Towards Teaching Markets as Complex Systems: A Web Based Simulation Assignment Implemented in NetLogo

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Abstract

This paper is based on a simulation model, programmed in NetLogo, that demonstrates changes in market structure that occur as marginal costs, demand, and barriers to entry change. Students predict and observe market structure changes in terms of number of firms, market concentration, market price and quantity, and average marginal costs, profits, and markups across the market as firms innovate. By adjusting the demand growth and barriers to entry, students can explore market changes in terms of the output variables mentioned above. The exercise allows students to synthesise information from several different chapters of the text that discuss differing market structures including perfect competition, monopoly, monopolistic competition, and oligopoly. Finally, the exercise exposes students to computational methods, simulation, and a dynamic perspective on the static models provided by the course text.

JEL classification: A22, C60, D40, D41, D42, D43

1. Introduction

While simulations can provide both a dynamic environment for static models of economics (Kochanski, 2007; Paetow, 1998; van Loo and Maks, 1996) and allow the implementation of agent based computational economic modelling, they also introduce students to the idea of building economic models and simulations themselves, leading them down a path toward programming proficiency. This paper describes how principles of economics students were introduced to a market simulation where they controlled two parameters (demand growth and barriers to entry) while firm innovation occurred via localised agent-environment interactions. The students were asked to make predictions, drawing from material introduced in their principles of economics text and after running the simulation, to reflect upon how the results compared to their predictions[1].

In the textbook, dynamic processes are reduced to simple static analyses where there are two points of interest, equilibrium before a supply or demand curve shifts and equilibrium after a shift. If the model is not in equilibrium then students are taught that the market mechanism will bring it to equilibrium. Unfortunately, today's textbooks do not explore models or explanations of how the dynamics of the market mechanism might play out as with zero intelligence traders for example (Gode and Sunder, 1993). In most cases, the text can even leave students unable to imagine a world where supply and demand curves are bouncing around due to continual changes in determinants of supply and demand

[1] Course textbook was Bradley R. Schiller, *The Economy Today* (Boston: McGraw-Hill Irwin, 2008).

leading to an endless dance of equilibrium. It can be even more difficult for students to imagine how to begin sorting out the many competing effects a mass of changing determinants has on an equilibrium.

This paper demonstrates how simulations can allow students a view into both the dancing dynamics of equilibrium models, a Cournot model in this case (Cournot, 1838), and the generative models of agent based modelling. Students can observe market outcomes of price and quantity, profit, market concentration, market power, and number of firms. By adjusting parameters students can study the behaviour and rate at which the market transitions over time. They can also experiment with combinations of parameter settings such as low barriers with falling demand to see which effects appear to dominate, giving them an appreciation for the complexities that arise from an interconnected set of parameters. The assignment also demonstrates the process of agentising a model through the innovation process mentioned above and gives them an appreciation for the complexities that arise when introducing heterogeneity and localised interactions to models.

NetLogo is a well-known agent based simulation package with applications across the disciplines. It provides powerful modelling, graphical, and statistical components for both the novice and expert modeller. Saving the simulation as a java applet also provides students with an easily accessible web based program containing a user-friendly graphical interface (dashboard), the NetLogo code, and a text editor allowing a display of the assignment.

The NetLogo code for the assignment is provided to the students so for this exercise they are not required to do any programming though the code is visible for them to examine and revise. With NetLogo students gain a better understanding of how iteration can turn static models into dynamic ones. Students gain an understanding of how computational models can be built and can begin to ponder the differences between top down analytic models of today's mainstream economics texts and the bottom up generative models slowly emerging on the discipline's horizon (Colander, 2003).

In the following sections, I begin by providing some background on the computational modelling of markets and discussing implementation of the model within NetLogo. I then introduce the market simulation assignment, discuss the simulation results, and summarise student predictions and observations for the various questions. I end with a general discussion of the assignment, student responses to the assignment, and some concluding remarks.

