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Agent Based Modeling and Austrian Analysis of Accident Law

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Abstract:

The purpose of this project is to demonstrate that the economic analysis of the law should proceed from the notion that individuals form a spontaneous order in response to the institution of tort law, each other, and their environment. First, I address the methodological advantages of the emergent framework over that of the mainstream neoclassical position, as well as assess the Austrian contribution. I then attempt to reconcile agent-based modeling with the common methodological concerns. I subsequently attempt to demonstrate the efficacy of agent based modeling as an analytical tool that exploits its dynamic capabilities and develop an artificial society in which virtual agents endowed with varying attributes pursue productive, though inherently accident prone activity. The accidents are chance encounters and engaging in behavior that reduces the likelihood of accidents is costly. I consider the typical questions researchers working within the neoclassical tradition tend to pursue such as analysis of the relative benefits of strict liability and negligence. However, I also highlight that the agent-based approach is also useful in inspiring and answering wide ranges of questions that the neoclassical framework is incapable of identifying and examining.

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I. Introduction

It is appropriate that scholars working within the Austrian tradition would bring a unique perspective to economic analysis of the law, considering the school's founding fathers such as Carl Menger, Ludwig von Mises and Frederich Hayek all received their doctorates in law. These scholars are credited with creating a well developed theory of the market process (see for example Mises 1996; Hayek, 1948; Kirzner, 1973) and spontaneous order (Hayek, 1973) that serves as a methodological alternative to the mainstream neoclassical paradigm. It is the purpose of this essay to more fully exploit the insights of spontaneous order economics and apply them to the economic analysis of accident law. Through the course of this endeavor, I examine the suitability of agent based simulation as a tool towards this end.

The typical neoclassical analysis proceeds by imposing equilibrium upon the phenomena under examination and deducing the behavior of the individual actors that sustains that equilibrium. As an alternative, I argue that examining the law through the lens of spontaneous order economics gains substantial insight and can illuminate important characteristics that are often overlooked in the mainstream neoclassical theorizing. In addition, a gap is identified in the Austrian literature on accident law and an attempt is made to shore up what has heretofore been overlooked. I leverage the notion that many social phenomena are best understood as spontaneous orders. For example, Rizzo (1980) argues the static General Equilibrium construct underlying the neoclassical analysis of accident law is an inappropriate method to analyze a dynamic system constantly in a state of flux. He questions the usefulness of such concepts as "least cost avoider" and "last clear chance" and ultimately undermines neoclassical notions of

common law efficiency. I also draw from Wagner (2007) and argue in favor of a conjunctive view of society, as opposed to a teleological disjunctive perspective.

I then explain the manner in which agent-based modeling is consistent and complementary to Austrian theory and finally I provide an example of employing an agent-based computational model in the analysis of accident law. I present the situation faced by the inhabitants of Eggtopia, a fictitious society whose members search for and collect precious eggs. In the course of their productive efforts they occasionally experience destructive accidents with other individuals. The inhabitants face trade-offs in that engaging in behavior that increases their productivity may also increase the possibility of an accident. I demonstrate how the agent-based model of Eggtopian society developed in this paper can be used to answer the questions commonly addressed in the mainstream literature. The efficiency of various liability regimes is one such thread of analysis. Other threads include the effects of systematic uncertainty regarding the extant judicial precedent or in the court's ability to obtain the necessary information to appropriately apply the legal rule. The analysis within the neoclassical framework revolves around the economic efficiency of various rules given certain extensions and complications. The power of the evolutionary approach is not simply that it assists in developing a genetic-causal explanation as a means for determining the desirability of various liability rules, it is that the approach enables the exploration of population dynamics and a close examination of out of equilibrium behavior. Among the realizations this framework yields is the notion that system level steady state does not necessarily imply agent level steady state, agents may elect to be careful even when the neoclassical theory predicts otherwise, and liability rules differ in their ability to rid society of negligent behavior.

A search of the literature to find an agent-based simulation model applied to this aspect of economic analysis of tort law has proven unsuccessful. Diianni (2007) has applied such techniques to model disputants and the evolution of precedent. See also Yee (2005), and Picker (1997; 2002) for treatments on similar topics. The current project is an attempt to remedy this gap.

II. A Brief Review of the Literature

What I refer to as Neoclassical Economics in this paper describes the metatheory within which most mainstream economists currently work. Researchers working within this framework generally adhere to the following fundamental assumptions (Weintruab, 2008):

1. People have rational preferences among outcomes.
2. Individuals maximize utility and firms maximize profits.
3. People act independently on the basis of full and relevant information.

In "The Economic Approach to Human Behavior" (1976), Gary Becker states that the "combined assumptions of maximizing behavior, market equilibrium, and stable preferences, used relentlessly and unflinchingly, form the heart of the [neoclassical] economic approach (p.5)." While this approach is firmly embedded as the dominant mainstream paradigm, as other theorists would point out, namely the Austrians, this would come at the price of realism and conceptual clarity (see Boettke, 1997). For the purposes of this discussion, we will concentrate on two of these methodological tenants, rational utility maximization and the use of equilibrium analysis.

Do individuals actually maximize utility? Perhaps the more pertinent question is whether models that suggest they do are more useful and insightful than models that make the modest assertion that individuals merely economize between known choices. One could rather easily list at least fifty different items to include in an ice cream sundae (ice cream flavors, toppings,

syrups, fruit, etc). Choosing any five ingredients yields approximately 2.1 million different combinations of sundaes. If one were to eat three different sundaes every day, it would take nearly two thousand years to exhaustively test every possibility and decisively determine one's favorite. This combinatoric critique highlights two separate but related limitations of human rationality in that human beings are neither able to collect nor cope with all of the information they are purported to possess and analyze as rational utility maximizers. While the ice cream sundae example is certainly not a devastating critique of Max U, it begins to build the case that it is preferable to select mental models to organize thoughts on the basis of intelligibility as opposed to positivist predictability. To that end, an emergent critique of the hyper-rational utility maximizer is to call into question just how individuals are able to negotiate the maze of nearly infinite combinations of means to effectively achieve the myriad ends they seek. Individuals are only capable of selecting between means of which they are aware. There may be other means that prove more fruitful if only brought to their attention. From this perspective, entrepreneurs are seen as explorers of combinatoric space, providing maps to the previously uncharted universe of means-ends combinations.

Potts' (2000) provides an enlightening critique of the foundations of neoclassic economic theory and attempts to unify the heterodox schools of thought under the umbrella of an evolutionary microeconomics. He argues that:

> Underpinning all neowalrasian economic theory is the concept of the real field: $\mathbf{R}^n$… [I]n mathematics the real field is the generalization of arithmetic and the foundation of integral and differential calculus; one simply cannot do analysis without this concept…. And so from the marginal revolution onwards economics has appropriated this concept and … cemented it into the very foundations of the theoretical edifice. The result is what passes for modern economic orthodoxy is a special application of field theory. (p.11: citation omitted for clarity)

It is the notion of the field that underpins the fundamental assumptions of neoclassical economics. It is ultimately why any recognizable version of choice, competition, and action disappear from general equilibrium theory; it is why time is homogenous and Newtonian in character; and information is always complete or otherwise known as a probability distribution. The field as a concept was borrowed from physics on the notion that it provided economic science with a measure of rigor that was previously missing from the classical theory. While Potts is not the first theorist to identify the ontological and epistemic difference between physics and economics (for example, Mises 2006; Rothbard, 2004), he does provide an innovative graph theoretic foundation as an alternative. He argues that connections or relationships among elements in the economic system are the important evolutionary variables of change, which is a notion that the field construct obscures.

Most importantly, the static nature of general equilibrium theorizing purges all concept of time from the model. Time is a fundamental aspect of the market process as it has a profound effect on how individuals choose and act. Action is unthinkable without time. Since the future is unknowable, all choice – or action, takes place under a fog of uncertainty. Individuals working within the market process constantly adjust their behaviors and strategies as a result of information that becomes revealed in the execution of the plans they have formulated. As the plans of the entrepreneur come to fruition, she is able to measure her profit or loss, thus providing the ultimate criteria against which to measure the success of the plan formulated under the uncertain circumstances of the past.

