Policy Modelling Using Agent-Based Simulation

Computational Social Sciences

2018

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Course Description

Policymaking implies planning, and planning requires prediction - or at least some knowledge about the future. This course starts from the challenges of complexity, uncertainty, and agency, which refute the prediction of social systems. It is important to appreciate the limitations and consequences these diagnoses pose on policy making and policy modelling.

However, agent-based modelling and simulation now provide new options to address the challenges of planning and prediction in social systems.

This course will discuss these options for various policy areas with a particular emphasis on the contribution of the social sciences both in offering theoretical grounding and in providing empirical data. Social sciences can inform agent-based simulation models in a way that realistic representations of policy worlds can be brought to the computer. These computational worlds allow scenario analysis, experimentation, policy modelling and testing prior to any policy implementations in the real world.

The course will illustrate these opportunities for various policy areas including public policy and STI policy. Agent-based simulation can help us to shed light into the darkness of the future - not in predicting it, but in coping with the challenges of complexity, in understanding the dynamics of the system under investigation, and in finding potential access points for planning of its future through ‘weak prediction’.

The first part of the course introduces to the field of policy modelling relying on (partly external) lecturer inputs followed by class discussions. The second part of the course consists of a lecturer-assisted student exercise in policy modelling where student groups will work on their own small policy modelling projects applying concepts and methods introduced in the first part. The last part of the course compares and discusses results with a focus on the potential of ABM usage in the modelling exercises.

MODULE TIMETABLE & READINGS

Part I: The state of the art in policy modelling using ABM

Friday 14th September 2018

General introduction on complexity, policy and ABM (Nigel and Petra)

- An overview of the syllabus, explanations and guidelines for the policy modelling exercise (see information below)
- an overview of the development of agent-based modelling (ABM);
  -the reasons why agent-based simulation is especially adapted to helping with policy problems; bridging the micro-macro gap; the relation of ABM to the theory of complex social systems; the difficulties of analytical solutions; "real-world simulation" and ABM

Literature

Gilbert, N. (2007): *Agent-based Models*. Thousand Oaks.

Gilbert, N., Ahrweiler, P., Barbrook-Johnson, P., Narasimhan, K. and Wilkinson, H. (2018): Computational Modelling of Public Policy: Reflections on Practice, *Journal of Artificial Societies and Social Simulation* (JASSS) Vol. 21 (1) 14. DOI: 10.18564/jasss.3669. http://jasss.soc.surrey.ac.uk/21/1/14.html

Ahrweiler, P. (2017): Agent-based Simulation for Science, Technology, and Innovation Policy. *Scientometrics* Vol. 110 (1): 391-415. DOI: 10.1007/s11192-016-2105-0.

Ahrweiler, P. (2017): Simulationsexperimente realexperimenteller Politik – der Gewinn der Zukunftsdimension im Computerlabor. In: Boeschen, S., Gross, M. and W. Krohn (eds.): *Experimentelle Gesellschaft.* Nomos Verlagsgesellschaft, edition sigma: Baden-Baden, 199-237. (Simulation Experiments of Real-World Experimental Policy – Gaining the Dimension of the Future in the computational Laboratory).

Saturday 15th September 2018 (Guest Lecturer: Prof. Dr. Bruce Edmonds)

Finding out what could go wrong before it does - Policy Modelling for Risk Analysis

Lecture followed by discussion, after coffee break a follow-up with small groups working on questions related to Bruce's talk with a final plenary.

Abstract

Some of the kinds and purposes of policy modelling are reviewed. Two kinds of situation are distinguished - those where the impact of policies can approximately assessed to a reliable degree (simple situations), and those where this is infeasible (complex situations). The various reasons why this might be the case are discussed. For these reasons, it is likely that many situations that we collectively face are likely to be complex. This shift entails a change in thinking from probabilistic to possibilistic modelling. Even though they cannot predict in a narrow sense, simulation models can often be used to reveal the kinds of processes that *might* emerge in a situation (possibilities that are difficult to envisage otherwise). An example is given using a model of complex marine ecosystems and fishing policies. Thus whilst other techniques might be used to attempt a "surprise free" projection into the future, agent-based simulation might inform a more comprehensive risk-analysis. Such an approach could be used for contingency planning and the monitoring of identified emergent risks.

