



Agent-Based Modeling as a Legal Theory Tool

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Agent-based modeling (ABM) is a versatile social scientific research tool that adapts insights from sociology and physics to study complex social systems. Currently, ABM is nearly absent from legal literature that evaluates and proposes laws and regulations to achieve various social goals. Rather, quantitative legal scholarship is currently most characterized by the Law and Economics (L&E) approach, which relies on a more limited modeling framework. The time is ripe for more use of ABM in this scholarship. Recent developments in legal theory have highlighted the complexity of society and law's structural and systemic effects on it. ABM's wide adoption as a method in the social sciences, including recently in economics, demonstrates its ability to address precisely these regulatory design issues.

Keywords: agent-based modeling, simulation, complexity, law and economics, law and macroeconomics, law and political economy

OPEN ACCESS

Edited by:

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Specialty section:

This article was submitted to
Social Physics,
a section of the journal
Frontiers in Physics

Received: 10 February 2021

Accepted: 28 May 2021

Published: 21 June 2021

Citation:

Benthall S and Strandburg KJ (2021)
Agent-Based Modeling as a Legal
Theory Tool.
Front. Phys. 9:666386.
doi: 10.3389/fphy.2021.666386

INTRODUCTION

The time is ripe for legal scholars to use agent-based modeling (ABM) to produce actionable theoretical insights. One major strand of legal scholarship attempts to design or evaluate potential regulatory approaches based on their anticipated effectiveness at achieving societal goals [1, 2, 3]. This is an inherently normative project: both the overall consequentialist perspective and particular choices of appropriate goals are contestable. This sort of legal scholarly project also has social scientific underpinnings, however, because its success depends on the quality of its predictions about how society will respond to legal changes. Indeed, legal scholarship of this sort is often explicitly interdisciplinary, relying on theoretical concepts, models and methods from various fields of social science fields to inform those predictions. Microeconomics has been particularly influential, spawning a sub-field known as “law and economics,” (“L&E”) or sometimes “economic analysis of law” [4–7]. (As one rough measure of this impact, the LEXIS database of law journal articles contains more than 35,000 articles mentioning “law and economics” or “economic analysis of law,” just over 3,000 articles mentioning “law and sociology” or “sociology of law” and just about 1,500 mentioning each of “law and political science” and “law and psychology.”)

ABM is a computer simulation approach that has been increasingly deployed in social science to study the societal implications of various specifications of agents (who can be modeled as individuals, firms or other entities), their incentives and decision-making strategies, the interactions between those agents, and the social frameworks in which they interact. The computer simulation approach allows agent-based models to incorporate heterogeneity, nonlinearity and feedback effects in ways that are not possible with more traditional analytical solutions and approximation techniques [8, 9]. Using ABM's bottom-up “generative social science” approach, “fundamental social structures and group behaviors emerge from the interaction of individuals operating in artificial environments under rules that place only bounded demands on each agent's information and computational capacity” [10].

ABM's strengths would appear to make it an attractive approach for exploring the potential societal implications of proposed changes to laws and regulations, particularly in light of the difficulty of employing experimental methods to probe these issues. Moreover, laws and regulations intersect with many aspects of social life that have been studied with ABMs. Yet the legal literature seems surprisingly oblivious to ABM's potential to inform the evaluation of proposals for legal and regulatory change. Because ABM is an increasingly important social scientific tool, its lackluster uptake by legal scholars who aim to predict the effects of regulatory proposals is disappointing. Nonetheless, we believe that several developments make a more robust incorporation of ABM into legal scholarship possible now. A first set relates to legal scholarly demand for less individualistic and more systemic, structural, and political approaches to regulatory design, while a second set relates to the legal academy's capacity for and openness to computational modeling. Both sets are usefully understood in relation to "law and economics," which has been one of the most (arguably the most) influential—and controversial—strands of legal scholarship since the seminal work by Posner and others in the mid-1980s [6, 7, 11].

