Profit Maximization, Industry Structure, and Competition: A critique of neoclassical theory

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As scientists, econophysicists first went to where the data was: to finance, with its terabytes of well defined and finely grained time series. Many important discoveries were made, many of which went counter to established beliefs in academic economics.

Our paper indicates that similar success may also lie where the data is not: in the areas of economics where *a priori* reasoning rules. Our specific example is the theory of profit-maximizing behavior by firms, which is an integral part of the "supply and demand" paradigm that sits at the heart of conventional economics. Careful examination of the models of competition accepted by economists shows that the simplest version—Marshallian "atomistic" competition—is simply wrong, while the more advanced version—Cournot-Nash game theoretic competition—does not describe the behavior of truly rational profit maximizers. Just as importantly, the empirical record shows that the assumptions made by economists are seriously at odds with reality: the accepted assumptions are not simplifications of reality, but counterfactuals to it. There is therefore much work to be done to develop a sound and realistic theory of competition, and econophysicists are ideally placed to do it.

1 From reductionism to complexity

Economics in general has an emphasis upon reductionism which appears strange to visitors from other disciplines, where complexity and emergent behavior are now established concepts. Reductionism has driven the post-WWII development of economics, with "macroeconomics"—the study of the economy as a whole—being reshaped largely because it "did not have good microeconomic foundations". The so-called "microfoundations of macroeconomics" debate rejected Keynesian macroeconomics because "Keynesian" results—insufficient aggregate demand, sustained unemployment, etc.—could not be derived from neoclassical models of optimizing behavior by consumers, and profit-maximizing behavior by firms. This seemed to matter more than the empirical question of whether such results could be found in the data—which clearly they could.

What the neoclassical critics of Keynesian economics meant by "could not be derived from" was the assertion that optimizing behavior by individuals could not result in non-optimal collective outcomes. In other words, they were making the reductionist assertion that, if the individual components of the economic system lacked some property—for example, "misallocation of resources"—then the system as a whole could not have that property.

The fallacy of composition here is obvious—it is akin to the belief that water can only be wet because every individual water molecule has the property of "wetness".

Ironically, advanced reasoning in economics has established that reductionism does not apply in the demand half of "supply and demand" theory: the "Sonnenshein-Mantel-Debreu conditions" show that, even if every consumer in an economy had "well behaved" demand curves for every commodity, there could then be market demand curves that were not "well behaved". Emergent properties emerge even where they are not wanted.

Our contribution is to show that a similar principle applies in the case of supply, the other half of the canonical economic totem of intersecting supply and demand curves.[1] Individual profit-maximizing behavior does not lead to the "supply curve" so beloved of conventional economic reasoning.

We incidentally reveal a potentially rich source of pseudo-data for econophysics to investigate: an artificial market of extremely simple profit-maximizing agents that has a very complex set of behaviors.

2 Popular fallacies

We begin with several popular falsehoods in economic folklore. The first is, we estimate, believed by over 90 per cent of academic economists.[2] This is that the market demand function $P(Q)$, where $Q = \sum_{i=1}^{n} q_i$and $\frac{\partial q_i}{\partial q_j} = 0 \ \forall i \neq j$, has the twin properties that $P'(Q) < 0$ and $P'(q_i) = 0$ for large n (where n is the number of firms in an industry). [3] Elementary calculus shows that this is false:

$$\frac{dP}{dq_i} = \frac{dP}{dQ}\frac{dQ}{dq_i} \tag{1}$$

where $\dfrac{dQ}{dq_i} = 1$ given $\frac{\partial q_i}{\partial q_j} = 0 \ \forall i \neq j$. Therefore $\dfrac{dP}{dq_i} = \dfrac{dP}{dQ}$.[4]

This false belief plays a major role in the derivation of the model of "perfect competition"—so called because, as well as being the alleged limiting case of competitive behavior, it also fulfils the neoclassical definition of nirvana: welfare maximization with no "deadweight loss". In physics terms, this is a state of zero entropy.

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[1] Physicists in search of an explanation for the state of economic theory should read Leijonhufvud's wonderful satire "Life amongst the econ" ([Leijonhufvud (1973)]).

[2] This is an informal guess based on critical reactions of academic economists to [Keen (2001)], where this argument was first developed. This belief is held even by economists who are critical of neoclassical economics—and there are many. Even most of those who don't believe it appear to regard it as an approximation, as if $\dfrac{dP}{dq_i} \to 0$ as $n \to \infty$.

[3] The required size of n was never specified, but had to be when $\dfrac{q_i}{Q}$ is very small for any given firm. Given the popularity of wheat farming as an example of "perfect competition", a value of $n \geq 1000$ probably suffices.

[4] In a telling commentary on the mendacity that rules in economic education and research, this simple result is not new: it was first derived in 1957 by the leading neoclassical economist George Stigler, and published in a highly influential journal ([Stigler (1957)]).

This welfare maximum occurs when $P(Q)$—which represents the marginal benefit to society—equals the marginal cost of production $MC(Q)$. The equality of the two marginals at the market level ensures the gap between total benefit and total cost is maximized. The "Marshallian" version of neoclassical theory alleges that this can only occur if $\frac{dP}{dq_i} = 0$, since only then would profit-maximizing behavior by individual firms result in market price equaling marginal cost. The "proof" of this allegation—which can be found in every introductory economics textbook, and most advanced ones—starts from the proposition that a profit maximizing firm will produce where its Marginal Cost $\left(\frac{d}{dq_i} TC(q_i)\right)$ equals its Marginal Revenue $\left(\frac{d}{dq_i}(P(Q)\, q_i)\right)$:

$$\pi_{\max} : \frac{d}{dq_i}\pi(q_i) = MR(q_i) - MC(q_i) = 0 \tag{2}$$

We call this the Cournot output rule. The proposition that this rule actually does maximize profits for the i^{th} firm, which is believed by almost all economists, is our second fallacy. In a multi-firm industry, profit is maximized not where the *partial* derivative of profit is zero, but where the *total* derivative is zero—since the actions of other firms affect the profitability of any given firm, even though (or rather, especially because) the i^{th} firm cannot control what the other firms in the industry do. The Cournot rule maximizes profit for the i^{th} firm only with respect to changes in its own output; this is the partial derivative, not the total.

