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Understanding Insurance Cycles
An agent-based modelling approach

Introduction: Purpose of research

- Insurance cycle is a phenomenon that has been recognised since the 1920s, it has a pattern but unpredictable nature.

- Daykin et al. (1994) argue that cycles are hard to be analysed by any individual explanation alone. It is a dynamic phenomenon that involves many interactions among different agents and contributing factors.

- Agent-based Modelling (ABM) tries to simulate the dynamic interactions of agents in a complex system. It provides a method to better understand the complexity of the real world.

- We apply some basic real-world behaviour rules of insurers in the market. Despite its simplicity, the model produces many stylised facts of the market: we will focus on cycles.
Introduction: Existing Explanations of Cycles

Major existing explanations of insurance cycles:

- Market competitions cause structure fluctuations;
- Irrational forecasting errors cause pricing cycles;
- Time delays and reporting lags cause accounting cycles;
- Interest rate movements cause “cashflow underwriting” cycles;
- Cycles in line with “Mass psychology” of the underwriters;
- Other contributing factors: capital constraints, reserving errors, price regulations and insolvency risks, etc.

Introduction: Agent-based Simulation Models

ABM models complex systems from the bottom-up:

- Actions and interactions of heterogeneous agents through time
- Agents are continually adopting new strategies and be adaptive
- Bounded rationality, with capacity to gather/process information
- Agents as local players, interacting within closed “neighbours”
- Feedback loops and externalities between agents and system
- Modeler only decides agents' initial resources, rules, objectives

Recent contributions: Arifovic (JPE, 1996); Arthur (AER, 1991); Banal-Estaol and Ruperez-Micola (Management Science, 2009); LeBaron et al (JoF, 1992); Kirman (QJE, 1993); Hart (Econometrica, 2005); Noe et al (JoF, 2003 and 2006).
Our ABM Model: **Potential Benefits**

- A cheap way to experiment different scenarios of contributing cycle factors, and test relations

- Studies dynamic interactions of micro-behaviours (the insurers) and macro-dynamics (the market)

- Useful complement to traditional top-down approach of market price analysis

- Beyond explanation and prediction: guide data collection, discover new questions, demonstrate real world tradeoffs, understand complexity, train staffs, etc.
Our Model: **ABM application to Insurance Market**

- **System:** Insurance market with its unique features
  - **Insurance:** horizontal product differentiation (Location models)
  - **Contract:** price now but exchange goods future (Cobweb models)
  - **Competition:** on business strategies and information process

- **Agents:** Underwriters and/or insurance companies
  - **Behaviour:** obey simple rules to be adaptive in complex systems
  - **Objective:** earn more profits and balance risk to return
  - **Interaction:** competition with “neighbours” through prices

- **Targets:** Customers and/or future claims
  - **Customers decision rules:** cheapest price and past experience
  - **Future claims:** model several specific cases (claim distributions)
Our Model: An example of simplified real world

- A closed Motor Insurance sector
- Two rating factors (age of driver and cost of car)
- A few individual (or group) insurance companies

1. Insurer 1 is more focused on the business of experienced drivers

2. New Drivers

- Many customers with different risks (depend on expected future claim, past data or experience, etc.)
Our Model: An example of customers
Our Model: An example of insurers
Our Model: An example of the system
Our Model: **Price, profit, capacity**

The above snapshot is from the early system, it shows:

- Insurer **RED** has a total capital $K1$ (area), offers a price $AE$ to a customer **BLUE**
- The business with **BLUE** requires a minimum capital of $K2$ (area, depend on radius $DE$)
- Radius $DE$ is the insurer's expected average future claim of this customer (a number)
- $CD$ is a profit loading (a ratio), that is 1-to-1 match to $DE$ (higher claim, higher profit)
- $BC$ measures the information set about this customer (longer $BC$, more uncertainty)
- $AB$ measures the market competition level (longer $AB$, less competition)

Therefore: **Price $AE = function (AB, BC, CD, DE)$**
Model element (1): Market Structure

• Demand Side (white space)
  - Customers' risk classification
  - Define expected average claim
  - Define required capacity
  - Define profitability (risk vs return)

• Supply Side (gray space)
  - Insurers as agents move in space
  - Define existing capacity $K$
  - Define business strategy
  - Define “neighbourhoods”
Our Model: **Basic Rules of Agents (insurers)**

The beauty of ABM, it is based on simple rules from real world.

- **Rule 1:** Insurers offer different prices, customers select lowest
- **Rule 2:** Select the more profitable customers first (involve risk)
- **Rule 3:** If same profitability, then select the one with lower risk
- **Rule 4:** If capacity is full, it stops further potential customers
- **Rule 5:** If capacity is not full, increase competitions to neighbours
- **Rule 6:** If potential profit from neighbours, increase competitions
- **Rule 7:** If no potential profit/competition, refine existing business
Model element (2): Interactions of Agents

Rule 1: Insurers offer different prices, and customers select the lowest ones

- As example
  - Four insurers offer different prices
  - Prices depend on customers' risks
  - AND depend on business focuses
  - Customers will select the lowest prices
  - On the diagram, the prices are measured by the distance from insurers to each customer, and customers' decisions are reflected in different color.
**Model element (2): Interactions of Agents**

