

ECON 421(562)/CPSC412(512)

Yale University

Fall 2016

Instructor: E. Glen Weyl (Microsoft Research, visiting Yale)

## Designing the Digital Economy

**Course objectives:** It used to be common to speak of the “high-tech sector” of the economy, but increasingly information technology is transforming how almost every market works: finance has been transformed by algorithmic trading and bitcoin, ridesharing is changing the nature of public transportation, Amazon is revolutionizing logistics and Airbnb is now the most valuable accommodation provider in the world. This transformation, which has been led by a series of start-ups and newly-dominant technology companies, inherently combines technical and economic aspects, as entrepreneurs take advantage of the potential of technology to facilitate exchanges that were previously infeasible. The exploding opportunities for employment and research in these areas therefore require students to have an exposure to the intersection between the technical possibilities that are opening and the ways in which they can create economic value. This course aims to plunge students into this intersection by offering both a crash course in the key tools from economics and computer science that are being used to design digital markets, and exposing students to a range of concrete and topical practical problems in the area. The overarching aim is to prepare students for careers and/or dissertations in this field.

**Idiosyncrasies:** This course will differ from a typical economics or computer science elective in several ways that are worth highlighting up front:

1. The course is cross-listed between economics and computer science and is intended equally for advanced undergraduates and graduate students. Students are thus expected to have very heterogeneous backgrounds. This diversity will play an important role in the course as it will allow students to learn from one another and harness the skills of other students who have background they lack.
2. Because graduate and undergraduate students have very different preparation levels, the expectations and standards for these students will be significantly different. Undergraduates will be given additional opportunities for explicit guidance on the development of the independent project (especially as they begin forming groups after the midterm), will have different expectations on and a different grading scale for this project and will only be expected to complete a subset of the problem set and exam questions graduate students will be expected to complete. Cold calling on students will also be tailored to their background. However, because it is in the nature of the course to encourage collaboration between different skill sets, joint undergraduate-graduate teams will be allowed in exceptional on the final project (more on this below).
3. The course will be *highly* interdisciplinary, teaching tools not just from one area of economics and computer science, but from a variety of subfields within each field. This will mean that most students will at least find some parts of the class very easy and probably even repetitive with material they already know, while they will find other parts so challenging that they will seem hard to follow. This is okay. Please draw on the TAs (one from each field) and on your classmates, who will know what you do not, and help your classmates on things they find hard to follow.

4. Building off the last point, the course will be highly collaborative both for the reasons stated above, but also in how it is graded. There will be a final project in lieu of a final exam and it will be a group project where students will have to form teams with a diverse set of skills that they will have to defend as the right mix of skills needed for the project. Please collaborate on problem sets, but also please note who you worked with and groups should not be larger than 3 individuals. The midterm exam will be the only part of the course where collaboration is not allowed.
5. The teaching of the course, given its broad scope, will also be collaborative. While I will run the whole class, in most classes I will be in conversation with guests I will bring to class who are more expert on many of the topics I will cover than I am. Please take advantage of the guests, who are extremely distinguished scholars and thinkers with a lot to offer you.
6. Participation and reading are very important to being able to absorb this diverse material. There will be cold calling.
7. Because I only visit Yale one day a week, the class will be 3 hours for a single day, on which office hours will also occur. I will not be very available in person outside of that time. However, you are always welcome to visit me at my lab in New York City.
8. Please call me by whatever name you are comfortable with: Glen, Professor Weyl, broccolini (one nickname), etc. We respect ideas in this course, not titles.

**Prerequisites:** All students taking this class should have some formal training (even if minimal) in both economics or computer science. Most will be majors or graduate student in one field or the other. A typical profile of an undergraduate student will be one who has taken intermediate microeconomics and econometrics and an introductory CS course or who has taken most of the second-year undergraduate CS curriculum and introductory microeconomics. However, we will be quite flexible in allowing students with useful skills but diverse backgrounds to take the class. Useful skills include anything covered on the course schedule below. The course is also open to management and law students with sufficient technical background.

**Admission to the course:** I would like to keep the maximum enrollment in this course at 75, but the course is highly oversubscribed as of the first day of classes. If needs be, I may expand the class, but I also plan to be selective about who is admitted to the class. The problem sets will also be challenging and may discourage students with weaker preparation. Please take the admission quiz/survey on the course webpage to help me determine your preparation. I will consider a variety of factors. First priority will go to seniors who preregistered for this course and need it to graduate.