We provide the true profit maximization formula below, in a manner which integrates the previously incompatible Marshallian and Cournot-Nash approaches to competition. The Marshallian approach, as noted above, assumes $\frac{\partial q_i}{\partial q_j} = 0$ $\forall i \neq j$, known as the assumption of "atomistic" behavior, and is normally portrayed in terms of calculus and optimization given revenue and cost functions. The Nash-Cournot assumes that $\frac{\partial q_i}{\partial q_j} \neq 0$, and is normally presented in terms of set theory where only discontinuous options are considered.[5] We provide a functional analysis where the value of $\frac{\partial q_i}{\partial q_j}$ is an input to the firm's optimum behavior.

3 The true profit maximization formula

We start from the most general specification that firm j has a unique reaction coefficient $\theta_{j,i}$ to hypothetical changes in output by the i^{th} firm:

$$\frac{\partial q_i}{\partial q_j} = \theta_{j,i} \ \forall i \neq j \tag{3}$$

Profit $\pi(q_i)$ for the i^{th} firm is its revenue minus its costs, so that its profit maximum is given by:

$$\frac{d}{dQ}\pi(q_i) = \frac{d}{dQ}(P(Q)\, q_i - TC(q_i)) = 0 \tag{4}$$

.

[5] Note that this is not the specifiation of a time-based reaction by one firm to the other's output, but an *instantaneous* reaction by one firm to the other.

Since $Q = \sum_{j=1}^{n} q_j$, this total differential can be expanded to

$$\sum_{j=1}^{n} \left(\frac{\partial}{\partial q_j} \left(P \left(\sum_{j=1}^{n} q_j \right) q_i - TC\left(q_i\right) \right) \frac{dq_j}{dQ} \right) = 0 \tag{5}$$

This reduces to

$$P \sum_{j=1}^{n} \left(\theta_{j,i} \sum_{k=1}^{n} \theta_{k,j} \right) + q_i \frac{dP}{dQ} \sum_{j=1}^{n} \sum_{k=1}^{n} \theta_{k,j} - MC\left(q_i\right) \sum_{j=1}^{n} \theta_{j,i} = 0 \tag{6}$$

With the Marshallian assumption of "atomism", $\theta_{j,i} = 0, \forall i \neq j$. Then equation (6) reduces to

$$P + nq_i \frac{dP}{dQ} - MC\left(q_i\right) = 0 \tag{7}$$

We call (6) the Keen output rule, which as we show below, is the true profit maximizing output level in any industry structure. This rule contradicts the neoclassical belief that, in the context of atomistic behavior, profit is maximized by equating marginal revenue and marginal cost, since (7) can be rearranged to yield:

$$MR\left(q_i\right) - MC\left(q_i\right) = \frac{n-1}{n} \left(P - MC\left(q_i\right)\right) \tag{8}$$

This equals zero only in the case of a monopoly—which is the one time that the accepted Marshallian formula is correct. At all other times, the profit maximum for an individual firm will occur where marginal revenue *exceeds* marginal cost.

In Cournot-Nash game theoretic analysis, firms decide their own actions on the basis of the hypothesized reactions of other firms, in such a way that each firm's "best response" is to set $MR\left(q_i\right) = MC\left(q_i\right)$. In our terms, this is equivalent to setting $\theta = \frac{1}{nE}$—where E is the market elasticity of demand $(E = \frac{P}{Q}\frac{dQ}{dP})$.

We combine Marshallian and Cournot-Nash analysis by considering an industry of n identical firms (a common heuristic device in economic theory) in which $\frac{\partial q_i}{\partial q_j} = \theta \ \forall i \neq j$ and $\frac{\partial q_i}{\partial q_i} = 1$, where θ can take on any value. Then (6) reduces to:

$$\left(n-1\right) P\theta + P + nq_i \frac{dP}{dQ} = MC\left(q_i\right) \tag{9}$$

This defines the maximum profit achievable by the individual firm in the context of strategic behavior—if each firm reacts to output changes by other firms with a reaction coefficient of θ. We can now consider what value of θ would be chosen by a profit-maximizing firm. It transpires that the optimum value of this parameter is in fact zero.

4 True profit-maximizing behavior

In the heuristic case of n identical firms where $\theta_{j,i} = 0, \forall i \neq j$, the optimum value for θ for the i^{th} firm occurs where $\frac{d}{d\theta}\pi(q_i) = 0$. This condition reduces to:

$$\frac{d}{d\theta}\pi(q_i) = \frac{1}{n}\frac{d}{d\theta}Q\left(P + nq_i\frac{dP}{dQ} - MC(q_i)\right) \tag{10}$$

Since $\frac{d}{d\theta}Q \neq 0$, (10) equals zero if and only if $P + nq_i\frac{dP}{dQ} - MC(q_i) = 0$. As shown above, this is only possible if $\theta = 0$. In the classic words of the movie *War Games*, Cournot-Nash strategic behavior is thus "a strange game. The only winning strategy is not to play".

