FULL TITLE: **Dynamics of Competitive Industries: A Micro Behavioural Framework**[*]

SHORT TITLE: Dynamics of Competitive Industries

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Abstract

Most published work in business dynamics is conducted either at the level of the individual firm or at the level of an industry comprising an aggregate of similar firms. However, there are situations where the performance of industries is better understood by modelling the behaviour of competing individual firms. When firms in the same industry adopt quite different views of the 'best set' of resources and the overall system of resources in the industry is tightly interconnected, it is important to model the heterogeneity of rival firms. We propose a micro-behavioural approach that captures the essential interactions between firms. To illustrate our approach we run a series of experiments using Fish Banks, Ltd. to show the wide range of firm and industry performance arising from such heterogeneity. We further develop our micro-behavioural approach into a framework for understanding the dynamics and evolution of industries based on selected ideas from system dynamics, the resource-based view of the firm and managerial cognition.

KEYWORDS: INDUSTRY DYNAMICS; MICRO BEHAVIOURAL MODELLING; COMPETITION AND RIVALRY; INDUSTRY EVOLUTION; MANAGERIAL COGNITION; FISH BANKS

Introduction

The field of system dynamics[1] has adopted two distinct perspectives to analyse the dynamics of business performance. There are individual firm models and there are aggregate industry models. But there are few models pitched at an intermediate level.

In firm-level modelling the dynamic behaviour of individual firms is assumed to be generated endogenously. The competitive environment is represented passively and exogenously by specifying benchmarks for competitive factors such as delivery delay, price or quality that reveal the relative attractiveness of the firm's product or service to the customer. For example, Forrester's (1966) widely cited "market growth model" represents a firm that fails to grow even under the assumption of an unlimited market. Growth is prematurely stifled by dysfunctional and unintended interactions between operating policies for expanding salesforce and manufacturing capacity that inadvertently result in high delivery delay. In such models, the purpose of the exogenous benchmark is not to mimic the behaviour of competitors but rather to represent, as concisely as possible, the external standards by which customers judge product attractiveness (Forrester, 1961). These individual firm-level models (e.g.: Hall, 1976) have been very important in understanding puzzling, dysfunctional behaviour and underperformance of firms under circumstances where any individual firm's actions do not significantly alter the environment, or where feedback effects to the environment are small within the time horizon defined by the modeller.

System dynamics researchers have also developed models of aggregate industry dynamics. For example, Forrester (1961) presented a highly aggregated model of manufacturing industry to understand the dynamics of supply chains and their contribution to business cycles. Among others, Sterman (2000) developed a generic model of the behaviour of commodities industries, which is based on the relationships between production, inventory, capacity utilization, capacity acquisition, demand and price. Related to these industry models, Sterman (1987) suggested that the continuous rule used to describe aggregate behaviour of an industry in system dynamics behavioural simulation models while it is not an exact statement of how firm-level decisions are made, may be an acceptable simplification[2].

However, not all business dynamics problems can be modelled as individual firms or as aggregate industries. Industry evolution is one important exception. During the evolution of industries, the process of mutual adjustment between heterogeneous firms is particularly relevant because the actions of individual firms sooner or later influence the responses of other firms in the same industry. In other words, operating policies are contingent on other firms' operating policies. Schelling has described similar contingent behaviour among individuals who comprise social aggregates (1978: p. 14 and 17), of which rival firms are particular examples:

> People are responding to an environment that consists of other people responding to *their* environment, which consists of people responding to an environment of people's responses. Sometimes the dynamics are sequential.... Sometimes the dynamics are reciprocal.
>
> The goals or purposes or objectives [of people] relate directly to other people and *their* behaviour, or are constrained by an environment that consists of other people who are pursuing their goals or their purposes or their objectives. What we typically have is a mode of *contingent behaviour* - behaviour that depends on what others are doing." (emphasis added to the original).

Schelling also offers a hint on the type of analysis necessary to address this view of the firm-environment relationships (1978: p. 14):

> These situations, in which people's behaviour or people's choices depend on the behaviour or choices of other people, are the ones that usually don't permit any simple summation or extrapolation to the aggregates. To make that connection we usually have to look at the *system of interaction* between individuals and their environment, that is between individuals and other individuals or between individuals and the collectivity.... Sometimes the analysis is inconclusive. But even inconclusive analysis can warn against jumping to conclusions about individual intentions from observations of aggregates, or jumping to conclusions about the behaviour of aggregates from what one knows or can guess about individual intentions. (emphasis added to the original)

We propose a modelling framework, suitable for analysing medium-term dynamics of firms in fast evolving industries (or equivalently, long-term dynamics in slowly evolving industries) based on contingent behaviour. In this framework an industry is represented as two or more heterogeneous individual firms, strongly interconnected through their shared environment. Here the industry environment for any individual firm is endogenous and includes rival firms as well as shared customers. Firm performance is no longer judged relative to fixed industry standards but instead evolves from interactions within a network of heterogeneous decision-makers in rival firms, each configuring a system of resources or strategic asset stocks to achieve a sustainable competitive advantage. Moreover, these decision-makers, as boundedly rational actors (March and Simon, 1958; Morecroft, 1983), do not necessarily agree on which particular configuration of resources is 'best' to serve their shared market (in other words they perceive the intended system of resources differently). Nor, when deciding which resources to expand or contract, do they necessarily give equal weight or importance to known resource imbalances, shortages or surpluses. Therefore, their decisions cannot be aggregated because they are based on different assumptions.