Literature

Edmonds, B. (2017) Different Modelling Purposes. In Edmonds, B. & Meyer, R. (eds.) *Simulating Social Complexity - a handbook*, 2nd edition. Springer, 39-58. (Previous version http://cfpm.org/discussionpapers/192)

Aodha, L. and Edmonds, B. (2017) Some pitfalls to beware when applying models to issues of policy relevance. In Edmonds, B. & Meyer, R. (eds.) *Simulating Social Complexity - a handbook*, 2nd edition. Springer, 801-822. (A version http://cfpm.org/discussionpapers/213)

Jager, W. & Edmonds, B. (2015) Policy Making and Modelling in a Complex world. In Janssen, M., Wimmer, M. and Deljoo, A. (eds.) *Policy Practice and Digital Science*. Springer, pp. 57-74. DOI:10.1007/978-3-319-12784-2_4 (Previous version at: http://cfpm.org/discussionpapers/176)

Sunday 16th September 2018 (Guest lecturer: Dr. Corinna Elsenbroich)

Complex policy evaluation methods

Lecture followed by discussion, after coffee break a follow-up with small groups working on questions related to Corinna's talk with a final plenary.

Abstract

Societies result from the relationships and interactions of people, meaning they can be viewed as complex systems. Complexity poses challenges for the social scientist to understand and the policy maker to intervene in social phenomena. The challenges are brought on in particular through the impossibility of isolating system parts, emergence as a feature of complex causality and the essential dynamic and adaptive features of complex systems. A range of methods is being developed to take on these challenges, among them Process Tracing, Qualitative Comparative Analysis, Systems Mapping and Agent-based Modelling.

Literature

Befani, B. Choosing appropriate evaluation methods. Retrieved 20 July 2018 from: https:// www.bond.org.uk/resources/evaluation-methods-tool

Byrne, David (2010) Comparison, Diversity and Complexity in P. Cilliers, R. Preiser (eds.), *Complexity, Difference and Identity*, 61 Issues in Business Ethics 26.

Gilbert, N. & Bullock, S. (2014). Complexity at the social science interface. *Complexity*, 19(6): 1-4.

Gilbert, Nigel, Ahrweiler, Petra, Barbrook-Johnson, Pete, Narasimhan, Kavin Preethi and Wilkinson, Helen (2018) Computational Modelling of Public Policy: Reflections on Practice *Journal of Artificial Societies and Social Simulation* 21 (1) 14. http://jasss.soc.surrey.ac.uk/21/1/14.html

Part II: Policy modelling exercise

Improving Air Quality in Cambridge

Many cities in Europe suffer from excessive air pollution, which can be a danger to health. In Cambridge, the main sources of pollution are from vehicle exhausts and to a lesser extent form wood burning stoves. In this exercise, we invite you to devise a policy to reduce nitrogen dioxide (NO_2), one of the main pollutants from vehicles, to safer levels.

The EU has mandated an annual average of 40 $\mu g/m^3$ of NO_2, with no more than 18 'exceedances' of 200 $\mu g/m^3$ per year, which was supposed to be achieved by 2010. In fact, the UK failed to meet this objective, and was taken to court. The High Court ruled that the policy on air pollution was unlawful and the government has been required to produce more effective plans (Guardian 2018a). The issue is now before the European Court of Justice (Guardian 2018b).

Nitrogen dioxide pollution from vehicles can be reduced in several ways, amongst which are:

- Reduce the NO_2 emission from vehicles. The prime sources of NO_2 are older engines, especially diesel cars. Replacing these with Ultra Low Emission Vehicles (e.g. electric or hybrid) or recent diesel or petrol engines (that conform to the Euro 6 standard, https://en.wikipedia.org/wiki/European_emission_standards) will reduce roadside emissions.
- Reduce the number of vehicle trips. This can be done in a number of ways:
    - Ban vehicles entirely from an area (e.g. by making the area a pedestrianised zone)
    - Ban vehicles from an area at certain times of day, to avoid peak flows causing emission spikes
    - Impose charges in a 'Clean Air Zone'. These charges may vary by time of day, by type of vehicle, by amount of NO_2 emitted, by function of vehicle (e.g. whether a lorry, bus, taxi, or car) and so on.
- Provide incentives to change the travel mode, e.g. get people to walk or cycle instead of using a car.

