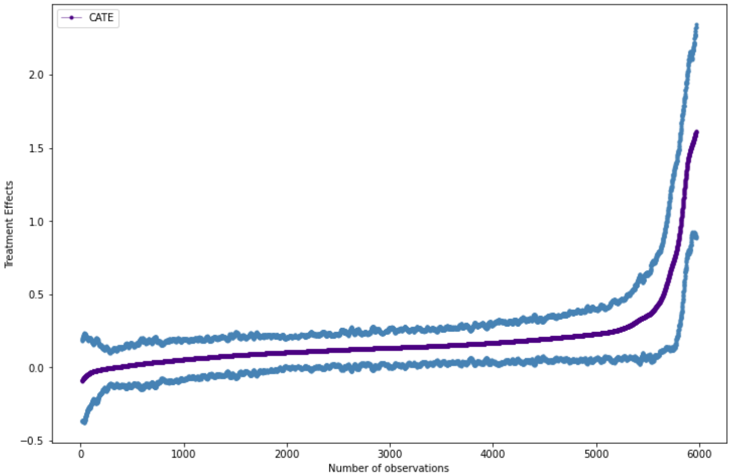

Figure 12: CATE for HOA Treatments

Adjustments between observations are small, but such a result should be anticipated as individual homes add very little to the broader size of the network effect. The key insight is that for all neighborhoods in the counties examined, there does exist some level of heterogeneity conditioning on the covariates.

An Agent-based Model of Property Systems

To determine if the addition of a governance structure with some rent-seeking properly creates the wealth enhancing outcome observed in the data, I construct an agent-based model derived from the theory presented earlier in the piece. There will be two simplifications. First, payoffs will be equal to zero as it will be assumed people do not derive income from their homes as assets. This adjustment changes nothing of particular importance in the model. Second, as in the simple case of the model, given the HOA increases single-family home value by 16% over a similar house, we will assume that the fraction γ of MV_a impacting MV_b is once again equal to one. The final addition is to determine the mean number of homes present in ungoverned neighborhoods, approximately 224, and add the necessary HOA size increase of 172. From these values, the network effect can be derived and is approximately 1.66. The market value used for MV_a is the mean single-family neighborhood just value conditional on not being a member of an HOA.

In the agent-based model, three main frameworks will be tested, a pure market system, a pure political system, and the system including a political authority, rent-seeking, and democracy[6]. The same set of agents will be sent through all algorithmic interaction systems. These agents are identical in all facets except their selling date T. As before, the goal remains to maximize the stream of payments possible. The sell dates are uniformly distributed between 1 and 1,000 with the model persisting for 500 periods. Only one agent can sell in any given period. The market value of the property right is found by examining the average just value of single-family homes and is equal for both uses absent the network effect as $\gamma = 1$. The political revenue will be a value schema and the tax rate λ will equal 10%[7], representing the collection of fees over the lifetime of holding the property. The model's parameters are provided below.

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[6] These selections reflect the general institutional arrangements observed in residential housing.

[7] This value is the single exogenous parameter untuned by data.

Table 9: HOA Model Parameters

Parameter	Value
δ	1.656
MV_a	112,510.29
P_a, P_b	0
λ	$.1$
Politician Population	1

The model will begin with only two pieces of property and add an additional home to the neighborhood until reaching a size of 500.

Results and Implications

The model demonstrates there exists a critical size necessary for this alternative governance to be a profitable, efficient arrangement over the market alternative. Specifically, two key points emerge. First, in world with non-zero taxation as well as other costs not included in the model, there exists a point at which the alternative institutional algorithm is its most welfare destroying if a switch occurred. Second, there exists a critical mass of size which makes the transition between arrangements profitable. Taken in concert, the alternative algorithm set is only an efficient option for taking advantage of the network effect once a certain potential size is reached. This outcome would explain why some neighborhoods do not possess such institutions while others do. Their operating size simply does not make such a transition an efficient option. The figure below plots the difference between the governance mechanisms and the market mechanism for each neighborhood size.

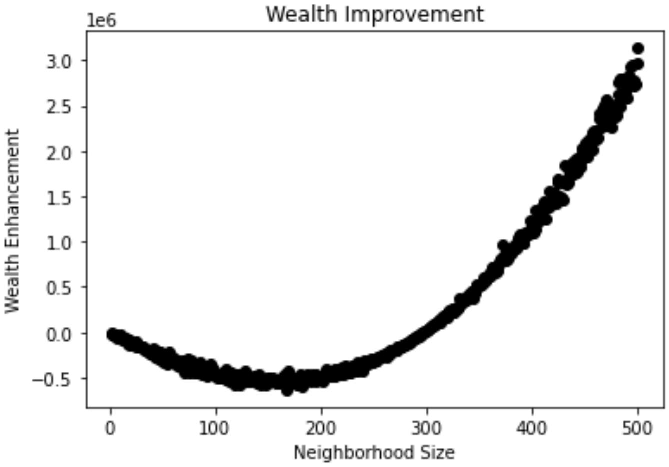

Figure 13: Network Effect Function for Marginal House

This outcome explains why not all neighborhoods possess HOAs. The emergence of governance as a viable strategy for coordination and welfare improvement is entirely dependent upon the choices of others to move into a particular locale. No one individual can possess the resources to fulfill all the bargains necessary to ensure the coordination occurs. Instead, the number of bargains necessary is condensed through the introduction of a government structure. Further, the feedback loop generated by the rent-seeking and democratic interaction also necessarily leads to the highest gain. Testing the average neighborhood sizes for HOA and non-HOA bodies, the model demonstrates that the proper welfare maximizing algorithm is being utilized. In other words, the agents endogenously arrived at the proper structure.

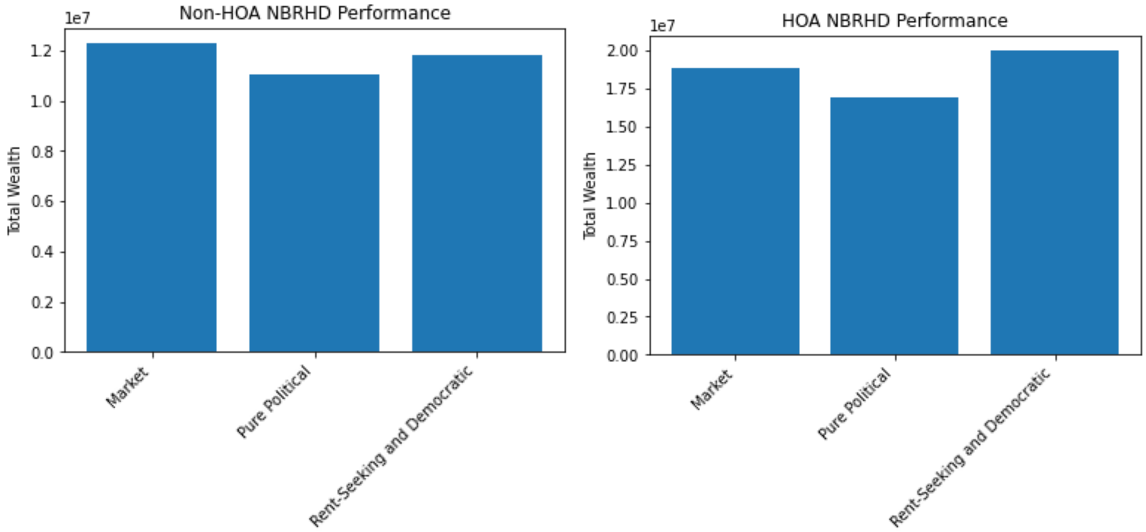

Figure 14: Comparative NBRHD Performance under Alternative Algorithms

It can also be noted that a pure political structure, in other words a politician acting of their own accord, is outperformed in both settings.

The key implication of this model is that by allowing for interaction among agents in different algorithmic capacities, a system can unlock welfare enhancing outcomes. In this instance, the enhancement being the generation of a property network that results in higher wealth. By allowing for increasing returns to size of the network, a pure market mechanism can struggle to exploit these benefits. Additional interactive mechanisms are needed. The applications to HOA governance empirically tie this outcome to a previously unexplored area, explaining both the premium observed as well as why only a subset of locales choose this particular method of governance. Further, through the utilization of computational methods, one can demonstrate the impact of placing the same set of agents through a variety of processes.