AGENT BASED MODELING AND ITS ABSENCE FROM THE LEGAL LITERATURE

Arguably rooted in mathematical sociology [12, 13], ABM is an alternative to analytical calculation that leverages computational resources to permit a wide and flexible range of specifications of agents, their incentives and decisionmaking strategies, and the interactions between them [8, 9]. The modeler is also free to specify features of the social, legal and policy frameworks in which the agents interact.

ABMs have been used in many social scientific domains of public policy relevance. We mention only a few examples. Notably, economists have begun to use ABM, especially since the 2008 financial crisis [14, 15, 16, 17, 18]. ABMs have also been used to study housing segregation beginning with models based on ethnic homophily and over time introducing models of market dynamics [13, 19–24]. Another line of research investigates labor markets, referrer networks, segregation, and affirmative action [25–28]. These studies are obviously relevant to questions in legal theory about antidiscrimination law. ABM models of the formation and adoption of norms [29–31] have general relevance to theories about the need for and effects of regulation.

Though Picker [29] article noted the potential usefulness of ABMs in understanding the interaction between norms and law, other legal scholars have not, for the most part, followed his lead. For example, a search of the LEXIS database of law journals for mentions of "agent-based model" or "agent-based modeling" turned up only 80 articles in total. Of those, 61 mention ABM only in footnotes (52) or in passing (9). Of the 19 articles that do more, seven merely propose ABM as a potentially useful technique for addressing policy issues related to: market panic [32]; water pollution in a river basin [33]; "exploratory analysis of policy options" in telecommunications [34, 35]; administrative rulemaking [36]; telecommunications complexity in comparative law [37]; and taxpayer behavior [38]. Seven others cite results from previously published ABM studies:

[39] (citing ABM results about dependence of social structure on initial conditions to refute argument for genetic determinism of societal differences); [40] (citing ABM studies in discussion of environmental justice); [41] (citing ABM studies of crime displacement); [42]; (using results of ABM of the effects of economic-based college admissions criteria on racial diversity); [43] (further analysis based on the residential segregation ABM described below); [44] (relating ABM results about collective behavior formation to the formation of customary international law); [45] (using concepts from ABM to consider diffusion of innovations).

Thus, only five articles uncovered by our LEXIS search report new ABM studies designed to address a legal issue. [46], uses ABM to test and critique the assumptions underlying the Supreme Court's invocation of "critical mass" in its affirmative action jurisprudence. [47], uses a detailed agent-based model of the Lake Champlain Basin as part of a larger project aimed at designing policies to ensure clean water. [48], reports the results of an ABM model designed to test theories about what factors influence tax compliance. [29], uses ABM to explore social norm formation as part of an inquiry into when legal regulation is required. [22], uses an ABM to explore how residential segregation can be locked in by historical events that create wealth and social disparities even in the absence of intentional discrimination or any preference for racial homophily. She then argues that current housing discrimination law cannot overcome these lock-in effects. Another seven articles apply the results of a previous ABM study to analyze a legal issue.

Of course, this quick survey is not an exhaustive search of the legal literature: for example, some articles may rely on agent-based modeling without using the term. These numbers also do not capture publications by legal scholars in non-law journals or other venues not included in the LEXIS database. Nonetheless, one can only conclude that ABM has made few inroads into legal scholarship, despite earlier discussions of its potential benefits [49–52].

LAW AND ECONOMICS, ITS CRITICS AND THE ABM OPPORTUNITY

Both the strengths and the weaknesses of Law and Economics make it an important backdrop for understanding the current potential for a more robust incorporation of ABM into legal scholarship. L&E adopts the consequentialist goal of steering the social system toward a desirable state and conceptualizes law primarily in terms of the incentives for individual behavior that it provides (rather than, for example, primarily as a means for compensating harms or providing "just deserts"). It thus requires some method for predicting how society will respond to a legal regime and some way to normatively evaluate the states of the world that are likely to result. Normatively, L&E adopts the goal of designing legal rules that will maximize social welfare, ordinarily defined as the sum of individual utility functions. It traditionally leaves distributional concerns to be addressed (if at all) through the tax system. To predict how society will respond to a proposed legal regime, L&E analyses often employ mathematical models and game theory, adopting simplifying assumptions from neoclassical microeconomics that favor analytical tractability over

realistic portrayal of social dynamics and complexity. L&E analysis also tends to focus on designing rules to incentivize transaction-by-transaction efficiency, under the assumption that the cumulative effect will be social welfare maximizing.