Law and economics scholars in the neoclassical tradition, such as Landes and Posner (1981) typically develop an explicit mathematical function that describes the social welfare function for actors related to a particular type of accident (see Posner (1985), Shavell (1987), and

Cooter and Ulen (2007) for textbook treatments). A representative injurer and a representative victim are selected to simplify the analysis and delineate the roles of the disputants. The social welfare function for a default of no liability is constructed that ultimately embodies the notion that the overall costs of accidents include both the damages that occur as a result of physical accidents, as well as the costs of prevention. The effects of various other liability rules are deduced from manipulations of the social welfare function. Posner asserts that the judiciary should strive to select the liability rule that minimizes these costs for each situation. In fact, his Positive Theory of Tort Law asserts that the common law with regard to tort has evolved through the generations as if judges, through their holdings, have attempted to minimize these accident costs (Landes and Posner, 1981).

B. A critique of Austrian Accident Law and Economics

Rizzo (1980; 1985) calls into question the application of typical neoclassical techniques, such as General Equilibrium analysis, to the realm of accident law due to the framework's inability to appropriately handle the dynamic nature of this facet of society. He demonstrates the hollowness of such doctrinal concepts as "least cost avoider" and "last clear chance", among others. As well he questions the court's ability to calculate the social consequences of certain activity in light of the out-of-equilibrium prices that persist in the market (pp.309-310). While Rizzo's analysis culminates in the determination that the rule of strict liability is superior to the rule of negligence in terms of institutional efficiency, I refrain from judgment on this particular issue at this time. I contend that Rizzo's dissatisfaction for the neoclassical framework ultimately stems from his realization, though implicit, that the static neoclassical analysis is an inappropriate tool for the study of spontaneous orders. A method that does not rely on static,

formal mathematical descriptions of behavior and instead embraces the dynamic nature of the system with outcomes that emerge as a result of individuals' decentralized decision making would be superior and perhaps satisfy some of Rizzo's criticisms. Agent based computational modeling provides a powerful tool that allows a researcher to relax the general equilibrium assumptions, thus enabling greater realism while maintaining a tractable model. The result is the ability to develop models of interest to social scientists that are recognizable reflections of reality and ultimately capable of enhancing understanding of complex phenomena.

Rothbard (1997, pp.121-170) though an important contribution to the Austrian literature, is essentially an effort to justify a natural rights perspective using praxeological arguments and as such, is largely orthogonal to the discussion in this project. Beginning from his methodological origin of radical subjectivism and an ideological foundation in favor of strict property rights, he notes that intention is crucial in determining liability of an individual in a tort action. He examines the case of *Courvoisier v. Raymond* (1896), wherein a man is threatened by an angry mob. Another man emerges from the crowd and approaches the first. In his anxious state, the first man feels threatened and exercises his right to defend his person by shooting the second, who unfortunately turned out to be a plain-clothed policeman attempting to offer assistance. Rothbard argues that because the policeman's rights to security in his person were violated, the defendant should have been found strictly liable for damages.

Several other contributors from the Austrian School extend Rothbard's arguments (Hoppe, 2004; Kinsella and Tinsley, 2004; Sechrest. 2004). As far as genuine chance encounters are concerned, all tend to argue in favor of the rule of strict liability, for largely normative reasons. However, the moral implications of various liability rules are outside the scope of this

project. The model developed in this essay is meant to facilitate theorizing in an attempt to fill this gap with a more consequentialist perspective.

III. Law, Economics, and Spontaneous Order

Numerous researchers have noted that the body of laws that comprise the common law are the result of a spontaneous order (Hayek, 1973; Posner, 1972). These laws have been modified incrementally for countless generations and evolved through an evolutionary process of hierarchical, yet decentralized attempts by various judges attempting to decide cases on the basis of general principles. These laws also provide the foundation upon which the spontaneous order of society is built. Abstract, purposeless, and equally applicable laws facilitate the generation of order from the bottom up, as individuals are encouraged to use their particular knowledge of time and place to their own advantage. Fehl highlights the dual levels upon which spontaneous order exists:

> To identify the legal and moral framework as an important prerequisite of the spontaneous order is an essential point. As is well known, such 'rules' generate an order in themselves. They enable the individual to make plans involving the interaction with other individuals, insofar as the execution of contracts can, in principle, be expected by the actors (Fehl, 1994, p.200).

The institutions of private property and freedom of contract facilitate the spontaneous generation of the market and the emergence of the price mechanism. Individuals refer to prices as guides in pursuit of profits, the existence of which is an indication that they have been successful in satisfying the most urgent demands of consumers, while the lack thereof is an indication of their failure.

While certain institutions of the law enable the emergence of an explicit price mechanism through trade, i.e. certain facets of private property coupled with contract law, other legal institutions serve merely to impose an implicit price for particular behavior such as criminal or tort law. For instance, the fact that the courts enforce a farmer's property rights in his apples, as well as mutually agreed upon contracts that govern their exchange, ultimately enables a market for apples to emerge the outcome of which is a market price for a given quantity and quality of apples. In contrast, the fact that the courts enforce a farmer's property rights in his house by levying a punishment of, say, two years in prison for burglary means that potential burglars face an implicit price for engaging in such behavior. They must weigh their perceived probability of getting caught and punished, by their subjective valuation of the magnitude of the punishment (Becker, 1976). This section examines the characteristics of spontaneous orders that emerge as the result of such non-market decision making.

A. Accident Law and the Emergence of Spontaneous Order

Tort law governs interactions between strangers, such as chance encounter accidents, where circumstances prevent participants from reaching a contractual arrangement *ex ante*. The law as handed down in the rulings of judges ultimately results in the emergence of an implicit price for engaging in risky behavior. Individuals gauge the riskiness of their behavior in terms of damage suffered in the event of an accident, as well as an expectation of how the courts might assign liability. Even if we assume that all participants know the exact liability rule in effect and all of its implications, the ultimate effects of the law upon the individual also depend upon the behavior of every other individual. Even if, say negligence was set at a particular level of care, some individuals may decide upon a behavior whose perceived expected value may result in

either greater or less care, simply due to their unique preferences. The process through which individuals compare their perceived expectations with objective reality is highly stochastic due to the variation and interdependence of all other agents and greatly complicates an agent's ability to select behavior that achieves her desired outcome. In this way an implicit price emerges as a result of human action, but not of human design, in a manner parallel to a market price. So, just as the behavior of individuals engaging in market behavior may be considered a complex adaptive system, so may the interaction of individuals engaging in productive, yet accident prone activity.

There are two ways to conceptually frame the relationship between the judicial system and the individuals in society. The first is the more common perspective of the state as a unitary being that stands outside of the market, and intervenes, as necessary to correct deficiencies. Wagner (2007) describes this as the disjunctive perspective. It is disjunctive in the sense that the state is separate from the society of individuals that it governs. In applying these notions to the economic analysis of the law, the implication is that disjunctive analysis treats the judiciary as a monolithic organization that pursues goals with singular focus. The alternative paradigm is a conjunctive perspective, which acknowledges that even the state exhibits the qualities of a spontaneous order as opposed to an organization. "Within the framework of a conjunctive political economy, the state is not a sentient being that intervenes into the market, but rather is an institutionalized process or forum within which people interact with one another (Wagner, 2007, p.14)." In Wagner's analysis, there exists a market square for private transactions, and a public square for collective transactions where private property and residual claimancy is simply absent or attenuated. Individuals who seek to start an enterprise may select either forum to build the

necessary relationships. In this view, the courts are simply another forum that resides in the public square.

A disjunctive analysis of tort law identifies the presence of externalities and market failure that give rise to disputes, such as the fact that people might drive too fast and impose too high a threat of accidents upon others. They recognize that the existence of transactions costs form a barrier to bargaining between accident disputants *ex ante*. So, it is incumbent upon the judiciary to decide matters such that the efficient outcome obtains and teleologically impose decisions or policy towards that end. Along the spectrum of concepts that range from the teleological to spontaneous, the interaction of the judiciary and those governed does lend itself to a teleological explanation from a certain perspective. An indifferent judge stands outside the case at hand and decides on matters of fact and matters of law that have repercussions to the individuals in society at large. Indeed, in much economic research, the institutions of private property, freedom of contract, and law of torts are assumed to work flawlessly and are relegated to the background. In neoclassical law and economics, the judiciary is seen as an independent body that intervenes as necessary to fine tune the rules governing the interactions of individuals such that society's wealth is maximized.