Section Five: Conclusion

This piece outlines not only the first application of network theory to property rights, but also utilizes computational tools to show why only certain algorithmic processes regulating the interaction between agents can generate these results. It empirically ties an agent-based model to a micro-level dataset and uses the estimated effects to tune the computational model which outputs results consistent with the observed data. By applying this process to housing, the HOA premium associated with a neighborhood as well as the explanation for its emergence only under certain conditions is provided in a novel capacity. Future work can apply this algorithmic approach to not only replicate the observed world but also hypothesize about alternative possibilities.

CHAPTER THREE

Economic cybernetics, a long dormant field, remains ignored in the traditional discussions of policy, politics, and economic dynamics. Pioneered by Oskar Lange, the approach largely declines with his failings in the calculation debate due to their inherent connection. This project proposes a revitalization is needed given the rise of modern computational capabilities, data science, and AI. In this paper I will develop a framework for programming institutions as computational algorithms meant to mechanistically regulate interactions between market and political agents. Applying this approach to central bank organizations operating within a basic New Keynesian model, I demonstrate that alternative institutions such as independent, democratic, or parliamentary central banks, perform in superior capacities relative to one another dependent upon the parameters of the underlying economy.

Section One: Introduction

Social forces stand unique relative to their physical counterparts. Unlike the behavior of intelligent individuals, a physicist never needs to concern herself with the possibility that gravity will alter its impact along any margin other than the mass of the object. The oxygen molecule does not consider the morality of its bonding with hydrogen to form water. People can choose certain social behaviors as ideal according to a host of potential margins. However, even given these fundamental differences, the social sciences achieve a remarkable degree of accuracy in predicting behavior. This capacity emerges because individuals, in an effort to ensure those around them behave predictably, construct institutions which render their actions into certain expected lanes. By forming these structures, agents can expand their capacity to cooperate and seize opportunities only possible from their collective intelligence. Analysis of these types of self-designed control mechanisms require a discipline that largely has fallen to the wayside, economic cybernetics.

Oskar Lange describes the purpose of economic cybernetics as a way "…new light can be shed on the problem of proper control of the course of these [economic] processes…" (pg.1 1970). Building from the initial founding of cybernetics (Weiner 1961), Lange's interest in this topic stemmed from his desire to plan the productive and financial components of the economy through use of various political mechanisms. These components expressed no active interest in the operations of the economy and therefore would only engage with the system in such directed, welfare-maximizing interests as were needed to ensure optimality. This conceptualization of the political apparatus clearly failed to live up to Lange's lofty expectations for a variety of reasons (Hayek 1945, Mises 1935), but the core conceit of cybernetics, the nature of automatic control, still offers potential gains for economics and political economy. However, unlike Lange's formulation which centered upon the capabilities of a central institution to control the economy, the new iteration of this framework takes a much more holistic perspective. The updated approach recognizes the self-interest of all agents regardless of environment (Buchanan and Tullock 1962; Tullock 1967; Krueger 1974), the difficulty in complex acts of coordination (Coase 1960; Williamson 1983; Joskow 1987; Crocker and Masten

1996), as well as the singularity of the social environment rather than a dichotomous perspective (Podemska and Wagner 2013; Wagner 2016).

The core goal of the new economic cybernetics is to utilize advances in computer science, data science, artificial intelligence, and control theory to properly model social institutions. It achieves this task by examining an institution as an algorithm, taking a collection of inputs and producing an expected output. The inputs in this case being humans of various persuasions with heterogenous goals and intents and the outputs can be any variety of things: a price, interest rate, law, information, new technology, or policy. In any case, the logic remains. The algorithm determines the types of interactions possible and pushes the agents towards those lanes via the reward functions present, facilitating better use of their respective intelligence and skills. The use of computational algorithms in the formal modeling of institutions is also useful as it allows for an explicit introduction of efficiency analysis to social process (Lewis and Papadimitriou 1978; Smale 1985). This paper continues as follows. First, I review the general framework of the new economic cybernetics and examine its ties to control theory and computer science. Second, the present New Keynesian modeling paradigm is offered and then the adjustments that allow for the cybernetic analysis to transpire are explained. Finally, the results of the simulation model under different algorithmic institutions are reviewed before addressing some of the implications and concluding the piece.

Section Two: The New Economic Cybernetics Framework

The probability an action or choice generates a particular expected result is often given in traditional economic modeling. At some micro-level of behavior, this type of assumption is certainly suitable as any individual act likely does not influence this probability. However, in the long run, as with all inputs, the ability of agents to endogenously invest in certain procedures will alter this probability. Investments in these structures produce real changes in the well-being of the participating agents. Let us separate the probability an action leads to the outcome the agent anticipates and the economic reward of that action. Throughout history, agents often chose to operate within high probability, low economic reward[8] environments such as families and tribes (Redfield 1955; Waite 2000) or small-scale, curated networks (Jackson and Watts 2002; Jackson 2010; Baird and Gray 2014; Acemoglu et al 2014) driven by repeated dealings (Abreu and Pearce 2007). However, over time as economic rewards increased, the relative cost of low probability environments also increased. Because of this fact, agents began to invest in processes and structures to adjust these probabilities, leading to the exploitation of new opportunities. As agents endogenously design the probability space they act within, the expansion of economic rewards now possible leads to further expansion, economic growth. The cycle continues as new processes are created which then expand the possibility set of economic rewards and so on[9].

With the introduction of this sequential design of procedures or algorithms, a critical insight springs to the forefront. By acknowledging the sequential design of institutional processes, an introduction of the efficiency of such arrangements can be

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[8] By "low" reward, I refer to the relative potential rewards available should agents optimize around more traditional microeconomic concepts such as specialization in skill, marginal returns, etc. In other words, non-probability space selections.

[9] This type of self-generating procedure is discussed within Schelling (1978) and Ostrom (1990).

broached, drawing from the literature on algorithm development in computer science (Yui 2000; Paenke et al 2006). Others examined the endogenous formation of institutions but chose not to provide any type of statement on the efficiency of those designs (Buchanan 1975; Ostrom 1990). This study does not claim to perfectly epitomize the efficiency of an institutional process. To some extent one might define an institution as "efficient" if it simply works as the agents within the system desire. However, this analysis circumvents the well-documented pitfalls of interlopers attempting to improve a group's functioning institutions (Leeson and Harris 2018) with the addition of the algorithmic approach to modeling the institution itself. Not only do the agents present define the goals, this particular component of the approach existed in the past, they also define the algorithms present, albeit indirectly. This second component is critical as it constrains the economic cyberneticist in a fundamental way. The agents already answered their respective questions and designed the solutions to achieve their goals. The economic cyberneticist can construct a model which emulates this environment the agents defined and potentially provide improvements on those algorithms[10]. This level of simulation is now possible mainly due to the recent advances in data generation in creating massive datasets either in terms of frequency or micro-level of collection. It is this synthesis of opportunities created by expanding datasets tempered by the constraint of algorithmic procedures to replicate this data which enables the power economic cybernetics can hold.

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[10] A natural example for algorithmic improvement is the multitude of manners in which numerical analysis constructs alternative methods for solving various polynomials (Hentenryck et al 1997), differential equations (Liniger and Willoughby 1970), multidimensional problems (Stone 1968), or other types of systems (Grajewski et al 2009).

However, implied by defining this procedure as "new" economic cybernetics, there is need for corrections to a previous model. As stated above, the major point of differentiation between the older economic cybernetic framework[11] and the revitalization advocated for here is the formal acknowledgement of the active interest of the agent. For example, consider a generic controller which adjusts some policy in an economy[12]. The traditional economic cybernetics of Lange might model such an economy in the following manner. There will exist a controlling object regulating an economy object by enacting some policy input and receiving feedback to adjust that policy. This regulation leads to a stable macroeconomy.

