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Complexity-Minded Antitrust

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"I think the next century will be the century of complexity"
(Stephen Hawking, 2000)

Abstract

Complexity science is widely used across the policy spectrum but not in antitrust. This is unfortunate. Complexity science enables a rich understanding of competition beyond the simplistic descriptions of markets and firms proposed by neoclassical models and their contemporary neo-Brandeisian critique. Many novel insights can be gained by supporting more openness to some of its key teachings, like feedback loops and the role of uncertainty. The present article lays down the building blocks of a complexity-minded antitrust method.

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Introduction

Antitrust law is again in the spotlight. Rising levels of concentration in the economy fuels demands for antitrust to do more. The neoclassical economic methods applied in antitrust law however condemn the field to minimal, worse, misguided results. The practice of antitrust law is governed by a set of protocols, rules, and tools that makes limitative assumptions about the economy. The methods of antitrust law were good enough for a simple agrarian economy with decreasing returns, fungible production factors, and technological maturity. The sophistication brought by price theory and microeconomics also worked appropriately in the context of the 20th-century industrial economy, with the growth of large, multi-product firms and global markets. But today, the method of antitrust law appears inappropriate to a complex economy with unprecedented levels of increasing returns, feedback loops, and technological dynamism. Unless neoclassical antitrust makes a 'complexity' leap, it is doomed to irrelevance, and a diminishing role on the "broader gestalt of technology and industrial policies".[1]

1. Problems of Methods in Antitrust

The task of antitrust is to maintain a competitive economy.[2] Thus, the central question is whether the economy is competitive. To find out, antitrust relies on analytical methods derived from neoclassical economics (**1.1**).[3] These methods are reaching their limits in an ever-complexifying economy (**1.2**). Unfortunately, contemporary debates amongst antitrust experts have not (yet) invited a reexamination, but have tended to correlate with ideological predispositions, and an overly stylized view of the economy (**1.3**).

1.1. Neoclassical Antitrust

One main activity in antitrust consists in defining whether there is competition. The search for information about the existence and degree of competition in the economy is constrained by application of methods drawn from a modernized version of neoclassical economics. The main question of interest under a neoclassical economics method is whether positions of control over output result from monopoly or efficiency. A related question of interest consists in studying the conditions of minimization of probability of errors and costs of decision incurred by antitrust and regulatory institutions.[4]

[1] David J. Teece, *Pivoting Toward Schumpeter*, 32 Antitrust 32 (2018).
[2] We talk of antitrust in the broad sense, including market power regulation.
[3] We leave aside here the institutional question, which is about evidence-based fact-finding processes (e.g., litigation).
[4] For example, the Courts have held that no elaborate market inquiry was required in areas where there is "sufficiently reliable and robust experience for the view" that business conduct injures competition, *see* CJEU, *Budapest Bank*, ECLI:EU:C:2020:265, para 76.

In addressing these questions, an ambition of exactitude and practicality has justified reliance on a method of competitive analysis that works on a set of limitative assumptions, units of analysis, and focal points.[5] These limitations concern the business environment (i), markets (ii), and firms (iii).

(i) The business environment is stable, so investment is a quantifiable tradeoff between risks and returns (experts talk of expected value). Limited government and application of the rule of law are deemed the norm. Under these constraints, markets move towards predictable equilibrium positions. The role of antitrust and regulation is to align firms' incentives with the competitive equilibrium conditions described in static representations of the economy.

(ii) Antitrust and regulation focus on individual "markets," an approach known as "partial equilibrium" optimization. The assumption is that competition in individual markets averages well over the economy. In the same averaging spirit, neoclassical antitrust overlooks asymmetries and heterogeneity amongst agents. Instead, neoclassical antitrust assumes all agents pursue utility maximization.

In addition, not all markets matter to a neoclassical eye. Markets where firms compete for labor and capital are neglected. Product market competition is the focal point. Moreover, not all products brought within a market are accounted for as competition. Product rivalry is only deemed to exist under conditions of substitutability. The term of art is that antitrust and regulation consider the "relevant market."

(iii) Monopoly or efficiency are considered at the level of the firm. Rivalry with decreasing returns amongst profit-maximizing firms determines performance, prices, costs, and output levels. Gains in "consumer welfare" can be achieved by increasing the number of firms or by decreasing opportunities for interfirm cooperation. Limited attention is given to the role of divisional, organizational or managerial competition within the firm.

Some further issues are given short shrift in neoclassical methods. An assumption of fungible labor, for example, implies that the development of firm-level competitive advantages from organization or human resources is not a central issue in antitrust and regulation fact-finding. Relatedly, the role of technological competition in market outcomes has been considered as a footnote. Until the 1970s, innovation was treated as an exogenous force in

[5] Thomas E. Kauper, *Influence of Conservative Economic Analysis on the Development of the Law of Antitrust*, in How the Chicago School Overshot the Mark: The Effect of Conservative Economic Analysis on U.S. Antitrust (Oxford, 2008).

mainstream economics.[6] The learning changed in economics with the recognition that innovation is endogenous. But antitrust and regulation methods remain wedded to methods that give at best a nominal role to innovation in practice.

1.2. The Knowledge-Economy

As the economy is complexifying, the limitations of neoclassical methods are exposed like the Emperor's clothes. Antitrust and regulation methods' inaptitude to answer fundamental questions motivates a methodological reexamination.

(i) Complexification of the Economy

The economy is increasingly complex, meaning there is a global increase in the number of activities, and interactions between them.[7] One critical channel of economic complexification is the transition from an industrial to a knowledge-economy. Since the early 1970s and the Intel microprocessor announcement in Santa Clara, the economic system has experienced tremendous growth. The decoupling of information from matter has expanded the production possibility frontier.[8] New markets, industries, and economic sectors have relentlessly emerged fueled by entrepreneurial effort and public investments in technological infrastructure. Today, a universe of economic opportunities is on the horizon with the advent of new value creation propositions (like the metaverse), new forms of value capture (like non-fungible tokens), and new modes of economic transaction (like blockchain).

The nature of competition is also changing. The years that followed the wave of economic destruction of the 1999 Dot-Com crash witnessed the formation of dozens of very large digital firms in the US (and in China).[9] Google, Apple, Facebook, Amazon, and Microsoft are household names. But there are many more big firms in this group than just a few consumer-facing companies.

The big digital firms challenge our understanding of competition in ways that the good old big oil, big aluminum, and big tobacco monopoly suppliers did not. First, large digital firms sit at the center of interdependent ecosystems

[6] Robert M. Solow, *A Contribution to the Theory of Economic Growth*, 70 Q. J. Econ. 65, 85-87 (1956); Trevor W. Swan, *Economic Growth and Capital Accumulation*, 32 Econ. Rec. 334 (1956).
[7] César A. Hidalgo & Ricardo Hausmann, *The Building Blocks of Economic Complexity*, 106 Proc. NaVl Acad. Sci 10570 (2009); Ricardo Hausmann, César A. Hidalgo, Sebastián Bustos, Michele Coscia, Alexander Simoes & Muhammed A. Yildirim, The Atlas of Economic Complexity: Mapping Paths to Prosperity (MIT Press, 2014). To explore economic complexity, *see* The Harvard's Atlas of Economic Complexity, http://globe.cid.harvard.edu/; the MIT's Observatory of Economic Complexity https://atlas.media.mit.edu/en/; the Economic Complexity Legacy Rankings https://oec.world/en/rankings/legacy/eci.
[8] This idea is Marc Andreeseen's, *see* Antonio García Martínez, *The Man Whose Software Ate the World*, The Pull Request (Jun. 25, 2021).
[9] G. Thomas Goodnight & Sandu Green, *Rhetoric, Risk, and Markets: The Dot-Com Bubble*, 96 Q. J. Speech 115 (2010)

that connect their own services ("platforms")[10] and multiple agents with whom they entertain cooperative or/and competitive relationships. Second, increasing returns on the supply and demand side due to economies of scale and network effects create powerful incentives for efficient growth and diversification amongst all ecosystems agents.[11] Third, compared to the industrial economy, competitive advantage — and business survival — appear dependent on the firm's environment (e.g., dynamics at the industry, not market level) and technological resources.

