G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outline

Introduction

The Model

Simulations: N=

Summar

Where we are goir

A Multi-product Monopolist with Local Knowledge of Demand

G.Ricchiuti, J. Tuinstra, F. Wagener

MDEF Urbino, 25-27th Sept 2008

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outlin

minoducti

The Model

Simulations: N

Summar

Where we are goir

We study a learning model for a (quantity setting) monopolist that has incomplete knowledge of the demand:

n products

- the monopolist produces a certain quantity of each commodity and observes the set of corresponding market clearing prices as well as the matrix of (cross-)price effects at those quantities.
- she estimates n linear subjective demand curves for her products
- on the basis of this estimated demand system the monopolist updates her perceived profit maximizing vector of quantities

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outli

madada

The Model

Simulations: I

Summar

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

Introduction
The Model

Simulations: N=

Where we are goir

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

Introduction
The Model
Simulations: N=2

Where we are goir

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outline

Simulations: N

Odiffillary

Where we are goir

Introduction

- The Model
- Main Results
- Preliminary Simulations
- Future Work

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outline

Simulations: N

Summar

- Introduction
- The Model
- Main Results
- Preliminary Simulations
- Future Work

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outline

_

Simulations: N:

Outilities

- Introduction
- The Model
- Main Results
- Preliminary Simulations
- Future Work

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outline

.

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Sillulations. N

Summary

- Introduction
- The Model
- Main Results
- Preliminary Simulations
- Future Work

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outline

Simulations: N

ouiiiiiui ,

- Introduction
- The Model
- Main Results
- Preliminary Simulations
- Future Work

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

Introduction

research
Local Knowledge of the
Demand Function with

The Model

Simulations: N=

Summar

we are going

In a perfectly competitive world the individual agent needs to know 'only' the relevant prices in order to choose an optimal action, in frameworks in which agents are price-maker (monopolistic competition, oligopoly and monopoly), the information set required is broader and goes from the shape of the demand curve to the possible replies of other players. Bonanno (1990, p. 299)

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outil

Two main lines of research

Local Knowledge of Demand Function was Learning Process

The Model

imulations: N=

Summar

here we are going

Two different lines of research have investigated agents' behavior when market information is limited. The agents

- a) either make decisions using a simple rule of thumb, such as the gradient rule (Baumol and Quandt, 1964; Furth,1986; Bischi and Naimzada, 1999; Puu, 1995)
- b) or reconstruct the demand extrapolating information from the interaction between past decisions and market mechanisms (Negishi, 1961; Nikaido, 1975; Silvestre, 1977; Bonanno, 1990 for a survey of the Literature)

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outlin

Two main lines of research

Local Knowledge of Demand Function w Learning Process

The Model

Simulations: N=

Summar

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G.Ricchiuti, J. Tuinstra, F. Wagener

Local Knowledge of the **Demand Function with Learning Process**

The Model

- Tuinstra (2004) analyzes a discrete time dynamic system to describe the price adjustment process within a Betrand oligopoly
- Naimzada and Ricchiuti (2008) analyzes a discrete time
- Our model is a generalization of Naimzada and Ricchiuti

G.Ricchiuti, J. Tuinstra, F. Wagener

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G.Ricchiuti, J. Tuinstra, F. Wagener

A Brief Outline

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G.Ricchiuti, J. Tuinstra, F. Wagener

A Brief Outline

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- Naimzada and Ricchiuti (2008) analyzes a discrete time dynamic system within a monopoly framework with an homogeneous good
- Our model is a generalization of Naimzada and Ricchiuti (2008), it is richer because it allows for studying the effects of complements and substitutes on stability of the learning model.

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outi

Introductio

The Model Environment

Expectation

The Map Main Result

Main Results

imulations: N:

Summar

Where we are goin

A quantity setting monopolist

- n goods
- n objective inverse demand functions: f_i
- substitutes: $\frac{\partial f_i}{\partial q_j} > 0$
- complements: $\frac{\partial f_i}{\partial q_j} < 0$
- a linear cost function, C(q) = cq, as in Silvestre (1977)
- the objective profit function is:

$$\prod(q) = \sum q^i f_i(q) - \sum c_i q^i \tag{1}$$

$$Df(q_*)^T q_* + f(q_*) - c = 0 (2)$$

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstra

A Brief Outl

Introductio

The Model Environment

Expectation

Main Results

Main Results

Simulations: N=

Summar

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outi

Introductio

The Model Environment

Expectation

The Map
Main Results

Main Results

Simulations: N=

Summar

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Out

Introductio

The Model Environment

Expectation

Main Results

Main Results

Simulations: N=

Summar

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outl

Introduction

The Model Environment

Expectation

Main Results

Main Results

Simulations: N=

Summar

Where we are goin

A quantity setting monopolist

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outli

Introduction

The Model Environment

Expectation
The Map

Main Results

Main Results

Simulations: N=

Summar

ere we are going

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outlin

Introduction

The Model Environment

Expectation The Man

Main Results

Main Results

Simulations: N=

Summai

Where we are going

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 (2)