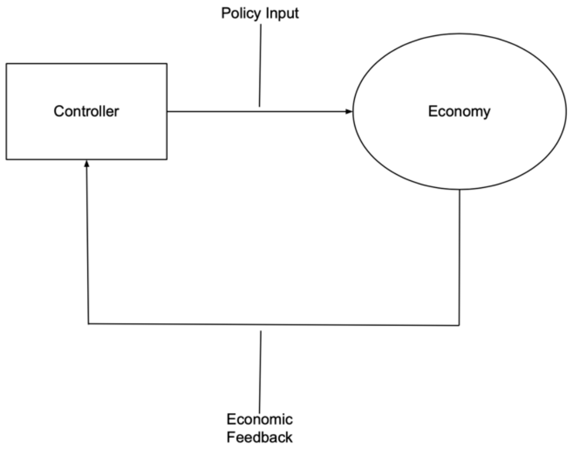

Figure 15: Automatic Control Model of Policymaking – Basic Version

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[11] This older framework draws from traditional control theory and systems theory (Bertalanffy 1972; Weinberg 1975; and Fracois 2000) remains a staple of engineering and has seen some social applications (Luhmann 1984)

[12] This situation resembles the basic automatic thermostat problem in control theory (Yao 1972).

However, as outlined earlier this model ignores the nature of the controlling agent who is not simply a machine. She explores and participates in her environment, potentially acting in unpredictable ways rendering the mechanistic perspective of the traditional approach an act of folly. Even further, agents within the "economy" object will choose to interact with the controller due to her specialized position, reflecting insights from public choice. Due to this fact, the key goal of designing an effective controller object to regulate the economy and render various unfamiliar social interactions more predictable falters[13].

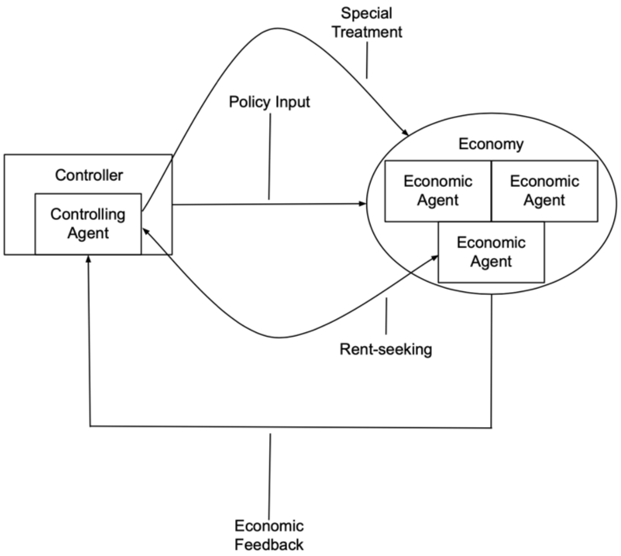

Figure 16: Automatic Control Model of Policymaking – Realistic Version

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[13] It should be noted that the agents within the system already are aware of this realistic operation and the cyberneticist should likely ask if the types of interactions made possible are in fact the purpose of the structure developed.

In an effort to address this problem, the agents will introduce a new controller object to regulate the previous controller in some capacity, per the sequential design process outlined earlier. However, by creating this new controller, a new set of intervention opportunities exist requiring the introduction of another controller and so on. This endogenous challenge will be called the infinite controller problem.

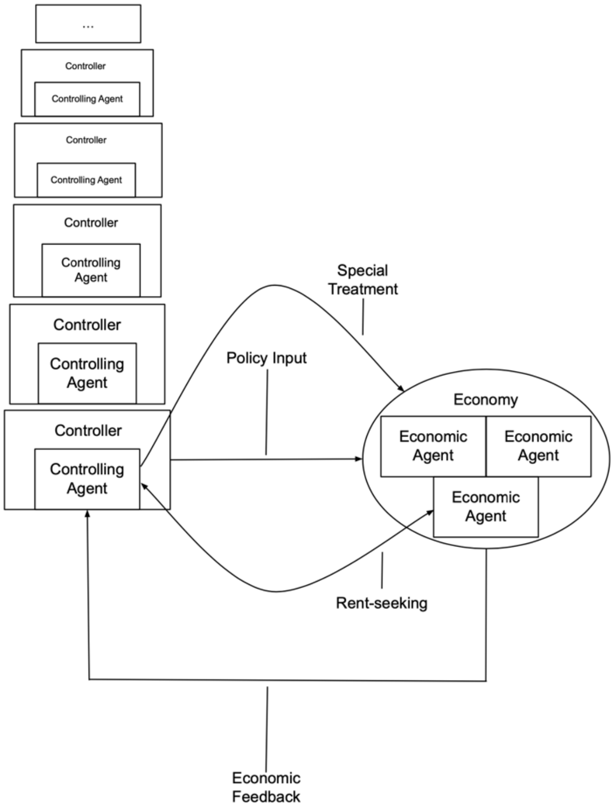

Figure 17: Representation of the Infinite Control Problem in Social Systems

The agents within the environment need some method to close this loop. Otherwise, the complexity of the system overwhelms it, and it collapses. There have been numerous methods employed by societies to solve this issue, to close the system in effect. Buchanan argued constitutions solved this problem by formalizing the rules of this system (Buchanan and Tullock 1962). Historically, one might argue religious belief acted in this manner as well as presently in communities with widespread adoption of faith (Orbell et al 1992). In the modern day, the "rule of law" might suffice. These examples focus more on top-down imposition. However, bottom-up emergent solutions also exist. Ostrom saw the endogenous formation of a system as closing this loop (1990). Others have argued cultural and social norms assist in addressing the situation (Williamson and Kerekes 2011). In any case, every system in which individuals must interact with one another will require the closing of this loop. Some object or process must exist that sufficiently serves to constrain all agents. Functionally, each of these methods achieve the same end goal. Because of this fact, the ability to simulate certain institutions is possible as there exists a collection of constraints that apply broadly to all agents within a particular social system. The example above represents only a basic outline of a generic structure. There will exist a multitude of such algorithms, regulating interactions between agents in a variety of settings. Each is part of the broader social system. Though the image presented may convey a sense of separation between the controller object and the economy, in reality these objects are tools within the whole, singular environment all agents occupy. The agents simply need institutional processes to coordinate and mixing political, legal, moral, and economic tools together facilitate the success of this endeavor. Before transitioning to the application of this approach to policy analysis, allow us to review the basics of the model being examined.

New Keynesian Models and Behavioral Assumptions

One of the present standard frameworks in macroeconomics is the three-equation New Keynesian model. Newer work in macroeconomics and the study of the business cycle centers the role of heterogeneity in the economy (Kaplan et al 2018; Auclert et al 2020; Ravn and Sterk 2021), transitioning away from the basic representative agent models of the past. Further, relaxation of assumptions of rationality has led to a broader approach for behavioral macroeconomics (De Grauwe 2012; Hommes et al 2019; Hommes 2021). However, for the basic introduction desired here, the model will be sufficient. The three equations, the IS curve, New Keynesian Phillips Curve, and Taylor Rule, are provided below.

$$y_t = a_1 \tilde{E}_t y_{t+1} + (1 - a_1) y_{t-1} + a_2 \left(r_t - \tilde{E}_t \pi_{t+1} \right) + \epsilon_t$$

Equation 24

$$\pi_t = b_1 \tilde{E}_t \pi_{t+1} + (1 - b_1) \pi_{t-1} + b_2 y_t + \eta_t$$

Equation 25

$$r_t = c_1 (\pi_t - \pi^*) + c_2 y_t + c_3 r_{t-1} + u_t$$

Equation 26

Section Three: Computational Alterations to the Traditional Framework

This piece alters the original model by replacing the Taylor equation with different algorithmic institutions that direct the actions of a policy-making agent. The agent will possess an objective to achieve the highest level of reward possible. Note this separation of the agent's actual motivation from the objective of the institution. Most models assume the agent's and the institution's objective are entirely equivalent. Recall in the cybernetic approach the algorithm or institution defines the reward function. The agent simply wants to find the actions within the probability space outlined by the institution which leads to the highest achievable reward total at the conclusion of the time interval[14]. For this first iteration, let us define the algorithm in a manner resembling the goals of the United States Federal Reserve. The Federal Reserve possesses two main objectives, maintain price level stability and ensure the macroeconomy reaches full employment. Though a simplified concept, these goals are serviced by adjusting the federal funds rate. Both these objectives and actions are encoded within the reward function and environment generated by the institutional setting, rather than stemming inherently from the agent. The agent must learn what actions lead to the most rewards. Computationally, this goal is accomplished through reinforcement learning algorithms. In reality, a person would possess a set of perceptions influenced by their education and life experience. She would plan certain actions and anticipate specific responses. However, an effective institution renders this underlying heterogeneity moot as the algorithm homogenizes people to increase the predictability of the social world[15]. Because of this fact, the liberties taken in using an artificially intelligent agent who learns without possessing priors impart negligible effects on the final conclusions.