The impact of interaction on profits is starkly illustrated by the example of an industry with a linear market demand curve $P(Q) = a - bQ$ and n identical firms with constant marginal cost c.[6] The profit-maximizing output level for the i^{th} firm as a function of θ and n can be derived from (9):

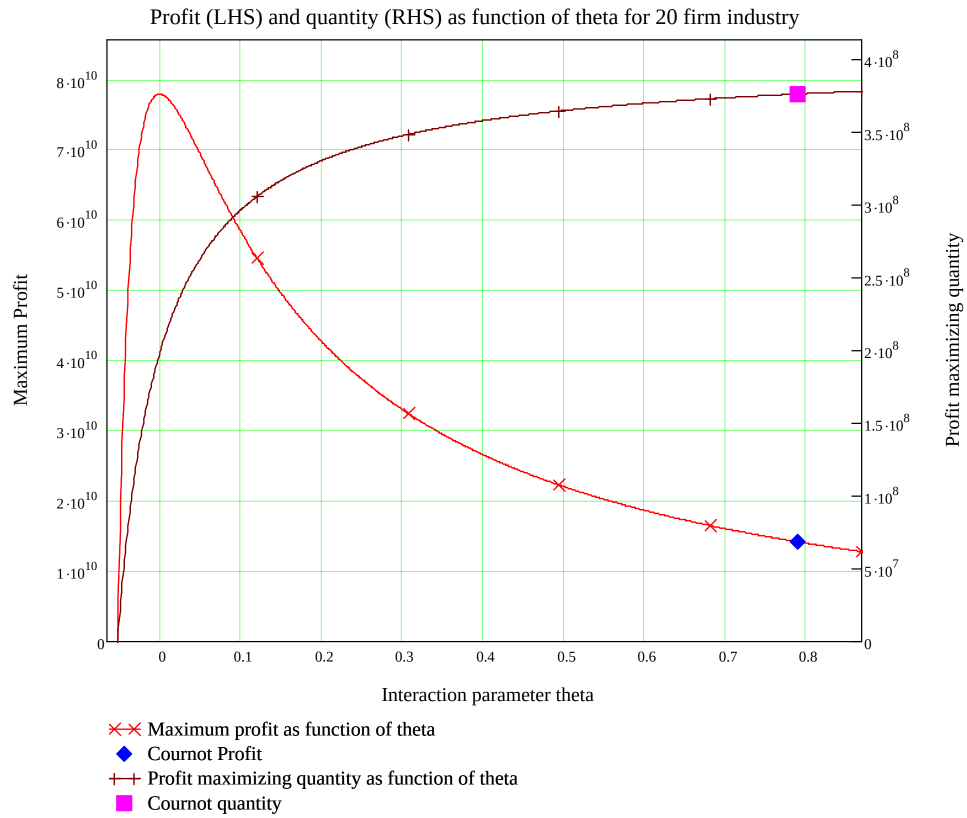
$$q(\theta, n) = \frac{((n-1)\theta + 1)a - c}{nb((n-1)\theta + 2)}$$

The maximum individual firm profit as a function of θ and n is thus:

$$\pi_{\max}(\theta, n) = \frac{(((n-1)\theta + 1)a - c)(a - c)}{nb((n-1)\theta + 2)} - \left(\frac{(((n-1)\theta + 1)a - c)^2}{nb((n-1)\theta + 2)^2} + k\right)$$

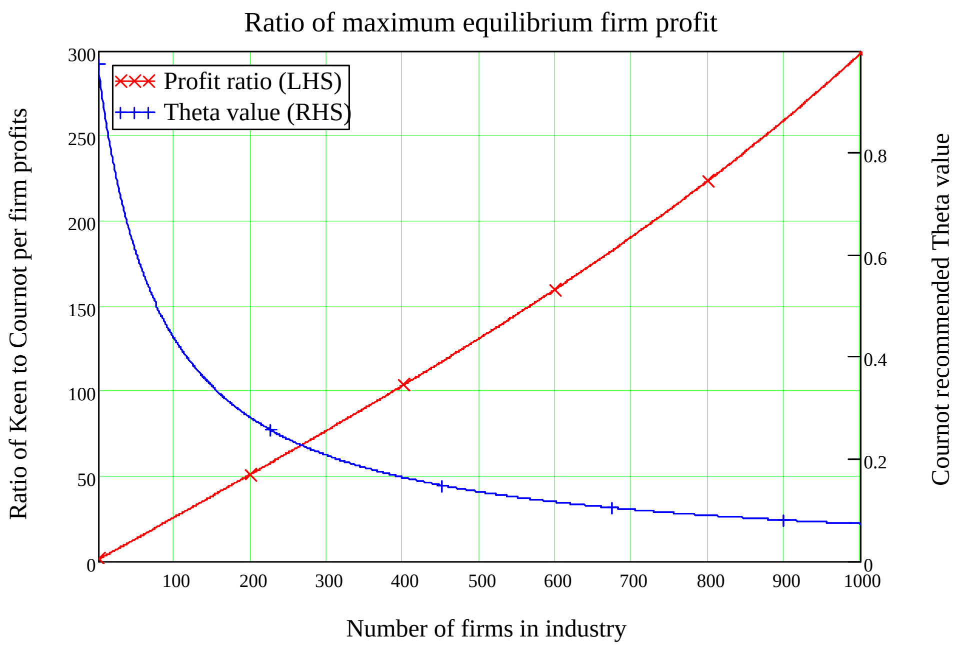
As predicted, the maximum of this function occurs where $\theta = 0$. In the following graphs, a=*800*, b=*10*$^{-8}$, c=*100* and k=*10*^{6}.
The LHS of Figure **??** plots equilibrium maximum profit per firm as a function of the degree of strategic interaction θ, in a 20 firm industry. The maximum profit clearly results from an interaction level of zero. By comparison, the Cournot-Nash recommended level ($\theta = \frac{1}{nE}$) results in an equilibrium profit level per firm that is one fifth the level attained from no strategic interaction.
Since per firm output increases monotonically with θ, it is also clear that output in excess of where $\theta = 0$ is produced at a loss. While marginal revenue as defined by economists exceeds marginal cost until $\theta = \frac{1}{nE}$, the revenue actually received by the firm (the *total* derivative of revenue) is below marginal cost.

[6] We show later that this is the only condition under which the sum of marginal cost curves of an n-firm industry can be identical to the marginal cost curve for a single firm. However our analysis generalizes to the situation of non-comparable cost functions.