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outil

Introductio

The Model Environment Expectations

Main Results

Main Results

Simulations: N

Summar

Where we are goin

• the monopolist knows the actual price, $p_{i,t}$, the related quantity demanded, $q_{i,t}$, and the slope, $f_i'(q_t)$

- n subjective demand function are estimated
- expected profits are given by

$$\prod_{i=1}^{e} (q_i) = \sum_{i=1}^{e} q^i \left(f_i(q_t) + \frac{\partial f_i}{\partial q^j} (q_t) (q^j - q_t^j) \right) - \sum_{i=1}^{e} c_i q^i \quad (3)$$

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outli

Introductio

The Model
Environment
Expectations
The Map
Main Results

Main Results 2

Simulations: N

Summai

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$$\prod^{e}(q) = \sum q^{i} \left(f_{i}(q_{t}) + \frac{\partial f_{i}}{\partial q^{j}}(q_{t})(q^{j} - q_{t}^{j}) \right) - \sum c_{i}q^{i} \quad (3)$$

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outi

Introductio

The Model
Environment
Expectations
The Map
Main Results

Main Results 2

Simulations: N:

Summai

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

71 21101 041

Introductio

The Model Environmen

Expectation

The Map

Main Poculte

Ominiations. 14

Summar

Where we are goin

From the maximization of the expected profit, we get the following map:

$$q_{t+1} = (Df + Df^{T})^{-1}(c + Df^{T}q_{t} - f)$$
 (4)

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

71 21101 044

Introductio

The Model Environmen

The Map
Main Results 1

Main Results

Walli Hesults 2

Simulations: N=

Summar

ere we are goir

Proposition 1.

There is a one-to-one relationship between steady states of the learning process and critical points of the objective profit function;

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outli

introducti

The Model Environmen Expectation The Map

Main Results 2

Simulations:

Summa

e we are going

Proposition 2.

Every local minimum of the objective profit function is an unstable steady state of the learning process. Local maxima, on the other hand, may correspond to either locally stable or unstable steady states of the learning process, depending upon the curvature of the demand system;

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outli

....

The Model

Simulations: N=2

Convexity
Convexity and Quanti
Convexity and Profits
Concavity
Concavity
Concavity
Concavity

Summar

Where we are goin

The inverse demand function is:

$$f_i = a \exp(dq_i^{\gamma} q_j^{\delta}) + b$$
 $i, j = 1, 2$ and $i \neq j$ (5)

Hence:

$$\frac{\partial f_i}{\partial q_i} = ad\gamma \exp(dq_i^{\gamma} q_j^{\delta}) q_i^{(\gamma - 1)} q_j^{\delta}$$
 (6)

given $\gamma > 0$ the demand functions are downward-sloping if a and d have opposite signs. Moreover

$$\frac{\partial f_i}{\partial q_i} = ad\delta \exp(dq_i^{\gamma} q_j^{\delta}) q_i^{(\gamma)} q_j^{\delta - 1} \tag{7}$$

Hence for $\delta < 0$ the goods are substitute while for $\delta > 0$ are complements. For $\delta = 0$ they are independent.

G.Ricchiuti, J. Tuinstra, F. Wagener

The Model

Convexity

We have convexity of the demand functions for a > 0 and d < 0. Assuming the b = c = 0.5, a = 7 and d = -1 We have the following results:

- for $\delta = 0$: the system is stable and converge to the max of the objective profit function (as shown in Naimzada and Ricchiuti, 2008).

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outli

....

The Model

Simulations: N= Convexity

Convexity and Quantit Convexity and Profits Concavity Concavity Concavity Concavity On the Diagonal:

Summar

Where we are goin

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- 2 moreover the higher the complementarity, the lower the production, the higher the profits.

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outli

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Convexity

Convexity and Quantity

Convexity and Profits
Concavity

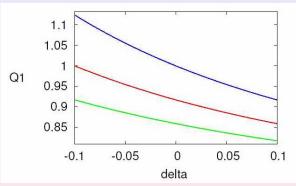
Concavity
Concavity
Concavity

Concavity
On the Diag

Summar

Where we are going

Figure: Convexity and quantity/profits: from substitute to complement



Note: $a = 7, d = -1, b = c = 0.5, blue : \gamma = 1, red : \gamma = 1.1, green : \gamma = 1.2$

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outlin

Introduction

The Mod

Simulations: N=2
Convexity

Convexity and Quan

Convexity and Profits

Concavity

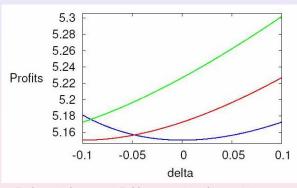
Concavity

On the Diago $q_{1,t} = q_{2,t}$

Summar

Where we are going

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outil

....

The Model

Convexity

Convexity and Quantif

Convexity and Profits

Concavity

Concavity
Concavity
On the Diagor $q_{1,t} = q_{2,t}$

Summar

Where we are goin

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- for $\delta = 0$: the system is stable and converge to the max of the objective profit function (as shown in Naimzada and Ricchiuti,2008).
- 2 for $\delta = 0$ and $a \in (-0.3, -0.01)$: route to chaos through period doubling bifurcations.