Defining the Central Bank Algorithm

Let us say a macroeconomic series can be described by a sequential set of states $\mathbb{S}$. At each state S_i, it is possible to move to some n number of alternative states. These states are defined by the macroeconomic variables inflation π and output y though any

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[14] This approach to agent behavior resembles that presented in the literature on reinforcement learning in artificial intelligence (Kaelbling et al 1996).

[15] One could argue the economic cybernetic approach assumes complete heterogeneity among the population of agents and it is the role of the designed or emergent algorithms to render that world homogenous.

host of others could be included as well. The reward R_j at state S_i is defined by the difference between inflation now and in the previous state plus the difference between output in the present period and its prior. To ensure the reward is never undefined, ς is some infinitesimally small value with a lower bound determined by the computational system being utilized.

$$R_j = \frac{1}{|\pi_t - \pi_{t-1}| + \varsigma} + (y_t - y_{t-1})$$

Equation 27

Here the reward R_j that corresponds to some macroeconomic state S_i is a function of one divided by the difference in the inflation rate between two states or periods and the difference between present and previous output. In other words, the central bank is rewarded based upon its ability to stabilize the inflation gap[16] and maintain a growing economy. To transition between states of the macroeconomy, the agent will alter the predetermined policy interest rate.[17] Unlike other applications of reinforcement learning in which the action space can be utterly massive in size (Silver et al 2017), generally human institutions only allow a few types of actions, by design. For example, in a market where no agents know one another, a consumer agent can only choose to purchase or not purchase a good. Though the agent may want to simply take the good in question, this action is removed out of hand from their choice set[18]. Once again, the institution

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[16] This function could be easily altered to reflect differing institutional objectives.

[17] For simplicity, feasible actions such as quantitative easing or liquidity injections will be assumed away though they could be added in for a future project.

[18] Note that even in this incredibly simple example the set of institutions necessary to render the system into these two viable lanes. These can be legal, cultural, or some alternative institutions but must fulfill very specifical roles such as monitoring, punishment, or exclusion.

homogenizes the set of possibilities. Returning to the context of the central bank algorithm, this simplicity manifests as only three core options, raise the policy rate, lower the policy rate, or keep it the same.

The final component to consider is the probability of transitioning to a particular state following an action. Within the New Keynesian model, a variety of shocks are possible. The probability of transitioning to a particular macroeconomic state then is dependent upon the type of shock experienced. This specification generates the value function.

$$V(S) = \sum_{i=1}^{n} \sum_{j} P(S_i, R_j | S)(R_j + \beta V(S_i))$$

Equation 28

This value function is read as the probability of moving to some particular state with a certain reward given the agent's present position times the reward of that state plus the discounted value of other possibilities.

With this defined, the agent then has a policy function, po, (policy here is akin to strategy as is the case in the reinforcement learning literature (Ding et al 2020)) for all possible actions a and is provided below.

$$V_{po}(S) = \sum_{a}^{3} po(a|S) * V(S)$$

Equation 29

Read as the probability of choosing a particular action given the present state times the value function shown earlier for all other states. The goal is for the agent to choose the policy (strategy) that maximizes its reward. Note again the agent possesses no traits itself.

Instead, the institution/algorithm alters both the way the agent is rewarded, through the socially determined goals, and the possible ways to reach those goals, the set of actions. This specification ensures that regardless of the individual coming into serve in the desired role, the structure still generates predictability within the broader macroeconomy. Using our cybernetic framework from earlier, the institution described can be presented graphically in the following manner.

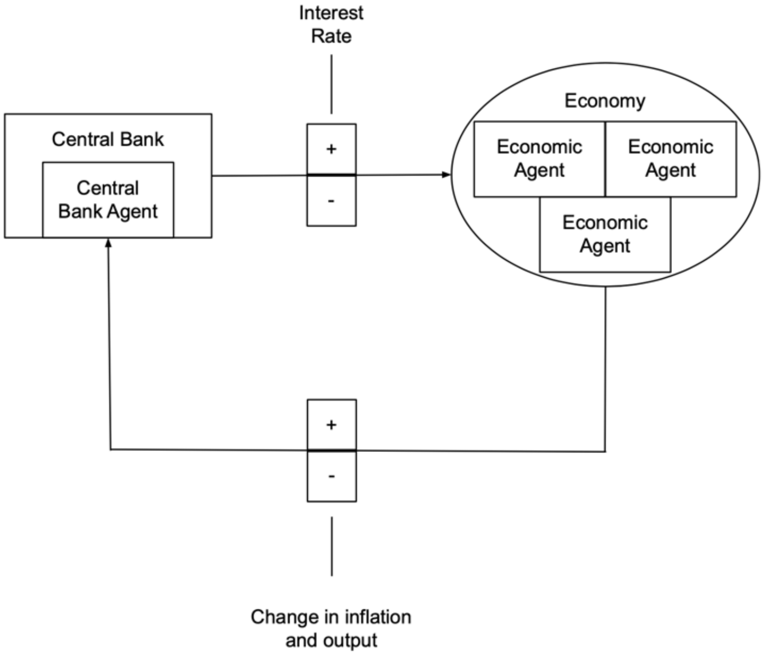

Figure 18: Basic Central Bank Control Mechanism

Adjusting the Algorithm for External Influences

This policy making agent operates within an entirely independent entity, immune from any external interference. Functionally, the framework described mirrors that of the

Taylor rule and the control problem outlined earlier has yet to be addressed. This purely independent central bank is certainly a type of institutional arrangement that may exist and presents a useful baseline for analysis, but in reality, few central banks are organized in this capacity. As a cyberneticist, this fact signals something important about the nature of the institutional arrangement desired by agents. One might have a democratically elected central bank or the policy making agent is chosen by a representative of that population. In either case, the agent choosing policy in the central bank algorithm faces the possibility of entering a terminal state. Once again, we revisit the cybernetic question of what mechanistic role these sequential additions serve in the broader system.

For computational translation, I will look at two basic alternatives to the purely independent bank outlined in the prior section. First, given the representative agent approach of the New Keynesian model, it will be assumed this individual is approximately the median voter. Therefore, she holds decision-making sway in an electoral setting. Second, in a representative democracy the algorithm adjustment looks different. The median voter elects an intermediary agent who then selects whether to reappoint or replace the central bank agent. In an algorithmic sense, these additional mechanisms can be said to introduce certain terminal states for the agent inhabiting the structure created by the institution. However, unlike traditional examples with well-defined terminal states such as the end of a game, the potential terminal states for something like a central bank are fuzzy (in the mathematical sense). This fact stems from the contextual nature of policy in a dynamic macroeconomy. The conceptualization of failure, or in this context entering the terminal state for the agent, must be dependent upon the broader trends of the macroeconomy as the agent's environment is not entirely defined by their own action set. As such, the terminal state must be determined endogenously by alternative agents. The task becomes who defines whether a state should be terminal for the central bank agent.