L&E is a powerful methodology because, once one accepts its simplifying assumptions, it can be used to explore many questions about legal design, such as whether a negligence rule or a strict liability rule will induce the socially optimal level of precautions in a particular context, what combination of punishment severity and enforcement certainty most effectively deters crime, and whether the costs of implementing a regulatory regime outweigh its benefits. The legal academy's experience with L&E also demonstrates the value of mathematical models for sharpening analysis and clarifying assumptions, as well as (for better or for worse) the persuasive force of simple models. Beyond L&E's appeal as a basis for detailed models, its foundational assumptions, such as that incentives matter and that rational self-interest drives much of human behavior, can usefully be deployed to make "hand-waving," but plausible, informal assessments of incentives and trade-offs. This flexibility means that the L&E approach can be used not only by L&E scholars, but also by a wide range of legally relevant actors, including judges, attorneys, legislators and administrative policymakers.

To predict how affected individuals might respond to a legal change, traditional L&E models individuals as self-interested, informed and rational actors, whose goals are to maximize individual utility by satisfying their preferences. Because utility cannot be easily determined, compared or summed across individuals, L&E typically focuses on arranging society's rules to facilitate "efficient" voluntary transactions, in which participants decide for themselves whether they are made better off. When, as is often the case, transactions have spillover effects ("externalities") on the utility of outsiders, however, the L&E analyst must somehow account for those effects. One approach is to design regulatory mechanisms aimed at forcing the transactors to internalize—or at least account for—the social costs of the externalities. Often, however, L&E analyses simply redefine efficiency in terms of "Kaldor-Hicks" improvement [53, 54], in which "state A is to be preferred to state B if those who gain from the move to A gain enough to compensate those who lose" [55]. This approach requires an interpersonal comparison of utilities that is ordinarily performed using a monetary metric. L&E analyses thus often boil down to transaction-by-transaction marginal cost-benefit analyses. Because the goal is to maximize *total* social utility, the analysis need not consider whether the Kaldor-Hicks losers are actually compensated.

Of course, predicting how individuals will react to legal changes and how the state of the world will evolve as a result is a Herculean (or perhaps Sisyphean) task. Legal systems are thus designed to facilitate revisions when existing law begins to have socially undesirable effects. The marginal, transaction-based approach of L&E implicitly assumes that when this happens, problems with current laws can be detected and incremental course corrections can effectively guide society toward an optimal legal regime. This expectation has led some L&E scholars to embrace the common law system, in which legal doctrine shifts gradually as cases come to court.

The assumptions made in traditional L&E analyses are advantageous for tractability, but have well-known practical, conceptual and normative weaknesses [11]. L&E has always been

criticized for its simplified, rational actor model of human motivations and behavior. The subfield of "behavioral economics" arose to develop and implement more realistic models of human beings as boundedly rational, subject to cognitive biases and not fully informed [56]. While such more realistic representations of individual behavior can sometimes be incorporated into L&E's traditional analytical methods, this is more easily done in an ABM, which can incorporate heterogeneity, limited information and various forms of motivations and behavioral rules without the need for analytical tractability. Nonetheless, better modeling of individual behavior is not ABM's most important contribution. Indeed, while ABM can be used for highly detailed and realistic modeling of specific situations (see [33, 47]), ABM's main strength is its ability to demonstrate and explore the ways in which unexpected system-level properties can arise from relatively simple models of individual behavior. In this respect, most applications of ABM to legal theory are likely to retain both the advantages and some of the disadvantages of L&E's simple modeling of individual behavior.