Figure

Obviously, firms pay a large price for strategic interaction, and Figure **??** shows that this price rises as the number of firms in an industry increases. The LHS of Figure **??** shows that the ratio of maximum profit per firm rises from a relatively low level for a small number of firms (1.125 for a duopoly; 2.042 for six firms) to extremely high levels for large numbers of firms—with 400 firms, equilibrium profit per firm without strategic interaction is over 100 times higher than with interaction at the Cournot-Nash level.



We thus have a dilemma: in industries where firms do not react strategically to the actions of others, firms achieve much higher profits than in those where strategic interaction does occur. What practice is likely to evolve in real-world markets? We surmise that experience may teach firms that it is indeed irrational to play the Cournot-Nash game. Instead, they may learn to simply ignore the hypothetical actions of other firms when deciding how much to produce. We consider this question using a multi-agent model of instrumentally rational profit maximizers facing comparable marginal cost functions.

4.1 Operationally rational profit-maximizers

Our hypothetical market has a linear demand curve ($P = a - bQ$ with $a = 800$ and $b = 10^{-7}$) and a variable number of instrumentally rational profit-maximizing agents—in that each agent alters its output in a search for the profit-maximizing level of production; if a change in output in a given direction leads to an increase in profit, it continues to change output in that direction; otherwise it changes output in the other direction.

Total cost functions for the agents are identical, and defined in a way that makes marginal costs in different industry structures (different values of n) strictly comparable:[7]

$$tc\,(q,n) = k + Cq + \frac{1}{2}Dnq^2 + \frac{1}{3}En^2q^3$$

In the following simulations, $k = 10^6$, $C = 10$, $D = 10^{-8}$and $E = 10^{-17}$ and n ranges between 2 and 500. Firms start with a randomly determined initial output level that lies between the Keen and Cournot predictions, and have a randomly determined amount by which output is varied. We consider the

[7] The reasons for the choice of this functional form are given in the Appendix.

results of Monte Carlo simulations under a variety of conditions: 10,000 runs were undertaken for each of 10 Monte Carlo simulations.

1. A fixed step size for altering output by each firm, with either constant or rising identical marginal cost.

2. A normally distributed range of step sizes for altering output with constant identical marginal cost; and

3. A normally distributed range of step sizes for altering output with rising identical marginal cost.

The simulations reveal a rich range of interactions, and in general confirm our expectation that instrumentally rational profit-maximizers will learn "not to play" the Cournot-Nash game. In cases 1 and 2, output converges to the Keen equilibrium for all industry structures (values of n). Only in case 3 does the Cournot-Nash outcome occur, and then only for a large disperal of dq values. We interpret this as indicating that there are stochastic differential effects taking place as the dispersal of individual output changes rises.

4.2 The model

The program for condition 1 is shown in Figure **??**:[8]

[8] All programs are written in the functional programming language of the mathematics package [Mathcad]. The horizontal bar over an expression signifies that the operation is performed element by element across the vectors.

```
F[0,0] ← q.K(1, a, b, C, D, E)
F[1,0] ← q.K(1, a, b, C, D, E)
for i ∈ firms.min, firms.min + firms.steps .. firms.max
    for j ∈ 0 .. rand − 1
        Seed(j + 1)
        Q[0] ← round(runif(i, q.K(i, a, b, C, D, E), q.C(i, a, b, C, D, E)))
        p[0] ← P(ΣQ[0], a, b)
        dq ← 50000 sign(runif(i, −1, 1))
        for k ∈ 1 .. runs
            Q[k] ← Q[k−1] + dq
            p[k] ← P(ΣQ[k], a, b)
            dq ← vectorize( sign[(p[k]·Q[k] − p[k−1]·Q[k−1]) − (tc(Q[k], i, C, D, E, k) − tc(Q[k−1], i, C, D, E, k))]·dq )
        Q.end[j] ← (ΣQ[k] + ΣQ[k−1] + ΣQ[k−2] + ΣQ[k−3]) / 4
    F[i,0] ← mean(Q.end)
    F[i,1] ← stdev(Q.end)
    Q.end ← 0
F
```

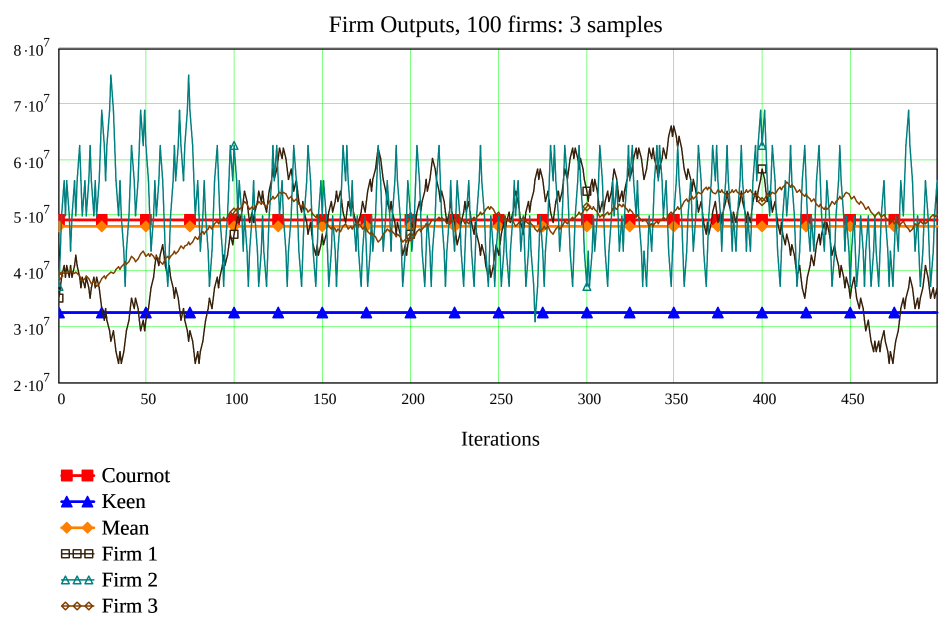
The program takes as its arguments a range of firms from $firms_{\min}$ to $firms_{\max}$ in $firms_{step}$ steps, the number of Monte Carlo simulations to perform rand, and the number of iterations per simulations *runs*. Working through the program line by line:

1. Output for zero firms set to monopoly level
2. Value for one firm set to monopoly level
3. For loop initialized to iterate from $firms_{\min}$ to $firms_{\max}$ by $firms_{step}$
4. For loop initialized for *rand* Monte Carlo runs
5. Random seed initialized for each run
6. Initial output set for each firm on a uniform distribution between the Keen and Cournot predictions for each industry structure
7. Initial price calculated from initial market output
8. An amount of ± 50000 units randomly allocated to each firm as the initial amount dq by which output is varied
9. For loop initialized for number of iterations
10. Output is varied for each firm by dq.

11. New market price is calculated
12. Sign of dq varied for each firm: maintained if previous iteration increased profit, reversed if previous change reduced profit
13. Average of last 4 iterations stored
14. Mean of Monte Carlo simulations stored
15. Standard deviation of simulations stored
16. Temporary variable for Monte Carlo loop reset to zero
17. Mean and standard deviation for all industry structures (values of n) returned.

4.3 Non-neoclassical outcomes: Keen convergence and emergent complexity

One key aspect of this simulation that may appear counter-intuitive to economists is that, despite the extremely simple definition of agents, and the fact that they have identical cost functions, the behavior of agents is extremely diverse. Figure **??** shows three sample firms from a single run with 100 firms, rising marginal cost, and a wide dispersal of dq values), compared to the Keen and Cournot predictions. As is evident, the firms follow many different strategies (complexity is also evident in the other situations explored, though it is not as marked). The complexity of individual behaviors emerges from the interactions between firms and the market, rather than from the innate "complexity" of the agents themselves.



The following figures show the both the mean output and a ± 2 standard deviation range around the mean of the Monte Carlo simulations, plotted against the predictions given by the Cournot rule and Keen rule respectively. Figure

?? shows that the model with fixed stepsize converges very tightly to the Keen prediction, regardless of the number of firms in the industry. This is in contrast to standard Marshallian and Cournot-Nash predictions about the outcome of competitive behavior, which is expected to start near the "monopoly" level (equivalent to the Keen prediction) and rise towards the Cournot level as the number of firms rises.

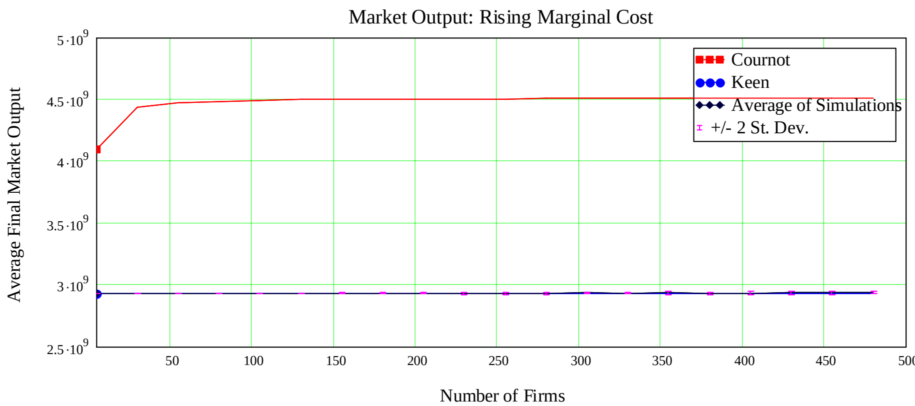
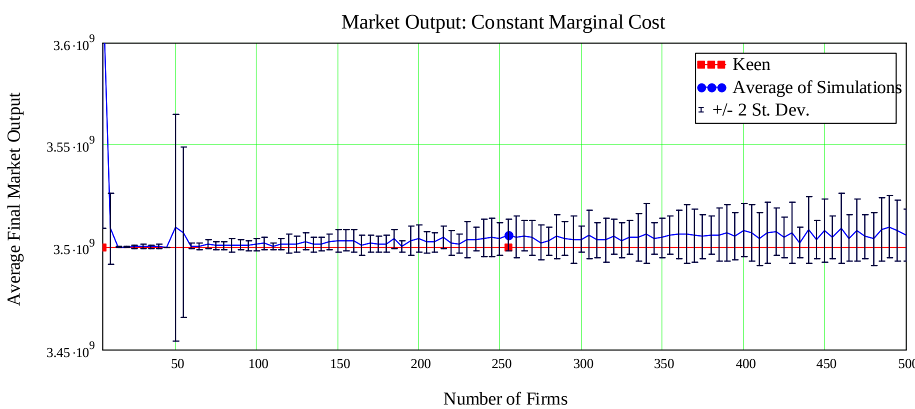
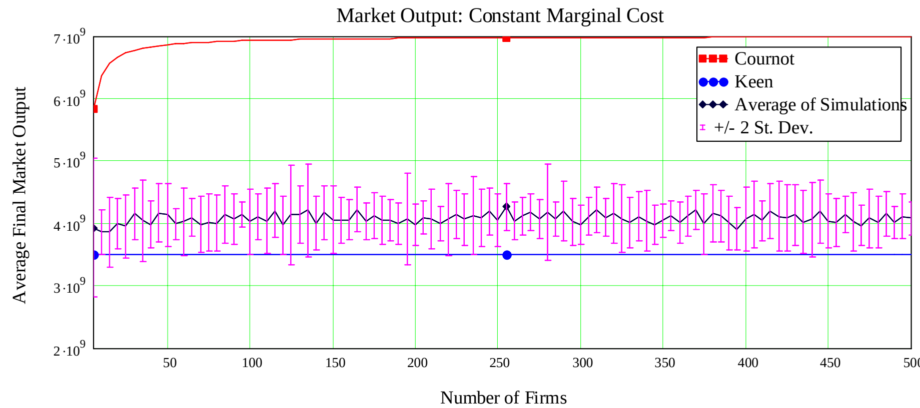