Return to the first permutation of the original institutional algorithm being examined, a democratically elected central bank agent. For an evaluation to occur, a set period of time must lapse in the environment, T^*. Upon completion of this period, the evaluator, in this case the citizenship or median voter, makes a determination on whether to reappoint or retire the central bank agent. This action requires an evaluation standard. Per the framework of the New Keynesian model and given the representative agent approximates a median voter, since consumption determines utility, the median voter will examine her average level of income $\bar{y}_{T^*}$ over the period under consideration and compares it to the previous evaluation period $\bar{y}_{T^*-1}$. This relative position determines the probability that a state is in fact a terminal state S_T for the central bank agent.

$$P(S = S_T) = \begin{cases} 1\ if\ \bar{y}_{T^*} < y_{T^*-1} \\ .5\ if\ \bar{y}_{T^*} = \bar{y}_{T^*-1} \\ 0\ if\ \bar{y}_{T^*} > y_{T^*-1} \end{cases}$$

The central bank agent can learn of these criteria and certainly has access to consumption data. The probability enters into the policy function and adjusts choices as the agent wishes to remain within the central bank algorithm. Now stepping outside the computational component, the cybernetic question requires us to ask why endogenous terminal state definition from a population via a voting mechanism is beneficial. Briefly consider what voting, relative to a more traditional market mechanism, does with respect to participatory decisions. Markets allocate towards those highest valued ends. If the populace interacted with the central bank object in this capacity, those most willing to pay receive their ideal monetary policy. For a social mechanism such as money, these imbalances lead to poor coordination as evidenced by corrupt central banks (Dimakou 2015). The reason a voting mechanism overcomes this specific, potential problem is the homogeneity created by the method of interaction. Transitioning to this algorithm generates the following model.

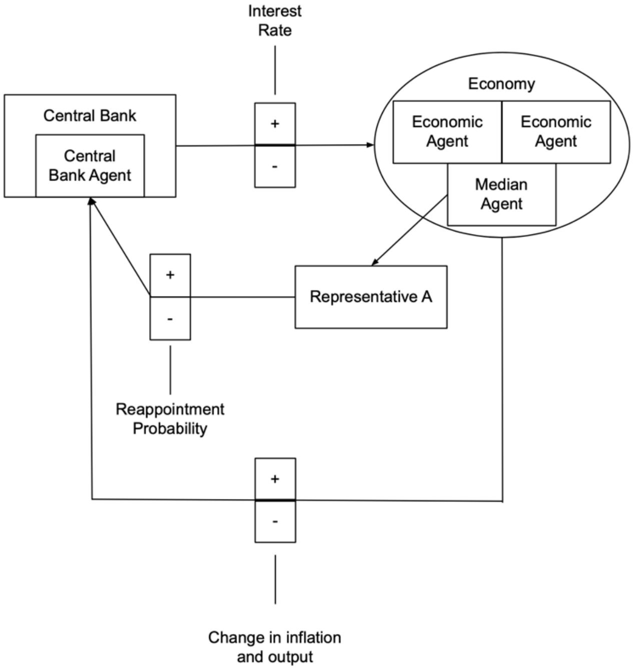

Figure 19: Democratic Central Bank Control Mechanism

The information revealed through the median voter is beneficial as a method to check the general satisfaction of the population for achieving the goals set out in the reward function. However, because of the less direct internalization, a whole host of secondary problems are introduced. Returning to that sequential problem-solving procedure, another mechanism is needed to address these faults.

The main issue to be resolved by the introduction of the voting mechanism is the non-logical nature of the action (Patrick and Wagner 2015). The information revealed by the median voter's signal is useful but given well-documented problems (Brennan and Hamlin 1998) that information may not be correct or relevant. Here the third institutional structure considered in this piece can be addressed. In a desire to reduce the inherent noise in the median voter's signal and ensure a longer time horizon in determination of the terminal state, a secondary approval beyond the median voter or her representative is beneficial. This individual will operate on a longer time horizon, akin to the manner in which those serving in the U.S. Senate hold longer terms and possess the power to accept or reject nominations from the population's representative, the President. The evaluation period of this intermediary agent will be γT^*, where γ is some multiple altering the length of the evaluation period. A state then becomes terminal given the definition below.

$$P(S = S_T) = \begin{cases} 1\ if\ \bar{y}_{T^*} < \bar{y}_{T^*-1}\ \wedge\ \bar{y}_{\gamma T^*} < \bar{y}_{\gamma T^*-1} \\ .5\ if\ \bar{y}_{T^*} = y_{T^*-1}\ \wedge\ \bar{y}_{\gamma T^*} = \bar{y}_{\gamma T^*-1} \\ 0\ if\ \bar{y}_{\gamma T^*} > \bar{y}_{\gamma T^*-1}\ \vee\ \bar{y}_{T^*} > \bar{y}_{T^*-1} \end{cases}$$

This process introduces the need for some type of parliamentary procedure that regulates the interaction of the two representatives empowered by the democratic process. Modeling this final algorithm generates the following control chart.

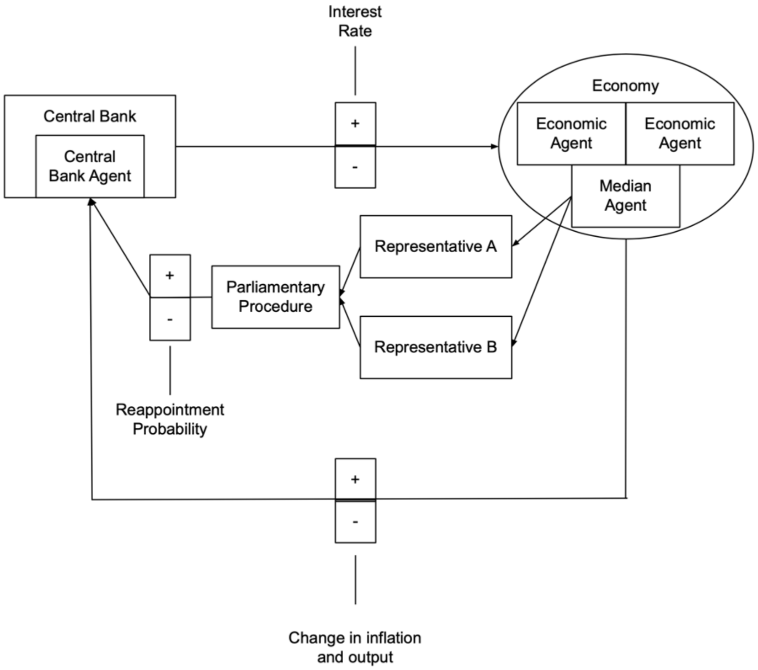

Figure 20: Parliamentary Central Bank Control Mechanism

With this declaration, the institutional algorithm is complete, and the impact of these various adjustments on macroeconomic stability can be determined. Though the agent will be terminated from the algorithm, the institution will receive a penalty of τ if the condition outlined above is met. In this way, the institution has a memory of sorts to avoid the impact of this cost in the future.

Section Four: Testing the Impact of Different Institutional Algorithms

This reinforcement learning algorithm uses a basic policy gradient method. The agent observes four main variables, present inflation and the previous period's inflation as well as present output and the previous period's output. To be clear, the agent is unaware of the functional relationships of these variables. It does not know what the potential of the economy is and has no concept of what an "optimal" monetary policy might be. It merely attempts to increase the reward it receives over time. The AI being taught here is not particularly forward looking as well with a discount rate of 10%. The goal of this exercise is to examine the impact of changing the institutional structure on policy. To this end, there will be two tests. First, I will examine the ability of agents to perform monetary policy in the absence of any stochastic elements. Second, noise will be incorporated to determine the impact of random elements. For both tests, the a_1 and b_1 parameters will be adjusted to examine alternative weightings of expectations and habit formation. Agents will forecast the output gap to be zero and possesses naïve inflation expectations for computational simplicity though this can be altered later. The remaining parameter values are provided in the table below.

Table 10: RL Model Parameters

Parameter	Value
a_1	.1-1
b_1	.1-1
a_2	.5
b_2	.5
ϵ_t	$N(0,.1)$
η_t	$N(0,.1)$
Simulations	100
τ	-100
γ	6
β	.1

Algorithmic Institutional Performance with No Shocks

Once again to be clear, the central bank agent does not know the underlying model or have access to the holistic set of data the economy generates. They possess imperfect information. However, even with these constraints the agent's policy choices converge into three main states. The first is stabilizing policy which closes the output gap almost completely and keeps inflation constant. The second is cyclical policy which endogenously creates a business cycle type outcome with an output gap centered around zero. Finally, the agent creates an amplifying policy in which there exists an ever-growing business cycle. The prevalence of a particular outcome in a certain parameter space is the direct result of the algorithm being utilized.