When there are important enduring 'cognitive asymmetries' between decision-makers in rival firms then individual firm performance cannot be reliably inferred from a single-firm model. Equally, industry evolution cannot be deduced from an aggregate industry-level model. For example it is possible that some strategies may be dysfunctional when they are pursued by most of the firms in an industry, but they can provide a competitive advantage when only one individual firm as a leader employs them, such as 'first-mover advantage' (Lieberman and Montgomery, 1988),

Our contribution to the system dynamics literature is to present a *frog-pond*[3] theory for the evolution of industries and firm performance (Klein; Dansereau, and Hall, 1994). This type of theory has two distinctive features: the effects of variables are context dependent, and a comparative process is used to specify heterogeneity among individuals within the group. Consequently, this paper presents a framework to analyse the evolution of industries and its effect on the performance of firms from a micro-behavioural point of view. To introduce the framework, we first present the results of a series of experiments using Fish Banks Ltd (Meadows; Fiddaman, and Shannon, 1993). This widely known simulation game of the fishing industry illustrates the meaning of important constructs like heterogeneous rivals and cognitive asymmetries, and demonstrates their pervasive effect on firm and industry performance. We then continue to develop the framework. Finally, we conclude with some implications for system dynamics researchers and practitioners.

Experimental Setting

The use of the fishing industry as a metaphor to illustrate the framework

A commercial fishery is a self-contained industry comprising natural fish stocks and multiple rival firms each operating a small fleet of ships. These firms are interconnected because they share a regional population of fish. Sometimes the interconnection and mutual dependence is very strong and generates surprisingly complex dynamics in the real world. The feedback structure of such a fishery is simple but dynamically complex due to the effect of nonlinearities and interactions between participants. The essence of the managerial dynamical problem for fishing fleet operators (the firms) is to achieve a sustainable competitive advantage and growth while maintaining the 'right' balance between the natural renewable resource, fish, and the man-made resource, ships. However, the 'Tragedy of the Commons' (Gordon, 1954; Moxnes, 1998) characterizes the typical and dismal dynamics of this industry and firms' dynamic behaviour. Individual firms, that try to maximise their wealth and their share of the catch, find themselves engaged in a race to grow until, unexpectedly, the natural resource collapses. The usual and catastrophic outcome is an ocean without fish and, at the same time, large idle fishing fleets.

Different firms adopt different resource building policies and strategies. Even in a deliberately simplified experimental setting, it can be difficult for any individual firm to interpret rivals' policies and behaviour, and even more difficult to infer the resulting diverse industry dynamics. It is a huge challenge for any firm (and management team) to survive in such dynamically complex conditions where performance is so critically dependent on an appropriate balance of resources. Here the regeneration rate of fish is a non-linear function of an imperfectly known fish stock and the catch depends on diverse motives and actions of rivals as they build and deploy their fleets.

Experiment Description

While Fish Banks is chiefly a role-playing simulation game that illustrates the management (and mismanagement) of renewable natural resources, we used this role-playing game to observe competitive behaviour of teams and its effect on the dynamics of the industry.

The Fish Banks experiments involved 28 teams from Executive and MBA programs grouped into 5 separate competitive environments. Each team, whose members were chosen randomly, had to manage a fishing company competing against 5 other teams in the same ocean. All participants received the same information at the beginning of the game, and we allowed teams 30 minutes to discuss strategy before making their first decision. Each team's objective was to maximize asset value by the end of the game, where asset value is defined as the salvage value of the fishing fleet plus the accumulated bank balance.

The game is a good illustration of our proposed dynamics of competitive industries framework due to several distinctive design features:

- each team started with identical internal resources (ships and cash) and received the same estimates for the size range of the fish population (shared external resource) and its regeneration rate,
- all teams had similar productivity per ship and received the same price per fish, so their income was determined entirely by their fleet size and fleet allocation (resource configuration) among fishing areas,

- all teams had access to the same information: competitors' actions like fleet allocation among the fishing areas, competitors' fleet size and competitors' total assets,
- the business concept was very simple as well as the set of choices: expand or not expand the fishing fleet, allocate the fishing fleet between two fishing areas or not send to fish at all, and trade or buy ships from other teams, and,
- there were three uncertainties similar for all teams: fish population size, real catch rate per ship, and competitors' intentions/strategies.
- the true set of asset stocks or resources was known by the experimenters, and, consequently, the experimenters could compare this known set with teams' different perceptions of the resources and its effects on the decision-making process.

Each management team had two basic decisions: fleet expansion and fleet allocation. These two decisions parallel basic concepts in the resource-based view literature: fleet expansion corresponds to the resource accumulation process (Dierickx and Cool, 1989); and fleet allocation represents the concept of resource configuration (Teece; Pisano, and Shuen, 1997; Adner and Helfat, 2003). A representation of the resource system using a stock and flow diagram is shown in figures 1 and 2.

INSERT FIGURE 1 HERE

Figure 1 presents the external resources. The external resources consist of two stocks 'Fish Population Coastal Area' and 'Fish Population Deep Sea Area' representing two independent fish populations. Each fish population increases through a regeneration rate, which depends on the relationship between the actual fish population and a maximum natural fishery size. Each fish population decreases through a harvest rate proportional to the allocated fleet size. The fish population in either area (coastal or deep sea) has a natural limit to growth and can fall to zero if the outflow from harvesting exceeds the inflow from regeneration over a period of time long enough to deplete the resource. Thus, the dynamic behaviour of the external resources in this imaginary fishing industry depends on an adequate balance between regeneration and harvest rate. If teams build big fleets, the harvest rate will be higher than the regeneration rate and all teams will lose money. If teams build small fleets, they may not optimise the economic exploitation of the fish population. The exact size of these two fish populations and the regeneration rate was not revealed to the teams at any point in the game. Participants knew only the size range of the initial populations which was 2000-4000 fish for the deep sea and 1000-2000 fish in the coastal area.