(ii) Problems in Policy

Neoclassical antitrust methods would be unproblematic if they did a good enough job finding the existence or absence of competition. However, in the context of a complex knowledge-economy, neoclassical methods appear to provide unsatisfactory answers. Some examples of inconsistent results and sometimes absurd implications drive the point home.

The application of neoclassical methods led the European Commission to consider that Apple and Google are not competitors in an antitrust-relevant market.[12] Does this imply that the EC would treat a merger between Apple and Google as presumptively lawful, in line with its approach towards mergers between non-competitors? The Competition and Markets Authority in the UK considered Giphy a close competitor to Facebook. But a decade before, it refused to consider Instagram a potential competitor to Facebook. Why?

In a complaint, the US government has alleged that Google's payment to Apple in exchange for exclusive pre-installation of its search engine constituted exclusionary monopolization. But without any serious competitor in search, Google has no one to exclude. By contrast, it defies understanding that the US government never asks whether Apple extracting billions of dollars for preferential access to iPhones constitutes evidence of monopoly power in use.

More than 20 years after the case, the jury is still out on whether the antitrust litigation in *US v Microsoft* promoted, reduced, or was irrelevant on competition and innovation in digital industries. To paraphrase Frank Easterbrook, we are approaching a point where we have as many *ex-post* rationalizations about the *Microsoft* case as there were positions on what dragons looked like 600 years ago.[13]

[10] Thibault Schrepel, *Platforms or Aggregators: Implications for Digital Antitrust Law*, 12 J. Eur. Compet. Law Pract. 1 (2021).
[11] Brian Arthur, Increasing Returns and Path Dependence in The Economy (Michigan, 1994) (exploring four types of increasing returns: scale economies, learning effects, adaptive expectations, network economies).
[12] European Commission, 18 June 2018, Case AT.40099, *Google Android*, para. 241.
[13] Frank H. Easterbrook, *Predatory Strategies and Counterstrategies*, 48 U. Chi. L. Rev. 263 (1981).

1.3. Complexity Denialism

Different reactions have emerged from the antitrust field in reaction to the creation, expansion, and maturation of the knowledge-economy. The Neo-Brandesians have been first to propose a complete antitrust analysis of the knowledge-economy. Neo-Brandeisians recognize complexity to the extent that they consider that large digital firms hold a specific form of structural power over markets.[14] According to Neo-Brandeisians, "gauging real competition in the twenty-first century marketplace—especially in the case of online platforms—requires analyzing the underlying structure and dynamics of markets (...) a company's power and the potential anticompetitive nature of that power cannot be fully understood without looking to the structure of a business and the structural role it plays in markets".

Failing to translate that methodological observation into practice, however, Neo-Brandesians paint a one size fits all "big is bad"' picture of large digital firms.[15] The solutions proposed are the same as those advocated by Justice Brandeis in the early 20th century. Against the background of an assumption of decreasing returns, neo-Brandesians defend break-ups and want to classify platforms as "public utilities". There is little interest in empirical facts, except those denoting corporate size, dominant shares, and conglomeration. The industry environment and technological resources are ignored.

The Neo-Chicagoan reply has been equally ideological in analyzing the knowledge-economy. Neo-Chicagoans rely on observations of rising output in the digital sector to draw a general inference of economic efficiency and justify a blanket *laissez-faire* approach. Emergent issues like privacy loss or excessive ad load are glossed over. According to Neo-Chicagoans, rational users freely barter their privacy in exchange for free goods and services. The ever-increasing amount of targeted advertisement supplied by large digital firms is treated as an informational improvement. Where Neo Brandesians see bigness everywhere, Neo Chicagoans see gains in consumer surplus.

In last analysis, Neo-Chicagoans double down on the methods developed by the Chicago school.[16] They model the economy as an equilibrium system in which firms have equal initial access to technology, capital, and information, and compete for advantage through product and cost-efficiency. Monopoly

[14] See Lina Khan, *The New Brandeis Movement: America's Antimonopoly Debate*, 9 J. Eur. Compet. Law Pract. 131 (2018) ("The Chicago School assumes that market structures emerge in large part through 'natural forces.' The New Brandeisians, by contrast, believe the political economy is structured only through law and policy").
[15] *Ibid*.
[16] Joshua D. Wright, *Abandoning Antitrust's Chicago Obsession: The Case for Evidence-Based Antitrust*, 78 Antitrust L.J. 241, 250 (2012) (underlining the lack of differences between the Neo-Chicago School and the original Chicago School).

rents cannot exist unless firms enjoy government protection. Neo-Chicagoans' disinterest in technology allows them to turn a blind eye to specific properties of the knowledge-economy.[17] Increasing returns to adoption, lock-in by historical events, and path dependence[18] which play a determinant role in selecting market outcomes, and raise complexity, are looked down upon as fables.[19] A hidden assumption appears to be that if a market is locked into an inferior technology, the costs of improving this outcome through government intervention will exceed its benefits.

In contrast to Neo-Brandeisians and Neo-Chicagoans, Neo-Schumpeterians draw richer methodological implications from economic complexification.[20] Neo-Schumpeterians also consider markets as the main focus of interest. But markets are envisioned as a "selective device" amongst different firms.[21] Firms struggle to survive, and the reason why they win or fail matter. From this Darwinian predicate, Neo-Schumpeterians look at competition through a whole array of perspectives. A wide variety of analytical paradigms exist in the literature, like dynamic capabilities,[22] organizational routines, and the resource-based theory.[23] In their inquiries, Neo-Schumpeterians place heavy emphasis on technology and dynamism.[24] But their work predates the knowledge-economy and has not yet been updated to account for new empirics.[25] Moreover, Neo-Schumpeterians' overlook the role of the public sector in the economy in general and in relation to technological capability in particular. A related implication is that Neo-Schumpeterian hardly ever give a role of antitrust policies in their discussion of competitive outcomes.[26]

In the 1990s, Ken Arrow called upon his profession to develop a new approach to the theory of oligopoly in response to the rise of the knowledge

[17] Thomas J. Horton, *Unraveling the Chicago/Harvard Antitrust Double Helix: Applying Evolutionary Theory to Guard Competitors and Revive Antitrust Jury Trials*, 41 U. Balt L. Rev. 615, 644 (2012) (arguing that Chicago School and its modern ramifications "completely ignores the risks of lost variation, diversity, and complexity")

[18] Luis Araujo & Debbie Harrison, *Path Dependence, Agency and Technological Evolution*, 14 Technol. Anal. Strateg. Manag. 5 (2022) ("path dependence is associated with two types of event sequences: self-reinforcing and reactive sequences (...) self-reinforcing sequences are dominated by structural mechanisms, often remote in terms of their spatial and temporal origins, which keep events moving along a particular track. Reactive sequences are characterized by consequential, path shaping actions that often rearticulate existing structures and carve new trajectories").

[19] S.J. Liebowitz & Stephen E. Margolis, *The Fable of the Keys*, 33 J.L. & Econ. 1 (1990).

[20] For an overview of the Neo-Schumpetarian movement, *see* Chris Freeman, *The Economics of Technical Change*, 18 Camb. J. Econ. 463 (1994); Horst Hanusch & Andreas Pyka, *Principles of Neo-Schumpeterian Economics*, 31 Camb. J. Econ. 275 (2006).

[21] Giovanni Dosi, *Technological Paradigms and Technological Trajectories: A Suggested Reinterpretation of the Determinants and Directions of Technical Change*, 11 Res. Policy 147 (1982).

[22] David Teece, Gary Pisano & Amy Shuen, *Dynamic Capabilities and Strategic Management*, 18 Strategic Mgmt. J. 509 (1997).

[23] Richard Nelson & Sidney Winter, An Evolutionary Theory of Economic Change (Harvard, 1982).

[24] W. Brian Arthur, *Competing Technologies, Increasing Returns, and Lock-In by Historical Events*, 99 Econ. J. 116 (1989); Giovanni Dosi, *Technological Paradigms and Technological Trajectories: A Suggested Interpretation of The Determinants and Directions of Technical Change*, 11 Res. Pol'Y 147 (1982); Giovanni Dosi, *Sources, Procedures, and Microeconomic Effects of Innovation,* 26 J. Econ. Lit. 1120 (1988).