These are not exclusive: a policy could for example, encourage individuals to upgrade their cars, while charging lorries a substantial fee to enter a clean air zone.

The policy problem the government faces is to devise a suite of policies that will have the desired effect on pollution while not having undesirable side effects and being capable of securing sufficient local and national political support. Side effect s could include having excessive effects on business (e.g. banning lorries from a shopping centre may mean that shops cannot get stock in); having adverse distributional effects (e.g. imposing a high charge on buses will either reduce the profitability of bus companies, leading to fewer buses, or raise fares, both of which will selectively impact poorer people, who use buses more than the richer); and shifting traffic from one location to another, raising pollution levels in the new routes. Some possible policies would need to be enforced through legislation or regulation, requiring political action at local (City Council) or national (Government) levels, or would require voluntary compliance, possibly involving changing norms of acceptable behaviour.

If one wants to design a policy to reduce roadside NO_2, there are several inter-related steps one must take:

1. Identify the current ('baseline') level of pollution
2. Develop and validate a model of traffic flows

3. Develop and validate a model of the consequent air pollution
4. Devise a policy (e.g., a charging zone)
5. Determine (or assume) what the 'behavioural response' to that policy would be (e.g. what the reduction in the number of journeys as a result of imposing a charge will be).
6. Re-run the traffic and air quality models to see whether the roadside NO_2 level would be reduced and whether it now meets the required threshold.
7. Estimate whether there is sufficient political support for the policy to be enacted. This might require a cost/benefit analysis and consideration of the effects on sub-groups.

There are some standard traffic and air quality models (for an introduction to the principles of transport modelling in the UK see DfT (2014) and for air quality modelling, see https://en.wikipedia.org/wiki/Roadway_air_dispersion_modeling), but these have to be calibrated for a local area and validated, typically using historical and current data. However, data collection is expensive and often not very accurate. For example, the traffic along a road can be observed using ANPR (Automatic Number Plate Recognition – a video camera that 'sees' vehicle number plates) coupled to a link to the national vehicle registration database to identify the type of vehicle (and its pollution potential). NO_2 levels can be observed using either diffusion tubes (which provide longer term average concentrations), or much more expensive continuous monitors. In either case, these measurements relate only to the specific locations where the instruments are placed.

Cambridge City's air quality is much better than in large UK cities such as London, but nevertheless has some local problems. There are a lot of traffic congestion, and Cambridge is adjacent to the A14 trunk road which is a main artery for freight. There is therefore an intention to develop a policy to improve, or at least prevent a deterioration in, air quality, although the city and its population is growing rapidly (CCC 2018a; CCC 2018b).

Your task

Devise and justify a policy or policies for reducing roadside NO_2 in and around Cambridge that can be applied by the City Council. Since you don't have access to a traffic or air quality model, you will need to make plausible assumptions about the effectiveness of your proposed policies (if this was for real, you would then input those assumptions into the models to see whether the policies were likely to have the desired effect).

In considering suitable policies, you need to bear in mind the powers of a city council (e.g. a city council cannot force all owners of old diesel cars to scrap them, although it could provide incentives to local residents to do so, but not to those living elsewhere). You should also consider carefully the implications of your policies on other public policies (e.g. land use zoning, waste disposal etc.) and any unintended consequences (e.g. on the attractiveness of the area and on the local environment).