INSERT FIGURE 2 HERE

There are four internal resources. Three of them - named 'Ships in Coastal Area', 'Ships in Deep Sea Area' and 'Ships in Harbor'- represent the fleet of each team. Ships at sea contribute to an outcome (the overall catch) according to their deployment in the two fishing areas. The catch is equal to the number of ships (the level of the resource) multiplied the productivity per ship. The intrinsic productivity ('Catch per ship'), which is equal for all teams, depends non-linearly on the fish population. Each team has two decisions: fleet size or resource accumulation (shown as a diamond named 'Team's Fleet Size Decisions'), and fleet allocation or resource configuration (shown as a diamond named ‘Team’s Fleet Allocation Decisions’). Basically, each team decides a goal for its fleet size, and, either acquires new ships from the shipyard or trades ships with rivals (the resource accumulation decision is reflected in the flow regulator named ‘Fleet Size Change’). In addition, each team adjusts its deployment of ships (by controlling the resource flows named ‘Ship allocated to Coastal area’, ‘Ship transferred between fishing areas’ and ‘Ships allocated to Deep sea area’). Thus, team’s decisions affect not only the size of their firms but also the external resource in an uncertain and competitive environment.

Finally, the fourth resource -‘Bank Account’- reflects the monetary effects of the resource configuration such as income and operating costs. Increases or decreases in the bank account are influenced by fleet size decisions (resource accumulation) and the results of fleet allocation (resource configuration). As mentioned previously, the resources that define team performance are ‘Bank Account’, ‘Ships in Coastal Area’, ‘Ships in Deep Sea Area’ and ‘Ships in Harbor’.

Data Description

We used four data sources to capture the teams’ decision-making processes and their effect on the environment and firm performance: decision forms, computer generated results, team notes and subjects’ comments about their team performance. The duration of the role-playing game is restricted to 10 periods, but normally it is much shorter because there are no fish left in the ocean. Most of our experiments lasted just five periods. One experiment lasted only four periods, while another lasted 8 periods.

We analyse the information obtained from the experiments using two variables: ‘Total assets’ and ‘Ships’. ‘Total assets’ measures the overall performance achieved by each team. Total assets are the sum of the resource 'Bank account' and the salvage value of the team's fleet (sum of the resources 'Ships in Deep Sea Area', 'Ships in Coastal Area', and 'Ships in Harbor' multiplied by the salvage value per ship). The final value of total assets is the outcome of two separate processes: the number (and salvage value) of ships reflects each team's emphasis on fleet expansion, while the final level of the 'bank account' captures the ability of the team to manage the resource configuration effectively. Teams that manage their resources strategically achieve higher net income and a larger bank balance.

'Ships' represents the outcome of the decision-making process controlling internal resource accumulation. Teams expand their fleets based on their beliefs about the best structure of the resource system and the information received from the evolution of external resources.

Results

We found some results surprising. Figure 3 is a scatter plot of internal resources (ships) and performance (total assets). While a high number of ships often implies low total assets, due to operating losses caused by the over expansion of the fleet, there is too much variation in individual team performance to assume that aggressive expansion is the sole cause of underperformance, or that aggressive expansion can never yield superior performance (as an aggregate model of fishery dynamics would suggest).

INSERT FIGURE 3 HERE

Even with identical initial resources, access to similar information, and subject to the same natural fish regeneration constraints, teams neither followed a unique strategy nor achieved identical performance. Some teams with similar final fleet size achieved polar opposite performance. For example the lowest and highest performing teams (in terms of total assets) both acquired around 60 ships. Other teams obtained similar performance with huge differences in resources (for example total assets of approximately $10,000 for teams which had acquired 10, 20 and 55 ships respectively). Even two teams in the same experiment with the same number of ships achieved a 15% difference in performance (teams 3 and 4 in experiment 2). Table 1 presents year-by-year results for all five experiments while Table 2 provides summary statistics for each experiment at the end of year 5.

INSERT TABLE 1 HERE

INSERT TABLE 2 HERE

The results show important variations in resources and performance between and across experiments as Table 2 depicts. The individual teams in experiments 2, 3 and 5 performed well. They all achieved positive total assets by the end of year 5. Moreover, the overall performance of teams is similar. The standard deviation of total assets is low and the mean is high. In contrast the individual teams in experiment 1 and 4 performed poorly. Many teams were left with negative total assets by the end of year 5 and collectively they lost money. There were also large differences between the overall performance of teams and the size of their resources. The standard deviation of both total assets and ships is high. Surprisingly, we obtained these contrasting strategies and performances in a relatively simple resource system (only two resources: fish and ships) with identical information available to players. We therefore need to understand the factors that have contributed to such dissimilar outcomes. While there are many potential reasons why firms perform differently, the characteristics of Fish Banks, Ltd. (see experiment description) reduce the possible sources of dissimilar performance to only two: 1. each team's own process of decision making, and 2. the effect of competing teams' actions on the effectiveness of a given team's decisions. In other words, any individual team's performance is not only determined by its own decision-making process but is also contingent on other teams' behaviour.

Categorising teams' decision-making process

Given the simplicity of this system of resources we have been able to categorize the decision-making processes in terms of the observed relationship between fishing fleet size and fish sales. We identified three distinct styles of decision-making: reactive, proactive type 1 and proactive type 2 – corresponding to three regular patterns of behaviour. Figure 4 illustrates these categories, using results from teams 1,2 and 5 in experiment 2.

INSERT FIGURE 4 HERE

These three teams exhibited diverse performance typical of the categories they represent. The team labelled 'reactive' reacted to growth in sales by continuously adding ships: more sales, more ships. The team labelled 'proactive type 1' tried proactively to achieve and sustain a pre-planned market share by expanding its fleet almost instantaneously before obtaining any feedback from its actions on the evolution of fish sales or observing the actions of competing teams. On the other hand, the team labelled 'proactive type 2' tried proactively to avoid losses due to an anticipated collapse of the fish population, and, consequently, not only didn't expand its fleet but also sold it before the game finished.