**Plagiarism:** You must document all of your source material. If you take any text from somebody else, you must make it clear the text is being quoted and where the text comes from. You must also cite any sources from which you obtain numbers, ideas, or other material. If you have any questions about what does or does not constitute plagiarism, ask! Plagiarism is a serious offense and will not be treated lightly. Fortunately, it is also easy to avoid and if you are the least bit careful about giving credit where credit is due you should not run into any problems. <sup>[1]</sup><sub>SEP</sub>

**Evaluations:** Students in the course will be evaluated based on four factors. TFs will grade factors 2) and 3) while I will primarily grade 1) and 4).

1. Participation (10%): attendance of all lectures and TF sessions is mandatory unless you have a good excuse. You are grown up enough to know what a good excuse is. There will be cold calls during at least some lectures and answering these is part of participation.

2. Problem sets (20%): There will be 3 problem sets during the first half of the semester. The schedule for due dates on the problem sets is included below. About one-third of the problems on each problem set will be for graduate students only. Undergraduates should not complete these problem and they will not inform the parts of the exam intended for undergraduates.
3. Midterm exam (20%): This will take place during an extended version of the discussion session in the sixth week of class. It will be two hours long and will build off of the material in the problem sets closely. So please study your problem sets and their solutions carefully. As with the problem sets, a third of the exam will be for graduate students only and based on the parts of the problem sets that are only for graduate students.
4. Final project (50%): There will be a final project that students will work on during the second half of the class. This project may *one* of the following forms, though we are open to other potential projects if they are clearly articulated and of comparable scope to the below. Evaluations of projects will be different for graduate and undergraduate students, as described below:
  - a. A detailed research proposal for a potentially publishable paper. The proposal should be 10-20 double-spaced pages (low end for pure undergraduate teams, high end for pure graduate student teams) and will be graded on the basis of the journal it could eventually get into if executed at the quality at which the proposal is executed (A roughly corresponds to a top field journal in economics or top computer science conference for a graduate student and a widely-read international journal for an undergraduate).
  - b. A very short and preliminary research paper of 20-30 double-spaced pages (again low end for pure undergraduate teams, high end for pure graduate teams). This will be judged on the basis of comparing it to a senior thesis and graded on a similar scale for a graduate student and to an upper-division term paper in a course evaluated only based on this paper for undergraduates.
  - c. A policy white paper of 10-20 double-spaced pages (as above depending on team composition). This will be judged on the basis of its ability to be published by a think tank in the area, such as the Data and Society Institute, and to be condensed into an op-ed in a leading outlet. Something of that quality would get an A or an A+ for a graduate student, and down from there; for an undergraduate something publishable in the best student policy outlets or essay competitions would receive that grade.
  - d. An app that the group hacks together to solve some problem in this space or set up a marketplace for a service. This will be graded on a scale similar to typical Hackathon events, where an A corresponds to an app that would win a prize at, say, the Microsoft Research Hackathon for graduate students and a Yale undergraduate Hackathon for undergraduates.
  - e. A business plan for a start-up, which may be formatted either as a 10-page double-spaced document or a slide deck accompanied by a pitch made to me of 30 minutes. This will be judged by the standards of an investor. An A or A+ corresponds to something I would be willing to make a seed investment of \$20-30 thousand dollars in if I were an angel investor and would plan to encourage the students to pursue seriously for graduate students and for undergraduates something that would win a prize in a student business plan competition, but perhaps not actually be funded.

However, will be open to any plan that seems feasible and sufficiently valuable. There will be several milestones in preparing the project. Students will first have to form teams and defend the mix of skills they included in their teams relative to a general idea of the project. The course website will list skills of each student to aid in team formation. Teams should be

roughly 2-5 members, though we are somewhat flexible as long as larger teams take on a correspondingly more ambitious project. Teams should typically consist of either all graduate or all undergraduate students, as the projects graduate students take on should be roughly 50% more ambitious, in correspondence with the standards for grading described above. In exceptional cases and with strong justifications we will consider mixed teams and such teams will be graded on a scale somewhere between the two standards.

Teams, once formed, will then have to write-up a sketch of the project and have it approved. Then a draft of the project will be submitted near the end of the term for comments and a final version will be due at the final projects due date. To assign credit among members of the group, there are two options. Either the team may write a document of roughly one paragraph per team member indicating clearly and precisely what each member did *or* we will use an incentive-compatible credit allocation mechanism in which each team member will determine the relative contribution of all team members other than herself (that is, each team member will have to submit, via a secret ballot handed to the TA in person on piece of paper the fraction of credit they believe belongs to all members other than herself). These options will be explained in greater detail in a handout.