However, there are some characteristics of the law that are illumined from taking a more conjunctive perspective. The conjunctive view of the legal world embraces the notion that society is not a fully connected graph such that each element is connected to all others. While a single judge might reach a decision and set a precedent, that judge’s power to actively change society is limited, because laws as handed down in judicial decisions still require the general consent or adherence of those to whom the law applies. In other words, judges should not expect the decisions they pass down to garner unquestioning obedience from all affected individuals. In

a Hayekian sense, a judge's ruling in a case is not a command to an organization in the same way that a military leader commands his subordinates, but rather it helps form the rules of conduct that individuals consider before ultimately deciding upon a course of action suitable to meet their unique goals.

In addition, since judges often must rely on members of the executive branch of government to enforce the ruling, their ability to craft decisions to fully correct the deficiencies they perceive is even more attenuated. Finally, a judge's ruling might also be overturned on appeal; so many judges confine their decisions so as to limit the likelihood of being overturned. A main theme of this paper not only highlights the difficulties judges face when attempting to determine the wealth maximizing liability rule, but also the difficulty in anticipating how the individuals that comprise the complex adaptive system that is society will react to the ruling. This notion is similar to Lucas's famous critique (Lucas, 1976) for macroeconomic policy. When applied to this setting, it suggests that even if judges faced no knowledge problem regarding the determination of the optimal rule given the datum of behavior under the current rule, they still face difficulties in predicting how individuals will react to the new purportedly better rule.

IV. Spontaneous Order Economics and Agent-Based Modeling

Spontaneous orders are also known as complex adaptive systems in the artificial intelligence and computational economics literatures. Complex systems are composed of interacting agents that exhibit emergent properties (Tesfatsion, 2006, p.836). A system is complex if it is composed of interacting units and exhibits emergent properties that cannot simply be deduced from aggregating the system's components and emergent properties are those

"properties arising from the interactions of the units that are not properties of the individual units themselves (p.836)." Further, a compex adaptive system is "a complex system that includes *goal-directed* units, i.e. units that are reactive and that direct at least some of their reactions towards the achievement of built-in (or evolved) goals (p.837)." Agent-based models, properly constructed, are themselves complex adaptive systems in that goal-directed agents interact to exhibit emergent properties. Thus, to the extent that phenomena exhibit complexity, agent based modeling represents a potential tool to facilitate the development of an invisible hand explanation of such phenomena.

In the present case the emergent object is the implicit price of a particular behavior and is the result of the complex process of interactions of individuals. These individuals do not set out to minimize the social costs of accidents, they simply select courses of action on the basis of their subjectively valued ends and their perception of the means available to achieve them. Researchers working in the fields of Agent-Based Modeling and various facets of simulation study inform this analysis, but it is also heavily influenced by numerous scholars of the Austrian School, particularly their contributions to the theory of the spontaneous order. As such, I attempt to show that agent-based simulation, appropriately applied, can be a useful tool for all scholars who study both market and non-market processes.

Boettke and Leeson (2002) offer an outline of the core tenants of how the Austrian school of economics frames its theorizing. While many of the tenants have been (at least superficially) absorbed into neoclassical economics to some degree, taken together, they outline the basic methodology and substance of Austrian economics. The three core methodological tenants are methodological individualism, subjectivism, and the notion of the market as a process (Boettke, 1994). Austrian theorists, perhaps more than many other economists embrace the notion of the

market as a process through which the subjective demands of consumers are met with the scarce resources available. The fact that process, individual choice under uncertainty, and subjectivism are in the foreground of their analyses has led the scholars following this tradition to turn their attention to the coordinating effects of entrepreneurship, money, and social institutions that enable individuals to better cope with uncertainty.

Hayek dedicated the vast majority of his life's work elucidating the intricacies of spontaneous order. According to him, order is achieved when the individuals in a society adjust their behavior such that accurate expectations might be formed regarding their future conduct (Hayek, 1973, p.36). The price mechanism is one social institution responsible for enabling individuals to pursue and achieve coordination of consumption and production plans in a decentralized manner. The division of labor is a grown order in which individuals pursue their own goals and are able to coordinate their behavior by sending, receiving, and interpreting price signals communicated as a result of their participation in the market. Alternatively, an organization is a made order, where relationships are formed exogenously and information flows through consciously developed channels (Hayek, 1973, p.37). In organizations, subordinate units carry out the plans of superior units and execute only the tasks assigned them.

The quintessential organization is a military unit. The members of the organization constantly look for guidance from their leader, as they are rarely delegated the authority to make decisions based purely on their local knowledge. Rather, they feed this local knowledge up the chain-of-command so that the commander may make his decision based on the aggregation of all the subordinate knowledge. The nature of organizational decision making and the concomitant limitations of the human mind's ability to process information place significant constraints on the complexity of organizations and their ability to adapt to rapidly changing situations. In an

organization, order is maintained by the unitary action of the leader and the alacrity with which his commands are executed.

Order is grown endogenously in a spontaneous order as individuals adhere to rules of conduct on the basis of particular information of time and place (Hayek, 1973, p.37). Outcomes emerge as result of purposive action on the part of agents, rather than the result of the design of any one particular mind. Hayek argues that it is the nature of the rules that govern individual interaction that determine whether order is grown, made, or achieved at all. While the rules that govern an organization tend to be concrete and provide relatively specific instructions to specific individuals with the intent of accomplishing a stated goal of the organization, the rules that govern a spontaneous order are abstract, purposeless in the sense that particular collective outcomes are not pursued, and equally applicable to all individuals. Such rules enable individuals to make the most appropriate use of their specific knowledge of time and place while enabling order to emerge spontaneously.

While agent-based simulation, properly employed, as a method appears capable of complementing Hayek's spontaneous order economics, there are certain aspects of the body of Austrian work that may not be as accommodating. For instance, it would appear that the extreme apriorism of praxeology as a method of inquiry should cause Austrians to reject agent-based modeling as too empirically oriented and arbitrary. However, I intend to show that most of the apparent differences can be adequately resolved.

It is difficult to argue that agent-based modeling is as rigorous as the demanding methodological constraints of praxeology. Praxeology begins with the action axiom that states that human beings act to remove a certain felt uneasiness (Mises, 1996; Rothbard, 1997). This axiom is held to be true *a priori*. Any theories deduced from the axiom are held to be true with

didactic certainty, as long as the chain of logical reasoning is valid. Certain postulates may also be added, such as the notion that individuals perceive a disutility of labor, which change only the domain under which the resultant theories are operative. Thus, any theories derived from such a postulate are held to be true, but only in those instances where (ceteris perabis) leisure is preferred to labor.

Agent-based models are representations of particular sets of assumptions instantiated in computer code. Each simulation run is a realization of the chain of deductions based on the set of assumptions, or as Epstein (2006) notes, every simulation replication is essentially a sufficiency theorem. Upon completion of an experimental design, the researcher uses inductive techniques and statistical analysis to choose among the population of candidate theories that the simulation has produced. While this process of induction is not necessarily of the same character as the scientistic empiricism that Austrians tend to criticize and seek to avoid with aprioristic techniques, it is possible a model may produce competing theories. The criteria developed to select between competing theories would not be immune from the arbitrary opinions of the researcher and thereby limit the theory's universality. However, it does represent a step in the direction of greater realism relative to the neoclassical framework. And, while the conclusions arrived at would not necessarily be true with didactic certainty, the goal of such research should be to achieve pattern predictions and explanation of principles rather than universal laws.