Monday 17th September 2018 (Nigel and Petra)

Starting the policy modelling exercise

Student class presentations: reviews and expositions of the existing evidence on

- air quality modelling
- traffic modelling
- forecasting 'behavioural responses'
- legal and practical issues

Formation of small working groups on models

Literature

AQEG (2004) Nitrogen Dioxide in the United Kingdom. https://uk-air.defra.gov.uk/assets/documents/reports/aqeg/nd-summary.pdf

Guardian (2018a) Air pollution: UK government loses third court case as plans ruled 'unlawful'. https://www.theguardian.com/environment/2018/feb/21/high-court-rules-uk-air-pollution-plans-unlawful

Guardian (2018b) UK taken to Europe's highest court over air pollution. https://www.theguardian.com/environment/2018/may/17/uk-taken-to-europes-highest-court-over-air-pollution

DfT (2014) TAG Unit M1: principles of Modelling and Forecasting. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/427118/webtag-tag-unit-m1-1-principles-of-modelling-and-forecasting.pdf

CCC (2018a) Air pollution https://www.cambridge.gov.uk/air-pollution

CCC (2018b) Clean air zone https://www.cambridge.gov.uk/clean-air-zone

Air quality policymaking / environmental protection policies in general:

Cole, D. H., & Grossman, P. Z. (2018). When is command-and-control efficient? Institutions, technology, and the comparative efficiency of alternative regulatory regimes for environmental protection. In *The Theory and Practice of Command and Control in Environmental Policy* (pp. 115-166). Routledge.

Hanley, N., Hallett, S., & Moffatt, I. (1990). Research policy and review 33. Why is more notice not taken of economists' prescriptions for the control of pollution?. *Environment and Planning A*, 22(11), 1421-1439.

Nemet, G. F., Holloway, T., & Meier, P. (2010). Implications of incorporating air-quality co-benefits into climate change policymaking. *Environmental Research Letters*, 5(1), 014007.

Some information on the amount of legal regulations involved:

Adam, C., Knill, C. and X. Fernandez-i-Marin (2017): Rule growth and government effectiveness: why it takes the capacity to learn and coordinate to constrain rule growth, *Policy Science* 50: 241–268.

Concrete measures / policies:

Sterner, T., Coria, J. (2012). *Policy Instruments for Environmental and Natural Resource Management*. New York: Routledge.

Harrington, W., Morgenstern, R. D., & Sterner, T. (Eds.). (2004). Choosing environmental policy: comparing instruments and outcomes in the United States and Europe. Resources for the Future.

Krupnick, A. J. (1986). Costs of alternative policies for the control of nitrogen dioxide in Baltimore. *Journal of Environmental Economics and Management*, 13(2), 189-197.

Seskin, E. P., Anderson Jr, R. J., & Reid, R. O. (1983). An empirical analysis of economic strategies for controlling air pollution. *Journal of environmental economics and management*, 10(2), 112-124.

O'ryan, R. E. (1996). Cost-effective policies to improve urban air quality in Santiago, Chile. *Journal of Environmental Economics and Management*, 31(3), 302-313.

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., & Sandler, R. (2011). Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. *Environmental Modelling & Software*, 26(12), 1489-1501.

Urban freight:

Dablanc, L. (2008). Urban goods movement and air quality policy and regulation issues in European cities. *Journal of Environmental Law*, 20(2), 245-266.

Stathopoulos, A., Valeri, E., & Marcucci, E. (2012). Stakeholder reactions to urban freight policy innovation. *Journal of Transport Geography*, 22, 34-45.

Behrends, S., Lindholm, M., & Woxenius, J. (2008). The impact of urban freight transport: A definition of sustainability from an actor's perspective. *Transportation planning and technology*, 31(6), 693-713.

Ballantyne, E. E., Lindholm, M., & Whiteing, A. (2013). A comparative study of urban freight transport planning: addressing stakeholder needs. *Journal of transport geography*, 32, 93-101.

Gatta, V., & Marcucci, E. (2016). Stakeholder-specific data acquisition and urban freight policy evaluation: evidence, implications and new suggestions. *Transport Reviews*, 36(5), 585-609.

Aditjandra, P. T., Galatioto, F., Bell, M. C., & Zunder, T. H. (2016). Evaluating the impacts of urban freight traffic: application of micro-simulation at a large establishment. *Eur J Transp Infrastruct Res*, 16(1), 4-22.