2. Background: computational modelling of a market

There are several ways to simulate markets, from designing zero intelligence traders (Gode and Sunder, 1993)[2] to simply placing the equations of an analytic model from a mainstream textbook into a computer package such as Mathematica and changing parameters iteratively (Kochanski, 2007). The model implemented here is essentially a hybrid. It is based on a Cournot solution for the *n*-firm case (Sarkar *et al*., 1998) where firms have heterogeneous cost structures (see Appendix A for derivation). The model is unique in that it produces exact monopoly and perfect competition solutions (at n=1 and as $n \rightarrow \infty$ respectively) and produces the intermediate equilibrium outcomes consistent with models of imperfect competition. That said it has characteristics of an agent-based model as well since firms follow a few simple rules as they interact locally with their environment in process innovations.

While students in the course learn the mathematical frameworks for perfect competitors and monopolists they were not exposed to the derivation of the Cournot solution. It was discussed during the section of the course covering imperfect competition. Several introductory texts, including the Schiller text used for the course, introduce students to the idea of firm interdependence with the

[2] Mark McBride has implemented the model designed by Gode and Sunder in NetLogo. http://mcbridme.sba.muohio.edu/ace/labs/zitrade/zitradenetlogo.html

oligopolist's kinked demand curve and the game theory payoff matrix. The Cournot model of firm interdependence dovetails nicely into this section of the course material.

In the context of imperfect competition, typical classroom discussions include oil cartels, collusion, the airline industry during deregulation, and how the interactions of a changing business environment with differing cost structures can drastically shift each firm’s respective market share and affect market concentration.

When studying imperfect competition, students see the powerful price cutting incentives behind cartels such as OPEC and gain a deeper understanding of how firms, such as Pan Am in the 1980's can lose market share and ultimately exit a market. Finally, they can see how falling costs and changing demand affect market price and output and how changing barriers affect market entry. They also gain understanding of how all the above affect market concentration.

3. Implementing the model in NetLogo and running the simulation

Students are first introduced to the basic mechanics of the model and instructed on how it works. Then they are instructed on how to use the parameter adjustments on the NetLogo dashboard and how to interpret the simulation's graphical output. Finally they are asked to try several different parameter configurations, to make predictions based on theory from the textbook and course material, to comment on what they observe, and at the end of the assignment to comment on how market simulations might serve businesses and policy makers. The sections below outline the assignment as provided to the students.

What is it?

This is a Cournot model named after the French economist Antoine Augustin Cournot (1801-1877). It is commonly used to model imperfect competition in cases where firms have some market power and must choose a level of output to produce that considers the responses of their competitors as well. The resulting price and output end up somewhere between what perfect competition and monopoly markets would produce and is a Nash Equilibrium.

How it works:

The simulation begins with 20 firms when you click the [SETUP] button. When you click the [GO] button the simulation begins and runs for 1000 time periods (days). At each point in time we can see on the graphs: 1) the Cournot equilibrium market price and quantity, as well as average MC in the market, 2) the average profit of firms in the market, 3) the market concentration as measured with the HHI (Herfindal-Hirschman Index), 4) the number of firms in the market, and 5) the average price markup or (Price/Avg.MC).

In this simulation, firms are moving randomly across a business landscape. When they enter the green patch in the centre they spend some of their accumulated profits on productivity innovations, assuming they have accumulated such profits. This lowers their marginal costs and gives them an advantage over their competitors. For the innovating firm, this leads to more market share, higher profits, and increased market concentration.

How to use it:

There are two parameters that can be adjusted to affect how the simulation plays out.

1) Demand growth, setting this to a positive value means that the market demand curve gradually increases over time.

2) Barriers to entry, determine how costly it is for new firms to enter the market. At the lowest setting we have perfect competition conditions. At high setting we have oligopoly or even monopoly conditions.

Things to notice:

1) If HHI is increasing then either some firms are gaining market share from others, or, firms are exiting the market creating more market share for the remaining firms. It is likely that both affects are occurring simultaneously.

2) If number of firms is increasing then HHI should on average decrease (unless, due to the other affect discussed above some firms are gaining market share over the new entrants).

3) As the market becomes more concentrated market prices should increase.

4) As average profitability increases this creates the incentive for new firms to enter (depending on the level of barriers).

5) Chaotic events can happen in a dynamic setting with several interacting components. As new firms enter, innovate, increase profits, etc. the results may be quite predictable and smooth or in some cases may be chaotic with wild fluctuations.