[25] Andreas Pyka & Richard R. Nelson, *Schumpeterian Competition and Industrial Dynamics*, in Modern Evolutionary Economics (Cambridge, 2018); Giovanni Dosi, Technical Change and Industrial Transformation (Palgrave, 1984).

[26] For example, although groundbreaking, Modern Evolutionary Economics: An Overview, ed. Nelson et al. (Cambridge, 2018) does not feature any mention of "antitrust".

economy.[27] What have antitrust experts done? In hindsight, all three schools have circled back on ideology.[28] This background is what motivates taking a different direction in response to the advent of the knowledge-economy, and avoiding knee-jerk denialism of the knowledge-economy's complexity. If established antitrust ideologies have limited answers to propose, a promising place to start a methodological reexamination might lie in the complexity science, as Ken Arrow pointed out.

2. Perspectives from Complexity Science

Complexity science is widely used across disciplines (**2.1**), but not in antitrust. We fill this gap showing that it allows for a better understanding of what competition is (**2.2**), and we explore the resulting antitrust framework (**2.3**).

2.1. Definition, History, and Applications

Complexity science studies how "micro-level interactions lead to the emergence of macro-level patterns of behavior" and how these patterns influence back micro-level interactions.[29] Another conventional description of complexity science stresses its focus on *systems* and how they adaptively change through the backpropagation of the *context* they create.[30]

In the 19th century, Darwin pioneered works on complexity by studying the relationship between species, varieties, and their environment.[31] Though not phrased in such terms, Darwin laid down the foundations of what would become systems thinking, multilevel analysis, and evolutionary theory. In the following century, complexity science irrigated various fields, including biology,[32] political economy,[33] physics,[34] game theory,[35] archeology,[36]

[27] Kenneth J. Arrow, *Technical Information and Industrial Structure*, 2 Indus. & Corp. Change 645 (1996).
[28] *Ibid*.
[29] Richard S. Whitt & Stephen J. Schultze, *The New "Emergence Economics" of Innovation and Growth, and What It Means for Communications Policy*, 7 J. on Telecomm. & High Tech. L. 217, 225 (2009)
[30] For an introduction, *see* John H. Holland, *Complexity: A Very Short Introduction* (Oxford, 2014); Stefan Thurner, Rudolf Hanel & Peter Klimek, Introduction to the Theory of Complex Systems (Oxford, 2018); M.M. Waldrop, Complexity: The Emerging Science at the Edge of Order and Chaos (Simon & Schuster, 1992); Melanie Mitchell, Complexity: A Guided Tour (Oxford, 2009).
[31] Kurt Dopfer & Richard R. Nelson, *The Evolution of Evolutionary Economics*, in Modern Evolutionary Economics: An Overview (Cambridge, 2018) (underlining that "the proposition that cultural, social, political, and economic structures and modes of operation should be understood as evolving predates Darwin", see "Mandeville (1714) regarding the evolution of ship design. Hume's description, in 1762, of how the British social structure and culture of his day came to be clearly is evolutionary in spirit, as is Smith's (1776) analysis of what is going on in the economy").
[32] Deborah Gordon, Ants at Work: How an Insect Society Is Organized (Free Press, 2011)
[33] Robert Axelrod, *An Evolutionary Approach to Norms*, 80 Am. Polit. Sci. Rev. 1095 (1986).
[34] Yurij Holovatch, Ralph Kenna & Stefan Thurner, *Complex Systems: Physics Beyond Physics*, 38 Eur. J. Phys. 1 (2017).
[35] Kristian Lindgren, Evolutionary Phenomena in Simple Dynamics, in Artificial life II: Proceedings of the Workshop on Artificial Life, ed. Christopher G. Langton et al. (Addison-Wesley, Reading, MA, 1991).
[36] Timothy A. Kohler, *Complex Systems and Archaeology*, SFI Working Paper (2011).

finance,[37] sociology,[38] biochemistry,[39] history,[40] musicology,[41] trading networks,[42] biochemistry,[43] medicine,[44] cultural studies,[45] etc.

In so far as economics is concerned, complexity science has also gained momentum.[46] Since the 1980s, an increasing number of studies have considered the economic system as a living organism instead of a machine. The economy is looked at as a set of systems made of components that combine and recombine. A complexity perspective considers that economic systems and their elements grow, shrink, and change. The ambition is to provide insights into the determinants of evolutionary processes in the economy. In complexity economics, the focus of analysis is on:

1. Organizational characteristics of the firm, e.g., resources, capabilities, management, ownership, etc.
2. Business strategy, e.g., products and services sold; transactional relations with suppliers, customers, and consumers; learning from experience,[47] routines,[48] etc.
3. Competitive environment, e.g., industrial, institutional, and technological forces.
4. Interaction between the above-mentioned variables.[49]

[37] Ramon Marimon, Ellen McGrattan & Thomas Sargent, *Money as a Medium of Exchange in an Economy with Artificially Intelligent Agents*, 14 J. Econ. Dyn. Control 329 (1990).
[38] Brian Castellani & Frederic William Hafferty, *Sociology and Complexity Science* (Springer, 2009).
[39] Mark E. Ritchie, *Reaction and Diffusion Thermodynamics Explain Optimal Temperatures of Biochemical Reactions*, 8 Sci. Rep. 1 (2018).
[40] David C. Krakauer, John Gaddis & Kenneth Pomeranz, History, Big History, & Metahistory (Santa Fe Press, 2017).
[41] Matt Setzler, Tyler Marghetis & Minje Kim, *Creative Leaps in Musical Ecosystems: Early Warning Signals of Critical Transitions in Professional Jazz*, CogSci Proceedings (2018); Helena Miton, Thomas Wolf, Cordula Vesper, Günther Knoblich & Dan Sperber, *Motor Constraints Influence Cultural Evolution of Rhythm*, 287 Proc. R. Soc. B. (2020).
[42] Leigh Tesfatsion, *Agent-Based Computational Economics: Growing Economies from the Bottom Up*, 8 Artif. Life 55 (2002).
[43] Danail Bonchev & Dennis H. Rouvray, Complexity in Chemistry, Biology, and Ecology (Springer, 2005).
[44] Trisha Greenhalgh & Chrysanthi Papoutsi, *Studying Complexity in Health Services Research: Desperately Seeking an Overdue Paradigm Shift*, 16 BMC Med. 1 (2018).
[45] Jeffrey Johnson & Karen Cham, *Complexity Theory: A Science of Cultural Systems?*, 10 M/C Journal 21 (2007); Richard E. Lee, *Cultural Studies, Complexity Studies And The Transformation of The Structures of Knowledge*, 10 Int. J. Cult. Stud. 11 (2007).
[46] W. Brian Arthur, *Foundations of Complexity Economics*, 3 Nat. Rev. Phys. 136 (2021); Giovanni Dosi & Richard R. Nelson, *An Introduction to Evolutionary Theories in Economics*, 4 J. Evol. Econ. 153 (1994) ("Nelson and Winter (1982) has been followed by several other works also exploring evolutionary theory in economics (among others, Dosi et al. (1988), Saviotti and Metcalfe (1991), Anderson, Arrow and Pines (1989), Day and Eliasson (1986), Winter (1984) and (1987), Witt (1992), DeBresson (1988), Langlois and Everett (1992), Metcalfe (1992), Stiglitz (1992)"); Alan Kirman, *The Intrinsic Limits of Modern Economic Theory: The Emperor has No Clothes*, 99 Econ. J. 126 (1989); Koen Frenken, *Technological Innovation and Complexity Theory*, 15 Econ. Innov 137 (2006). Please note, however, that economists have been questioning economic assumptions for a long time, *see* Thorstein Veblen, *Why is Economics not an Evolutionary Science?*, 12 Q. J. Econ. 373 (1898); T. J. Sargent, *Bounded Rationality in Macroeconomics* (Clarendon Press, 1993); W. Brian Arthur, *Complexity and the Economy* (Oxford, 2014).
[47] Richard R. Nelson, The Sources of Economic Growth, 83 (Harvard, 1996); Shlomo Maital et al., *The Relation Between the Average Complexity of High-Tech Products And Their Diversity: An Empirical Test of Evolutionary Models*, 4 J. Evol. Econ. 273 (1994).
[48] Richard S. Whitt & Stephen J. Schultze, *The New "Emergence Economics" of Innovation and Growth, and What It Means for Communications Policy*, 7 J. On Telecomm. & High Tech. L. 217, 242 (2009)
[49] Schumpeter mentioned dynamism at the macro-level, but failed to analyze the reasons explaining it, including the ones at the micro-level such as technological combination and evolution. Instead, he simply mentioned that innovation often results from the "carrying out of new combinations," Joseph Schumpeter, The Theory of Economic Development (Routledge, 1934).