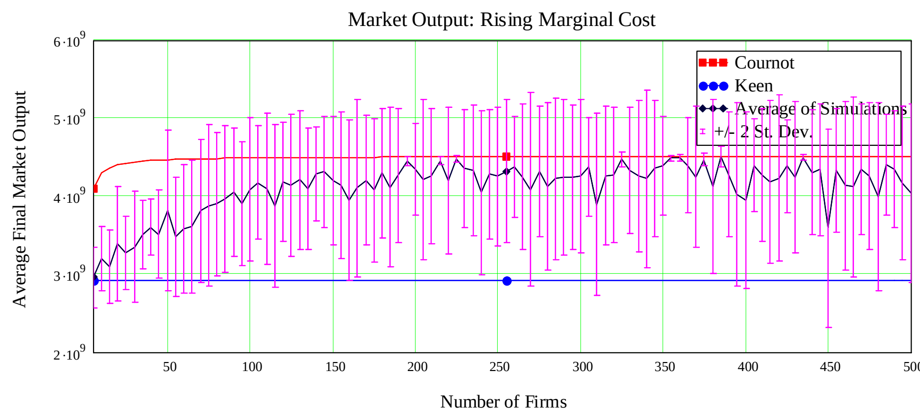
Figure **??** shows the results for constant marginal cost and fixed stepsize, using a much more compressed Y-axis range ($3.5 - 3.6 \times 10^9$ versus $2.5 - 5 \times 10^9$ for Figure **??**). The only discernible impact of increasing n was an increase in the variance of the Monte Carlo simulations—and even then there were aberrant, more extreme variances for 5, 50 and 55 firm industries.



The program with a normally distributed range of changes in output levels per firm simply replaced line 8 in the program with a vector of n normally distributed numbers with mean zero and standard deviation equal to 10 per cent of the Cournot prediction for per firm output: $dq \leftarrow \mathrm{round}\left(\mathrm{rnorm}\left(i, 0, \frac{q_C(i,a,b,C,D,E)}{10}\right)\right)$ As noted above, there was little discernible impact with constant marginal cost. As Figure **??** indicates, the variance of the Monte Carlo simulations was higher than for fixed dq, but the mean outcome remained close to the Keen equilibrium.



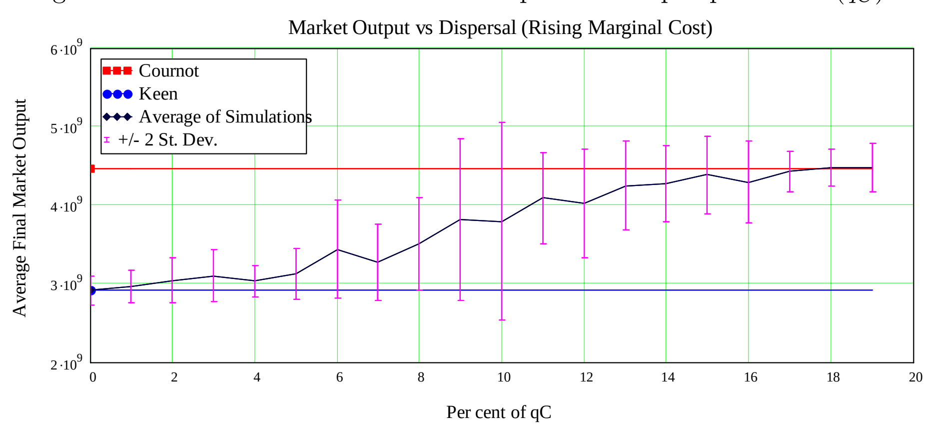
However in the case of rising marginal cost, there appeared to be a trend to increasing output as the number of firms in the industry rose, as is evident in Figure **??**. The variance of the Monte Carlo simulations is also much higher.



Closer inspection showed that the real cause of the phenomenon was the degree of dispersal in the units by which each firm altered its output on each iteration (dq). The program in Figure **??** has the number of firms as an input to the program, and loops (line 3) over the size of the deviation of change in output by each firm around a mean of zero (line 8), with dispersal starting at 1% of the Cournot predicted output level and rising to *dispersal* per cent of this level..