A computer model, such as an agent-based simulation, must be built upon much narrower assumptions than the action axiom. As such, it is necessary to make arbitrary decisions regarding the assumptions that govern agents' behavior. For instance, in their Sugarscape model, Epstein and Axtell (1996) found it necessary to make assumptions regarding the particular characteristics of the agents' motivation for collecting and consuming sugar. Among the infinite

number of mechanisms to govern agent behavior, one must be chosen and instantiated in the model. So, a critic might argue that the conclusions arrived at in the Sugarscape study are only valid for humans that eat only sugar and have significantly restricted vision, etc. However, that charge misses the point of a simulation study of simply gaining an understanding of the complex mechanism under examination.

Mises developed his methodology to study praxeology in an attempt to craft a universal theory of human action independent of time and place. As such, it was necessary to purge any ad hoc or contingent elements from the framework, since the presence of arbitrary premises would ultimately limit the application of the theory. Arbitrary designs might creep into the development of an agent-based model, and thus limit its application to only that domain in which the peculiar notion is operational. However, it is important to note that there is much more to good economic theorizing than praxeology. After all, as Lavoie (1994) states, "doing economics in an Austrian way is tracing systemic (spontaneous order) patterns of events to the (subjectively) meaningful purposes of (individual) human actors (p.56; parentheticals in the original)." As such, I intend to show that agent-based simulation is consistent with much of *the rest* of Austrian economics.

Mises recognized that the science of human action has a theoretical and a historic aspect (Mises, 2003; 2006). Properly understood, theory is a tool that the student of human action employs in order to make sense of history. The employment of conjectural history, is a technique in which the theorist develops historically contingent theory. When conducting conjectural history, reference is made to specific institutions, policies, or other arrangements that were present in reality at the time.

> Such conjectural histories therefore make use of the ideal-type constructs (these constructs, to be sure, never refer to ideal-typical *people*, but only to ideal-type *objects* or *consequences* of action), although their truth follows apodictically where all the real-life equivalents of the specified ideal-types are present in a given historical circumstances. Causal-genetic or "evolutionary" theories such as Menger's theory of the origin of money fall into this category of conjectural history (Selgin, 1988, p.27; emphasis his).

Theory developed in this manner is highly contingent on the underlying assumptions, but it is indispensable to the analysis of economic phenomena that appear in reality. Agent based simulation can assist researchers in the conduct of conjectural history by facilitating the examination of complex processes. It is capable of employing ideal-types, both agents and institutions, and ultimately assists the researcher in providing a genetic-causal explanation of social phenomena.

In his discussion of the use of ideal types in economics, Koppl (1994a) notes that ideal types are "intelligible" representations of actions or actors (p.72). He goes on to explain that the generality of an argument based on the use of ideal types depends upon the anonymity of the ideal type used. "The anonymity of a personal ideal type is the degree to which it is empty of particular content (p.73)." Thus, the more anonomously the agents inhabiting artificial societies are developed, while remaining recognizable to human beings as actors, the more effective will be their employment as ideal types.

In Cowan (1994) and Cowan and Rizzo (1996), the authors elucidate the importance of the notion of causation in economic analysis. The genetic-causal approach they outline embraces the notion that the cause of an outcome "creates a unidirectional *process* the outcome of which is the effect (1996, p.274)." Purposive human behavior, traced back to the tastes and expectations of individuals, are the endogeneous causes of these outcomes. Typical mainstream equilibrium economics eschews notions of causations. After all, in order for a cause to originate,

a change must occur, but change is essentially precluded in the equilibrium framework. Agent-based modeling is uniquely suited to illuminate these complicated chains of causation that result in emergent unintended outcomes. The models are capable of providing researchers with comprehensive information regarding the state of each and every individual agent in the population, which enables the researcher to follow chains of causation from their inception to their ultimate end. However, it should be stressed that such endeavors are truly only fruitful if they lead to greater understanding of actual processes.

Cowen and Rizzo (1996, p.301) borrow what Bunge (1960, p.401) terms as a *poistem*, or "a system of interrelated qualities or variables." They demonstrate that certain mainstream analyses conclude in a poistem, simply because the answer is mathematically derived and lacks any notion of asymmetrical causation. See Seagren (2009, especially Ch 5) for a more thorough analysis of this concept and how it applies to neoclassical law and economics models. These models may be used to derive optimal agent behavior given a particular liability rule, however, they lack a description of the process by which individual, self interested agents are provided the appropriate incentives that induce socially optimal behavior. If individuals' response functions are sufficiently interdependent, then achieving individual maxima may not achieve the social optimal. I demonstrate in the next section that an agent-based model that implements an evolutionary algorithm for individual agent strategy selection overcomes this quandary. Such a model embraces the genetic-causal tradition to which Austrians have contributed and I argue that it provides a reasonable example of how an agent-based model may contribute to the Austrian perspective of law and economics.

It is difficult in the extreme to imbue artificial agents with the full character and quality of purposive human action. The inability to capture the open-endedness of how humans manage

their subjective means-ends framework is a shortcoming that agent-based simulation as a method may never fully overcome. To the extent that the agents in the model capture relevant characteristics of the action axiom, then the more effective the simulation model is bound to be in illuminating the phenomena under consideration. While it is true that the artificial societies depicted in agent-based models lack the complexity and richness of human society, and the agents that populate these virtual worlds lack the intelligence of human beings, it is also true that the agents' relative ability to act within their society might be comparable (Lavoie, 1994b, p.554). Virtual agents certainly are not as creative or innovative as the individuals they mean to portray, but relative to their world, they could be considered creative as they are capable of learning from experience and adopting courses of actions as a result of trial and error (Lavoie, 1994b, p.554). Thus, artificial agents are subject to the criticism that they are not and perhaps never will be capable of achieving the intelligence and creativity of human beings, but they are capable of innovation relative to the worlds they inhabit.

Mises makes clear that "specific method of economics is the method of imaginary constructions (1996, p.236)." Of course some imaginary constructions are more useful than others when it comes to promoting the understanding of social phenomena. In this section I have argued that agent-based modeling can assist in the development of such imaginary constructions. To date, most Austrians have refrained from exploiting the capabilities inherent in agent-based modeling. However, there have been scholars that have recognized its potential contribution. Lavoie notes that "Agent based simulation may be a useful way to expand the Austrian School's set of expositional tools (Lavoie, 1994b, p.549)." He, correctly I believe, points out that "The theorist might use visualization of dynamic market processes to help think through the logic of the dynamics (p.552)." Agent-based simulation provides the theorist with a means to elucidate

the dynamic processes of the target phenomena and lead her to develop a meaningful genetic-causal explanation of its emergence.

V. An Example of Agent-Based Modeling and Economic Analysis of the Law

Imagine a society known as Eggtopia. The inhabitants are human beings, and are just like any other human beings in their ability to use their senses to collect information about their environment, as well as the ability to take action on the basis of that information in conjunction with their subjective valuation of the relative benefits of means and ends. In addition, these individuals possess the same physical attributes as any other human being such as visual acuity, strength, ability to move, etc. The members of Eggtopian society enjoy access to relatively free markets and a moderately liberal order based on private property and freedom of contract. Among other services, there exists a civil court system in which parties resolve private disputes relating to contracts, property, and torts. In many respects, Eggtopian society is indistinguishable from nearly any other in the Western world.

A significant source of income in the Eggtopian economy is based on the sale of eggs and egg products. These eggs are scarce, extremely fragile, and incredibly valuable, thus a large proportion of Eggtopians are employed in their collection. Unfortunately, for all their skill and talent, the process of searching for eggs, extracting them from the ground, and storing them securely is fraught with danger. In their haste to collect as many eggs as possible, accidents between Eggtopians occur with great frequency and typically destroys any eggs the victim was carrying. When an accident occurs, the parties to the accident decide upon how to proceed pursuant to the relevant accident law and pertinent facts of the case at hand. In this sense, Eggtopians face a challenge similar to that of many members of this society. That is, engaging

in productive activity also brings with it distinct risk of accidental damage to self or property. Changing behavior along margins that improve productivity, such as speed of travel, also may increase the possibility of an accident occurring.