Mainstream economics has a troubled relationship with complexity science. The idea of incommensurability of complex phenomena has been a hard pill to swallow in a field that reifies measurement and quantitative analysis. Friedrich Hayek explained the problem:[50]

> "Unlike the position that exists in the physical sciences, in economics and other disciplines that deal with essentially complex phenomena, the aspects of the events to be accounted for about which we can get quantitative data are necessarily limited and may not include the important ones. While in the physical sciences it is generally assumed, probably with good reason, that any important factor which determines the observed events will itself be directly observable and measurable, in the study of such complex phenomena as the market, which depend on the actions of many individuals, all the circumstances which will determine the outcome of a process."[51]

This predicament has long ostracized complexity science in subfields like Austrian economics, evolutionary economics, or institutional economics. But a wind of change can be felt. Progresses in techniques — essentially computational — like agent-based and pattern-oriented modeling are allowing improved observation, estimation, and prediction.[52]Fruitful applications of complexity theory arise in fields such as the economics of technological change,[53] ecological economics,[54] economics of disease transmission,[55] economics of climate change,[56] economics of human activities and physical environments,[57] economics of public-good management.[58]

[50] See Paul Lewis, *The Ostroms and Hayek as Theorists of Complex Adaptive Systems: Commonality and Complementarity*, in The Austrian and Bloomington Schools of Political Economy, 49 (Emerald 2017); W. Brian Arthur, *Foundations of Complexity Economics*, 3 Nat. Rev. Phys. 136 (2021) (explaining that complexity science "has roots in thinking developed in the 1970s in Brussels, Ann Arbor and Stuttgart")

[51] Friedrich August von Hayek, *The Pretence of Knowledge*, Nobel Memorial Lecture (Dec. 11, 1974).

[52] Cara A. Gallagher, Magda Chudzinska, Angela Larsen-Gray, Christopher J. Pollock, Sarah N. Sells, Patrick J. C. White & Uta Berger, *From Theory to Practice in Pattern-Oriented Modelling: Identifying And Using Empirical Patterns In Predictive Models*, 96 Biol. 1868 (2021).

[53] Edward W. Constant, The Origins of the Turbojet Revolution (Johns Hopkins, 1980); George Basalla, The Evolution of Technology (Cambridge, 1988); Joel Mokyr, The Lever of Riches: Technological Creativity and Economic Progress (Oxford, 1990); W. Brian Arthur, The Nature of Technology: What it is and How it Evolves (Simon & Schuster, 2009).

[54] Jürgen Essletzbichler & David L. Rigby, *Exploring Evolutionary Economic Geographies*, 7 J. Econ. Geogr. 549 (2007); Ronald Martin & Peter Sunley, *The Place of Path Dependence in an Evolutionary Perspective on the Economic Landscape*, in The Handbook of Evolutionary Economic Geography (Edward Elgar, 2010).

[55] Anton Pichler, Marco Pangallo, R. Maria del Rio-Chanona, François Lafond & J. Doyne Farmer, *Production Networks and Epidemic Spreading: How to Restart the UK Economy?* (2020).

[56] Kurt Dopfer & Richard R. Nelson, The Evolution of Evolutionary Economics, in Modern Evolutionary Economics (Cambridge, 2018)

[57] Christian Rammel, Sigrid Stagl & Harald Wilfing, *Managing Complex Adaptive Systems -- A Co-Evolutionary Perspective on Natural Resource Management*, 63 Ecol. Econ. 9 (2007); Julien-François Gerber & Rolf Steppacher, Towards an Integrated Paradigm in Heterodox Economics (Palgrave, 2012).

[58] Elinor Ostrom, *Beyond Markets and States: Polycentric Governance of Complex Economic Systems*, 100 American Econ. Rev. 641 (2010).

Of course, computational techniques capture at best a fraction of economic complexity. Even in advanced computational models, many aspects of economic systems are ignored. But computational techniques walk in the right direction. They highlight the necessity (and difficulty) of considering more dimensions of economic systems. They also stress the relevance of change, dynamism, and processes. In some important fields, like financial economics, experts are today opening their eyes to the relevance of complex, evolutionary, and multi-level dynamics.[59] The same new perspectives can inform a reexamination of antitrust methods.

2.2. Complexity in Antitrust: Channels of Relevance

Complexity science was never deployed in an antitrust context.[60] A claim that an introduction of complexity science in antitrust can improve the state of affairs is necessarily fragile. But the same holds true for a claim that complexity science holds limited potential to ameliorate antitrust short of empirical testing in real-life cases.

Two reasons allow a belief that complexity science holds relevant insights for antitrust. First, complexity science provides the multilevel lens on competition that has been long called for by antitrust scholars and practitioners. Second, complexity science supplies an understanding of competition as uncertainty that is richer than contemporary associations with rivalry.

(i) Multilevel Analysis

Complexity science develops abstract frameworks that consider interdependent multilevel systems. How can this help antitrust? An understanding of competition as a multilevel system provides a broad lens on competitive and anticompetitive forces discarded in a single-level neoclassical antitrust evaluation. What are the levels at which one can attempt to observe competition dynamics with a complexity mindset?

At this stage of elaboration, one can draw a line between the macro, meso, and micro-levels of a competitive system.[61] These levels are not selected

[59] George Soros, *Fallibility, Reflexivity, and the Human Uncertainty Principle*, 20 J. Econ. Methodology 309 (2013); Andrew W. Lo, Adaptive Markets: Financial Evolution at the Speed of Thought (Princeton, 2017); Richard Bookstaber, The End of Theory: Financial Crises, the Failure of Economics, and the Sweep of Human Interaction (Princeton, 2017).

[60] There are a few articles discussing the usefulness of complexity science in antitrust analysis, but they are not deploying a new and related antitrust method, *see* Gregory T. Gundlach, *Complexity Science and Antitrust*, 51 Antitrust Bull. 17 (2006); Thomas J. Horton, *Competition or Monopoly – The Implications of Complexity Science, Chaos Theory, and Evolutionary Biology for Antitrust and Competition Policy*, 51 Antitrust Bull. 195 (2006); Joseph Farrell, *Complexity, Diversity, and Antitrust*, 51 Antitrust Bull. 165 (2006); Gregory T. Gundlach & Albert A. Foer, *Complexity, Networks, and the Modernization of Antitrust: The American Antitrust Institute's Roundtable on the Science of Complexity and Antitrust*, 51 Antitrust Bull. 1 (2006).

[61] For an illustration, *see* here.

arbitrarily. They correspond to established understandings of competition developed by scholars outside of neoclassical economics.

The macro-level of a competitive system is the industry. Within an industry, firms of different sizes, positions, and countries engage in "related," not just rival activity. The focus of firms within an industry is on short-term growth and long-term survival.[62] Firms within an industry seek competitive parity. Firms compete in the sense that they try to maintain financial, managerial, and technological capabilities comparable to their peers.[63] An example is the ICT and software industry.