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outli

.

The Model

Convexity

Convexity and Quantit

Convexity and Profits

Concavity

Concavity

Concavity

On the Diagona $a_1 = a_2$

Summar

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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstrac

A Brief Outlin

Introductio

The Model

Simulations: N=2
Convexity

Convexity and Quan
Convexity and Profit

Concavity

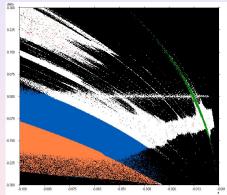
Concavity Concavity

On the Diago

Summar

Where we are going

Figure: Concavity: Parameters Basin of Attraction $\delta \in (-0.3, 0-3)$ and $\delta \in (-0.001, -0.1)$



Note: $d=0.001, b=7, c=0.1, \gamma=1, q_1=q_2=1$, black=divergence, white=non convergence, red=stable,orange=period 2, green=period 3, blue=period 4 and beyond

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outlin

Introduction

The Mode

Simulations: N=2
Convexity
Convexity and Quanti

Convexity and Profits

Concavi

Concavity

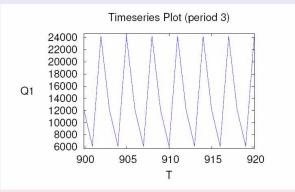
Concavit

On the Diag $q_{1,t} = q_2$

Summar

Where we are going

Figure: Period 3



Note: a = -0.00938, $\delta = -0.066081$, d = 0.001, b = 7, c = 0.1, $\gamma = 1$

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outli

Introduction

The Model

Simulations: N=2
Convexity

Convexity and Quantit

Convexity and Profits

Concavity

Concavity

Concav

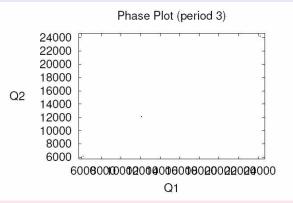
Concavity

On the Dia

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Where we are going

Figure: Phase plot Period 3



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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outli

The Model
Simulations: N=

Simulations: N=2
Convexity
Convexity and Quantity
Convexity and Profits
Concavity
Concavity
Concavity

Concavity
On the Diagonal:

Summar

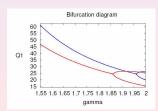
Where we are going

If $q_{1,t} = q_{2,t} = q_t$ the system becomes the following one-dimensional difference equation:

$$q_{t+1} = \frac{1}{2}q_t + \frac{1}{2}\frac{c - a\exp(dq_t^{(\gamma+\delta)}) - b}{ad\exp(dq_t^{(\gamma+\delta)})q_t^{(\gamma+\delta-1)}(\gamma+\delta)}$$
(8)

- the diagonal is an invariant set of the system (5);
- 2 for $\gamma \in (1.5, 2)$:the higher δ the lower q_1 and a flip bifurcation is anticipated.

Figure: Bifurcation Diagram γ



Note: a = -2, blue: $\delta = 0$ red: $\delta = 0.1$, d = 0.001, b = 7, c = 0.1

Monopolist with Local Knowledge of Demand

G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outli

....

The Model
Simulations: N=

Convexity

Convexity and Quantit

Convexity and Profits

Concavity

Concavity

Concavity
Concavity
On the Diagonal:

 $q_{1,t}=q_{2,t}$

Summar

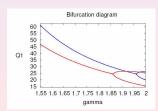
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G.Ricchiuti, J. Tuinstra, F. Wagener

A short Abstract

A Brief Outlin

muoddott

The Mode

Simulations: N

Summary

Where we are goi

We show that:

- As in Tuinstra (2004) and Bischi et al. (2006) there is a one-to-one relationship between steady states of the learning process and critical points of the objective profit function;
- Every local minimum of the objective profit function is an unstable steady state of the learning process. Local maxima, on the other hand, may correspond to either locally stable or unstable steady states of the learning process, depending upon the curvature of the demand system;
- By means of numerical simulations, that the learning process may lead to complicated behavior and endogenous fluctuations.

G.Ricchiuti, J. Tuinstra, F. Wagener

A Brief Outline
Introduction
The Model

Summary

Where we are going

We show that:

- As in Tuinstra (2004) and Bischi et al. (2006) there is a one-to-one relationship between steady states of the learning process and critical points of the objective profit function;
- Every local minimum of the objective profit function is an unstable steady state of the learning process. Local maxima, on the other hand, may correspond to either locally stable or unstable steady states of the learning process, depending upon the curvature of the demand system;
- By means of numerical simulations, that the learning process may lead to complicated behavior and endogenous fluctuations.

G.Ricchiuti, J. Tuinstra, F. Wagener

A Brief Outline Introduction The Model Simulations: N=2 Summary

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- Study of the impact of complements/substitutes on the stability of the dynamics
- Comparison of multi-product monopolist with single product oligopolists
- Relation between quantity-setting and price-setting multi-product monopolists

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Thanks!