The fictional Eggtopian society is rather stylized concerning the circumstances surrounding the egg collection and production, but is still recognizable enough to reality to glean insights common to individuals' behaviors regarding accidents. The general keys to analysis of accidents in the virtual world of the model are no different than analyzing accidents in the real word. In reality, accidents typically occur while both parties are engaged in otherwise productive behavior. In the course of their behavior, individuals may take measures that reduce the likelihood of an accident occurring, however, these activities may simultaneously inhibit productive behavior, i.e. if the driver of a delivery truck were to maintain a relatively slower speed, it may reduce the probability of an accident, but it also increases the time it takes to transport the goods she is hauling. In fact, the idea is so general as to apply to almost any productive, yet risky, endeavor.

The intent of this mental construct is to serve as the target of an economic analysis of accident law. Since Eggtopia is a figment of the author's imagination (and now the reader's), no empirical data, case law, or historical record exists that describe in detail the activities of its inhabitants. The agent-based computational model provides the mechanism with which data are generated to test the effectiveness of various approaches to economic analysis of accident law. Part of the reason for the relative dearth of empirical law and economics studies is the difficulty of obtaining data conducive to analysis and testing. In this case, agent-based modeling overcomes this challenge.

A. The Model: An Artificial Implementation of Eggtopia

The virtual model of Eggtopia is comprised of a two-dimensional torus grid that is rather densely populated with both heterogeneous agents and eggs. An agent's strategy consists of his egg carrying capacity, visual range, and speed of movement. Upon locating an egg, the agent picks it up and carries it with him while continuing his search for additional eggs. Agents are limited in their ability to simultaneously carry multiple eggs and upon reaching their maximum capacities they must return "home" to unload their collection before resuming their search[1]. In the course of maneuvering through their environment, agents occasionally collide with one another. When agents collide, the eggs the victim was carrying are destroyed. Different tort rules are immediately employed to adjudicate the disputes the arise surrounding the aftermath of these accidents.

The agents that populate the model single-mindedly pursue the goal of collecting eggs. They possess no explicit choice algorithm nor do they form expectations regarding the future. One might say that if they possess a utility function at all, it is a lexicographic preference for eggs to the exclusion of all other goods, to include leisure, safety, etc. Modeling such zero intelligence agents has precedence in the computational and behavioral finance literature. In an influential article, Gode and Sunder (1993) utilized what they termed zero intelligence traders to examine the institutional effects of particular auction rules. See Duffy (2006) for a comprehensive survey and assessment of this literature.

While Gode and Sunder's agents selected their bids randomly, there is no randomness when it comes to an agent's choice in this model. That the agent pursues the collection of eggs is given, however, agents do select the strategy to carry out that end. While such an algorithm is perhaps a poor description of human action, it does provide a blank slate of sorts to allow for all

[1] For simplicity, the agent's initial position at the beginning of the simulation run is deemed its home position.

sorts of behavior that may depart from traditional notions of rationality and it emphasizes the institution's role in guiding behavior, as opposed to relying on notions of rationality or a particular level of intelligence.

B. Evolution of Behavior

This model relaxes certain assumptions that provide the foundation for neoclassical economic models which Axtell (2007, pp.106-108) characterizes as the neoclassical "sweet spot." The sweet spot consists of assumptions of agent rationality and homogeneity, as well as non-interaction and equilibrium, necessary to achieve the researchers' desired performance of the model in terms of formality, generality, and tractability. The neoclassical theory is one attempt to make sense of the spontaneous order that individuals collectively form when interacting with tort law as an institution, interacting with other agents, and interacting with their environment. This order is ultimately the subject of economic analysis of tort law. Spontaneous order economics in general and agent-based computational modeling in particular embraces the dynamic nature of this order and allows the researcher to trace emergent macro-level phenomena through the genetic-causal chain of interactions to its origin in individual behavior.

Employing agents that adapt their behavior in an evolutionary manner necessarily requires heterogeneous characteristics and a decision-making process that is much less ambitious than neoclassical rationality. Modeling agent behavior in this manner acknowledges that Eggtopians confront a significant challenge concerning how to best employ their skills in pursuit of egg collection since, contrary to neoclassical agents, they lack the information required to systematically identify and implement an unambiguous globally optimal strategy. While most neoclassical models differentiate between injurers and victims, the flexibility of agent based

modeling allows us to jettison this artificial dichotomy because in reality individuals often do not know when or if they will cause or be the victim of an accident.

Agents select from a wide array of parameter combinations, as all of their individual attributes may vary between 1 and 33. The task placed before each agent is daunting. Individuals must select the strategy that, given all other agents strategies and behavior, will improve or at least maintain their current level of income over the course of a generation. However, they have exactly 33^3 or 35,937 strategies from which to choose. Their choice is based on the perceived effectiveness of their current strategy and their most recent reasonably successful strategy. As opposed to the elegant continuous, twice differentiable field upon which neoclassical agents are assumed to maximize their utility, these agents are, more realistically, confronted with an enormous combinatoric problem.

Potts (2000) provides an analysis of the shortcomings inherent in basing a model of individual decision-making on a mathematical field and illustrates how it ultimately assumes an impossible level of knowledge concerning the state of the world on the part of the individual. The interconnectedness of the elements of the field, that is, the continuous function in **R** space, implies that the individual has at his disposal a complete understanding of the world and is easily able to identify and implement an optimal response. Potts asserts that the economic space upon which individuals operate is better perceived as a less than fully connected set of elements. The individual's task is to explore this space by experimenting with various combinations of elements in order to discover the means which best serve her ends. This combinatoric problem goes beyond the largely artificial necessity of only choosing integer values for strategy parameters, rather it implies massive amounts of uncertainty in the agent's choice due to a paucity of information concerning the relative values of various strategic choices.

Agents are allowed to change their strategies at particular intervals. The algorithm employed contains aspects of trial and error, as well as hill-climbing and satisficing. Upon completion of each generation of 500 timesteps, each agent examines the success of her current strategy in terms of wealth. Let us assume that the agent has employed her incumbent strategy, which simply means that strategy which has proven successful in the recent past. If her current wealth exceeds that from the previous generation, meaning that the incumbent strategy has succeeded again in bettering her condition, it will remain her incumbent strategy and she will employ it in the next generation. This is the satisficing characteristic, in that the agent is satisfied with a relatively well performing strategy and does not seek to "fix what is not broken." See Brenner (2006, pp.913-4) for a description of satisficing strategies, and see Nelson and Winter (1976) for a well known and successful implementation in terms profit seeking firms.

If the agent's current wealth is less than that observed in her previous generation, that is, if the incumbent strategy does not succeed in improving her condition, she will select a candidate strategy and employ it in the next generation. This is the hill-climbing and the trial and error characteristic of the algorithm. Candidate strategies are selected with equal probability from the set of neighbors of the current strategy. In the current implementation, neighbors are all strategies whose parameters are no more than +/- 2 levels from the current one. This means that most strategies have 5^3, or 125, neighbors including itself.

At the end of the next generation, the candidate strategy's success is measured against the level of wealth the incumbent strategy garnered the last time it was employed. If the candidate strategy yields greater wealth, it is deemed the new incumbent strategy and employed in the next generation. If the candidate strategy's performance is less than that of the incumbent, then the incumbent remains as such and is employed in the next generation. Thus, the upper level of the

model is a classic evolutionary process in which the agents adapt their strategies or attributes according to the strategies and attributes that have exhibited success in that particular generation, or stage, of the model.

C. Results

In this section I report a few of the more interesting results of the initial analysis of the model. The following is not intended to be the final word on any subject; rather it is to identify a path for future research that appears promising. The agents in the model form a complex adaptive system with many characteristics that maintain a state of flux. Aggregate wealth appears to exhibit a transient state for a period of time before settling into a steady state. In Law and Kelton's (2000, p.502) terminology, this is a nonterminating simulation and aggregate wealth is a steady state parameter. In order to appropriately analyze the steady state behavior, a run time must be selected of sufficient length for the system to not only enter steady state but to collect a substantial sample of steady state data as well. I use Welch's Method to determine when steady state is achieved (Law and Kelton, 2004, pp.520-525) and conclude that for all scenarios, this occurs by 350,000 timesteps. I then use the replication/deletion method (Law and Kelton, 2004, pp.525-6) to measure the level of steady state parameters of interest. Each replication is run for 400k timesteps and all data for time < 350k is neglected. In all subsequent scenarios, the model is run for 800 generations, or 400,000 timesteps. All data is considered for the analysis of transient variables, but only data after 350k timesteps is considered for steady state variables. In order to economize on time and computer space, only the results of every 10^{th} generation are output and thus available for analysis. In all instances, the scenario where Eggtopia is inhabited by 100 agents in search of 1,000 eggs is examined. Each scenario is tested between 10 to 30 replications each in order to shrink confidence intervals sufficiently to

approach statistically significant results. However, throughout the analysis emphasis is placed on the practical significance of various outcomes.