To begin, the baseline New Keynesian model in which parameters a_1 and b_1 equal one represents an entirely forward-looking economy. In other words, the agents within the economy engage in their own act of computation and forecasting and do not weight past behavior at all.

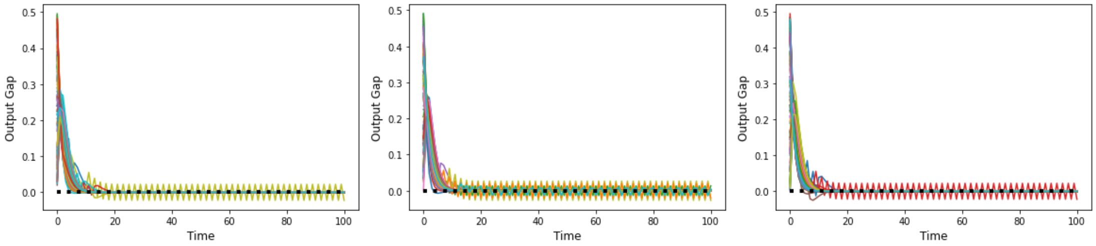

Figure 21: Output Gap (1) (a) Independent, (b) Democratic, (c) Parliamentary

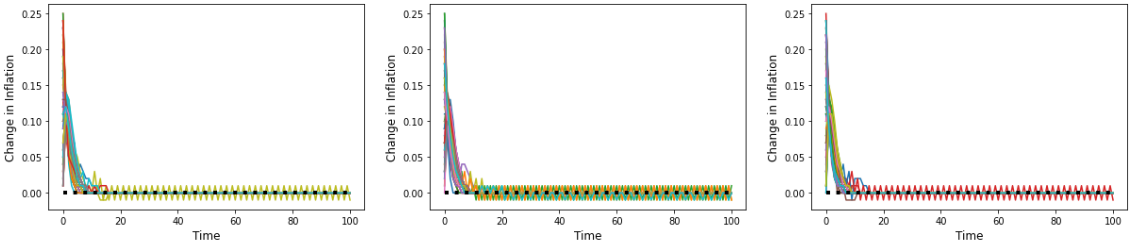

Figure 22: Change in Inflation (1) (a) Independent, (b) Democratic, (c) Parliamentary

Agents governed by the independent and parliamentary institutions converge to the stabilizing outcome in 99% of simulations whereas democratic institutions achieve this result in 97% of simulations with the remaining 3% becoming cyclical. These results are effectively identical but demonstrate the institution can have some effect even in this type of forward-looking economy. As these values for a_1 and b_1 decrease, the economy becomes more habitual in nature. Agents within the economy perform less computation of their own and instead simply look to their past. The real test for the institutions under consideration is when the computational load is placed on the policy agent[19].

The next presented result sets a_1 and b_1 equal to .7, resulting in some habit formation but the majority of weight placed on expectations.

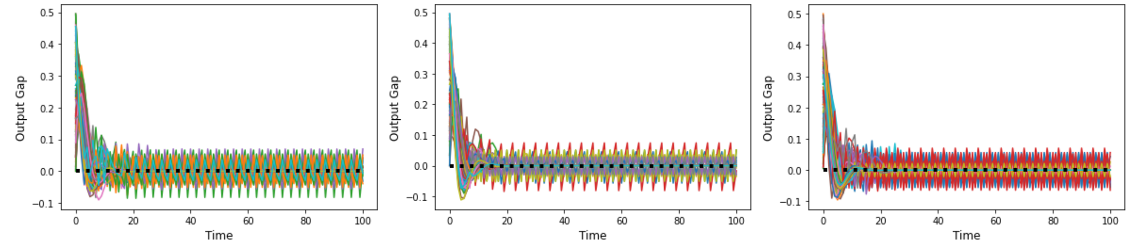

Figure 23: Output Gap (.7) (a) Independent, (b) Democratic, (c) Parliamentary

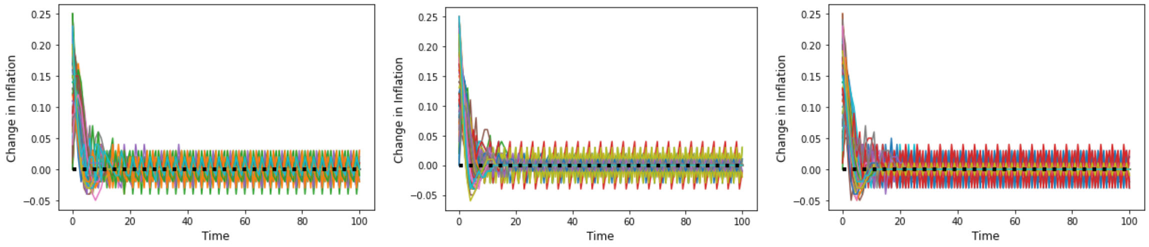

Figure 24: Change in Inflation (.7) (a) Independent, (b) Democratic, (c) Parliamentary

Agents in the democratic institution perform the best, converging towards stable policy in 90% of simulations while independent and parliamentary achieve stabilizing policy in 86% of simulations. The two important findings to note are the superior performance of democratic institutions with increasing habitual behavior and the ability of the

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[19] Not all simulations for each parameter value will be provided here but are available on request.

parliamentary institution to mostly recover the outcomes of the independent institutional algorithm.

The final results presented in the body of this work set the values of the a_1 and b_1 parameters equal to .3, an economy with heavy habit formation.

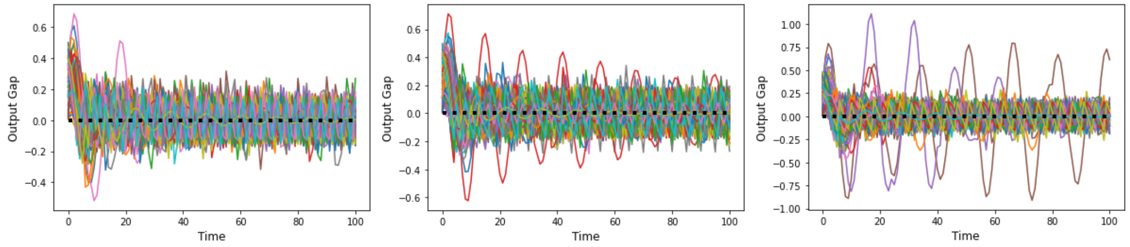

Figure 25: Output Gap (.3) (a) Independent, (b) Democratic, (c) Parliamentary

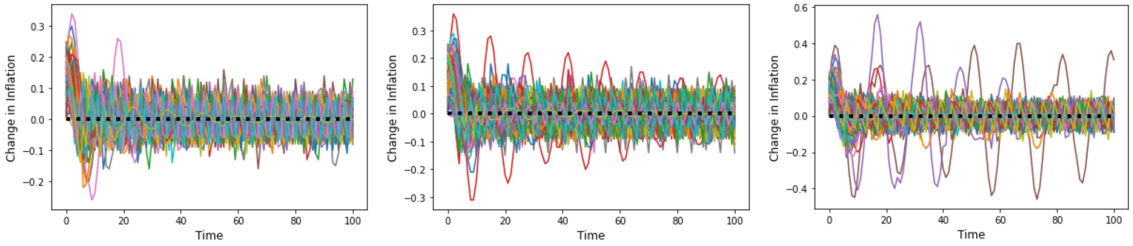

Figure 26: Change in Inflation (.3) (a) Independent, (b) Democratic, (c) Parliamentary

Here all agents are subject to the cyclical outcome regardless of the best policies they can locate within their institutional environment. However, differences still exist. The average size of the business cycle, from trough to peak, is heterogenous among institutions. An independent institution achieves a cycle nearly 10% smaller than those in a democratic system. A parliamentary institution recovers only about half of this result with a cycle 5% smaller than that of democratic institutions[20].