From an analysis of teams' decisions, notes and comments, we identify the basic characteristics of reactive or proactive teams. Reactive teams (65% of all teams) accumulated fleets varying in size between 6 and 20 ships. We could not infer from their behaviour that they were consciously managing the limited resource (fish population). Although they seemed to adopt cautious expansion, they myopically kept expanding their fleet even when industry-wide fish sales were decreasing, as can be seen in figure 4. A typical reactive team simply followed the local outcome information provided (team fish sales) without any indication that team members foresaw the industry-wide effect of their decisions to build internal resource (fleet size) on the external resource (fish population) or on rivals' decisions. For example reactive teams increased their fleet when they observed growth in the volume of fish caught, but they failed to notice related erosion of the external resource (which could be inferred from productivity per ship). Reactive teams also configured their resources on the basis of outcome information. For example they kept their fleets allocated to a particular fishing area until they found there were no fish left. To summarize, reactive teams seem not to perceive any causal relationship between their actions and the dynamic behaviour of the external resource. They appear to follow simple linear cause-effect logic for the dynamic management of asset stocks based on immediate local outcome information.

Most of the proactive teams (35% of all teams) had fleets between 0 and 5 (type 2) or bigger than 20 ships (type 1). Proactive teams seem to have analysed and inferred causal relationships between internal resources and the external resource. They planned ahead by judgmentally forecasting the effect of the two principal uncertainties: fish population size and competitors' actions. Proactive teams type 2 were concerned with the effect of the actions of competitors on the external resource (fish population) and guessed that other teams would build their fleet slowly. Consequently, they built their own fleet quickly, and allocated it for a short period in one fishing area, then moved it to a second area, and sold the fleet before the fish disappeared (fleet = 0 ships and high bank account); or they did not expand the fleet and sometimes sold it, as in the example presented in figure 4, when they observed aggressive expansion by other teams. Proactive teams did not wait for outcome information to confirm their forecasts; they somehow visualized the likely dynamics of the feedback system and acted on their expectations.

Other proactive teams, which we called type 1, also tried to guess their competitors' actions, but they were focused on the effect of competitors' actions on their own internal resource accumulation, particularly the bank account. Hence, they built huge fleets in an attempt to pre-empt other teams without waiting to receive any outcome information about external resources or competitors' actions. But only one of these pre-emptive teams (team 1 in experiment 2, figure 4) was very successful (55 ships and total assets of $11,000). This team not only configured its resources by considering the external resource dynamics, but also benefited from the reactive behaviour of competing teams in the same experiment. In conclusion, proactive teams appear to perceive causal relationships between their actions and the dynamic behaviour of the resources. Using these perceptions, they develop expectations to feed their decision-making process. Some expectations anticipate the performance of both internal and external resources; other expectations are simpler and only anticipate the effect of competition on the performance of internal resources. Table 3 presents some comments from the teams as anecdotal confirmation of a relationship between styles of decisionmaking and patterns of behaviour.

INSERT TABLE 3 HERE

While the two main categories (reactive and proactive) help to illustrate that decisionmaking style and mental models influence performance, their effect on any one team's overall performance cannot be directly inferred as a simple recipe for success. Performance is also contingent on the behaviour of competitors.

The influence of competing teams on performance and the effectiveness of the decision-making process

Each individual team's actions are important to its overall performance, but competitor teams' actions are also influential because rival firms are strongly interconnected through their environment. Consequently, we need to consider the relationships between teams' decision-making processes to interpret industry and team performance. Table 4 shows the performance of each type of team depending on the proportion of other types of behaviour in the experiment.

INSERT TABLE 4 HERE

We can observe in Table 4 the effect of the competitive situation (proportion of teams' behavioural type) on the performance of each team in the experiments. For example, in experiment 3 all teams except one adopted reactive decision-making as they continuously expanded their fleets in response to revenue growth. Teams' performances were quite similar (as reflected in the small standard deviation in performance) for two reasons: (a) they expanded gradually, and (b) they moved their fleets together from one fishing area to the other area when the first fishing area collapsed. In experiment 5, all teams except one adopted reactive decision-making, again achieving similar performance. In this experiment, however, the only proactive team (team 6) exploited other teams' reactive decision-making by expanding and allocating its fleet aggressively and then finally selling it to another team. But, in comparison to other proactive teams, team 6 recognised that the natural dynamics of fish regeneration would impose a limit to the overall number of ships. So the team quickly built a fleet big enough to obtain a reasonable income and market share without causing a collapse of the fishery. In experiment 2, three teams adopted reactive decision-making, leaving the exploitation of the fish population to an aggressive proactive team (type 1) that obtained superior performance. In this experiment, a second proactive team (type 2) sold its fleet early expecting a collapse, a move that helped the aggressive proactive team. In experiments 1 and 4, two teams simultaneously adopted very aggressive proactive decision-making (type 1) trying to pre-empt the other teams. But this duplicate pre-emption caused an early collapse of fish stocks (the external resource), adversely affecting all teams except the proactive type 2 teams, which sold or did not expand their fleet expecting the collapse of the fishery.

To summarise, the results show that the dynamic behaviour of individual firms is not always a reliable guide to aggregate industry dynamic behaviour in competitive and tightly coupled resource systems. Heterogeneous decision-makers in rival firms perceive the industry's feedback structure differently and adopt different policies and strategies for resource building and growth.

There are two important implications for system dynamics models of industries and firms. First, the dynamics of industries cannot always be deduced by modelling an aggregation of individual firms and by assuming these firms share a common feedback structure. Second, dysfunctional behaviour of individual firms does not always arise from flawed internal feedback structure but may also stem from competitive interactions among rival firms. To address these implications we now develop a general modelling framework for industries comprising heterogeneous rivals.

Competitive Industry Dynamics: A Micro Behavioural View

In our proposed framework, two main factors determine the performance and dynamic behaviour of rival firms in an industry. First, the set of resources that define the industry (both internal to individual firms and external) is important. Rival firms as open systems not only acquire resources from their environment but also lose resources either to competitors or through attrition in dynamic interactions with their environment (Warren, 2001; Warren 2002). Thus, organizational survival in competitive industries is based on the ability to acquire and maintain resources from an environment consisting of rival organizations, which compete for shared resources or own the resources required for surviving and prospering.