Consistent with typical neoclassical analysis, the evolutionary approach is capable of differentiating among any of several liability rules and identifying the superior performing rule. In the present case the measure of effectiveness is aggregate wealth, but alternative metrics are imaginable. The framework allows for the researcher to actually employ the various liability rules in artificial societies to examine the rules' effects directly, as opposed to only analyzing the effects of a rule of no-liability and deducing the effects of subsequent rules. A number of other questions concerning the distribution of wealth, the distribution of strategies, individuals' steady state behavior, and transient behavior is examined as well.

Identifying the Wealth Maximizing Rule

The rules of strict liability, no liability, and negligence, where due care is defined in terms of various levels of each strategy parameter, are all examined. Table 1 provides an overall comparison of the best performing tort rules. For each of five liability rules, agents' per capita wealth is measured over the course of a generation. The negligence rules shown are the best rules for each parameter. For example, the best performing negligence rule on the basis of speed is one where due care is defined as *speed* > 9.[2] The rule of no liability achieves the highest per capita wealth, while strict liability performs relatively poorly. The difference between strict liability and all other rules is not only highly statistically significant, but is of practical significance as well. Per capita losses and accidents are also shown for each rule as well as compensation and strategy changes. Per capita compensation is the average amount of wealth each agent transfers as a result of a dispute over the course of a generation.

[2] Rules where due care is defined in terms of speed > 17 and 25, as well as speed < 9, 17, 25 were considered.

Table 1. Overall Comparison of Tort Rules. [3]

(100 , 1000)					
	Liability		Negligence due care in terms of		
	None	Strict	Vision	Capacity	Speed
due care	**n/a**	**n/a**	**< 25**	**< 25**	**> 9**
avg wealth	**223.9**	**36.8**	**217.7**	**217.7**	**220.5**
avg losses	**128.4**	**256.3**	**133.3**	**124.3**	**131.5**
avg accidents	**40.3**	**26.0**	**38.4**	**42.9**	**42.1**
avg compensation	**0.0**	**256.3**	**4.0**	**1.8**	**0.5**
avg strategy changes	**161.96**	**172.32**	**153.38**	**157.70**	**160.58**

The evolutionary perspective provides a richer understanding of the complexities of Eggtopian society because, as we have shown, it is possible to demonstrate from a genetic-causal standpoint the process through which a system generates particular steady-state outcomes. There is no confusion regarding whether it is appropriate to optimize individual, or social, outcomes, as it is when employing the poistem that is the neoclassical model (see Seagren, 2009, esp Ch 5). Unraveling the sweet spot and enabling heterogeneous agents to pursue their own interests on the basis of their local knowledge is sufficient to achieve a steady state condition for each of the liability rules under investigation. The agents employ a simple satisficing algorithm with limited neighborhood search in pursuit of their own well-being, to the exclusion of all other concerns. Agent interaction tends to drive social wealth asymptotically to the vicinity of the maximum achievable for a given liability rule and is an unintended, though seemingly beneficial, consequence of agent behavior.

These results, namely that strict liability performs poorly relative to other negligence rules and even no liability rule would seem to militate against Rizzo's argument that in a world of flux, the rule of strict liability is superior. However, Rizzo's thesis is that given an uncertain

[3] Differences between all pairs are statistically significant with the exception of the negligence rules for vision and capacity. Metrics shown are per capita averaged over all replications.

world of flux, the rule of strict liability provides an institutionally efficient rule by reducing uncertainty as to how the courts will handle disputes. Given the relative *ex ante* certainty of the rule of strict liability, individuals are better able to plan their activities and assess the consequences of risky behavior. This effect is magnified in a world of technological change that effects relationships in unimaginable ways. Since the present version of the model includes neither agent expectations nor a mechanism for technological change, these results should serve to simply inform this debate rather than provide weight to either side. In this stage of its development, the model may be considered a foil. Adding time and process to the analysis is not sufficient to conclude that strict liability is superior to negligence rule in a dynamic society.

Macro-Steady State, Micro-Turbulence

The previous section outlined the relative performance of various liability regimes in terms of average wealth achieved during steady state as a measure of effectiveness. Steady-state is determined to have arrived when aggregate wealth ceases to vary significantly with time. One of the benefits of the agent-based modeling approach to the analysis of the current problem is the ability to examine the behavior of the entire distribution of agents. While the macro-level outcome of time-invariant aggregate wealth is the result of the interaction of heterogeneous agents and their environment, it is not obvious what individual behavior is necessary to achieve it. Agent based modeling enables us to answer this question.

If it were the case that individual equilibrium is a necessary condition for system level steady-state, we would expect that agents would decrease the frequency with which they change their strategies as the system achieves equilibrium, at or around 350k timesteps. Figure 1 is a graph of average agent strategy changes through time, with separate lines depicting the effects of

a number of different liability regimes. As the graph indicates, there is no reduction in the frequency of strategy selection upon entering steady state. That is, agents do not seem to settle on a particular strategy that is a robust response to the strategies employed by all of the other agents. Agents continue to grope for strategies as a means to improve upon the outcomes they currently experience.

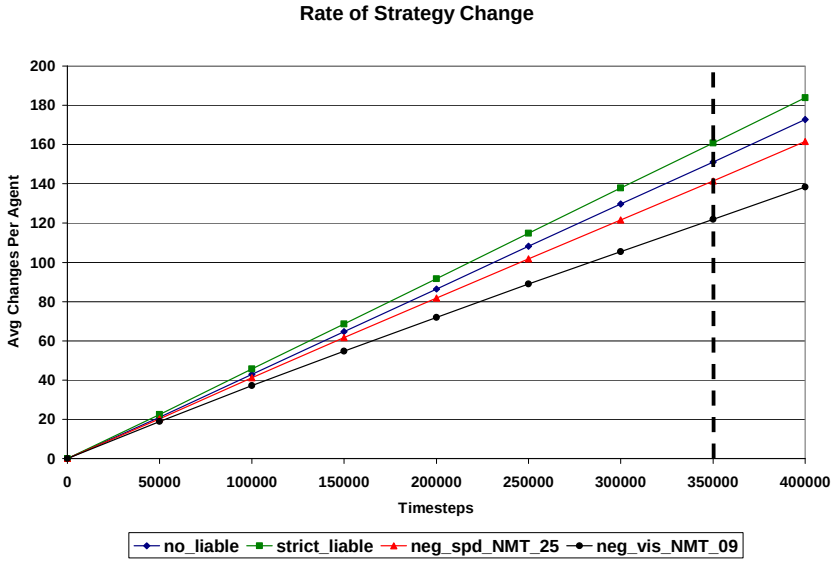

Figure 1. Agents' Average Cumulative Strategy Changes Through Time..[4]

While we establish that agents continue to change their strategies in light of their attempt to respond to an ever changing world, it is not clear whether this flux also affects the agents' outcomes that ultimately obtain. Figure 2 outlines the how widely agents' outcomes in terms of wealth vary during steady state. Recall that steady state is achieved at approximately 350k timesteps.

[4] The onset of system-level steady state appears to have no effect on the rate at which individual agents change their strategies.