From these results two key narratives emerge. First, differential performance occurs among institutions dependent upon the actual workings of the economy and the behavior of the underlying agents. In some instances, a democratic institution leads to a superior performance and others an independent institution performs better. Second, the inclusion of the secondary approval in the parliamentary institution recovers the majority of the performance gain of the independent institution, indicating that additional mechanisms can in fact improve the performance of an algorithm. However, this highly stylized setting assumed no random shocks and no noise added to the values the agent observes. Obviously unrealistic to the real world, the next set of tests add this noise back into the macroeconomy to determine the impact on agent performance in these same institutional algorithms.

Algorithmic Institutional Performance with Shocks

With the addition of shocks, the same parameter values are examined, first for values of a_1 and b_1 equal to one. Due to the nature of the additional noise, to determine policy performance, the mean output gap for a given simulation is calculated and compared across institutions. The scale of this chart is presented in such a way such that a value of .005 corresponds to exceeding potential outcome by .5%.

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[20] Amplifying policy occurs at lower levels of a_1 and b_1 that are not presented here.

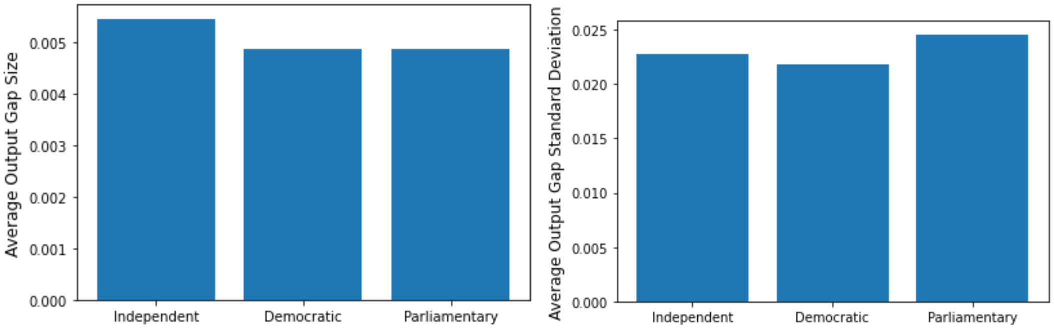

Figure 27: Output Gap (1) by Institution with Shocks

The democratic and parliamentary institutions fare better than the independent institution in this context, reducing the errors of the agent by 10%. The size of the errors is similar between a democratic and independent institution, with a democratic system reducing deviations more so than a parliamentary procedure.

The next simulation presented sets a_1 and b_1 equal to .7.

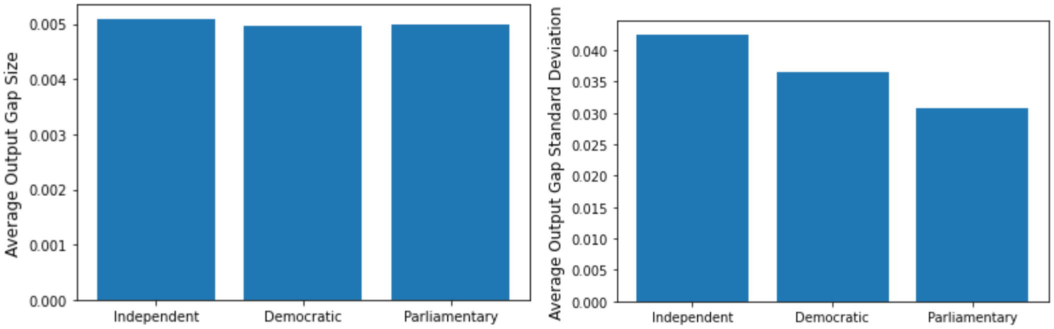

Figure 28: Output Gap (.7) by Institution with Shocks

With moderate habit formation, the average error is effectively equivalent for all institutional structures. However, the democratic and parliamentary error reduce the deviations of that error, with the parliamentary institutions performing best, leading to a more stable overall economy.

Finally, the last results presented sets the parameter values for a_1 and b_1 equal to .3 reflecting an economy with significant habit formation among the economic agents.

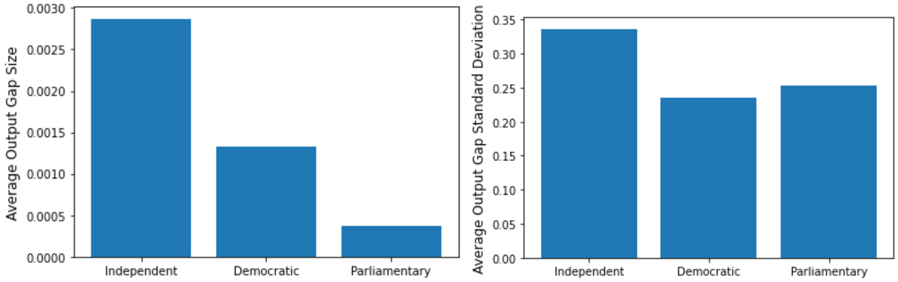

Figure 29: Output Gap (.3) by Institution with Shocks

In this economy with shocks and significant habit formation, the parliamentary institution significantly outperforms all other institutions by a sizable margin. However, democratic institutions also perform rather well.

Section Five: Conclusion

This piece possesses two key results. First, near ideal policy can be achieved with an agent that is unaware of the underlying model and is incentivized towards certain behavior due solely to the institutional structure. Further, the agent does not need the full set of data generated by the economy to properly engage with the environment they inhabit. They only need to know how their specific sub-environment, in this case the central bank, rewards them within the context of the broader economy. Second, the institutional structure or algorithm can generate real differences in performance dependent upon the underlying behavior within the economy. The above results demonstrate that different institutions perform more admirably than others. The reason for this finding is because the additional types of interactions unlocked by altering the algorithm reveal new information that can be beneficial to the agent in control of the policy apparatus. However, it can also be detrimental to performance under alternative parameters in the model. This approach demonstrates that the optimality of particular institutional algorithms is context dependent, reflecting the point made earlier about individuals performing well in endogenously designing solutions to their own perceived problems. It also notes that as parameters change, an institution may no longer achieve its desired goals, emphasizing the role of change and the ability to move between algorithms.

This basic analysis provides evidence for the potential of using AI, data science, control theory, and computer science to analyze the operations of institutions as algorithms. By developing this new economic cybernetics, socials scientists can use a formal approach to understand and model more abstract concepts contained within differing fields of study. Outlining the interaction procedures of an agent with its environment or other agents in this manner, we can begin to more properly comprehend the empirical results and mechanistic outcomes in which differing rules alter behavior in creative and unintended ways as well as begin to develop institutions which might improve on present solutions. Further, the use of AI and reinforcement learning in particular enables analysts to understand potential holes in our legal, political, and economic institutions that human nature and its natural inclinations towards habitual action might seem to imply do not exist. This sort of robustness check for institutional procedures is simply one possible use of this new economic cybernetics. Overall, using modern computational tools enables the social scientist to understand our institutions to a degree not previously possible. This piece begins to outline and apply such a toolset to the key area of monetary policy and central bank organizations.