Grading in the class will be very tough and heavily curved. Please do not freak out if your numerical scores on problem sets are low. Please just try your hardest on the problem sets and try to be creative about solving the problems; don't worry if there are some that just stump you. The midterm will be particularly challenging as it will ask you to draw connections across the material covered in different classes. Identify questions where you have good ideas and focus on doing these well, rather than guessing on questions you don't get. Don't be afraid to try out something creative and that you are not certain about.

**Office hours:** I will hold office hours 1:15-2:15 in my office, 28 Hillhouse Ave., Room 107.

**Teaching fellows:** At present there are two teaching fellows for this course, but this number may expand if the enrollment stays as high as it has been. The current TFs are Mengting Gu ([Mengting.gu@yale.edu](mailto:Mengting.gu@yale.edu)) and Xinyang Wang ([Xinyang.wang@yale.edu](mailto:Xinyang.wang@yale.edu)). Mengting will cover the more empirical and computational aspects of the course, while Xinyang will focus on the economic and theoretical aspects. Mengting will hold her office hours 7-8:30 in Bass L30B. Xinyang has yet to determine his office hours and is available by appointment for the first two weeks of the course.

**Dinners after class:** I will host a dinner at a local pizzeria after every class. There will be 7 slots for students at each dinner. Slots will be allocated according to a mechanism that I invented jointly with Christina Lee of MIT (patent pending). The rules are as follows:

1. If there are fewer than 7 students signed up for a dinner (if the final total signed up including you is no greater than 7), you can sign up for free.
2. You can only sign up for *one dinner the whole semester* where there are more than 7 students signed up. I will randomly draw 7 students from those signed up. If you do not get in tough luck; you do not get your "ticket" back, so choose wisely. You can always erase your name from the sign up list to save it for another day until just before I pick.

**Course website:** The course website will be on Canvas, not on Classes\*v2. I have posted the syllabus on Classes\*v2 for courtesy, but please do not expect most materials to be posted there.

**Readings:** readings in the class will be drawn from a variety of sources. For the most part these will be relatively short and downloadable consistent with fair University access and fair use from the

course website. However, there are a few books that we will read larger pieces from and which you should therefore either check out from the library or purchase in fairness to the authors' intellectual property. These will be available from the University bookstore and all are short and cheap. They are

- *The Sharing Economy* by Arun Sundararajan
- *Who Owns the Future* by Jaron Lanier

There is also one textbook I will use in some lectures. It is from computer science and it is relatively basic, so students with a strong CS background need not purchase it. However, it is strongly recommended for all other students and will both appear in two lectures and be a very useful reference for difficult CS material in other lectures. The text is *Algorithm Design* (1<sup>st</sup> edition) by Jon Kleinberg and Éva Tardos.

In the reading list below, the bold readings under “If you want to learn more you can check out” are required for graduate students.

## Course Schedule:

### Lecture 1 (Friday, September 2; note the change of date due to Labor Day): Introduction (with guest Dirk Bergemann from Yale Economics)

Please read:

1. William Cronon, *Nature's Metropolis: Chicago and the Great West*, Chapter 3
2. *Who Gets What – And Why* by Alvin E. Roth, Introduction
3. “Matching Markets in the Digital Age” by Eduardo M. Azevedo and E. Glen Weyl
4. Jeremy Bulow and John Roberts, “The Simple Economics of Optimal Auctions”
5. T. Nicolaus Tideman and Gordon Tullock, “A New and Superior Process for Making Social Choices”

If you want to learn more, you can check out:

1. The rest of the Cronon book
2. Vijay Krishna, *Auction Theory*
3. **Lawrence M. Ausubel and Paul Milgrom, “The Lovely but Lonely Vickrey Auction”**
4. Alvin E. Roth, “The Economist as Engineer: Game Theory, Experimentation, and Computation as Tools for Design Economics”

### Lecture 2 (September 12): Prices; problem set 1 due at discussion session

Please read:

1. Jonathan D. Levin, “The Economics of Internet Markets”
2. E. Glen Weyl and Michal Fabinger, “Pass-Through as an Economic Tool: Principles of Incidence under Imperfect Competition”, Sections I-IV.
3. Carl Shapiro and Hal R. Varian, *Information Rules*, Chapter 2
4. Liran Einav and Amy Finkelstein, “Selection in Insurance Markets: Theory and Empirics in Pictures”
5. Course note on “Intellectual Property”