Note: when the simulation stops before 1000 rounds it means that all firms have exited the market, even the last remaining firm, which was a monopolist.

After being introduced to the graphical display of the simulation, students are then asked to perform several different operations, to make predictions based on theory introduced in the course, and to describe how the simulation performed relative to their predictions.

Things to try:

Please provide answers to the following questions. I prefer typed responses but hand written responses that are clearly legible will suffice. Feel free to incorporate graphs, equations, or sketches in your responses.

1) When you click [SETUP] the first time conditions similar to perfect competition are generated (no barriers). Additionally demand is held constant. What do you expect to happen when you run the simulation for the following: Average profitability, HHI, number of firms, market price, and market quantity? Just say if you expect them to increase for decrease. Will market price be close to marginal cost (MC pricing) or above average marginal cost (markup pricing)?

Make sure the settings are at:
[DEMAND GROWTH] = 0
[BARRIER] = 0
Now run the simulation. It might not finish if an infinite number of firms flood the market. If so, what happened to the above mentioned measures as firms entered?

The simulation produces results consistent with mainstream theory under conditions of perfect competition, namely falling prices and increased market output (to a point), low market concentration, low profit, a large number of firms, and little or no markup.

From the mainstream perspective this example is characterised by the market supply curve shifting to the right over time as new firms enter the market. The effect is not as dramatic however since firms that exist in the market become smaller and smaller as the market saturates. Since firms cannot accumulate profit they are unable to reduce costs by investing in cost reducing R&D projects.

Most students made predictions consistent with a perfectly competitive market where firms are reducing costs through innovation, namely that, with low barriers to entry and constantly falling costs, a large number of firms enter the market, causing low market concentration, falling prices, increased output, minimal or no profit, and no markup.

Figure 1

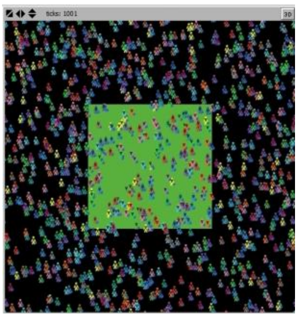
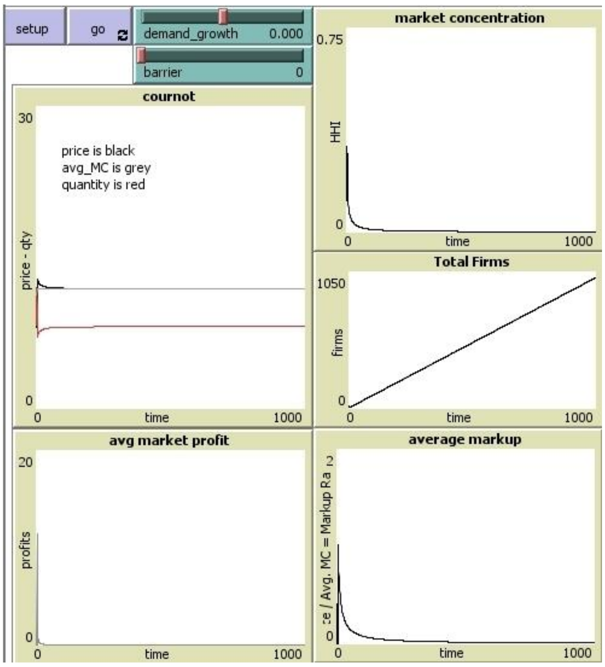