Defining social welfare in terms of total wealth maximization is normatively troubling, especially because the traditional L&E proposal to deal with the unfairness of Kaldor-Hicks efficiency through the add-on of redistributive taxation is both practically and politically infeasible. In practice, traditional L&E tolerates large disparities in its single-minded pursuit of increasing the size of the pie. Some scholars have suggested ways to tweak standard L&E analyses to account for other normatively important considerations such as equality. For example, one might posit individual preferences for altruism, equality, or reciprocity or for biodiversity or clean air [6] or introduce quantitative and qualitative mechanisms for taking non-monetary and distributional social values into account in cost-benefit analysis [57, 58]. These proposals certainly have some practical merit (indeed some of Sunstein's proposals for modified cost-benefit analysis were implemented during the Obama administration). Nonetheless, these attempts to maintain the tractability of L&E's utility maximization by representing other values in terms either of individual preferences or of add-ons to total social utility are difficult to calibrate empirically, do not direct account for the nuanced ways in which people care about the utility of others, and tend to frame policy debates in terms of "trade-offs" between total utility and other values.

Overall, by attempting to maintain L&E's basic framework—and analytical tractability—these tweaks continue to prioritize wealth maximization over other normative considerations. Moreover, adopting a more realistic model of individual behavior or a more complicated social welfare function deprives L&E of some of its main selling points—analytical tractability and simplicity—requiring further approximations elsewhere and reducing the range of questions which the model can address.

One example of an L&E regulatory design approach that has not aged well comes from privacy law. Early L&E literature argued that laws restricting use of personal information are suspect because they prevent allocative efficiency in the market [7]. While later work in Economics has challenged this view and provided more sophisticated models [51, 59, 60], these upgrades have not been sufficient to deal with the changing conditions of e-commerce and the breadth of social concerns implicated in digital technology's use of personal information. Alternative frameworks for understanding privacy in

terms of contextually defined norms [61] and systemic financial risk [62] suggest that legal scholarship could benefit from ABMs, perhaps adapted from those modeling norm formation [63–66] and bank stress testing [67, 68, 69], and enforcement policies [70].

[71], provides a direct comparison of ABM and traditional L&E approaches to the problem of devising tort law standards for accident compensation. While some findings are consistent between the two, the ABM demonstrates that when agents learn the rules from experience, they behave differently from the neoclassical predictions. Among other observations, results vary depending on how the duty of care is specified. Agents sometimes are careful even when they would not be liable under the applicable standard of negligence, but sometimes continue to behave negligently for long periods of time; and individual agents generally continue to experiment with safer and riskier strategies long after overall system variables appear to have settled at equilibrium values. This sort of heterogeneous experience of individual agents may affect long-term wealth distributions and might plausibly be relevant to the design of tort law.

ABM AND THE COMPLEXITY CRITIQUE

Fundamentally, even the most “souped up” L&E approaches tend to take an individualistic transaction-by-transaction perspective, implicitly assuming that society’s response to legal rules will approximate a linear cumulation of these assessments, where deviations can be handled by incremental course corrections. Unfortunately, complexity theory suggests that L&E’s faith in linearity and incrementalism is likely to be misguided. The networked nature of social systems makes non-linear cumulative effects and feedback between transactions not only likely, but increasingly so as technology increases global interconnectedness. As Miller and Page [72] explain:

Complexity arises when the dependencies among the elements become important. In such a system, removing [or altering] one such element destroys system behavior to an extent that goes well beyond what is embodied by the particular element that is removed [or altered]. (p. 9).

Complex systems are known to exhibit phenomena, such as phase transitions, tipping points and metastability, that have dramatic non-linear effects. Computational simulation has been the primary tool for studying these systems. When the world is complex, a head in the sand insistence on locally tractable models simply will not do. Indeed, the increasing reliance on ABM in the social sciences is a direct consequence of the recognition of complexity’s importance in social systems.