Organizations' actions aimed at meeting their own goals can, under conditions of intense rivalry, affect the resource system of other organizations, thereby generating reactions that later influence their own resources. External environments are not completely exogenous but are in part created by the organization and its decisions. Consequently, organizations have to fit into patterns of resource exchanges with other organizations forming adaptive systems embedded in feedback processes (March and Simon, 1958; Levinthal and Myatt, 1994). In these circumstances we need to observe and model the interactions *between* firms to understand both industry-level and firm-level dynamics. Moreover, we conceive of environment-strategy-structure alignment by firms as a feedback process of mutual adjustment between firms exchanging, sharing and competing for resources as outlined in figure 5.

INSERT FIGURE 5 HERE

Second, managerial decisionmaking is important. The dynamic complexity of industries comprising interlocking resources suggests that differences in the way managers interpret this complexity, set priorities and guide resource building will affect relative performance and even the survival of firms in competitive industries.

The Role of Management and Managerial Decision-making

In system dynamics, management is viewed as the process of converting information into action. This conversion process is decision-making. As Forrester (1961, 1994) notes, "if management is the process of converting information into action, then management success depends primarily on what information is chosen and how the conversion is executed. The difference between a good manager and a poor manager lies at this point between information and action". The difference between a high performing firm and a less-well performing rival also lies at this point.

In our framework we build on this view of management by separating managerial decision-making into two distinct information processing components. There is operating policy to control the acquisition and composition of resources, and there is strategic resource conceptualisation to define which resources the business really needs.

Operating policy is normally represented as purposive (though myopic) adjustment of asset stocks or resources through goal-seeking information feedback (Sterman 2000, Morecroft 2002). It is the essence of the feedback view of the firm. Decisions stemming from operating policy lead to corrective actions intended to close observed gaps between desired and actual resources. Defining and monitoring the gaps (shortages or excesses) in a firm's portfolio of resources is essentially an information processing activity. System dynamicists recognise that such information processing is imperfect, judgmental and behavioural – subject to the practical constraints of bounded rationality (Morecroft 1985, Sterman, 1985; Sterman, 2000 ch. 13). Every manager has available a large number of information sources to gauge the firm's resources. But each selects and uses only a small fraction of all available information. Through this behavioural decision-making process, managers collectively build and configure the resources for competing in the industry. Here *desired resource levels* are local operating goals, loosely linked to overall strategy. In a well-designed firm, the achievement of local resource goals will lead to successful implementation of strategy. But that's an ideal world. In reality firms inadvertently adopt operating policies at cross-purposes with strategy that degrade performance. Underperformance, arising from misperceptions of feedback, has been documented in experimental studies (Sterman, 1989; Paich and Sterman, 1993), and is the explanation of firm-level performance paradoxes such as capability traps in process improvement (Repenning and Sterman, 2002) and implementation failures in product innovation (Repenning, 2002).

Purposive, boundedly rational asset stock adjustment, with misperceptions of feedback, is a cornerstone of contemporary applied research in business dynamics. We adopt this approach and add to it a second component of managerial decision-making that we call strategic resource conceptualisation. We view this conceptualisation activity as strategic decisionmaking by top managers to define and communicate the resources they will need to realise their vision of the business.

The process of resource system conceptualisation is difficult to pin-down with precision, but we believe it is related to top managers' mental models of the intended resource system and the expected sources of competitive advantage. In other words, each manager has a blueprint in his or her mind of the system of asset stocks that drives performance and dynamic behaviour of the firm over time. Collectively these blueprints determine the resource building strategy as well as the markets in which the firm competes. As Senge (1999: 175) suggests "our mental models determine not only how we make sense of the world, but how we take action." Mental models affect what we see, and two people with different mental models can observe the same industry or even the same firm, and yet define the intended resource system differently. For example, in the Fish Banks' experiments we identified three distinct styles of decision-making. We suggest these styles reflect different mental models for managing a fishing fleet. In other words, teams conceptualised differently the system of resources that they need to observe and control in order to maximize asset value. Consequently, they developed diverse strategies[4].

Figure 6 is a stock and flow diagram to represent the mental model that we believe guided ship purchasing in reactive teams. The content of this diagram requires careful interpretation since we do not necessarily think that a player's mental model is literally a stock and flow diagram. Indeed such a one-to-one correspondence is most unlikely. Rather the figure conveys an impression of the scope and complexity of a typical reactive mental model for purchasing. The symbols in black capture a myopic, yet pragmatic view of fleet adjustment informed by the recent history of fish sales growth. In other words, a reactive team will continue to expand its fleet providing fish sales are rising. The greyed-out symbols show what's going on with the fish population, but that doesn't directly influence fleet expansion. The assumption is that, for the purpose of purchasing, reactive teams do not include the fish population in their mental representation of the system of resources. (However, that's not to say they are unaware there are fish in the sea. The problem may be they don't know for sure how many, and they are reluctant to guess, so they ignore population and effectively assume it will take care of itself). A similar myopia applies to competitors. Reactive teams do not appear to include competitor's resources in their mental representation for purchasing.

INSERT FIGURE 6 HERE

In comparison, the mental model of proactive type 1 teams was of greater scope and complexity. It seems likely they considered both their internal bank account and competitors' fleets when purchasing. The part of the network shown in black in figure 7 portrays this more ambitious mental model. A typical proactive type 1 team viewed competing teams' ships as a threat to their own ability to maximize the value of the bank account. Moreover, they viewed themselves as engaged in a race to expand their own fleet more quickly than rivals. Consequently they paid attention to competitors' fleet size and even tried to anticipate rivals' fleet expansion. However, despite this extra sophistication, fish population (which is the main resource affected by a competitive race and a limit to growth) was probably not included in their mental representation of the system.