Figure 2



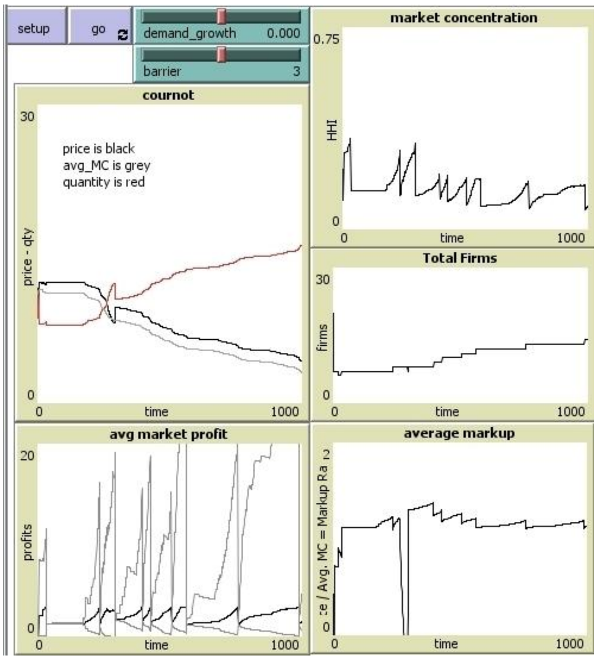
2) Next, we'll keep all settings as they were but we will increase [BARRIER] TO 3.
How do you expect the results to differ from question (1) in terms of: Average profitability, HHI, number of firms, market price, and market quantity and the price markup? Run the simulation. What happened? Were the results more chaotic or volatile?

The simulation produces results consistent with mainstream theory, a moderately concentrated market, moderate profit levels, a modest number of firms (about 30), and some degree of market power with price markups. With moderate barriers, profits are positive, allowing money for cost-reducing innovations, which cause falling prices and increased output. From the mainstream perspective this is characterised by the market supply curve shifting to the right over time as firms reduce marginal costs and a few new firms enter the market.

Most students predicted the higher barriers would lead to higher market concentration, fewer firms, and some degree of profit for firms in the market. They predicted increased output and falling prices and a few identified uncertainty due to the mix of effects on price resulting from falling costs, new entrants, and the markup associated with market power.

Figure 3

Figure 4



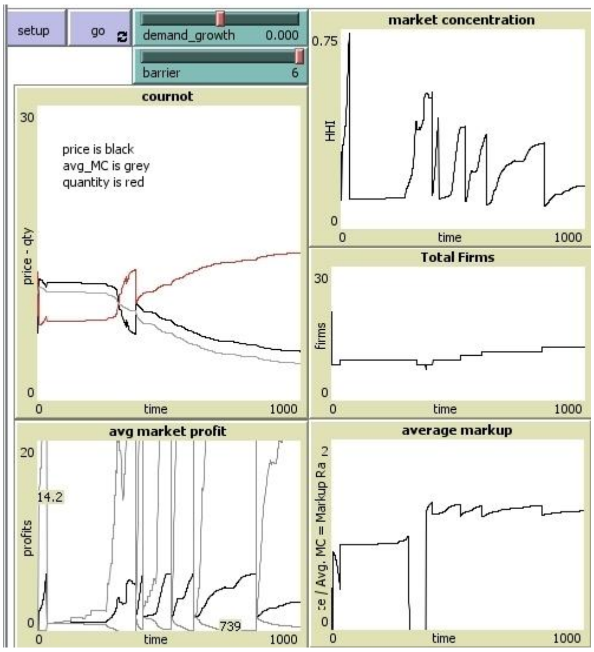
3) Keep the setting from question (2) but increase [BARRIER] TO 6 and run the simulation. What happened to: Average profitability, HHI, number of firms, market price, and market quantity and the price markup? Did the simulation run with more or less volatility?

In this question the results are similar to the previous case but with larger fluctuations in profit and market concentration. In general, the market experiences falling prices, increased market output, an even more concentrated market, moderate profit, fewer firms than in the previous question, and market power with some degree of markup.

Given the similarity between this question and the previous one, students generally predicted that the even higher barriers would lead to even fewer firms, a higher market concentration, and higher profits. Some also predicted longer delays between new firm entrants since the barriers to entry were higher.

Figure 5

Figure 6



4) Now set [BARRIER] TO 3 (moderate barriers) and increase [DEMAND GROWTH] TO .001. According to our text, what happens in a market when demand is increasing? Does equilibrium price increase or decrease? What about equilibrium quantity? Do you expect that the market would be able to accommodate more or fewer firms? Run the simulation. Do the results support your theory? Is price close to the average marginal cost for the industry? Try the simulation with [DEMAND GROWTH] set to –0.001. Does the opposite happen?

