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**Undergraduate Studies:**

A.B. in Mathematics, Harvard College, *summa cum laude*, 2018

**Graduate Studies:**

A.M. in Statistics, Harvard University, 2018

Ph.D. in Business Economics, Harvard University, 2020

Thesis Title: “Market Design for Matching and Auctions”

**Primary Academic Appointments:**

Postdoctoral Scholar, Department of Economics, Stanford University, 2020 – present

**References:**

Professor Scott Kominers

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**Teaching and Research Fields:**

Primary fields: Microeconomic Theory, Market Design

Secondary fields: Public Economics, Macroeconomics

**Teaching Experience:**

Fall 2018 and “Market Design” (Ph.D. Field Course), Harvard, Teaching Fellow for Professor  
 Fall 2019 Scott Kominers [*Certificate of Distinction in Teaching*, Derek Bok Center (x2)]

**Grants and Fellowships:**

2019 – 2022 Grant, Washington Center for Equitable Growth (with Mohammad Akbarpour,  
 Piotr Dworzak, and Scott Duke Kominers)  
 2018 – 2020 National Science Foundation Graduate Research Fellowship

**Honors and Awards:**

2019 Martin Award for Excellence in Doctoral Research in Business Economics,  
 Harvard Business School  
 2019 AMS–MAA–SIAM Frank and Brennie Morgan Prize for Outstanding Research in  
 Mathematics by an Undergraduate Student  
 2016 Jacob Wendell Scholarship Prize, Harvard University  
 2014 Putnam Fellow, William Lowell Putnam Mathematical Competition

**Selected Full-Length Publications:**

“Trading Networks with Frictions” (with Tamás Fleiner, Zsuzsanna Jankó, and Alexander Teytelboym).  
*Econometrica* 87(5):1633–1661, 2019. Extended abstract in *Proceedings of the 2018 ACM Conference  
 on Economics and Computation [EC’18]*.

We show how frictions and continuous transfers jointly affect equilibria in a model of matching in trading networks. Our model incorporates distortionary frictions such as transaction taxes and commissions. When contracts are fully substitutable for firms, competitive equilibria exist and coincide with outcomes that satisfy a cooperative solution concept called trail stability. However, competitive equilibria are generally neither stable nor Pareto-efficient.

“Cadet-Branch Matching in a Kelso-Crawford Economy.” *American Economic Journal: Microeconomics* 11(3):191–224, 2019. Extended abstract in *Proceedings of the 2016 ACM Conference on Economics and Computation [EC’16]*.

Sönmez (2013) and Sönmez and Switzer (2013) used matching theory with unilaterally substitutable priorities to propose mechanisms to match cadets to military branches. This paper shows that, alternatively, the Sönmez and Sönmez–Switzer mechanisms can be constructed as descending salary adjustment processes in Kelso–Crawford (1982) economies in which cadets are (grossly) substitutable. The lengths of service contracts serve as (inverse) salaries. The underlying substitutability explains the unilateral substitutability of the priorities utilized by Sönmez and Sönmez–Switzer.

“Designs for Estimating the Treatment Effect in Networks with Interference” (with Natesh S. Pillai and Alexander Volfovsky). *Annals of Statistics* 48(2):679–712, 2020.

In this paper, we introduce new, easily implementable designs for drawing causal inference from randomized experiments on networks with interference. Inspired by the idea of matching in observational studies, we introduce the notion of considering a treatment assignment as a “quasi-coloring” on a graph. Our idea of a perfect quasi-coloring strives to match every treated unit on a given network with a distinct control unit that has identical number of treated and control neighbors. For a wide range of interference functions encountered in applications, we show both by theory and simulations that the classical Neymanian estimator for the direct effect has desirable properties for our designs.

**Short Publications:**

“Lone Wolves in Competitive Equilibria” (with Scott Duke Kominers and Ross Rheingans-Yoo). *Social Choice and Welfare* 55(2):215–228, 2020.

“Matching in Networks with Bilateral Contracts: Corrigendum” (with John William Hatfield and Scott Duke Kominers). *American Economic Journal: Microeconomics* 12(3):277–285, 2020.

“Optimizing Reserves in School Choice: A Dynamic Programming Approach” (Franklyn Wang, Ravi Jagadeesan, and Scott Duke Kominers). *Operations Research Letters* 47(5):438–446, 2019.

“Lone Wolves in Infinite, Discrete Matching Markets.” *Games and Economic Behavior [Lloyd Shapley Memorial Issue]* 108:275–286, 2018.

“Strategy-Proofness of Worker-Optimal Matching with Continuously Transferable Utility” (with Scott Duke Kominers and Ross Rheingans-Yoo). *Games and Economic Behavior [Lloyd Shapley Memorial Issue]* 108:287–294, 2018.