INSERT FIGURE 7 HERE

The system of resources conceptualised by proactive type 2 teams was even more complex. These teams seemed to identify ships as a necessary resource to drive sales and, consequently, to accumulate money in the bank account. But, they also worried about the operating costs of the fleet. In their purchasing strategy, a focus on operating costs (relative to revenue) caused them to think about the behaviour of the main shared resource, fish population, and its likely impact on net income per ship. Consequently, these teams had in mind a more comprehensive model of the system, as figure 8 shows. Moreover, they still faced an important uncertainty: competitors' fleet expansion rate. So their purchasing decisions were contingent on their perception of rivals' behaviour. Some proactive type 2 teams played against cautious slow-to-expand competitors. These teams, operating in a benign competitive environment, were able to achieve high market share that helped them to maximize their income. Other teams faced aggressive competitors that built huge fleets quickly. These teams, operating in a hotly contested competitive environment, recognised the need to sell their fleet before the fishery collapsed.

INSERT FIGURE 8 HERE

In this interpretation of mental models for strategic decision-making we are implicitly assuming that top managers conceptualise their firm and strategy in terms of resource building. The strategies of rival firms may be guided by quite different imagined resource maps that reflect the particular shared vision of their top management teams and the practical opportunities and threats they perceive. A well-known example in the system dynamics literature of a competitive industry viewed differently by rivals is airlines (Sterman, 1988; Morecroft, 1999). While airplanes are a very common and tangible resource, competitors in the industry deploy them quite differently. For example, figure 9 depicts how the management of easyJet, one of the biggest low fare airlines in Europe, conceptualises aircraft usage and cost compared to full fare competitors, the traditional carriers.

INSERT FIGURE 9 HERE

However, mental models of resource systems are not right or wrong per se. Rather it is the context in which mental models are applied that determines their effectiveness. We define the enduring differences between managerial mental models in an industry as 'cognitive asymmetries'. Managers can exploit cognitive asymmetries to find resource system configurations overlooked by competitors, that are nevertheless highly profitable. However, when cognitive asymmetries are small, the key resources - where managers focus their attention and effort - are similar for all firms, suggesting that rival firms are likely to follow similar strategies.

To summarize, we view managerial decision-making in competitive industries as the resultant of two separate components. The first, operating policy, represents how organisations and functional managers guide the configuration of the resource system using goal-seeking feedback. The second, resource system conceptualisation, represents how, through mental models, top managers collectively identify and communicate the intended resource system.

Conclusion

The field of system dynamics has paid relatively little attention to interactions between competing firms when analysing the dynamics of business performance. Instead researchers and practitioners have tended to develop individual firm models or aggregate industry models. However, competitive interactions can shape the destiny of industries as well as the performance of individual firms. To illustrate we use the well-known Fish Banks gaming simulator as a practical example of rivalry among heterogeneous firms in the same industry. While the 'tragedy of the commons' is a typical result of the game, we observe that some fisheries perform much better than others and that some teams achieve sustained positive performance over the lifetime of the fishery while others fail dramatically.

Building on these results we propose a modelling framework for examining the performance of rival firms in evolving industries. In this framework an industry is represented as two or more distinctive individual firms, each advocating a different view of strategically important resources and each pursuing somewhat different resource-building policies, strongly interconnected through their shared environment and shared customers. Firm performance no longer arises solely from the internal policy interactions of individual firms but also from interactions among the rival firms and their heterogeneous decision-makers, as they attempt to configure a unique system of resources in order to achieve a sustainable competitive advantage.

When there are important enduring 'cognitive asymmetries' between decision-makers in rival firms then individual firm performance cannot be reliably inferred from a single-firm model. It is then important to explore industry and firm performance under a behavioural paradigm that explicitly recognises these cognitive asymmetries and their effect on feedback structure. The system dynamics literature already offers a rich process for capturing managerial knowledge in feedback models of individual firms and their internal policy structure (Morecroft and Sterman, 1994; Zagonel, 2002). Our framework for competitive industries calls for a similar process to capture the different ways that executives, in rival firms, conceptualise and manage strategically important resources.

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FIGURE 1

Stock and Flow Diagram of the External Resources in Fish Banks, Ltd.

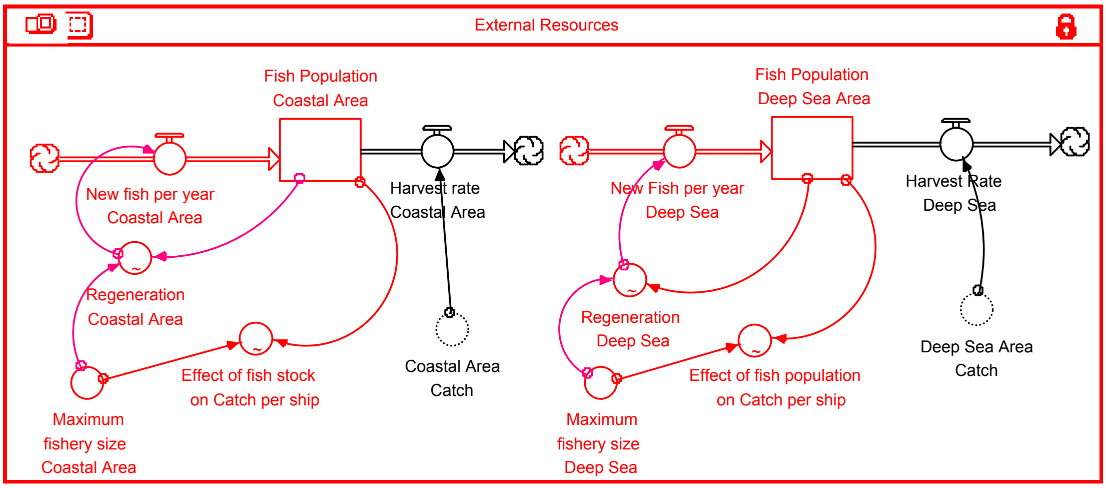


FIGURE 2

Stock and Flow Diagram of the Internal Resources in Fish Banks, Ltd.