Our unfortunate recent experiences with the mismanagement of the COVID-19 pandemic [73] and the spread of electoral misinformation highlight the importance of devising regulatory approaches responsive to complex phenomena. It is thus increasingly urgent for legal scholars to attend to those who have long been sounding the alarm about the challenges that complexity poses for law. (For overviews of complexity science and its applications in law, see [4, 74–81]). To date, the legal scholarly response to “complexity science” (also called “complex adaptive systems”) has focused mostly on environmental law and financial systems, where the focus has understandably been on designing legal structures and

institutions to avoid disastrous tipping points. Other systemic problems, such as the persistence of racial inequality, suggest that society has become stuck in a metastable state that cannot be escaped through incremental improvements. Though such metastability is to be expected in the social welfare landscape of a complex society, even less attention has been paid so far to the question of how law might be used to facilitate socially desirable systemic change. Moreover, as our above survey of the literature suggests, to date the legal literature addressing complex systems has mostly tried to spin out the implications of general observations about the nature of complex systems, rather than ABMs tailored to the problem under consideration. This translational work is extremely valuable, but more could be learned from more targeted ABM projects.

For example, Malcai and Shur-Ofry [74] point out that the conceptual toolbox of complexity theory can illuminate a longstanding, and polarized, debate about whether to apply cost-benefit analysis or a more constraining “precautionary principle” in shaping environmental regulation, particularly with regard to climate change. They contend that a complexity-based approach can alleviate concerns that the precautionary principle is insufficiently sensitive to the costs of environmental precautions by “delineating several factors, which may serve as guidelines for the principle’s application: phenomena that spread exponentially, in short time-scales, and pose systemic, existential, risk.” With that basic insight in hand, more specifically tailored ABM could help to further delineate these (and possibly other) factors and provide further guidance as to when they are likely to arise in real-world systems.

The stream of applications of ABM to residential segregation, discussed earlier, illustrates the value of this approach, as well as the unique perspective that legal scholars can bring to these questions. While sociologists have focused on understanding how small amounts of racial bias and preference for homophily can result in drastic segregation, legal scholars’ contributions [22, 43] emphasize the lasting effects of prior legal tolerance of enforced segregation and critique the way that current anti-discrimination law fails to address these “lock-in” effects. These two effects both arise from feedback effects characteristic of complex social systems, but they are quite different and might suggest different regulatory responses. To understand and address current housing segregation problems, both of these perspectives (and others) are undoubtedly needed.

DISCUSSION

While the number of scholarly articles discussing law and complexity is dwarfed by the law and economics literature, it is by no means negligible today. Nonetheless, as discussed above, ABM remains largely absent from the legal literature. As noted, however, we see two sorts of reasons—theoretical and practical—to be optimistic about the potential for growth in legal scholarly attention to ABM methods and results.

Theoretical Demand for Consideration of Law’s Structural and Systemic Effects

Two recent developments in legal theory, framed as critiques of L&E and highlighting current societal problems, draw attention to precisely

the sort of systemic, structural and dynamic effects that ABM may be able to model. These movements, termed “Law and Macroeconomics” and “Law and Political Economy” by their proponents, are still relatively nascent, but seem to be gaining traction among legal scholars. Moreover, both movements have so far lodged their critiques at a relatively abstract and theoretical level. ABM provides a method for translating at least some of these systemic critiques of L&E into actionable insights about legal and regulatory design that can be compared to and juxtaposed with those of traditional L&E. While ABM does require somewhat simplified models, it can avoid many of the most troublesome simplifying assumptions of traditional L&E, while maintaining the many advantages of using well-specified models to test and deepen qualitative insights.