Morana, J., Gonzalez-Feliu, J., & Semet, F. (2014). Urban consolidation and logistics pooling. In *Sustainable urban logistics: Concepts, methods and information systems* (pp. 187-210). Springer, Berlin, Heidelberg.

Road pricing:

Kopsacheili, A., Pnevmatikou, A., Yannis, G., & Diamandouros, K. (2017). A simplified transport model for the ex ante evaluation of road pricing on a project basis. *Infrastructure Asset Management*, 4(4), 128-136.

Rotaris, L., Danielis, R., Marcucci, E., & Massiani, J. (2010). The urban road pricing scheme to curb pollution in Milan, Italy: Description, impacts and preliminary cost–benefit analysis assessment. *Transportation Research Part A: Policy and Practice*, 44(5), 359-375.

Johansson, C., Burman, L., & Forsberg, B. (2009). The effects of congestions tax on air quality and health. *Atmospheric Environment*, 43(31), 4843-4854.

Gibson, M., & Carnovale, M. (2015). The effects of road pricing on driver behavior and air pollution. *Journal of Urban Economics*, 89, 62-73.

Coria, J., Bonilla, J., Grundström, M., & Pleijel, H. (2015). Air pollution dynamics and the need for temporally differentiated road pricing. *Transportation Research Part A: Policy and Practice*, 75, 178-195.

Jakobsson, C., Fujii, S., & Gärling, T. (2000). Determinants of private car users' acceptance of road pricing. *Transport policy*, 7(2), 153-158.

Choice of travel modes:

Braun, L. M., Rodriguez, D. A., Cole-Hunter, T., Ambros, A., Donaire-Gonzalez, D., Jerrett, M., ... & de Nazelle, A. (2016). Short-term planning and policy interventions to promote cycling in urban centers: Findings from a commute mode choice analysis in Barcelona, Spain. *Transportation Research Part A: Policy and Practice*, 89, 164-183.

Meyer, M. D. (1999). Demand management as an element of transportation policy: using carrots and sticks to influence travel behavior. *Transportation Research Part A: Policy and Practice*, 33(7-8), 575-599.

Bamberg, S., Ajzen, I., & Schmidt, P. (2003). Choice of travel mode in the theory of planned behavior: The roles of past behavior, habit, and reasoned action. *Basic and applied social psychology*, 25(3), 175-187.

Macmillan, A., Connor, J., Witten, K., Kearns, R., Rees, D., & Woodward, A. (2014). The societal costs and benefits of commuter bicycling: simulating the effects of specific policies using system dynamics modeling. *Environmental health perspectives*, 122(4), 335.

Ding, C., Wang, D., Liu, C., Zhang, Y., & Yang, J. (2017). Exploring the influence of built environment on travel mode choice considering the mediating effects of car ownership and travel distance. *Transportation Research Part A: Policy and Practice*, 100, 65-80.

Carsharing / carpooling:

Balac, M., Ciari, F., & Axhausen, K. W. (2017). Modeling the impact of parking price policy on free-floating carsharing: Case study for Zurich, Switzerland. *Transportation Research Part C: Emerging Technologies*, 77, 207-225.

Jorge, D., & Correia, G. (2013). Carsharing systems demand estimation and defined operations: a literature review. Euro*pean Journal of Transport and Infrastructure Research*, 13(3), 201-220.

Illgen, S., & Höck, M. (2018). Electric vehicles in car sharing networks–Challenges and simulation model analysis. *Transportation Research Part D: Transport and Environment*, 63, 377-387.

Ciari, F., Balac, M., & Axhausen, K. W. (2016). Modeling Carsharing with the Agent-Based Simulation MATSim: State of the Art, Applications, and Future Developments. *Transportation Research Record: Journal of the Transportation Research Board*, (2564), 14-20.

Ayed, H., Khadraoui, D., & Aggoune, R. (2015, June). Using MATSim to simulate carpooling and car-sharing trips. In Information Technology and Computer Applications Congress (WCITCA), 2015 World Congress on (pp. 1-5). IEEE.