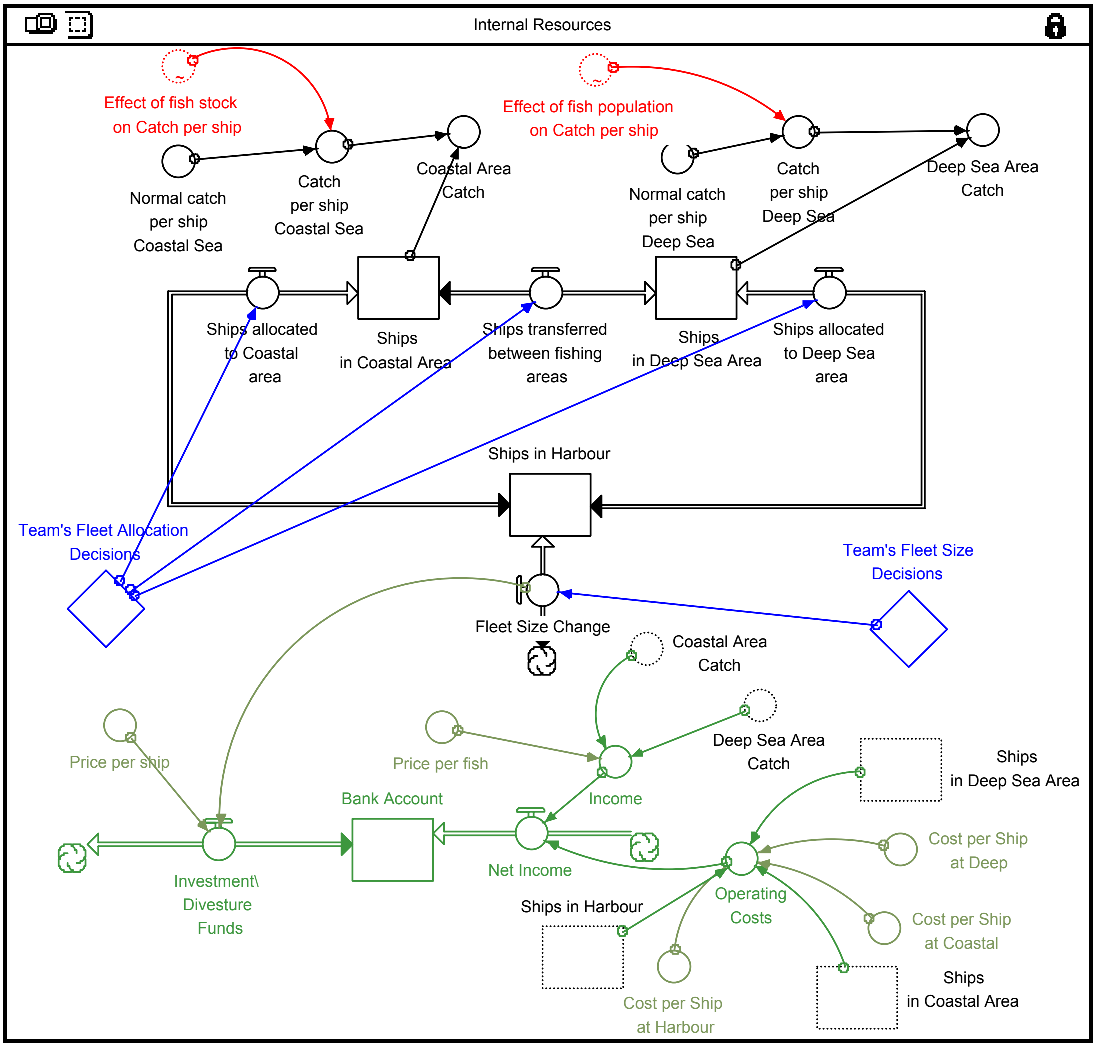


FIGURE 3

Performance (total assets) versus Resources (ships) Scatter Plot at the end of year 5.