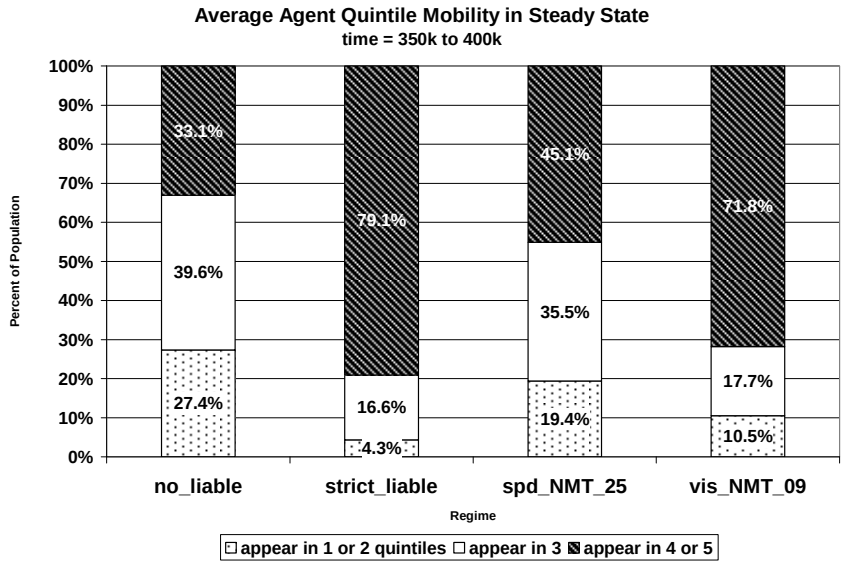

Figure 2. Comparison of Average Agent Mobility Among Wealth Quintiles in Steady State.[5]

If agents' outcomes achieved steady-state commensurate with that of the macro-level steady state, we would expect that agents that appear in a given quintile at the onset of steady state would remain there throughout. Indeed, a charitable expectation would be for most agents to appear in no more than two different quintiles. However, as the figure indicates, between 70% and 96% of agents appear in three or more quintiles throughout steady state, depending upon the liability rule in effect. The most variable outcomes result under the rule of strict liability, where approximately 96% of agents experience significant fluctuations in their success relative to other agents even while the system is in steady state. This result is counterintuitive in that one would expect that individual stability or "equilibrium" would be a necessary condition for system level stability.

[5] Once system-level steady state is achieved, the vast majority of agents still experience significant variance in the success of their selected strategies, as evidenced by the fact that they may find themselves in three or more different income quintiles during the given timeframe. As indicated, this result is robust across liability rules.

It is fortunate that the model achieves a steady state in terms of an important aggregate variable such as total wealth and enables a straight-forward method to compare different liability regimes. Whether this system we have created would behave in this manner was a question that could only be answered empirically. Furthermore, while the aggregate system may achieve a pattern of steady state behavior, this section demonstrates that the agents do not exhibit behavior recognizable as equilibrium. This finding tends to demonstrate the dangers of representative agent theorizing. Randomly selecting an agent would reveal an individual who continues to grope for the appropriate strategy in the face of a constantly changing environment.

Examining Population Distributions

A drawback of representative agent theorizing is that it is subject to untold error via expected value propagation and is blind to the effects of interactions between different agents, especially those who find themselves in the tails of their distributions. The more diverse a population, the more their individualized subjectivist views differ in light of their local knowledge of time and place, the more problematic is a representative agent approach. Indeed, one of the most compelling aspects of agent-based modeling and its ability to enable the researcher to unravel the neoclassical sweet spot is that it enables analysis of the entire population of agents, rather than reducing all behavior, and all interactions, into the activities of a single representative agent.

A major theoretical conclusion of neoclassical analysis is that in cases of joint care, that is when it is efficient for both the injurer and victim to exercise some level of care, neither the rules of no liability nor strict liability are efficient. Under no liability, since injurers are not forced to internalize the damage from the accidents they cause, they engage in an insufficiently low level of care. Similarly, under strict liability, victims are relieved from responsibility for

their actions and know that they will be fully compensated for any losses they may suffer in any accident, no matter the circumstances, so they too will engage in insufficiently low levels of care (Shavell, 1987).

It is not necessarily obvious how this conclusion regarding inefficient behavior scales up to a large population of heterogeneous agents. It may be the case that in the aggregate, injurers under a rule of no liability select lower levels of care on average and thus reduce the overall wealth in society by destroying an inefficiently large amount in accidents. Are the wealthiest (most successful) injurers those that cast caution to the wind and charge around Eggtopia in search of eggs, without regard to the accidents they are causing and the wealth they are destroying? Do victims under a rule of strict liability respond to their unaccountable status with similar disregard for the (social) consequences of their actions?

Figure 3 displays the steady state average accident rates (per generation) for each of several liability regimes separated by wealth quintile. A general inverse relationship between wealth quintile and accident rate is clearly discernable. In fact, agents in the highest wealth quintile cause the fewest accidents for each of the liability regimes considered. This effect is both statistically and practically significant for the rule of no liability, as well as the others.

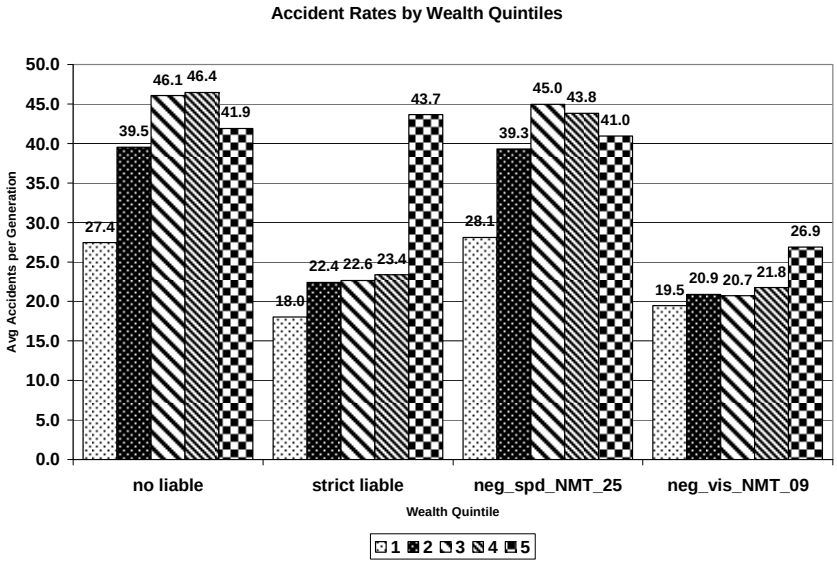

Figure 3. Accident Rates by Wealth Quintiles. [6]

Thus, the agent based approach enables us to unravel the sweet spot and examine questions that static equilibrium methods are unable to deal appropriately. Under either liability rule, it appears that the wealthiest agents are not the wealthiest because they successfully take advantage of the fact that the rule relieves them of financial responsibility of their actions, rather they are wealthy because they select those strategies that are most productive. This is another example of how this approach opens new doors for examining social phenomena more closely and inspires new questions to pursue.

Out of Equilibrium Dynamics

Another compelling feature of the evolutionary approach is that it provides the researcher with the ability to analyze out of equilibrium behavior. Rather than assert the existence of equilibrium and then deduce the conditions that must be present in order to sustain it, this

[6] For all rules shown, agents in the top of the income distribution cause the fewest accidents. Liability rules were chosen on the basis of providing a wide range of performance in terms of expected wealth.

approach begins from out of equilibrium conditions and enables analysis of the process through which agents achieve equilibrium – or a steady-state, if at all.