**Rule 2:** Insurers select the more profitable customers first (involve risk)

- As example
  - If RED insurer faces capacity constraint
  - It only selects a limited # of customers
  - It will select most profitable one first
  - Ranking selection
    - Customer 3 is better than others
    - Customers 2 are indifferent
    - Customer 1 is the last choice
**Model element (2): Interactions of Agents**

**Rule 3:** If same profitability, then select the one with lower risk

- As example
  - If RED insurer faces capacity constraint
  - If it moves to another location
  - There are six potential customers
  - Same profitability customers
    - Customer 3 (right) vs. Customer 1
      - It selects 1 instead of 3
    - Customer 2 (left) vs Customer 4
      - It selects 2 instead of 4
Model element (2): Interactions of Agents

Rule 4: If capacity is full, it stops further potential customers

- As example
  - If RED insurer faces capacity constraint
  - It only selects total capacity of 5 units
  - The selection depends on overall profit
  - Higher risk require higher capacity
  - In following case,
    1) Select bottom 2 and 3; OR
    2) Select 4 and 1
    - It will choose option (1) and stop others
Model element (2): **Interactions of Agents**

**Rule 5:** If capacity is not full, increase competitions to neighbors

- As example
  - If **RED** insurer has extra capacity
  - It takes all its potential customers
  - It'll try to move closer to its neighbors
  - This increases competitions
  - Lower prices attract new customers
  - BUT higher prices on existing ones
  - In this case, 1 and 2 (left) will increase prices, since **RED** faces low competition
Rule 6: If potential profit from neighbors, increase competitions

- As example
  - If RED insurer has enough capacity
  - But BLUE insurer has not
  - Some customers of BLUE rejected
  - In case of Customer 5 rejected
    - BLUE insurer cannot take this risk
    - RED insurer like it but has a low competitive advantage to GREEN
    - So RED move closer to 5, even it has no enough capacity to take it now
Model element (2): Interactions of Agents

Rule 7: If no potential profit or competition, refine existing business

- As example

- Every customers are occupied
- No potentials for Insurer RED or BLUE
- But they can increase profit still
- Increase prices on existing customers
- Since low competition on existing ones
- RED moves left and BLUE moves right
- In this case, one of them will move only when the other does it at the same time
Model element (3): Real World Constraints

- **Customers**
  - Risk classifications cannot change rapidly
  - In a short run, they are fixed (i.e.: cells in white space are unchanged)

- **Insurers**
  - They can move along the gray area, this means changing business strategy
  - But it only moves one step in each time period, since business strategy cannot change rapidly (time lags)
Model element (4): Emergence

Both market and capacity are balanced, but it is not in long-term equilibrium. Any small change in any insurer’s strategy (from Game Theory) will distort the result. Therefore, let’s look at the equilibrium results in next slide.
Model result (1): **Equilibrium Scenario**

- **Under following conditions**
  - Expected claims always equal actual results
  - No shocks or mis-priced
  - Profit Maximization

![Equilibrium Scenario Diagram]

**Diagram Description:**
- The diagram represents a model result with conditions under which expected claims equal actual results, with no shocks or mis-pricing, and profit maximization.
- The diagram includes a line graph showing total market profit over time, with markers indicating points of interest.
- The matrix represents the equilibrium scenario with strategies or variables represented by columns and rows, illustrating the interplay between different conditions and outcomes.
Model result (2): A case of single large shock

Movement of profits: Insurer 3 and Insurer 4

Movement of market shares

Back to equilibrium

A single shock

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Model result (3): A case of single large shock
Model proposal: **Model Expansion**

- Expansion
  - More customers
  - More classifications
  - More Insurers
  - Add density of groups
  - Risk distributions
  - Non-linear relations in pricing
  - Even more dimensions of risk factors
Our Model: Key Conclusions

Despite its simplicity,

- The model produces a market with a similar structure to real world: some insurers are large, others are small. Even though all of them start with the same size;

- It shows that the larger insurers are willing to take more risky customers and compete general business, while smaller insurers focus on their specialised areas;

- Niche business are emerged. Some insurers are specialised in one particular sector or a group of targeted customers, because their competitive advantages;

- Those unique features of Non-life insurance market create systemic movements of the market, cycles are emerged.
Future research: Some Improvements

• External capitals
  - New entry and exit
  - Dividends and other financial investment opportunities
  - Investor capital injection
  - Loan, reinsurance, co-insurance

• Different Insurers learning algorithms
  - Reactive reinforcement learning (Backward looking)
  - Anticipatory learning (Forward looking)
  - Evolutionary learning (GA: Genetic Algorithm)
  - Network learning (ANN: Artificial Neural Networks)
Question to think: Actuarial models

Alan Mills FSA ND (2010)* states that, “Although traditional actuarial models take many forms, in essence they simply project historical aggregate patterns into the future.” No matter if the model type employed is a micro-simulation, a statistical model, risk analysis model, the essential methodology is a top-down approach.

He argues, “By contrast, ABM is bottom-up. It seeks to understand and model the behaviour of a system's fundamental units, its agents. System-side attributes and behaviour, such as the aggregate patterns of actuarial models, are then a by-product, an emergent result.”

Exercise: From your experience, suggest a counter-example to the above statement on the view of traditional actuarial models.

*Reference: Mills (2010), a report to the Society of Actuaries, “Complexity Science: an introduction (and invitation) for actuaries”.

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