Tuesday is free

Wednesday 19th September 2018 (Nigel and Petra)

Progress in policy modelling

Groups reporting progress and problems, plenary discussion, small working groups continue work, ad hoc inputs such as:

Jascha Achterberg: overview over the role of Psychology / Neuroscience in policy decisions; influence of behavioural research on policy to make evidence-based decisions

Literature

https://www.routledge.com/Behavioral-Insights-for-Public-Policy-Concepts-and-Cases/Ruggeri/p/book/9781138484238

(not yet out; 14.8.2018)

Part III: Discussing results

Thursday *20th* September 2018 (Nigel and Petra)

Excursion to / Visit from Cambridge City Council CCC

Contribution from CCC, group presentations for CCC, discussion with CCC

Friday 21st September 2018 (Nigel and Petra)

Progress in policy modelling / The potential of ABM

Groups reporting progress, small working groups finalise work, plenary discussion

- Wrap Up Session: Future Directions in Computational Social Science Research
- Student Feedback
- Follow up information about Student assessment and other issues.

Further literature

Literature on the policy cycle and policy research

Harold Dwight Lasswell: *The decision process: seven categories of functional analysis*. Bureau of Governmental Research, College of Business and Public Administration, University of Maryland, 1956.

Wegrich, K., & Jann, W. (2006). Theories of the policy cycle. In *Handbook of public policy analysis* (pp. 69-88). Routledge.

Howlett, M., Ramesh, M., & Perl, A. (2009). *Studying public policy: Policy cycles and policy subsystems* (Vol. 3). Oxford: Oxford University Press.

Althaus, C., Bridgman, P., & Davis, G. (2007). *The Australian policy handbook* (pp. xii-268). Sydney: Allen & Unwin.

Young, John and Enrique Mendizabal. *Helping researchers become policy entrepreneurs*, Overseas Development Institute, London, September 2009.

Literature on experiments

Morgan, Mary. (2013). Nature´s Experiments and Natural Experiments in the Social Sciences. *Philosophy of the Social Sciences*. 43. 341-357. 10.1177/0048393113489100.

Frankfort-Nachmias, C., Nachmias, D., & DeWaard, J. (2015). Research designs: Experiments. *Research methods in the social sciences*, 81-101.

Martin, M. W., & Sell, J. (1979). The role of the experiment in the social sciences. *The Sociological Quarterly*, *20*(4), 581-590.

Dunning, T. (2012). *Natural experiments in the social sciences: a design-based approach*. Cambridge University Press.

Webster, M., & Sell, J. (Eds.). (2014). *Laboratory experiments in the social sciences*. Elsevier.

Basic research methods : an entry to social science research / Gerard Guthrie, Kapitel 8

Somekh, B., & Lewin, C. (2004). *Research Methods in the Social Sciences*. Sage Publications. (ein Kapitel darin über Foundations of Experimental/Empirical Research.

Literature on counterfactuals

a) General literature on the role of counterfactuals in the social sciences

Reiss, J. (2012). Counterfactuals. In *The Oxford handbook of philosophy of social science.* DOI: 10.1093/oxfordhb/9780195392753.013.0008

Cummings, R. 2006. "'What if': The Counterfactual in Program Evaluation." *Evaluation Journal of Australasia 6* (2): 6–15.

Reiss, J., and N. Cartwright. 2004. "Uncertainty in Econometrics: Evaluating Policy Counterfactuals." In Economic Policy Under Uncertainty: The Role of Truth and Accountability in Policy Advice, P. Mooslechner, H. Schuberth, and M. Schürz, eds., 204– 32. Cheltenham: Edward Elgar.

Cartwright, N. 2007. "Counterfactuals in Economics: A Commentary." In *Hunting Causes and Using Them*, 236–61. Cambridge: Cambridge University Press.

Balke, A., & Pearl, J. (1995, August). Counterfactuals and policy analysis in structural models. In *Proceedings of the Eleventh conference on Uncertainty in artificial intelligence* (pp. 11-18). Morgan Kaufmann Publishers Inc..