If you want to learn more, you can check out:

1. **E. Glen Weyl, “A Price Theory of Multi-Sided Platforms”**
2. **E. Glen Weyl and Anthony Lee Zhang, “Ownership of the Means of Production”**
3. André Veiga and E. Glen Weyl, “Product Design in Selection Markets”

### **Lecture 3 (September 19): Data (with guests Jake Hofman and Greg Lewis of Microsoft Research New York City and New England respectively)**

Please read:

1. Pedro Domingos, “A Few Useful Things to Know about Machine Learning”
2. Leo Breiman, “Statistical Modeling: The Two Cultures”
3. Jon Kleinberg and Éva Tardos, *Algorithm Design*, Chapter 2, Sections 1-2 and 4
4. Joshua D. Angrist and Alan B. Krueger, “Instrumental Variables and the Search for Identification”
5. Jon Kleinberg et al. “Prediction Policy Problems”

If you want to learn more, you can check out:

1. **Henry Brighton and Gerg Gigerenzer, “The Bias Bias”**
2. Jeffrey Dean and Sanja Ghemawat, “MapReduce: Simplified Data Processing on Large Clusters”
3. **Judea Pearl, *Causality: Models, Reasoning, and Inference*, “Epilogue”**
4. Joshua D. Angrist and Joris Pischke, “The Credibility Revolution in Empirical Economics”
5. Liran Einav and Jon Levin, “Empirical Industrial Organization: A Progress Report”

### **Lecture 4 (September 26): Design (with guests Nicole Immorlica and Vasilis Syrgkanis of Microsoft Research New England)**

Please read:

1. Alvin Roth, “What Have we Learned from Market Design?”
2. Douglas Gale and Lloyd Shapley, “College Admissions and the Stability of Marriage”
3. Tim Roughgarden, “Mechanism Design Basics”
4. Tim Roughgarden et al., “Price of Anarchy in Auctions”, Sections 1-2

If you want to learn more, you can check out:

1. **Jason D. Hartline, *Mechanism Design and Approximation*, Chapters 1-3**
2. Roughgarden et al., rest of article
3. Aanund Hylland and Richard Zeckhauser, “The Efficient Allocation of Individuals to Positions”

### **Lecture 5 (October 3): Interface (with guests César Hidalgo and Iyad Rahwan of the MIT Media Lab); problem set 2 due at discussion session**

Please read:

1. César A. Hidalgo, “Disconnected, Fragmented, or United? A Trans-Disciplinary Review of Network Science”
2. Galen Pickard et al. “Time-Critical Social Mobilization”
3. César A. Hidalgo et al., “The Product Space Conditions the Development of Nations”

If you want to learn more, you can check out:

1. **César A. Hidalgo and Ali Almosawi, “The Data-Visualization Revolution”**
2. Manuel Cebrian, “Searching for Someone”

### **Lecture 6 (October 10): Algorithms (with guest Bobby Kleinberg of Cornell University)**

Please read:

1. Itai Abraham et al., “Highway Dimension and Provably Efficient Shortest-Path Algorithms”, Sections 1-5, 10 and 12
2. Tim Roughgarden and Éva Tardos, “How Bad is Selfish Routing”, Sections 1-3
3. Jeremy Kun, [Optimism in the Face of Uncertainty: The UCB1 Algorithm](#)
4. Jon Kleinberg and Éva Tardos, *Algorithm Design*, Chapter 3

If you want to learn more, you can check out:

1. Bernard Chazelle, [“The Algorithm: Idiom of Modern Science”](#)
2. Tarleton Gillespie, “Algorithm”

**Midterm exam in and following discussion session (October 13)**

**Lecture 7 (October 17): Centralization (with guests Charles Elkan of Amazon and Jonathan Hall of the University of Toronto); team proposals due and to be defended at discussion session**

Please read:

1. Yifan Hu et al., “Collaborative Filtering for Implicit Feedback Datasets”
2. Zachary C. Lipton and Charles Elkan, “Playing the Imitation Game with Deep Learning”
3. William S. Vickrey, “Pricing in Urban and Suburban Transport”

If you want to learn more, you can check out:

1. Erik Verhoef, Michael Bliemer, Linda Steg and Bert van Wee, eds., *Pricing in Road Transport: A Multi-Disciplinary Perspective*

**Lecture 8 (October 24): Ethics (with guests Solon Barocas of Microsoft Research New York City and Aaron Roth of the University of Pennsylvania)**