APPENDIX

VARIABLES	(1) HOA Impact 2018	(2) HOA Impact 2018 Land	(3) HOA Impact 2018 Land and Size
HOA	0.565***	0.303***	0.216***
	(0.0252)	(0.0152)	(0.0130)
bradforddummy	-0.665***	-0.244***	-0.275***
	(0.149)	(0.0725)	(0.0585)
charlottedummy	-0.895***	-0.330***	-0.404***
	(0.159)	(0.0734)	(0.0812)
citrusdummy	-1.143***	0.147***	-0.0787*
	(0.0888)	(0.0569)	(0.0437)
desotodummy	-0.725***	0.0502	-0.115**
	(0.125)	(0.0598)	(0.0555)
duvaldummy	0.184***	0.0798***	0.0676***
	(0.0446)	(0.0209)	(0.0159)
gladesdummy	-2.048***	-0.690***	-0.895***
	(0.408)	(0.0850)	(0.186)
gulfdummy	-1.145***	-0.500***	-0.536***
	(0.214)	(0.124)	(0.0937)
highlandsdummy	-0.918***	0.132***	-0.0598
	(0.0637)	(0.0402)	(0.0368)
hillsboroughdummy	0.161**	0.180***	0.186***
	(0.0647)	(0.0415)	(0.0292)
indianriverdummy	0.262***	-0.0692	0.0924**
	(0.0856)	(0.0505)	(0.0403)
mariondummy	-0.570***	0.0791***	-0.0270
	(0.0500)	(0.0278)	(0.0234)
orangedummy	0.218***	-0.0189	0.0356*
	(0.0465)	(0.0229)	(0.0191)
osceoladummy	-0.181***	0.0686***	0.0846***
	(0.0521)	(0.0232)	(0.0178)
pinellasdummy	0.362***	-0.453***	-0.170***
	(0.0495)	(0.0374)	(0.0361)
sarasotadummy	0.106	-0.438***	-0.253***
	(0.0829)	(0.0309)	(0.0304)
sumnterdummy	0.0266	0.654***	0.611***
	(0.0714)	(0.0380)	(0.0299)
NBRHD18landmean		0.928***	0.707***
		(0.0142)	(0.0179)
NBRHD18lvgmean			0.496***
			(0.0314)
Constant	11.37***	1.838***	0.472***
	(0.0370)	(0.149)	(0.126)

Observations	8,228	7,975	7,494
R-squared	0.174	0.766	0.764

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)
VARIABLES	SF HOA Impact 2018	SF HOA Impact 2018 Land	SF HOA Impact 2018 Land and Size
HOA	0.314***	0.229***	0.167***
	(0.0203)	(0.0117)	(0.0113)
bradforddummy	-0.677***	-0.311***	-0.336***
	(0.130)	(0.0750)	(0.0739)
charlottedummy	-0.587***	-0.216*	-0.207
	(0.223)	(0.117)	(0.130)
citrusdummy	-0.808***	0.00308	-0.0228
	(0.0743)	(0.0494)	(0.0498)
desotodummy	-0.528***	-0.0341	-0.163***
	(0.113)	(0.0681)	(0.0628)
duvaldummy	-0.0337	-0.0305*	0.0387***
	(0.0377)	(0.0172)	(0.0147)
gladesdummy	-3.731***	-1.709***	-2.019***
	(0.0281)	(0.0377)	(0.0482)
gulfdummy	-0.983***	-0.813***	-0.624***
	(0.367)	(0.185)	(0.193)
highlandsdummy	-0.760***	0.0516	-0.0605
	(0.0638)	(0.0388)	(0.0388)
hillsboroughdummy	0.235***	0.160***	0.215***
	(0.0455)	(0.0302)	(0.0260)
indianriverdummy	0.113	0.0272	0.134***
	(0.0859)	(0.0468)	(0.0404)
mariondummy	-0.438***	0.0396	0.0465**
	(0.0426)	(0.0263)	(0.0229)
orangedummy	0.145***	-0.0130	0.0786***
	(0.0369)	(0.0192)	(0.0178)
osceoladummy	0.00861	0.150***	0.105***
	(0.0333)	(0.0186)	(0.0165)
pinellasdummy	0.314***	-0.296***	-0.00684
	(0.0399)	(0.0262)	(0.0288)
sarasotadummy	0.343***	-0.239***	-0.0650**
	(0.0598)	(0.0260)	(0.0294)
sumnterdummy	0.222***	0.681***	0.613***
	(0.0476)	(0.0280)	(0.0263)
NBRHD18landmean		0.725***	0.540***
		(0.0120)	(0.0192)
NBRHD18lvgmean			0.687***
			(0.0344)

Constant	11.72***	4.146***	0.867***
	(0.0281)	(0.128)	(0.120)
Observations	5,834	5,581	5,581
R-squared	0.208	0.737	0.786

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

VARIABLES	(1) HOA Count Impact 2018	(2) HOA Count Impact 2018 Land	(3) HOA Count Impact 2018 Land and Size
HOA	162.2***	188.0***	164.4***
	(17.94)	(18.48)	(19.05)
NBRHD18landmean		-53.25***	-139.5***
		(8.119)	(17.66)
NBRHD18lvgmean			99.81***
			(26.39)
bradforddummy	1,836**	1,814**	1,976**
	(768.3)	(765.2)	(834.2)
charlottedummy	918.5***	884.8***	919.1***
	(219.9)	(216.9)	(232.2)
citrusdummy	367.9***	292.9***	275.8***
	(35.47)	(36.44)	(38.54)
desotodummy	82.71**	40.30	-24.04
	(33.27)	(33.78)	(37.51)
duvaldummy	217.5***	222.9***	231.0***
	(11.37)	(11.36)	(12.03)
gladesdummy	1,024***	943.0***	851.3**
	(309.2)	(322.0)	(355.5)
gulfdummy	2,251***	2,211***	2,185***
	(767.6)	(778.5)	(797.3)
highlandsdummy	152.2***	92.68***	5.112
	(24.31)	(25.07)	(30.05)
hillsboroughdummy	803.2***	799.2***	903.0***
	(46.39)	(46.84)	(49.29)
indianriverdummy	256.5***	276.8***	335.8***
	(47.34)	(47.22)	(53.68)
mariondummy	158.7***	122.1***	75.39***
	(15.89)	(15.78)	(17.06)
orangedummy	333.2***	342.9***	381.2***
	(21.54)	(21.72)	(23.21)
osceoladummy	14.43*	0.564	-11.36
	(7.437)	(7.744)	(8.757)
pinellasdummy	284.7***	630.8***	772.9***
	(24.55)	(34.11)	(40.57)
sarasotadummy	582.2***	608.2***	729.1***

	(55.17)	(55.34)	(59.05)
sumnterdummy	34.26***	0.262	-46.89***
	(6.196)	(9.044)	(12.39)
Constant	45.05***	589.4***	740.6***
	(5.328)	(83.68)	(105.7)
Observations	8,237	7,975	7,494
R-squared	0.140	0.157	0.179

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

VARIABLES	(1) HOA Impact 2018	(2) HOA Impact 2018 Land	(3) HOA Impact 2018 Land and Size
HOA	150.1***	172.7***	172.6***
	(18.48)	(19.12)	(19.45)
NBRHD18landmean		-82.66***	-83.02***
		(14.43)	(20.61)
NBRHD18lvgmean			1.340
			(30.52)
bradforddummy	2,952**	2,913**	2,913**
	(1,288)	(1,279)	(1,278)
charlottedummy	1,057***	1,014***	1,014***
	(385.7)	(380.7)	(380.8)
citrusdummy	334.3***	240.4***	240.4***
	(54.68)	(54.44)	(54.56)
desotodummy	92.89*	39.39	39.14
	(54.00)	(53.85)	(55.06)
duvaldummy	217.4***	216.5***	216.6***
	(12.31)	(12.30)	(12.71)
gladesdummy	26.19***	-201.3***	-201.9***
	(6.152)	(40.53)	(50.38)
gulfdummy	3,032**	3,003**	3,004**
	(1,339)	(1,367)	(1,367)
highlandsdummy	117.1***	25.61	25.39
	(27.20)	(30.36)	(32.48)
hillsboroughdummy	859.6***	864.8***	864.9***
	(50.68)	(50.76)	(50.96)
indianriverdummy	317.6***	329.3***	329.5***
	(60.18)	(60.02)	(60.39)
mariondummy	111.2***	57.50***	57.51***
	(16.79)	(17.87)	(17.79)
orangedummy	345.6***	358.8***	359.0***
	(23.75)	(24.06)	(24.92)
osceoladummy	14.45*	-1.514	-1.603
	(7.559)	(8.316)	(9.001)

pinellasdummy	280.1***	743.6***	744.2***
	(25.47)	(35.38)	(40.68)
sarasotadummy	536.4***	596.1***	596.4***
	(47.63)	(48.35)	(50.70)
sumnterdummy	51.09***	1.490	1.357
	(7.178)	(12.13)	(13.89)
Constant	44.81***	905.1***	898.7***
	(6.152)	(150.6)	(127.7)
Observations	5,834	5,581	5,581
R-squared	0.173	0.196	0.196

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

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