Law and Macroeconomics

[82] proposal for “Law and Macroeconomics” argues that traditional L&E “should really be called ‘law and microeconomics,’” because of its inability to reckon with aggregate level constraints, such as financial recessions and the business cycle, that appear in macroeconomics. He argues that legal analysis should be more responsive to macroeconomic considerations, at least under some conditions. Meanwhile, the 2008 financial crisis was a wake-up call for macroeconomics, which has since revisited its assumptions about the connections between individual behavior and larger patterns and effects. Whereas macroeconomic models formerly depended on a “representative agent” that was somehow both a single agent and an average of all agents in the economy, now the field is moving toward heterogeneous agent modeling (HAM), explicitly modeling a variety of agents with *ex ante* and *ex post* differences [83]. HAM methods combine the classic economic tool of dynamic stochastic programming [84] with the flexibility of ABMs. ABM macro methods have found some traction in federal policy-making through research aimed at studying financial risk [68]. Further incorporation of ABM into relevant legal scholarship would be both a natural outgrowth of Listokin’s call for a “Law and Macroeconomics” approach and a method for conducting such studies.

Law and Political Economy

A new scholarly movement calling itself Law and Political Economy (LPE) has recently combined a number of earlier critiques of L&E to contend that L&E is reflective of a “[n]eoliberal political economy, with its underlying commitments to efficiency, neutrality, and antipolitics, [that] helped animate, shape, and legitimate a twentieth-century consensus that erased power, encased the market, and reinscribed racialized, economic, and gendered inequities.” [11] LPE scholars see a need to correct L&E’s erosion of antitrust, intellectual property, and environmental law (for example) through “a legal imaginary of democratic political economy, that takes seriously underlying concepts of power, equality, and democracy” to “amplify and accelerate [recent] movements for structural reform.”

One need not believe that computational models can account for all of these scholars’ criticisms of L&E to expect that the wider modeling scope made possible through ABM techniques can help to illuminate the effects of separated markets and power

imbalances, take into account the endogenous effects of the market on the law, and model various ways in which law and legal institutions can promote social values such as equality and democracy, rather than optimizing a linear representation of the atomistic preferences of individuals. These models would necessarily have a different view of social structure, taking less for granted and acknowledging new forms of social (in)stability and transformation.

Practical Developments Favoring Law and ABM

In addition to the current demand by legal scholars for ways to account for a broader set of normative values and systemic effects in evaluating legal and regulatory proposals, several more mundane developments favor greater use of ABM in legal scholars. Whatever L&E’s failings and limitations, several decades of L&E scholarship, along with other influences such as the emergence of the discipline of technology law, have created a significant cadre of legal scholars with the capacity to engage in mathematical and computational modeling, either alone or in interdisciplinary collaboration, as well as a much larger group that is now prepared to read, discuss and critique the resulting applications to legal questions. While some legal scholars are equipped to take on ABM projects alone, bringing such efforts to the wide range of legal arenas involving significant complexity is likely to require interdisciplinary collaborations between legal scholars and social scientists. Fortunately, as a result of various “law and . . . ” approaches and of the growing importance of technological understanding for regulatory design, interdisciplinary collaboration is now entirely unremarkable for legal scholars (at least in the U.S.) Moreover, the growing use of ABM methods in social science means that many new legal scholars will have been exposed to these techniques during their undergraduate or graduate studies prior to entering law school. The spread of ABM methods also means that open source software packages are now widely available for running fairly sophisticated simulations without deep programming expertise. This development, along with the widespread availability of cheap computing resources that are powerful enough to run meaningful simulations (indeed, a laptop will often suffice) reduces barriers to entry for this type of research.

In sum, the potential for ABM to contribute to progress on important issues in the evaluation and design of proposals for law and regulation is high in light of the complex problems confronting today’s society. Fortunately, for both theoretical and practical reasons, the ground is much more fertile for adoption of ABM methods than it has been in the past.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

FUNDING

One of the authors of this article is supported by the NYU Information Law Institute's Fellows program, which is funded in part by Microsoft Corporation. The funder was not involved in the study design, collection, analysis, interpretation of data, the writing of this article or the decision to submit it for publication.

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ACKNOWLEDGMENTS

KS acknowledges summer research funding from the Filomen D. Agostino and Max E. Greenberg Research Fund. This work benefitted greatly from conversations with Joshua Epstein, Erez Hatna, and Salome Viljoen and participants in the Physics of Law conference (November, 2020, online).

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