This is a two-part question identical to question (2) above but with the addition of shifting demand. Regarding the first part with increasing demand, firms in the industry have some markup power given the moderate barriers, yet profitability from increasing demand entices other firms to enter the market. While price reductions are comparable to above, the market quantity has increased dramatically and more firms (just over 30) are accommodated.

Many students predicted that increased demand would put upward pressure on price and increase market output while accommodating more firms in the market, lowering market concentration[3].

[3] Throughout the assignment, students occasionally made common errors regarding the direction of price and quantity changes associated with shifting curves.

Additionally many predicted the entrance of new firms would also increase output while placing downward pressure on price. Some commented on the indeterminate effect on price due to the competing pressures resulting from increased demand and increasing supply resulting from new entrants and cost reducing innovations.

Figure 7

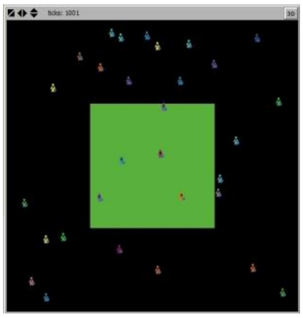
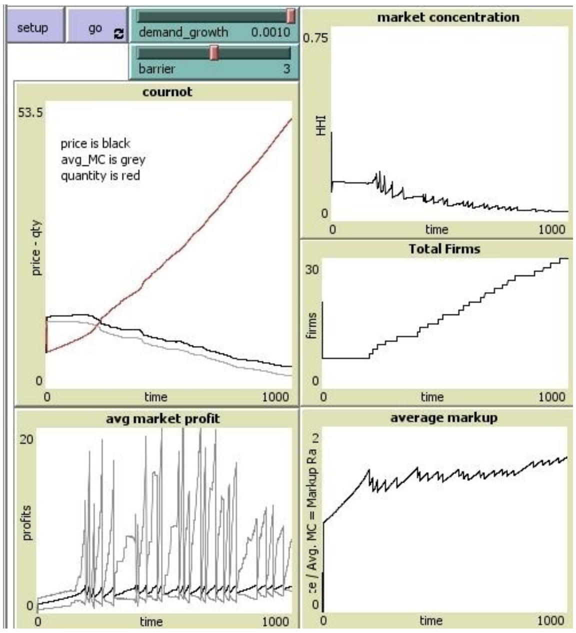


Figure 8



For part two of the question with moderate barriers and falling demand almost all firms are squeezed out of the market. The remaining firms are forced to lower prices as demand continues to fall and toward the end of the simulation price and profits approach zero. The result is a highly concentrated yet unsustainable market that ultimately collapses due to insufficient demand.

Most students simply predicted the opposite effect relative to part one (with increasing demand) though a few commented on the downward price pressure and decreased output that should result from falling demand. No students predicted market collapse due to insufficient demand.

Figure 9

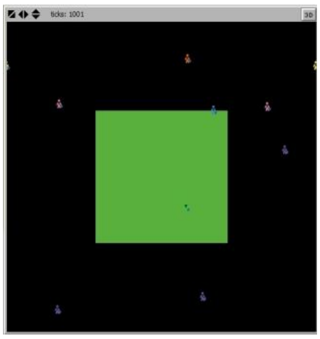
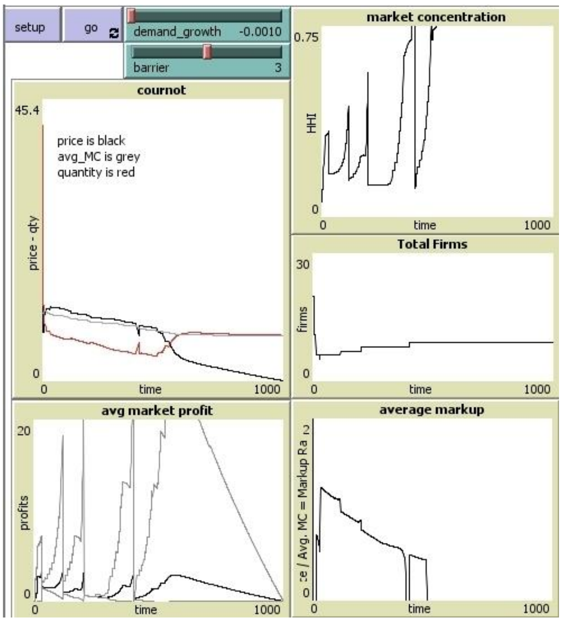


Figure 10



5) Write a few sentences about how market structure affects market performance. You might address the following: Do cost reducing innovations necessarily get passed on to consumers in the form of lower prices (do lower marginal costs mean lower prices necessarily)? Does it matter if innovations occur in a perfectly competitive market vs. a less competitive one? Why might regulators be concerned with industries that are characterised by high market concentrations?