The meso-level of a competitive system is the market.[64] Firms within a market supply (or purchase) substitutable products or services. The focus of firms within a market is on profit maximization. Firms within a market compete for share. An example is the market for online advertisement services where Facebook and Google compete to attract advertisers.[65]

The micro-level of a competitive system is the firm. Inside a firm, agents compete and/or cooperate to maximize individual payoffs. Corporate governance aligns agents' incentives with the firm's goals. A firm will select a mix of cooperation and competition called "co-opetition" between individuals, units, and divisions. And it will enforce co-opetition by exercise of hierarchical control over employees, managers, and contractors. A striking example of co-opetition is Meta where WhatsApp and Messenger compete and cooperate to develop messaging services.[66]

An understanding of competition as a multilevel system is already a progress. Neoclassical antitrust nominally acknowledges both rivalry beyond markets and organizational arrangements within firms. For analytical convenience, however, neoclassical antitrust treats practically both forces as irrelevant variables in an evaluation of competition.

But an even more relevant insight can be gained by considering interconnections between the various levels. What does complexity economics teach? That competitive selection at the meso-level might be a dependent variable of *competitive* changes at the macro and micro competitive levels, not just market rivalry. The history of Netflix in the 2000s

[62] Moshe Farjoun, *The End of Strategy?*, 5 Strateg. Organ 197 (2007)

[63] A complexity lens would discuss this level in terms of the "environment" of the competitive system. Other possible framings are innovation competition, broad spectrum competition, Schumpeterian competition, long-term competition.

[64] Or buy input, with exception of labor and capital.

[65] A complexity lens would discuss this level in terms of competition between "species." Michael Porter talked of "extended rivalry," *see* Michael E. Porter, Competitive Strategy (Free Press, 1980).

[66] A complexity lens would discuss this level in terms of the "organism" of the competitive system. Another possible framing is co-opetition, *see* Adam M. Brandenburger & Barry J. Nalebuff, Co-Opetition (Currency Doubleday, 1996).

provides a good anecdotal illustration of the importance of multilevel analysis.[67] Let us look at the sequence of events:

- In 2004, Netflix's main competitors are Blockbuster and Walmart in DVD rental;[68]
- In 2005, Netflix realizes that Internet delivery of content to the home will "*surpass DVD*" by virtue of increasingly competitive high-speed Internet and cloud services offerings;[69]
- In 2007, Netflix introduces a streaming service that competes with legacy DVD operations;
- In 2008, Netflix starts using Amazon AWS for cloud services, pivoting away from its own logistical operations;[70]
- In 2009, Netflix develops an internal prize programme to improve algorithmic recommendation accuracy in a context of increased competition with cable content providers;[71]
- In 2011, Netflix becomes the single largest source of Internet traffic in the US despite the lack of significant in-house infrastructures;[72]
- In 2013, Netflix gives into content production. Award-winning TV shows and movies (like House of Cards) now compete with major film studios;[73]
- In 2016, Netflix introduces a download-and-go feature that allows users to watch content offline and changes the way content is encoded to enable users to easily stream content on a smartphone.[74]
- Today, Netflix faces direct competition from Amazon Prime, Apple TV, HBO Max, Disney +, and Hulu.[75] And it recently entered the gaming industry.[76]

In stylized terms, growth of Netflix's industry peers at the macro-level prompted a reconfiguration of co-opetition arrangements at the micro-level, and led to the selection of new rivals at the meso-level.

[67] One could also look at Spotify, *see* Ben Thompson, *Shopify's Evolution*, Stratechery (Feb. 22, 2022).
[68] In 2006, Netflix was still involved in a price war with Blockbuster.
[69] As well as Amazon SimpleDB, S3, and Cassandra for file storage, *see* Saul J. Berman, Lynn Kesterson-Townes, Anthony Marshall & Rohini Srivathsa, *How Cloud Computing Enables Process and Business Model Innovation*, 40 Strategy Leadersh. 27 (2012).
[70] Adrian Cockroft, Cory Hicks & Greg Orzell, *Lessons Netflix Learned from the AWS Outage*, Netflix Blog (Apr. 29, 2011) ("Netflix manages to build its Internet video delivery service with little infrastructure of its own").
[71] Netflix offered a $1 million prize to anyone who could improve the accuracy of its algorithm recommendation by 10% and awarded it to BellKor Pragmatic Chaos in 2009, *see* Eliot Van Buskirk, *BellKor's Pragmatic Chaos Wins $1 Million Netflix Prize by Mere Minutes*, Wired (Sept. 21, 2009). The programme helped Netflix better identify an "addressable audience;" Yehuda Koren, *The BellKor Solution to the Netflix Grand Prize*, 81 Netflix Prize Documentation 1 (2009). The prize helped Netflix improve the baseline predictors and Restricted Boltzmann Machines, but also to address temporal dynamics.
[72] Vijay Kumar Adhikari et al., *Unreeling Netflix: Understanding and Improving Multi-CDN Movie Delivery*, *2012* Proceedings IEEE INFOCOM (2012); Erick Schonfeld, *Netflix Now the Largest Single Source of Internet Traffic In North America*, TechCrunch (May 17, 2011).
[73] Wikipedia, *List of Accolades Received by Netflix* (Mar. 2022), https://perma.cc/42H9-SXGL.
[74] Eddy Wu, *Downloads Make It Even Easier to Watch Netflix on the Go*, Netflix (Nov. 30, 2016); Andrey Norkin, Jan De Cock, Aditya Mavlankar & Anne Aaron, *More Efficient Mobile Encodes for Netflix Downloads*, Netflix Technology Blog (Dec. 1, 2016).
[75] Dan Gallagher, *Netflix Is Chill About Pandemic's End*, Wall Street Journal (Apr. 18, 2021).
[76] Mike Verdu, *Let the Games Begin: A New Way to Experience Entertainment on Mobile*, Netflix (Nov. 2, 2021).

Admittedly, it would be bad scholarship to derive a general rule from a simple anecdote. But complexity-minded scholars have made many similar observations in other industries. Together, their works suggest that markets are subject to a competitive force complementary to, and distinct from, product rivalry at the meso-level.

(ii) Uncertainty

In interconnected multilevel systems, firms face a challenge: make sense of the complexity. Depending on the concrete properties of the competitive system, macro, meso, and micro interconnections give rise to unexpected changes.[77] For industries, businesses, and managers, the challenge associated with predicting the future in a complex economy leads to uncertainty.[78] As the costs of opportunity seeking and risk avoidance increase, so does competitive pressure. A new paradigm emerges:

Complexity <—> Uncertainty <—> Competition

Firms respond to uncertainty in distinct ways. Some firms hustle under uncertainty.[79] Firms in this category "cognize". They do not make perfectly informed decisions. Firms that hustle *under* uncertainty diversify, explore, and innovate. Other firms hustle *against* uncertainty. To paraphrase George Stigler, they jump out of the uncertainty "frying pan".[80] Firms that hustle against uncertainty collude, lock in users and/or trading partners, and seek to maintain the status quo.[81]

The competitive pressure bearing on complex competitive systems highlights another objective for antitrust. In addition to rivalry, antitrust might work to maintain uncertainty. Granted, rivalry is a powerful adjuvant of uncertainty. And antitrust laws, to a certain extent, already embody an orientation towards

[77] Frank H. Knight, Risk, Uncertainty, And Profit (Houghton Mifflin, 1921) (making a distinction between risk and uncertainty. Risk occurs when the probabilities of different future states are known. On the contrary, uncertainty occurs when the probabilities of future states are not known).

[78] As Hayek put it, with social sciences, "it's the subject that's much more complicated [than in physical sciences]" because it changes behaviors depending on others, *see* Friedrich von Hayek & Leo Rosten Part III, YouTube (1978); also, George Soros, *Fallibility, Reflexivity, and the Human Uncertainty Principle*, 20 J. Econ. Methodology 309, 316-317 (2013) (explaining that in natural sciences, observation does not impact phenomenon. In social sciences, it does because the subject "thinks". He concludes that "[t]he resulting uncertainty hinders the social sciences in producing laws similar to Newton's physics").

[79] Kim B.Clark, *The Interaction of Design Hierarchies And Market Concepts In Technological Evolution*, 14 Res. Policy 235, 236 (1985) ("uncertainty is more than a precondition for evolution, it is also a determinant of its pattern (…) The pattern of innovation (…), the kinds of changes introduced, the timing of particular changes and so forth, will depend in part on the pattern of uncertainty, and the way in which new understanding is developed").