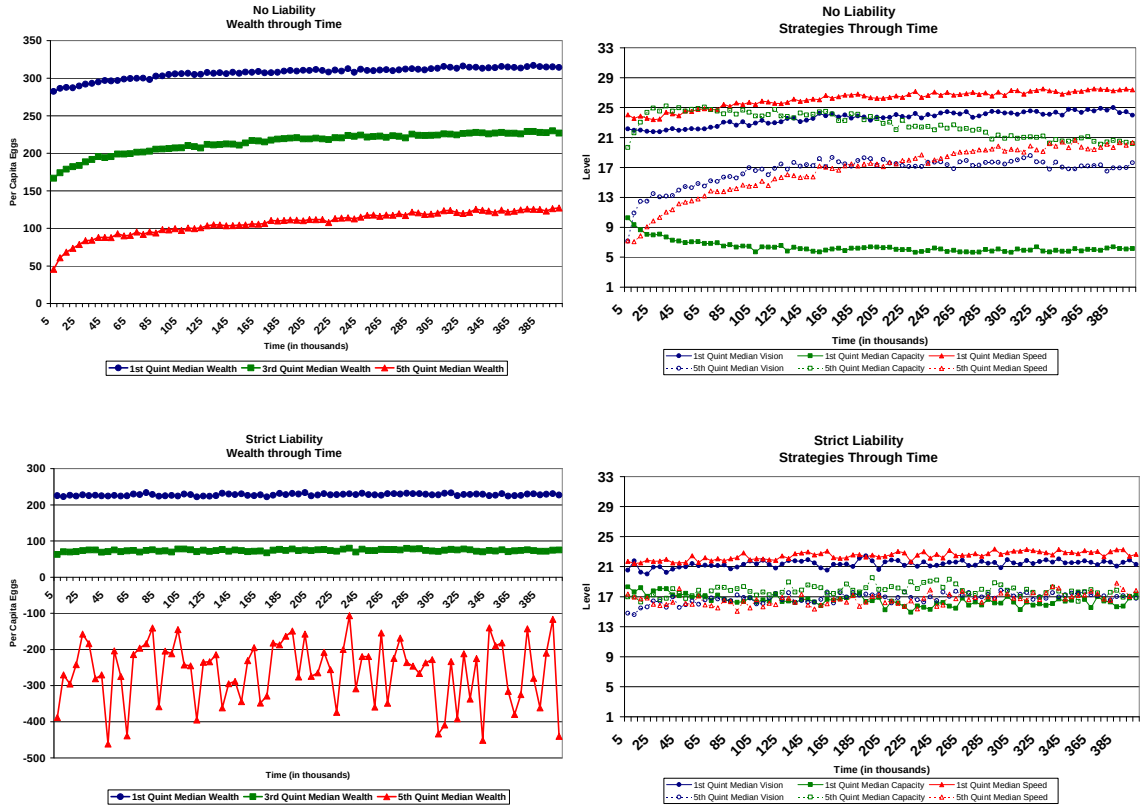

Figure 4. Transient Behavior for No Liability and Strict Liability.

Figure 4 is a depiction of the transient behavior of the system for both no liability (upper panels) and strict liability (lower panels). The panels on the left-hand side show the average wealth of agents in the 1st, 3rd, and 5th quintiles, and the panels on the right show the strategy changes over time for the top and bottom quintiles. The effect of the different rules on the relative wealth of the different quintiles is startling. While the average wealth levels for the

different quintiles under no liability simultaneously approach their asymptotes, under strict liability, the bottom quintile is highly variable and is always negative.

A possible explanation of this behavior is evident upon examining the right-hand panels. Under the no liability rule, agents in the top quintile locate the productive regions of the strategy space within approximately 400 generations or 200k timesteps. In contrast, all of the agents under strict liability seem to be concentrated around the middle of the strategy space, which is consistent with the notion that the agents are unable to reliably ascertain the correct strategy selection from their experiences.

In the neoclassical framework, agent rationality and perfect information essentially rule out negligent behavior by definition under most negligence rules. Agents know that if they fail to exercise care they will bear the full costs of accidents they cause, so it is rational to exercise the level of care that meets the legal standard and nothing more. The persistent presence of negligent injurers is indicative of an institutional failure to provide appropriate incentives to agents to engage in non-negligent behavior. However, it could also mean that individuals select negligent strategies because it is profitable for them to do so despite bearing liability for accidents. Figure 5 is a graph of the average number of negligent agents through time for several negligence rules where due care is defined in terms of speed. The top three speed based rules (spd_nlt_09, spd_nlt_17, and spd_NMT_25)[7] according to average wealth also tend to guide agents to attain non-negligent strategies. The other regimes considered fail to rid society of negligent behavior. Whether some number of negligent agents are present in the wealth maximizing scenario is an empirical matter, but one that Figure 5 begins to address.

[7] The convention is neg_spd_nlt_09 identifies a negligence rule where due care is defined as speed not less than 9. Likewise, neg_spd_NMT_25 identifies a negligence rule where due care is defined as speed not more than 25.

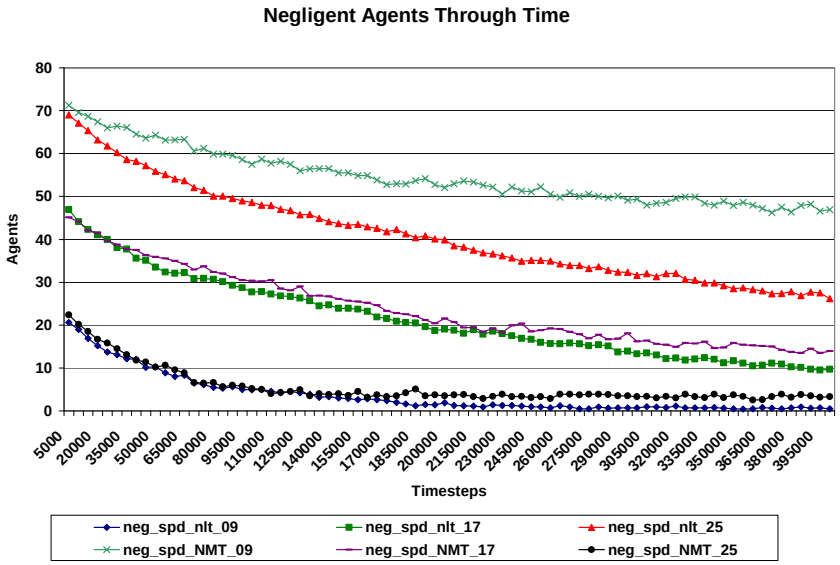

Figure 5. Average Number of Negligent Agents Through Time.

It appears the suboptimal negligence rules are possibly so due to their inability to provide agents with sufficient incentives to behave non-negligently. In cases where due care is improperly set, the incentives seem to be such that some agents are not guided to engage in non-negligent behavior. In contrast, typical neoclassical analysis concludes the an excessive negligence rule results in excessive care on the part of the injurer.

V. Conclusion

In this paper, we have demonstrated that the agent-based modeling approach is able to adjudicate between numerous liability rules and determine the rule or set of rules that achieve a particular performance standard in regards to any number of effectiveness measures. The evolutionary choice algorithm that agents employ to select their strategies drives the complex adaptive system that is the artificial society to eventually achieve an institutionally contingent social wealth maximizing steady state. The individual behavior also ultimately provides a

genetic-causal explanation for the observed macro-phenomena. Agents, in diligent pursuit of ever more eggs, search for strategies that tend to result in higher egg production, and gradually push the system to achieve a steady state level that is in the neighborhood of the highest achievable under that liability rule. So, an unintended consequence of the agents' quest for improving their state in life is to raise the aggregate level of wealth in society. This narrative contrasts starkly with the neoclassical version in which a system of deterministic equations is optimized, but robust micro-foundations are eschewed.

The power of the evolutionary approach is not simply that it provides a genetic- causal explanation as a means for differentiating between various liability rules, it is that the approach enables the exploration of population dynamics and the close examination of out of equilibrium behavior. Among the realizations this framework yields is the notion that while the aggregate system appears to achieve a relatively stable level, the components of the system continue to furiously grope around the domain in search of wealth enhancing strategies. In addition, agents may elect to be careful even when the neoclassical theory predicts otherwise, and liability rules tend to differ significantly in their ability to rid society of negligent behavior.

Finally, this essay also highlights the knowledge problem inherent in the pursuit of economic efficiency of judicial decision making. The fact that this approach arguably provided a relatively more consistent and coherent model for the theoretical determination of superior liability rules than the neoclassical effort should not be construed as an endorsement of the notion that judges should employ agent-based simulation studies to aid their decision making. In fact, this analysis only serves to highlight the enormous informational requirement such pursuits place upon judges. "Optimal" rules only emerged after systematic enumeration and experimentation of the rules considered. Indeed, only a relatively small proportion of all

possible rules were even considered. For example, due care could be defined in terms of various intervals along the strategy space, or even in terms of combinations of attributes. Such a realization would tend to militate against Posner's objective version of judges leading the common law to efficiency through their concerted effort to select the wealth maximizing ruling.

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