For this question students drew from the theory in the text identifying cost reductions with lower prices and increased output but also noting that increased market power leads to pricing above marginal cost (whether costs are falling or not). Additionally, they tended to state that markets characterised by high market concentration needed to be regulated.

6) At the beginning of the term, I stated that economists make observations of economic participants and their behaviour. They then develop theories based on those observations. Next, they build economic models that are consistent with those theories. Finally, they use the economic models to forecast change under different conditions. How might simulations be useful as a policy tool for modelling a market (or the economy)?

For this question students generally pointed to well-constructed simulations as useful for both firms and policy makers interested in studying the effects of various policies. Firms, for example, could use simulations to study the effects of increased demand on profitability and the structure of the market the firm is operating in. Policy makers could study the effects on market structure of allowing mergers or promoting policies that increase market demand. Students also proposed an idea common in other simulation texts that running simulation scenarios would allow decision makers to study the effects of various policies before tinkering with their business or the economy.

4. Student response to the assignment

This exercise was conducted as an extra credit homework assignment in two of my Introductory Microeconomic Theory courses at Portland State University. The class size was roughly 60 students per class with 28 participants in total. With such a large class size it is typically not feasible to conduct assignments that require all students to be online at the same time interacting in real-time (Schmidt, 2003; Wolf and Portegys, 2007)[4] or even working on the simulation while in a classroom setting (Sayama, 2006). The benefit of implementing the simulation in NetLogo is that files can be saved as java applets and run in a web browser at the students' convenience, requiring no software downloads or complicated installations.

This exercise provided an opportunity for students to synthesise the various market structure frameworks proposed within their text and to gain experience augmenting classic microeconomic models. Throughout the course animations were provided to instil a sense of static vs. dynamic processes.

The assignment was distributed during the middle of the term and throughout the remainder of the course discussion time was allowed regarding the assignment. Initially students were not familiar with the dashboard or simulation output as it was quite different from the graphical representations in the text. After running through the simulation a number of times, students gained an appreciation for the simulation and a better understanding of the output produced.

One weakness of mainstream texts is that while they introduce students to the short run and long run outcomes of different market structures, namely, perfect competition, monopoly, oligopoly, and monopolistic competition, there is little or no discussion of how markets might change along this continuum from perfect competition through imperfect competition toward monopoly and vice a versa. This can be a difficult task since each market structure is based on characteristics (e.g. number of firms, barriers to entry, product type (homogeneous or differentiated), and market power) that do not necessarily vary continuously[5].

That said the Schiller Economy Today text has a chapter featuring a case study with extensive coverage of the evolution of the personal computer market, which went through several changes between 1976 and 1983 as firms entered and exited the market. As mentioned above, the Schiller text also covers changes in the airline industry during the era of deregulation. This also led to significant market structure changes. It is these types of processes that simulations serve so well: allowing demonstrations of the dynamics behind market change.

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[4] In smaller courses I have scheduled lab time for students to play the web-based version of John Sterman's Beer Game. http://beergame.mit.edu/guide.htm. Other options for class simulations include turn based simulations such as the Greenland Game made available by the synthetic worlds initiative at Indiana University with the goal of providing large games as research environments.

[5] While it is possible to simulate a range of product types, the assignment for this course assumed homogeneous products and allowed for variation in the other characteristics.