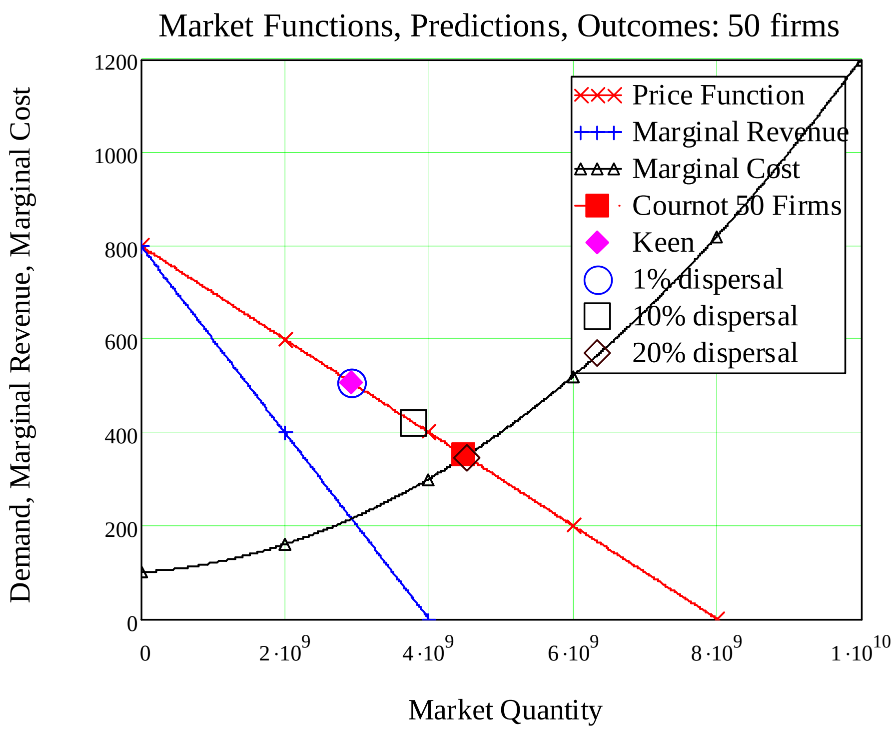
```
F[0,0] ← q.K(1, a, b, C, D, E)
F[1,0] ← q.K(1, a, b, C, D, E)
for i ∈ 0, dispersal.steps .. dispersal − 1
    for j ∈ 0.. rand − 1
        Seed(j + 1)
        Q[0] ← round(runif(firms, q.K(firms, a, b, C, D, E), q.C(firms, a, b, C, D, E)))
        p[0] ← P(ΣQ[0], a, b)
        dq ← round[rnorm[firms, 0, ((1 + i)/100)·q.C(firms, a, b, C, D, E)]]
        for k ∈ 1.. runs
            Q[k] ← Q[k−1] + dq
            p[k] ← P(ΣQ[k], a, b)
            dq ← vectorize([sign[(p[k]·Q[k] − p[k−1]·Q[k−1]) − (tc(Q[k], firms, C, D, E, k) − tc(Q[k−1], firms, C, D, E, k))]]·dq)
        Q.end[j] ← (ΣQ[k] + ΣQ[k−1] + ΣQ[k−2] + ΣQ[k−3]) / 4
    F[i,0] ← mean(Q.end)
    F[i,1] ← stdev(Q.end)
    Q.end ← 0
F
```

This program revealed a near monotonic trend for increasing output with an increasing value for dispersal of output changes, for any given industry structure (value of n). Figure **??** shows the results for a 50 firm industry, with dispersal rising from 1% to 20% of the Cournot-Nash per firm output prediction (q_C).



As noted above, we surmise that there may be stochastic differential effects occurring here, which are triggered in our simulations by the use of a random normal variable for dq. We infer this possibility from the existence of terms like $\sum_{j=1}^{n}(\theta_{j,i}\sum_{k=1}^{n}\theta_{k,j})$ in the expansion for the general profit maximization formula, equation (6), and the observation that strategic reaction parameter $\theta_{j,i}$ can be regarded as a stochastic variable. This remains a topic for future research.

Contrary to the beliefs of the vast majority of economists, equating marginal revenue and marginal cost is not profit-maximizing behavior, the number of firms in an industry has no discernible impact on the quantity produced, and "deadweight loss of welfare" exists regardless of how many firms there are in the industry—with true profit-maximizing behavior, there is no such thing as an "(entropy-)free lunch". Figure **??** portrays our results against the Keen and Cournot predictions, and shows that market output is a function, not of the number of firms, but of the degree of dispersal of output change.



5 Conclusion: from reductionism to reality

Our results contradict both the "beginner's" (Marshallian) and "cutting edge" (Cournot-Nash) versions of accepted neoclassical competition theory. Crucially, though both versions of the theory assert a link between the number of firms in an industry and the degree of both competition and consumer welfare, the fomer's proof is fallacious and the latter's tenuous—conditional, in our simulations, upon large dispersal in firm output step sizes, and the counterfactual of rising marginal cost. Whether any relationship of this nature exists in the real world is an open question—one of many on which neoclassical economics throws no light. The neoclassical reductionist agenda also fails, because of complexity. Only in the case of a monopoly is it true that "equating the marginals" maximizes profit; in all other cases, profit is maximized where marginal revenue *exceeds* marginal cost, because of the impact of other firms on the performance of individual ones.

If we are correct, then just as finance was "ripe for the picking" by econophysicists, with its dominant but manifestly false "Efficient Markets Hypothesis",[9] so too is the realm of the behavior of competitive firms, the interaction between them, the consumer-firm interaction and, for that matter, consumer behavior itself. The self-proclaimed Emperor of the theory of markets is naked, and a new theory of competition is needed.

The hopes that economists—neoclassical or otherwise—might provide it are not high. The potential contribution of the neoclassical sect deserves no further comment. There are other schools of thought whose views could be of merit in constructing a new theory, chiefly the Post Keynesian and Evolutionary Economics schools. [Lee (1998)] gives an excellent survey of the detailed empirical work that supports the former School's perspective; but only a minority of adherents to this minority School work in this area. The latter holds the most promise, with a model of evolutionary competition derived from the brilliant insights of Joseph Schumpeter ([Schumpeter (1926)] and [Schumpeter (1936)]). But as two of the leading practitioners observe, the range of skills needed to build an evolutionary model far exceed the training of most economists ([Andersen & Valente (2002)]: 44)

As scientists, econophysicists should turn first to the data on the behavior of actual firms—such as it is. Though there is nothing to compare to the enormous data sets in finance, there have been over 100 surveys of firms, and the results are conclusive: the behavior of actual firms does not conform to the expectations of neoclassical economists.[10]

Blinder et al. 1998 is the latest and possibly most authoritative to conclude that the empirical data is "overwhelmingly bad news . . . for economic theory. . . " (Blinder et al. 1998: 102).[11] Economists treat rising marginal cost as the rule, and constant or falling marginal cost as the exception; in Blinder's survey, 89 per cent of firms reported marginal costs that were either constant or declined with output (and earlier surveys found higher proportions still; see [Lee (1998)], [Downward & Lee]). Economists make much of the concept of elasticity as a vital operational concept for corporations, yet the data on demand elasticity in his survey led Blinder to ask rhetorically:

> Can it really be true that firms that sell 40 percent of GDP believe that their demand is totally insensitive to price, and that only about one-sixth of GDP is sold under conditions of elastic demand? ([Blinder et al.]: 101)

Prior to our research, economists dismissed survey results like this with the proposition that businessmen simply didn't understand the process of competition that lay beneath their actual behavior, and that asking them what they

[9] In [Fama & French (2004)], two long-time champions of the EMH, conclude that "The version of the CAPM developed by Sharpe and Lintner has never been an empirical success... The problems are serious enough to invalidate most applications of the CAPM." (44)

[10] [Lee (1998)] and [Downward & Lee] provide valuable surveys of this literature

[11] See Lee 1998 for a comprehensive survey of pre-Blinder research and Downward and Lee 2001 for an accessible summary and interpretation of Blinder's findings.

consciously did was a waste of time, compared to *a priori* reasoning. Friedman's infamous "methodology" paper of 1953, which economists still trot out to justify making counter-factual assumptions, is the archetypal statement of the neoclassical economic preference for a priori concepts over emprical data:

> Consider the problem of predicting the shots made by an expert billiard player... excellent predictions would be yielded by the hypothesis that the billiard player made his shots as if he knew the complicated mathematical formulas that would give the optimum directions of travel... Our confidence in this hypothesis ... derives rather from the belief that, unless in some way or other they were capable of reaching essentially the same result, they would not in fact be expert billiard players.
>
> It is only a short step from these examples to the economic hypothesis that under a wide range of circumstances individual firms behave as if they ... calculated marginal cost and marginal revenue ... and pushed each line of action to the point at which the relevant marginal cost and marginal revenue were equal. Now, of course, businessmen do not actually and literally solve the system of simultaneous equations ... any more than leaves or billiard players explicitly go through complicated mathematical calculations ... The billiard player, if asked how he decides where to hit the ball, may say that he "just figures it out" ... and the businessman may well say that he prices at average cost, with of course some minor deviations when the market makes it necessary. The one statement is about as helpful as the other, and neither is a relevant test of the associated hypothesis. (Friedman 1953)

We can now propose, au contraire, that firms may well be rational profit-maximizers, but neoclassical economists have mis-specified what rational profit-maximizing behavior actually is. The fact that factory managers regularly report that marginal revenue is irrelevant to their operations, that marginal costs are of only slightly greater relevance and fall, not rise; that fixed costs are seriously important and excess capacity a necessity, may indicate that they understand what true profit maximizing behavior is in the uncertain, evolving world of actual competition. We invite econophysicists to investigate this real world of competitive behavior, and take over where the *a priori*, reductionist endeavour of neoclassical economics has, once again, clearly failed.

6 Appendix: Comparable Cost Functions

In this appendix we explain the form used for our total cost functions, which is necessary if outputs from different hypothetical industry structures are to be comparable.

The standard graphical exposition of Marshallian theory draws a common "Supply" curve to represent both the marginal cost curve of a monopoly and the sum of the marginal cost curves of a "competitive" industry. In fact a single curve can be drawn for these two market structures only under three restrictive conditions: (a) the monopoly is created by taking over all the competitive firms;

(b) constant identical marginal costs; and (c) differing marginal costs which happen to be a function of the number of firms in the industry and coincide when aggregated.

The first condition is trivial (and would, on our analysis, result in no significant change in behavior); the second and third are implemented in the simulations above. This section proves that comparability is in general not the rule, and derives the two non-trivial conditions for comparability.

Taking condition (b) first, the identity of the aggregate marginal cost curves of two different market structures for all scales of aggregate market output Q imposes the condition that marginal products are identical for all scales of inputs. This in turn means that the production functions of the two market structures can only differ by a constant. Taking labor as the variable input, output with zero units of labor will be zero, so this constant can also be set to zero; therefore the condition of identity of aggregate marginal costs commutes into the condition that the aggregate output of the two industry structures must be the same for all levels of input.

Using f for the production function of n firms in one industry structure, g for the production function of m firms in another, x for the per firm labor input in the n-firm industry and y for the per firm input in the m-firm industry, the condition is:

$$n \times f(x) = m \times g(y) \tag{11}$$

where $nx = my$. Subsituting $y = \frac{nx}{m}$ into (11) and differentiating with respect to n yields:

$$f(x) = \frac{x}{m} g'\left(\frac{nx}{m}\right) \tag{12}$$

This gives us a second expression for f. Equating these two definitions and rearranging yields:

$$\frac{g\left(\frac{nx}{m}\right)}{n} = \frac{x}{m} g'\left(\frac{nx}{m}\right) \tag{13}$$

Substituting back $y = \frac{nx}{m}$ and rearranging yields an expression involving the differential of the log of g:

$$\frac{g'(y)}{g(y)} = \frac{1}{y} \tag{14}$$

Integrating both sides yields: $\ln(g(y)) = \ln(y) + c$. Thus g is a constant returns production function $g(y) = Cy$. From $y = \frac{nx}{m}$, it follows that f is the same constant returns production function $f(x) = \frac{m}{n} C \frac{nx}{m}$

Thus if marginal costs are to be identical across any scale of industry and output, they must be constant and identical.

Condition (c) allows marginal costs to differ at different scales of output, but requires that they aggregate to the same level. In this case, costs at each level of output must be a function of the number of firms in the industry. The rule for aggregating marginal cost is that the cost of producing q units where there are m firms in the industry equals the cost of producing Q units where $Q = mq$. When applied as a condition to ensure that the aggregate marginal cost curve for an n firm industry is equivalent to that for an m-firm industry, the number of firms in a given industry structure must be part of the argument for marginal cost.

In the example used in this chapter, we began with an aggregate marginal cost function:

$$MC\left(Q\right) = C + DQ + EQ^2$$

We then derived the firm level marginal cost function that was consistent with this rule in an n-firm industry:

$$mc\left(q,n\right) = MC\left(nq\right) = C + Dnq + E\left(nq\right)^2$$

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