Heckman, J. J., & Vytlacil, E. J. (2007). Econometric evaluation of social programs, part I: Causal models, structural models and econometric policy evaluation. *Handbook of econometrics*, *6*, 4779-4874.

Fearon, J. (1996). Causes and counterfactuals in social science. *Counterfactual thought experiments in world politics*, 39-67.

Tetlock, P. E., & Belkin, A. (Eds.). (1996). *Counterfactual thought experiments in world politics: Logical, methodological, and psychological perspectives*. Princeton University Press.

Cederman, L. E. (1996). Rerunning history: Counterfactual simulation in world politics. *Tetlock and Belkin (Eds.)*, 247-267.

Weber, S. (1996). Counterfactuals, past and future. *Tetlock and Belkin (eds.)*, 268-288.

b) Literature with relations to the simulating/modelling social sciences

Taylor, J. B. (2007). Housing and monetary policy (No. w13682). National Bureau of Economic Research.

He, J., Liu, Y., Yu, Y., Tang, W., Xiang, W., & Liu, D. (2013). A counterfactual scenario simulation approach for assessing the impact of farmland

preservation policies on urban sprawl and food security in a major grain-producing area of China. *Applied Geography*, 37, 127-138. https://doi.org/10.1016/j.apgeog.2012.11.005

Foerster, J., Farquhar, G., Afouras, T., Nardelli, N., & Whiteson, S. (2017). Counterfactual multi-agent policy gradients. arXiv preprint arXiv:1705.08926.

Assunção, J., Gandour, C., & Rocha, R. (2015). Deforestation slowdown in the Brazilian Amazon: prices or policies?. *Environment and Development Economics*, 20(6), 697-722.

Goettler, R. L., & Gordon, B. R. (2011). Does AMD spur Intel to innovate more?. *Journal of Political Economy*, 119(6), 1141-1200. https://www.jstor.org/stable/10.1086/664615

Literature on ex-ante evaluation

For a comprehensive list of suggested readings on ex-ante evaluations (conducted in 2013) by Petra Todd (University of Pennsylvania) see: https://www.ifs.org.uk/docs/Todd%20programme_june%202013.pdf

Todd, P. E., & Wolpin, K. I. (2008). Ex ante evaluation of social programs. *Annales d'Economie et de Statistique*, 263-291. DOI: 10.2307/27917248

Hertin, J., Turnpenny, J., Jordan, A., Nilsson, M., Russel, D., & Nykvist, B. (2009). Rationalising the policy mess? Ex ante policy assessment and the utilisation of knowledge in the policy process. Environment and Planning A, 41(5), 1185-1200. https://doi.org/10.1068/a40266

Wolpin, K. I. (2007). Ex ante policy evaluation, structural estimation and model selection. *American Economic Review*, 97(2), 48-52. https://www.jstor.org/stable/30034419

Janssens, F. J., & de Wolf, I. F. (2009). Analyzing the assumptions of a policy program: An ex-ante evaluation of ‘‘educational governance’’in the Netherlands. *American Journal of Evaluation*, 30(3), 411-425. https://doi.org/10.1177/1098214009341016

Gruber, J., Kihm, A., & Lenz, B. (2014). A new vehicle for urban freight? An ex-ante evaluation of electric cargo bikes in courier services. *Research in Transportation Business & Management*, 11, 53-62.

Niemöller, C., Metzger, D., Fellmann, M., Özcan, D., & Thomas, O. (2016). Shaping the future of mobile service support systems-ex-ante evaluation of smart glasses in technical customer service processes. *Informatik* 2016.

Shafie-khah, M., Moghaddam, M. P., & Sheikh-El-Eslami, M. K. (2016). Ex-ante evaluation and optimal mitigation of market power in electricity markets including renewable energy resources. *IET Generation, Transmission & Distribution*, 10(8), 1842-1852.

Samset, K., & Christensen, T. (2017). Ex ante project evaluation and the complexity of early decision-making. *Public Organization Review*, 17(1), 1-17.

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For a comprehensive list of suggested readings on ex-post evaluations (conducted in 2013) by Petra Todd (University of Pennsylvania) see:
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