[80] George J. Stigler, *The Economists' Traditional Theory of The Economic Functions of The State*, in The Citizen and The State: Essays on Regulation 103, 113 (Chicago, 1975).

[81] As Joliet noted, "cartels tend to preserve the status quo and keep less efficient business units in existence, thereby enabling the more efficient firms to make comfortable profits", René Joliet, Monopolization and Abuse of Dominant Position – A Comparative Study of the American and European Approaches to the Control of Economic Power, 259 (La Haye, Liege, 1970).

uncertainty at the meso-level. Cartel laws raise the cost of uncertainty-reducing communications between competitors. Monopolization laws increase uncertainty by maintaining opportunities for contestability to new entrants. Merger control systems prevent markets from falling under unified control, and allow firms to combine and recombine, thereby promoting uncertainty.

With uncertainty as a function for antitrust, new policy targets emerge. Uncertainty can be promoted at the macro and micro-level through antitrust intervention at the meso-level. For example, antitrust might impose access duties, line of business restrictions, and M&A bans on firms exposed to insufficient levels of uncertainty. Such policies foster competitive responses when they encourage market power firms to direct their efforts towards uncertain related products and services at the macro-level.[82] Another example of antitrust intervention might consist in raising the share of internal activities competing with core products and services at the micro-level.

An uncertainty mindset also helps when complex systems decomplexify. In a context of increasing returns, complex systems can lead to lock-in. Classic lock-in examples are QWERTY domination over the Dvorak Simplified keyboards;[83] VHS video cassette recorder standard over Betamax,[84] and light-water reactors over the gas-cooled reactors.[85] More recently, the prevalence of cable-chargers over wireless chargers, the constant domination of USB-A (1996) over faster and more versatile connetics such as USB-C (2014), and the use of Bluetooth (1998) over Low-Power WiFi solutions show how increasing returns arising from coordination externalities can result in lock-ins. Until now, neoclassical antitrust has not addressed the problem of lock-in. This is because lock-in can sometimes be beneficial. This is the case when the selected system is the superior one. Short of a test allowing to sort inferior from superior systems, antitrust has not been willing to address head on the issue of lock in. But under an uncertainty mindset, not an efficiency one, a reasonable rationale for intervention emerges to the extent that lock in suppresses complexity.

2.3 Complexity in Antitrust: A Framework

Compared to a neoclassical approach, what does a complexity-minded antitrust entail? A full treatment of the issue is beyond the ambition of this paper. Some building blocks can be identified.

[82] To illustrate, Facebook's Metaverse might be a reaction to rising regulation of its market power position in social media.
[83] Paul A. David, *Clio and the Economics of QWERTY*, 75 Am. Econ Rev., 332 (1985).
[84] Brian Arthur, *Positive Feedbacks in the Economy*, 262 Sci. Am. 92 (1990)
[85] W. Brian Arthur, *Competing Technologies, Increasing Returns, and Lock-In by Historical Events*, 99 Econ. J. 116 (1989).

(i) Feedback Loops

An understanding of feedback loops is critical to the development of complexity-minded antitrust. A feedback loop occurs when a system's output (O1) serves as input (I) for other output (O2). Feedback loops (also called "recursive loops" or just "loops") are intuitively easy to grasp, but their effects are hard to predict.[86]

Two types of feedback loops exist. In a system with positive feedback loops, the quantity or quality of output changes. The system moves away from its initial equilibrium. $O1 \ncong O2$ with $O1 < O2$ or $O1 > O2$. Output variations are amplified. The system is "alive". Consider the example of PayPal. Several strategic decisions affecting PayPal's customer base (O1) contributed to (I) further increases of its customer base (O2). In 1999, PayPal triggered a self-reinforcing network effect by offering new users $10 for joining.[87] With exponential growth of its customer base, PayPal could sell to eBay, and become its subsidiary in 2002. The acquisition helped democratize online payment and thus contributed to changing the online sales environment. In 2014, PayPal went back to being a separate publicly traded company and soon acquired Xoom Corporation (2015), iZettle (2018), Honey (2019), thus further expanding online payment solutions and use.

In a system experiencing negative feedback loops, the quantity or quality of output does not change. The system sticks towards its initial equilibrium position: $O1 \cong O2$. Output variations are minimal. The system is "dead". Consider the example of MySpace. In spite of substantial investments (O1), the social media platform did not manage to fuel (I) additional growth (O2). MySpace's position plateaued with increasing reports of inappropriate content on the platform. It eventually collapsed.

Both types of feedback loops can be good or bad for competition. Negative feedback loops are compatible with competition or monopoly. In the perfect competition model, a negative feedback loop prevents market monopolization. Capacity constrained sellers cannot successfully undercut rivals. Similarly, in the monopoly model, a negative feedback loop prevents competition. The monopolist control over output creates supply-side inelasticity.

Positive feedback loops are compatible with competition and monopoly too. The uncertainty arising from positive feedback loops produces competitive pressure, non-inertial behavior, and business dynamism. Positive feedback

[86] Mark Newman, Albert-László Barabási & Duncan J. Watts, The Structure and Dynamics of Networks (Princeton, 2006).
[87] Peter Thiel, Zero to One: Notes on Start-Ups, or How to Build the Future, 18 (Virgin Books, 2001).

loops are associated with technological change, the development of new products and services, and adoption of innovative business models. But positive feedback loops also reduce uncertainty when they create winner-takes-all advantages, market tipping, and path dependence.[88] Positive feedback loops are associated to the problems of lock-in of markets into inferior technologies, products, and services.

An understanding of feedback loops highlights a more comprehensive scope for antitrust. Rivalry is weakened when a system returns to the monopoly equilibrium by virtue of a negative feedback loop. Neoclassical antitrust understands this. But rivalry is also limited when a positive feedback loop locks a system into a rigid developmental path (and this regardless of whether the option is superior or inferior). Neoclassical antitrust does not understand this. A concrete example underscores the point. Today, output-increasing monopolies are dealt with in a binary manner. On the one hand, some agencies and courts equate large size with monopoly. This is the approach followed by the EU in digital markets. Gatekeeping firms are deemed structurally anticompetitive, regardless of output growth at firm and industry levels. On the one hand, US antitrust courts associate output growth with competition. In the *Amex* case of 2017, reported increases in payment card transactions at firm and industry levels allowed the Supreme Court to dismiss direct evidence of exercize of monopoly power by the defendant.

In both the *Google* and *Amex* cases, a more relevant question might have consisted in wondering whether a lock-in situation existed so that growth benefited defendant firms disproportionately relative to other industry participants. The reason why this question is relevant is not that lock-in reduces rivalry. The point is that lock-in might, or not, diminish change, limit uncertainty, and blunt competitive pressure at the various levels of a competitive system. The question is ultimately an empirical one.

(ii) Random events

What forces set positive feedback loops in motion? Complexity theory teaches that in increasing returns contexts, "random" events trigger positive feedback loops. Random events are not to be confused with events that happen by chance. Random events are often known facts. But they are facts whose possible *outcomes* are all equally likely. Complexity literature refers to this idea of contingency in outcomes by talking of "historical" events.

Diverse types of random events contribute to positive feedback loops. Some are technological. For example, Apple's anticipation of the success of form

[88] In this last case, the competitive system features both low uncertainty, and possibly inefficient outcome selection.

factors smaller than computer systems triggered massive expansions of output in industries like advertising, content creation, or finance. Others are economic. For example, business model innovation like Google's introduction of search advertising inspired the development of new modes of personalized advertising, marketing, and pricing across digital markets. Last, political and regulatory events also cause positive feedback loops. For example, Section 230 of the US 1996 Communications Decency Act has spurred the growth of online intermediaries by expressly shielding them from liability for publication, moderation, or censorship of content (including that posted by third parties).

Random events are costly to observe. Random events can be big or "small", substantial or "insignificant". What is more, random events have low predictability of outcomes. As Brian Arthur explains, random events by nature render costly to predict competitive or monopoly consequences with any degree of certainty.[89]

Given this, neoclassical antitrust understandably responds to random events by discounting their role as drivers of positive feedback loops.[90] Micro-level developments like firms' endogenous research and development efforts, monetization experimentation, or organizational and managerial changes are never really considered relevant in competition law analysis. The same is true of macro-level developments like exogenous government subsidies (for example, concessionary finance to state-owned firms) or the introduction of general-purpose technologies (for example, the adoption of new communications protocols) in upstream industries.