In general, the students expressed enjoyment in the act of testing hypotheses (e.g. what happens if I increase demand in a market with high barriers to entry). They also accepted the idea that the simulation presented was one of many potential models of how a market might function and something to be improved upon. In addition to being able to identify likely simulation outcomes for problems 1 to 4 above, students also showed an appreciation for many of the complexities associated with the interrelatedness of market structure, falling costs, and price, namely, how falling costs might affect prices differently in perfectly competitive markets versus imperfectly competitive markets. Many of their responses demonstrated an appreciation for the relationship between market structure and market power and how regulators need to be diligent in monitoring markets where market failures are evident. Finally, they noted how simulations can be used to run scenarios and test potential policies before implementing them in the real world economy, whether as a firm or a regulating agency.

5. Conclusion

Agent based simulations are increasingly implemented across the disciplines and it is unfortunate that many students of the social sciences are not exposed to the methods or software in their undergraduate coursework. Programmes like NetLogo serve as an excellent platform for students to begin developing their own models. Exposure to such programmes early in their studies will acclimatise students to modelling software and provide them with transferable skills since programming experience in one package often makes them more adept at acquiring proficiency in other programming languages. NetLogo is available as a free download for students or instructors and the java applet feature allows students to run the simulations at their convenience from a web browser with java installed.

Though time constraints may make programming exercises a stretch in principles courses, exposing students to the software in principles courses by having them run the simulation serves as an excellent introduction to programming projects implemented in upper division and elective courses. Interactions with the NetLogo dashboard provide students with a sense of how they might be able to build models from the text into a simulation, how they might build economic models of their own, and how they might tweak parameters to study outcomes and inform better policies for stronger economies.

An extension to this project might be to have the students modify existing sliders or add extra sliders to gain more control of additional parameters such as the rate at which costs fall as firms innovate, the degree of heterogeneity in costs that firms start out with, the slope of the demand curve, or the costs of process innovations. Thus introducing them to programming aspects of NetLogo and moving them down the path toward building their own models.

Appendix : derivation of Cournot solution

The n-Firm Cournot Element of the Model

To derive the *n*-firm Cournot solution Sarkar, Gupta, and Pal begin with inverse demand $P(Q) - mc_i - bq_i = 0$, where $a > 0$ and $b > 0$. Each firm chooses q_i to maximise profit, $\pi_i = q_i[P(Q) - mc_i]$. In words, profit equals total revenue minus total cost, where mc_i is each firm's marginal cost. Firm *i's* first-order condition for profit maximisation is:

$$P(Q) - mc_i - bq_i = 0 \tag{1}$$

Summing first-order conditions for all firms gives $NP(Q) - bQ = \sum_{i=1}^{N} mc_i$. Dividing this by N produces $P(Q) - \frac{bQ}{N} = \overline{mc}$, where $\overline{mc} = (\sum_{i=1}^{N} mc_i)/N_i$, the average marginal cost in the market. Substituting $P(Q) = a - bQ$ into the previous equation produces:

$$a - \left(\frac{N+1}{N}\right) bQ = \overline{mc}. \tag{2}$$

In equilibrium Q^*, market equilibrium can be found by setting $\overline{mc}$ equal to the linear function with the same intercept as demand but with a slope of $-\left(\frac{N+1}{N}\right)b$. So, $Q^* = \frac{a - \overline{mc}}{b}\left(\frac{N}{N+1}\right)$.

From here $P^* = a - bQ^*$. Substituting Q^* yields $P^* = a - b\left[\frac{(a-\overline{mc})}{b}\left(\frac{N}{N+1}\right)\right]$, which reduces to $P^* = a - (a - \overline{mc})\left(\frac{N}{N+1}\right)$. When $N = 1$ the monopoly Q^* and P^* are produced and, as N increases, the perfect competition Q^* and P^* are produced. Equation (1) above implies that for each individual firm $q_i^* = (P^* - mc_i) / b$. Plugging P^* into q_i^* yields the reaction function for the individual firm where each firm's output is dependent on its own marginal cost as well as the average marginal cost of the market.

$$q_i^* = \frac{a}{b} - \frac{a - \overline{mc}}{b}\left(\frac{N}{N+1}\right) - \frac{mc_i}{b} \tag{3}$$

Using the variables computed above I calculate among other things firm market share and market HHI where $HHI = \sum_{i=1}^{N}\left[\frac{q_i^*}{Q^*}\right]^2$ and ranges from 0.0 – 1.0.

NetLogo file is available for download at http://www.openabm.org/model/2313/version/2.

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