### **Research Papers:**

“Matching and Prices” (Job Market Paper, with Alexander Teytelboym; extended abstract in *Proceedings of the 22nd ACM Conference on Economics and Computation [EC’21]*)

Indivisibilities and budget constraints are pervasive features of many matching markets. But when taken together, these features typically cause failures of gross substitutability—a standard condition on preferences imposed in most matching models. To accommodate budget constraints and other income effects, we analyze matching markets under a weaker condition: net substitutability. Although competitive equilibria do not generally exist in our setting, we show that stable outcomes always exist and are efficient. However, standard auction and matching procedures, such as the Deferred Acceptance algorithm and the Cumulative Offer process, do not generally yield stable outcomes. We illustrate how the flexibility of prices is critical for our results. We also discuss how budget constraints and other income effects affect properties of the set of stable outcomes.

“The Equilibrium Existence Duality” (with Elizabeth Baldwin, Paul Klemperer, and Alexander Teytelboym)

We show that, with indivisible goods, the existence of competitive equilibrium fundamentally depends on agents’ substitution effects, not their income effects. Our Equilibrium Existence Duality allows us to transport results on the existence of competitive equilibrium from settings with transferable utility to settings with income effects. One consequence is that net substitutability—which is a strictly weaker condition than gross substitutability—is sufficient for the existence of competitive equilibrium. Further applications give new existence results beyond the case of (net) substitutes. Our results have implications for auction design.

“On Consumer Theory with Indivisible Goods” (with Elizabeth Baldwin, Paul Klemperer, and Alexander Teytelboym)

Baldwin and Klemperer (2019) classified valuations over indivisible goods into “demand types” by taking a particular geometric approach to analyze preferences. They showed that demand types have important economic properties related to the existence of competitive equilibrium with indivisible goods—leading to many novel domains for equilibrium existence. This paper shows how demand types can in fact be defined more conventionally in terms of simple conditions on the comparative statics of demand.

“Stability in Large Markets” (with Karolina Vocke)

In matching models, pairwise stable outcomes do not generally exist without substantial restrictions on both preferences and the topology of the network of contracts. We address the foundations of matching markets by developing a matching model with a continuum of agents that allows for complex preferences and network structures. We argue that *tree stability*, a refinement of pairwise stability, is the natural solution concept for this setting. Our main results show tree-stable outcomes exist for arbitrary

preferences and network topologies, and provide a noncooperative microfoundation for tree stability. Our framework can flexibly capture the extent to which agents can coordinate.

#### “Optimal Taxation with an Endogenous Growth Rate”

This paper analyzes optimal capital and labor income taxation when growth is endogenous. In the model, the social planner faces a dynamic equity–efficiency trade-off between redistribution and growth because tax policies affect the growth rate. I show that positive capital tax rates can be optimal and that redistributive considerations raise the optimal capital tax rate—contrary to the Chamley–Judd zero-tax result. On the other hand, growth considerations drive the optimal labor income tax rates to below their static values. In calibrations based on U.S. data, the optimal policies in my model differ substantially from the benchmark results in the literature.

#### “Markets for Crypto Tokens, and Security under Proof of Stake” (with Christian Catalini and Scott Duke Kominers)

Cryptocurrency systems based on proof of stake (PoS) grant governance rights to the holders of currency tokens and therefore are vulnerable to attack by adversaries who buy tokens in order to gain control. To evaluate the robustness of PoS cryptocurrencies to such attacks, we model the market for tokens and determine how the cost of attacking the system depends on the level and shape of token supply and demand. We show that, contrary to popular belief, the appreciation of tokens in response to demand by attackers plays a small role in securing the system. In particular, stablecoins can be less vulnerable to attack than cryptocurrencies that are freely floating. Moreover, PoS cryptocurrencies that primarily function as mediums of exchange are vulnerable to attack if the velocity of money is high.

#### **Selected Work in Progress:**

##### “Demand Types, Income Effects, and Equilibrium” (with Elizabeth Baldwin, Omer Edhan, Paul Klemperer, and Alexander Teytelboym)

We analyze agents' preferences over indivisible goods in the presence of income effects by placing conditions on the comparative statics of Hicksian demand. We obtain a sufficient condition for the existence of equilibrium for certain classes of preferences: the unimodularity of the “demand type” vector set. We also show that each unimodular “demand type” forms a maximal domain of preferences for equilibrium existence in the presence of income effects. For example, “strong net substitutability” is sufficient for, and defines a maximal domain for, the existence of equilibrium.

##### “The Limits of Capital Taxation: Optimal Taxation of Private Businesses”

In simple models with wealth inequality, there is no role for capital taxation as a redistributive tool: redistribution can be achieved through consumption taxation without introducing distortions. This paper studies how imperfections in consumption taxation, arising from the ability of owner-managers of private businesses to disguise consumption as a business expense, affect optimal capital tax policy. The analysis provides conditions under which the optimal dynamic tax policy features sustained intertemporal distortions, and characterizes the long-run distortions in terms of wedges. The solution to the planning problem can also be implemented via time-varying linear taxes and subsidies on wealth, net capital income, and consumption when there is a private market for risk-sharing between business owners.