But neoclassical antitrust does not neglect all random events. Antitrust intervention is regarded as a random event with power to trigger positive feedback loops. Most celebrated accounts of the *US v Microsoft* case implicitly develop a positive feedback loop argument to rationalize government intervention as the engine of innovation in the 2000s.

So, how should antitrust agencies and courts approach random events? Attempting to predict their impact on feedback loops appears illusory. Standard algebraic computation does not work. In the words of Hayek, "[a] theory of essentially complex phenomena must refer to a large number of particular facts; and to derive a prediction from it, or to test it, we have to

[89] W. Brian Arthur, *Competing Technologies, Increasing Returns, and Lock-In by Historical Events*, 99 Econ. J. 116 (1989).
[90] The low predictability of random events' outcomes complicates the evaluation of business conduct in the future, but also in the past. History is contingent. Assigning causality to established facts is hard. Besides, the low observability of random events undermines the restorative function of antitrust remedies. When antitrust agencies and courts seek to introduce a negative feedback loop to restore the previous procompetitive state, they do this ignoring possible events at the micro and macro-levels that prevent a competitive reset.

ascertain all these particular facts".[91] By contrast, a more humble research direction consists of enriching our empirical understanding of feedback loops. Will they be of the procompetitive kind, raising uncertainty? Or will they be of the anticompetitive kind, locking in users into rigid technological trajectories? And after how much time can an antitrust institution consider that change is long overdue? By studying cases, patterns will emerge, which will inform antitrust rulemaking and adjudication.[92]

[91] Friedrich August von Hayek, *The Pretence of Knowledge*, Nobel Memorial Lecture (Dec. 11, 1974).
[92] *Ibid* (exploring the concept of "pattern predictions" as "predictions of some of the general attributes of the structures that will form themselves, but not containing specific statements about the individual elements of which the structures will be made up").

(iii) Actionable items for policy improvements

	Neoclassical antitrust	Complexity-minded antitrust
Economic model	Equilibrium (static)	Disequilibrium (dynamic)
Agents' motivation and mode of action	Rationalize to maximize output	Cognize to maximize survival
Normative preference	Plurality is desirable	Change is desirable
Paradigm	Rivalry ←→ Competition	Complexity ←→ Uncertainty ←→ Competition
Unit of analysis	Meso ("markets")	Macro, meso, and micro
Function	Ensure rivalry within a relevant market	Ensure complexity within the ecosystem
Method	Mathematical modeling (algebra) to reach levels of confidence close to certainty	Computational thinking (algorithms) to detect patterns
Tool	Introduces negative feedback loops to recover the market previous state	Introduces positive feedback loops to create a new competitive dynamic
Mental model	Physicists engineering static and predictable outcomes	Park-rangers maintaining dynamic and unpredictable processes
Targets	Empirical difficulties in assessment of competitive pressure lead to ideological debates on how to best allocate the burden/costs of imperfect rules (error-cost framework, etc.)	Empirical difficulties in assessment of competitive pressure invite introduction of additional complexity to maintain state of uncertainty
Division of labor	Competition law and regulation ensure rivalry while addressing negative externalities	Competition law foster change (unfreeze markets); regulation address negative externalities (cool off changes)

Several improvements to neoclassical antitrust emerge from the above discussion.[93] First, complexity highlights an additional **function** for competition law: promoting uncertainty. Compared to the rivalry improvement function of neoclassical antitrust, a complexity-minded antitrust considers that increases in uncertainty can in some circumstances deliver important incentives to competitive effort, non-inertial behavior, and innovation.[94] True, rivalry often correlates with uncertainty. But rivalry is neither a necessary, nor a sufficient condition of uncertainty. Firms that compete under uncertainty are motivated by threats not limited to rival products, including the reconfiguration of supply and demand conditions by imperfect substitutes, complements, or new combinations.

Second, complexity highlights an additional **method** for competition law: that of "unfreezing" markets. Compared to the deconcentration method of neoclassical antitrust, a complexity-minded antitrust enables competition by complexificiation. Adding noise at one or more of the various levels of a frozen competitive system "destabiliz[es] rational speculation",[95] leading to new opportunities for natural selection.[96]

Third, complexity points to a specific **remedy** to administer an uncertainty-increasing approach. Compared to the negative feedback loop approach of neoclassical antitrust, a complexity-minded antitrust considers that positive feedback loops that grow output help prevent monopolies from living what Sir John Hicks called the "quiet life".[97] By adding a positive feedback loop, antitrust can '*shake*' markets. In the monopoly case, adding a positive feedback loop can be done by imposing a duty to deal on the dominant firm, so its inputs (I) are shared with rivals in support of a new composition of output (O2). In the lock-in case, a line of business restriction can be imposed on the output of the winning system (O1), so its input (I) cannot be leveraged in support of diversification, leaving external options an opportunity to grow (O2). Note that a remedy might create a negative feedback loop, depending on the circumstances. In the duty to deal case, if beneficiaries align their innovation trajectories on the winning system, the market will move back to the competitive equilibrium.[98] In the line of business restriction case, market partitioning, and monopoly power for the winning system and new entrants, is also a possible outcome.

[93] These findings are summarized in the above table. This section is dedicated to those we have not fully explored yet, starting with "function".
[94] We give competition law a broad meaning that includes the enforcement activities of competition authorities, but also ex-ante tools such as the Digital Markets Act.
[95] J. Bradford de Long, Andrei Shleifer, Lawrence H. Summers & Robert J. Waldmann, *Positive Feedback Investment Strategies and Destabilizing Rational Speculation*, 45 J. Finance 379 (1990)
[96] Richard S. Whitt & Stephen J. Schultze, *The New "Emergence Economics" of Innovation and Growth, and What It Means for Communications Policy*, 7 J. on Telecomm. & High Tech. L. 217, 304 (2009).
[97] In both cases of lost rivalry due to either output reducing monopoly or output increasing lock-in, market uncertainty is reduced.
[98] Access regulation in Western European telecom markets led new entrants to develop copper networks, modelling incumbents' technological choices. This retarded innovation into fiber.

Fourth, complexity highlights a distinct **mental model** for competition agencies and courts. Compared to the "physicist" spirit of neoclassical antitrust institutions, a complexity-minded antitrust institution will rethink its role in terms of what Brian Arthur has called a "park-ranger" spirit. The difference in mental models is that physicists seek to reach static and predictable outcomes (moving a monopoly towards competition), while park rangers seek to maintain dynamic and unpredictable processes (moving a monopoly towards competition or towards a new monopoly).[99]

Fifth, complexity highlights actionable **targets** for competition law. A firm has incentives to exploit market power where it is less costly. This is why monopolists market power strategies target predominantly core, adjacent, and related markets where uncertainty is limited. Anticompetitive leveraging is a case in point. Given the above, one way to promote competition is to inject cost-raising complexity in markets worth monopolizing and incentivize monopoly firms to compete in distant, long-term, and unrelated markets where uncertainty is higher.[100]

Sixth, complexity highlights a new **division of labor** between competition law and regulation. Not all competition, change or growth arising from positive feedback loops is welfare-enhancing. Unrestrained competitive innovation in the financial sector paved the way to the subprime crisis. Growth of digital advertisement coincides with unprecedented levels of privacy extraction, and free trade policies have raised the carbon footprint of the economy at possibly unsustainable levels. These few examples suggest that while a complexity-minded antitrust should work towards positive feedback loops, a complexity-minded regulation should seek to address their negative externalities. The clear division of labor between antitrust institutions 'unfreezing' markets, and regulators 'cooling off' changes in markets will allocate decision-making to those with the proper expertise rather than tasking enforcers to arbitrate between different objectives and opening the door to capture. It will also clarify the role of regulators when tackling competition issues.