Please read:

1. Cynthia Dwork et al., “Fairness Through Awareness”
2. Matthew Joseph et al., “Fairness in Learning: Classic and Contextual Bandits”
3. Solon Barocas and Andrew D. Selbst, “Big Data’s Disparate Impact”

If you want to learn more, you can check out:

1. Cynthia Dwork and Aaron Roth, *The Algorithmic Foundations of Differential Privacy*
2. danah boyd, *It’s Complicated*

**Lecture 9 (October 31): Infrastructure (with guests Jaron Lanier of Microsoft Next and Eduardo Azevedo of the University of Pennsylvania Wharton School of Business)**

Please read:

1. Jaron Lanier, *Who Owns the Future*, Chapters 1 and 19-30
2. Adam B. Jaffe and Josh Lerner, *Innovation and its Discontents*, “Introduction”
3. Michael Kermer, “Patent Buyouts: A Mechanism for Encouraging Innovation”, Introduction and Section I
4. Kevin M. Murphy and Robert H. Topel, “The Value of Health and Longevity”, Sections I and V

If you want to learn more, you can check out:

1. **The rest of the Lanier book**
2. **The rest of the Kremer and Murphy and Topel articles**
3. E. Glen Weyl and Jean Tirole, “Market Power Screens Willingness-to-Pay”

**Lecture 10 (November 7): Optimization (with guests John Langford of Microsoft Research New York City and Brendan Lucier of Microsoft Research New England)**

Please read:

1. Alekh Agarwal et al., “A Multiworld Testing Decision Service”
2. Michael Armbrust et al., “A View of Cloud Computing”
3. Soumya Sen et al., “Smart Data Pricing: Economic Solutions to Network Congestion”, Section 1

If you want to learn more, you can check out:

1. **The rest of the Sen et al. piece**
2. Liran Einav, Theresa Kuchler, Jonathan Levin and Neel Sundaresan, “Assessing Sale Strategies in Online Markets Using Matched Listings”

**Lecture 11 (November 14): Collectives (with guest David Rothschild of Microsoft Research New York City)**

Please read:

1. Steven P. Lalley and E. Glen Weyl, “Quadratic Voting”, Sections 1-2, 6
2. Rory Sutherland and E. Glen Weyl, “Humans are doing Democracy Wrong. Bees are Doing it Right.”
3. Donald N. Thompson, *Oracles*, Part 1
4. Andrew Gelman, Sharad Goel, Douglas Rivers and David Rothschild, “The Mythical Swing Voter”

If you want to learn more, you can check out:

1. Eric A. Posner and E. Glen Weyl, “Voting Squared: Quadratic Voting in Democratic Politics”
2. **David Quarfoot et al., “Quadratic Voting in the Wild: Real People, Real Votes”**
3. The rest of the Thompson book

**Lecture 12 (November 28): Advertising (with guests Justin Rao of Microsoft Research Redmond and David Reiley of Pandora); project proposal draft due at discussion session**

Please read:

1. Randall A. Lewis and David H. Reiley, “Online Ads and Offline Sales: Measuring the Effect of Retail Advertising via a Controlled Experiment on Yahoo!”
2. Andrey Simonov, Chris Nosko and Justin M. Rao, “Competition and Crowd-Out for Brand Keywords in Sponsored Search”

If you want to learn more, you can check out:

1. **Hal Varian, “Insights on the AdWords Auction”**  
(<https://www.youtube.com/watch?v=PjOHTFRaBWA>)
2. Randall A. Lewis and Justin M. Rao, “The Unfavorable Economics of Measuring the Returns to Advertising”

**Lecture 13 (December 5): Sharing (with guests Dan Knoepfle of Uber Technologies and Arun Sundararajan of NYU Sloan School of Management)**

Please read:



1. Jonathan Hall, Cory Kendrick and Chris Nosko, “The Effects of Uber’s Surge Pricing Algorithm: A Case Study”
2. Liran Einav, Chiara Farronato and Jonathan Levin, “Peer-to-Peer Markets”
3. Arun Sundararajan, *The Sharing Economy*, Introduction

If you want to learn more, you can check out:

1. Le Chen, Aland Mislove and Christo Wilson, “Peeking Beneath the Hood of Uber”
2. **Jonathan V. Hall and Alan B. Krueger, “An Analysis of the Labor Market for Uber’s Driver-Partners in the United States”**
3. **The rest of the Sundararajan book**