##### “Market Design for a Blockchain-Based Financial System” (with Christian Catalini and Scott Duke Kominers)

We develop a theory of long-run equilibrium in blockchain-based financial systems. Our theory elucidates the key market design features that separate proof of work and proof of stake approaches in the long run. Under proof of work, wasteful computation is used to secure the system, and users' utility in equilibrium is determined by the threat of a fork. Under proof of stake, by contrast, users' utility in equilibrium is generally above the fork threat level because custodians can use relational contracts to

incentivize a higher quality of service. Relational contracts under proof of stake rely only on local institutions—but combining them with cryptography can create a platform for formal global contracts.

**Other Refereed Publications:**

“Incidence Geometry in a Weyl Chamber, I:  $GL_n$ ” (with Mboyo Esole, Steven Glenn Jackson, and Alfred G. Noel). *Advances in Applied Mathematics* 119:102048, 2020.

“Incidence Geometry in a Weyl Chamber, II:  $SL_n$ ” (with Mboyo Esole, Steven Glenn Jackson, and Alfred G. Noel). *Advances in Applied Mathematics* 119:102049, 2020.

“A New Proof of Serre’s Homological Characterization of Regular Local Rings” (with A. Landesman). *Research in Number Theory* 2:18, 2016.

“A New  $\text{Gal}(\mathbb{Q}^-/\mathbb{Q})$ -Invariant of Dessins d’Enfants.” *Proceedings of the London Mathematical Society* 111(4):911–935, 2015.

“Ascent-Descent Young Diagrams and Pattern Avoidance in Alternating Permutatations.” *Electronic Journal of Combinatorics* 21(3):#P3.9, 2014.

“Beyond Alternating Permutations: Pattern Avoidance in Young Diagrams and Tableaux” (with Nihal Gowravaram). *Electronic Journal of Combinatorics* 20(4):#P13, 2013.

**Non-Refereed Publications:**

“Generalized Matching: Contracts and Networks” (with John William Hatfield, Scott Duke Kominers, Alexandru Nichifor, Michael Ostrovsky, Alexander Westkamp, and Alexander Teytelboym). To appear in *Online and Matching-Based Market Design* (eds. Federico Echenique, Nicole Immorlica, Vijay V. Vazirani), Cambridge University Press, 2021.

“Bitcoin and Beyond” (with Christian Catalini and Scott Duke Kominers). *Project Syndicate*, April 23, 2021.

**Professional Activities:**

Co-organizer for American Economic Association Meetings sessions: “Matching and Inequality: Implications for Policy” (2020); “New Advances in Matching with Contracts” (2019); “Technological Progress and Inequality: Perspectives from Optimal Tax Theory” (2019); “New Insights on Classical Questions in Matching Theory” (2018)

Program Committee Member, ACM Conference on Economics and Computation (2021)

SafeTOC Advocate, ACM Conference on Economics and Computation (2021)

Mentor, Research Science Institute (2017)

Conference presentations: ACM Conference on Economics and Computation (Maastricht 2016, Cambridge 2017, Ithaca 2018, 2020, 2021), American Economic Association Meetings (Philadelphia 2018, Atlanta 2019, San Diego 2020), Arne Ryde Conference: Frontiers of Market Design (Lund 2018), Becker Friedman Institute Cryptocurrencies and Blockchains Conference (2019), Conference on Economic Design (Budapest 2019), Design and Analysis of Experiments Conference (Knoxville 2019), Econometric Society North American Winter Meetings (Atlanta 2019), Harvard Center of Mathematical Sciences and Applications Big Data Conference (2018), INFORMS Annual Meeting (2021), International Workshop on Matching under Preferences (Cambridge 2017), Lisbon Game Theory

Meetings (2019), NBER Market Design Working Group Meeting (Stanford 2018, 2021), Stony Brook Game Theory Conference Workshop on Distributed Ledgers and Economics (2021)

Discussant for “Matching with Complementary Contracts” by Marzena Rostek and Nathan Yoder, “New Advances in Matching with Contracts” session, AEA Meetings (2019)

Seminar presentations: Boston College (2021, scheduled), CBADE/HKBU/Monash/NTU/RUC (2021), Harvard Center of Mathematical Sciences and Applications (2017), University of Melbourne (2019), University of Oxford (2019), University of Southern California (2020), Virtual Finance Theory Seminar (2020)

Referee for *ACM Transactions on Economics and Computation*, *American Economic Journal: Microeconomics*, *Econometrica*, *Electronic Journal of Combinatorics*, *Games and Economic Behavior*, *Journal of the American Statistical Association* (quick opinion), *Journal of Economic Theory*, *International Economic Review*, *International Journal of Game Theory*, *International Workshop on Matching under Preferences* (MATCHUP), *Management Science*, *Mathematical Social Sciences*, *Mathematics of Operations Research*, *Quantitative Economics*, *Quarterly Journal of Economics*, *Review of Economic Studies*, *Review of Industrial Organization*, and *Theoretical Economics*