Complexity is a mindset, not a rigid code of conduct. Competition law systems can select diverse insights from complexity. Some will emphasize

[99] Describing this objective as "[e]nabling without dictating," *see* Richard S. Whitt & Stephen J. Schultze, *The New Emergence Economics of Innovation and Growth, and What It Means for Communications Policy*, 7 J. on Telecomm. & High Tech. L. 217, 304 (2009); also, Eric D. Beinhocker, The Origin of Wealth: Evolution, Complexity, and the Radical Remaking of Economics, 426 (Harvard, 2006) (talking about "shaping the fitness" of the environment).

[100] This is consistent with Hayek: "If man is not to do more harm than good in his efforts to improve the social order, he will have to learn that in this, as in all other fields where essential complexity of an organized kind prevails, he cannot acquire the full knowledge which would make mastery of the events possible. He will therefore have to use what knowledge he can achieve, not to shape the results as the craftsman shapes his handiwork, but rather to cultivate a growth by providing the appropriate environment, in the manner in which the gardener does this for his plants," Friedrich August von Hayek, *The Pretence of Knowledge*, Nobel Memorial Lecture (Dec. 11, 1974).

the short-term, others the long-term. Some will focus on the macro-level, others on the micro-level. Several complexity-minded antitrust policies are thus possible. But their common feature is to work with a clear objective: ensuring uncertainty.[101]

(iv) Test and illustration

A complexity-minded test of legality is whether business conduct freezes or shakes the market. Some basic examples show how the test roughly works in concrete antitrust cases.

- In 2019, the Bundeskartellamt ("BdK") sanctioned Facebook for "combining user data from different sources" such as WhatsApp and Instagram.[102] The theory of harm underpinning the BdK decision was that Facebook had exploited its dominant position in social networks to extract excessive data from users across other business segments. A test of freezing versus shaking would have asked other questions: did Facebook's data combination practice shake the market, by leading to a positive feedback loop, a change of output, and raised levels of uncertainty; or did Facebook's data combination trigger a negative feedback loop by further consolidating its dominant position? Reports of (i) intense macro-level competition from innovative players like TikTok, and (ii) stagnation of Facebook's ability to capture new users at the meso-level cast doubt on the freezing hypothesis.[103]

- Several technology firms prohibit blockchain advertisements. The argument behind the ban is based on disputable security concerns.[104] Beyond this, however, the relevant test of legality for antitrust is whether technology firms' refusal to deal in blockchain advertisement is likely to freeze the market around existing technologies? This in turn, depends on considerations like the boycotting firms' position over advertisement at the meso-level, but also on whether other industries or governments at the macro-level sponsor blockchain technology. A random event likely to shake the market is Facebook's reversal of its ban for crypto

[101] To be clear, we do not say that agencies and policymakers should create unclear rules, but we say that they should ensure uncertainty about how agents should maximize profits.
[102] Bundeskartellamt, *Facebook*, B6-22/16 (Feb. 6, 2019), https://perma.cc/8U3J-R6QX.
[103] The company has since reported a decline in the number of users in February 2022. Furthermore, researchers have shown that new technologies emerge from components that previously exist, Francois Bar, Org. For Econ. Co-Operation & Dev., Information and Communications Technologies For Economic Development (1987) https://perma.cc/87W2-4XJL; *see* Thomas J. Horton, *Competition or Monopoly – The Implications of Complexity Science, Chaos Theory, and Evolutionary Biology for Antitrust and Competition Policy*, 51 Antitrust Bull. 195 (2006); and *see* Martin A. Nowak, Evolutionary Dynamics: Exploring the Equations of Life, 24 (Harvard, 2006).
[104] Chainalytics reports that only 0.15% of cryptocurrency transactions are of criminal origin, and money laundering accounted for just 0.05% of all cryptocurrency transaction volume in 2021, *see* Chainalysis Team, *DeFi Takes on Bigger Role in Money Laundering But Small Group of Centralized Services Still Dominate*, Chainalysis (Jan. 26, 2022), https://perma.cc/27F2-4GD2.

advertising right after the company presented its metaverse and crypto-compatible products.[105]

- On several occasions, Apple has denied compatibility to songs bought outside of iTunes by modifying encryption methods. Music platforms like RealNetworks and Harmony have occasionally tried to reintroduce interoperability. But Apple denied interoperability every time.[106] A good case can be made that Apple froze the market around its technology. Interoperability denials triggered a negative feedback loop. A complexity-minded antitrust remedy would have prohibited Apple from introducing innovation to remove interoperability developed by external parties on the basis of publicly available information.

- In the browser wars, Microsoft focused on acquiring and eliminating complementors of its ecosystem, hampering evolution and innovation of multiple software capabilities. Microsoft took Netscape's threat of disruption so literally that it preferred to "freeze" the technology around its Operating System, rather than trying to surf the "tidal wave" of new Internet applications.[107]

3. Research agenda

The neoclassical paradigm of antitrust policy is bounded. The limit is not ideology, but methodology. Antitrust policy relies on reductionist assumptions, frameworks and units of analysis on competition and innovation that harness just a fraction of economic complexity. Because antitrust policymaking operates under practical constraints, neoclassical economics has remained the best game in town absent better actionable concepts, methods, and tools.

With this background, this article introduces complexity theory and outlines the first steps toward a more complexity-minded antitrust. Multilevel analysis, feedback loops, and uncertainty-increasing intervention constitute the starting points for an intellectual renovation of neoclassical antitrust method.

Much work remains needed. Three directions of a future research agenda can be outlined. First, a complexity-minded antitrust requires a good understanding of when and why markets develop. Antitrust scholars should conduct *historical* work on the emergence and growth of markets, firms, and

[105] Jeff Benson, *Facebook Reverses Crypto Ad Ban Following Metaverse, NFT Push*, Decrypt (Dec. 1, 2021).
[106] Thibault Schrepel, *The 'Enhanced No Economic Sense Test': Experimenting With Predatory Innovation*, 7 N.Y.U. Journal of Intell. Prop. & Ent. Law 30 (2018).
[107] David J. Teece, *Next-Generation Competition: New Concepts for Understanding How Innovation Shapes Competition and Policy in the Digital Economy*, 9 J.L. Econ. & Pol'y 97, 106 (2013).

technologies. A key focus of analysis should be placed on the nature of feedback loops, their properties, duration, intensity, context dependence, and impacts on welfare.

Second, a complexity-minded antitrust must inevitably be a provisional system of market control. Short of predictive power, application of complexity theory in an antitrust context is bound to happen on the spot. Antitrust scholars should thus develop tools and methods that allow antitrust intervention to be more adaptive, but not abusive; timely, but not discretionary. In this context, a key question is how to adjust antitrust intervention and regulation in light of *real-time* data documenting feedback loops.[108]

Third, a complexity-minded antitrust demands affinity for methods that allow an understanding of uncertainty. Research on agent-based modeling is a fruitful area for progress. Computerized simulations of institutions and agents with individual characteristics will contribute to a better understanding of nonlinear behaviour. They will document the potential impact of antitrust policies on complex ecosystems, and perhaps more importantly, the limits of what we imagine we can design.[109]

Conclusion

Under neoclassical antitrust, uncertainty is often a pretext for discretion. Mainstream economic theory relies on algebra. When data are absent, ambiguous, or incomplete, measurement is difficult. Neoclassical antitrust institutions must in turn make a binary choice between intervention and non-intervention. Such choices are often based on experience, ideology, and/or opportunism. In a policymaking discipline committed to empirics, the drivers of these choices are faulty because they are disconnected from current facts. This is the advantage of a complexity-minded antitrust. Computing difficulties do not paralyze application of the law. Complexity-minded antitrust is action-oriented in the face of uncertainty.

[108] Thibault Schrepel, *Computational Antitrust: An Introduction and Research Agenda*, 1 Stanford J. of Comp. Antitrust 1, 9 (2021).

[109] In agent-based modeling, agents interact through prescribed rules, *see* J. Doyne Farmer & Duncan Foley, *The Economy Needs Agent-Based Modelling*, 460 Nature 685 (2009). Simulations often show that changing these rules the slightest impacts the entire ecosystem in hard-to-predict dimensions.