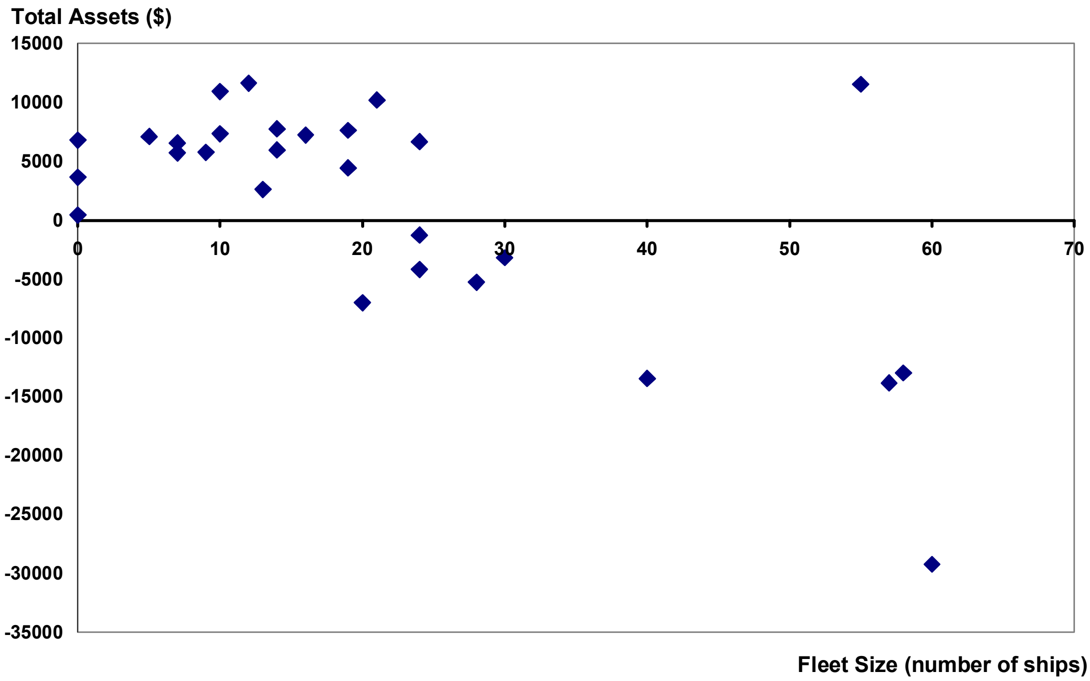


TABLE 1

Evolution of the Value of Assets and Ships Per Experiment from Year 1 to 5

Experiment 1

	Year 1 Total Assets	Year 1 Ships	Year 2 Total Assets	Year 2 Ships	Year 3 Total Assets	Year 3 Ships	Year 4 Total Assets	Year 4 Ships	Year 5 Total Assets	Year 5 Ships
Team 1	2530	4	1520	10	(7750)	60	(17730)	60	(29240)	60
Team 2	2530	4	3770	10	2650	15	420	30	(3170)	30
Team 3	2230	4	3120	16	160	40	(6380)	40	(13440)	40
Team 4	2530	4	4020	10	4630	10	4640	13	2610	13
Team 5	2230	4	3610	14	3830	24	460	24	(4170)	24
Team 6	2430	4	3710	12	3600	20	520	28	(5280)	28
TOTAL	14480	24	19750	72	7120	169	(18070)	195	(52690)	195

Experiment 2

	Year 1 Total Assets	Year 1 Ships	Year 2 Total Assets	Year 2 Ships	Year 3 Total Assets	Year 3 Ships	Year 4 Total Assets	Year 4 Ships	Year 5 Total Assets	Year 5 Ships
Team 1	1040	5	6670	55	11,350	55	14530	55	11550	55
Team 2	3440	5	4520	7	5,780	11	6210	14	5970	14
Team 3	3440	5	4720	7	6,030	7	6660	7	6560	7
Team 4	3540	5	4430	5	5,480	5	5800	5	5710	7
Team 5	3540	5	4570	5	5,780	5	6390	2	6790	0
TOTAL	15000	25	24910	79	34420	83	39590	83	36580	83

Experiment 3

	Year 1 Total Assets	Year 1 Ships	Year 2 Total Assets	Year 2 Ships	Year 3 Total Assets	Year 3 Ships	Year 4 Total Assets	Year 4 Ships	Year 5 Total Assets	Year 5 Ships
Team 1	3540	5	4570	5	6390	5	7130	5	7120	5
Team 2	3290	5	4790	10	8450	12	9560	12	11620	12
Team 3	3390	5	4560	8	7340	11	8570	16	10180	21
Team 4	3240	5	4780	11	8470	14	9120	14	6660	24
Team 5	3340	5	4340	9	8070	19	9230	19	4440	19
TOTAL	16800	25	23040	43	38720	61	43610	66	40020	81

Experiment 4

	Year 1 Total Assets	Year 1 Ships	Year 2 Total Assets	Year 2 Ships	Year 3 Total Assets	Year 3 Ships	Year 4 Total Assets	Year 4 Ships
Team 1	1830	4	3140	24	3130	24	(1260)	24
Team 2	180	4	2680	55	(605)	58	(12965)	58
Team 3	2030	4	3190	20	(2830)	20	(7010)	20
Team 4	1830	4	2340	24	(2710)	43	(13830)	57
Team 5	2330	4	3290	14	2440	14	450	0
Team 6	2730	4	3400	6	3325	0	3655	0
TOTAL	10930	24	18040	143	2750	159	(30960)	159

Experiment 5

	Year 1 Total Assets	Year 1 Ships	Year 2 Total Assets	Year 2 Ships	Year 3 Total Assets	Year 3 Ships	Year 4 Total Assets	Year 4 Ships	Year 5 Total Assets	Year 5 Ships
Team 1	2730	4	3530	6	5770	9	7110	12	7230	16
Team 2	2630	4	3790	8	6090	8	6930	10	7740	14
Team 3	2680	4	3700	7	6480	10	7720	10	7340	10
Team 4	2730	4	3760	6	6020	7	6840	7	5760	9
Team 5	2580	4	3420	7	5770	11	7440	15	7620	19
Team 6	2430	4	4110	12	7670	12	9400	12	10920	10
TOTAL	15780	24	22310	46	37800	57	45440	66	46610	78

TABLE 2

Total Assets and Fleet Size per experiment at the end of year 5.

	Experiment 1		*Experiment 2*		*Experiment 3*		*Experiment 4*		*Experiment 5*	
	Total Assets	**Ships**	**Total Assets**	**Ships**	**Total Assets**	**Ships**	**Total Assets**	**Ships**	**Total Assets**	**Ships**
Team 1	(29240)	60	11550	55	7120	5	(1260)	24	7230	16
Team 2	(3170)	30	5970	14	11620	12	(12965)	58	7740	14
Team 3	(13440)	40	6560	7	10180	21	(7010)	20	7340	10
Team 4	2610	13	5710	7	6660	24	(13830)	57	5760	9
Team 5	(4170)	24	6790	0	4440	19	450	0	7620	19
Team 6	(5280)	28					3655	0	10920	10
Total	**(52690)**	**195**	**36580**	**83**	**40020**	**81**	**(30960)**	**159**	**46610**	**78**
Mean	**(8782)**	**33**	**7316**	**17**	**8004**	**16**	**(5160)**	**27**	**7768**	**13**
Std Dev.	**11270**	**16**	**2407**	**22**	**2877**	**8**	**7265**	**26**	**1701**	**4**

FIGURE 4

Evolution of Fleet Size for Three Teams in comparison to Overall Fish Sales

(the figure presents results from teams 1, 2 and 5 in experiment 2 and shows three typical patterns of behaviour also observed in other experiments)

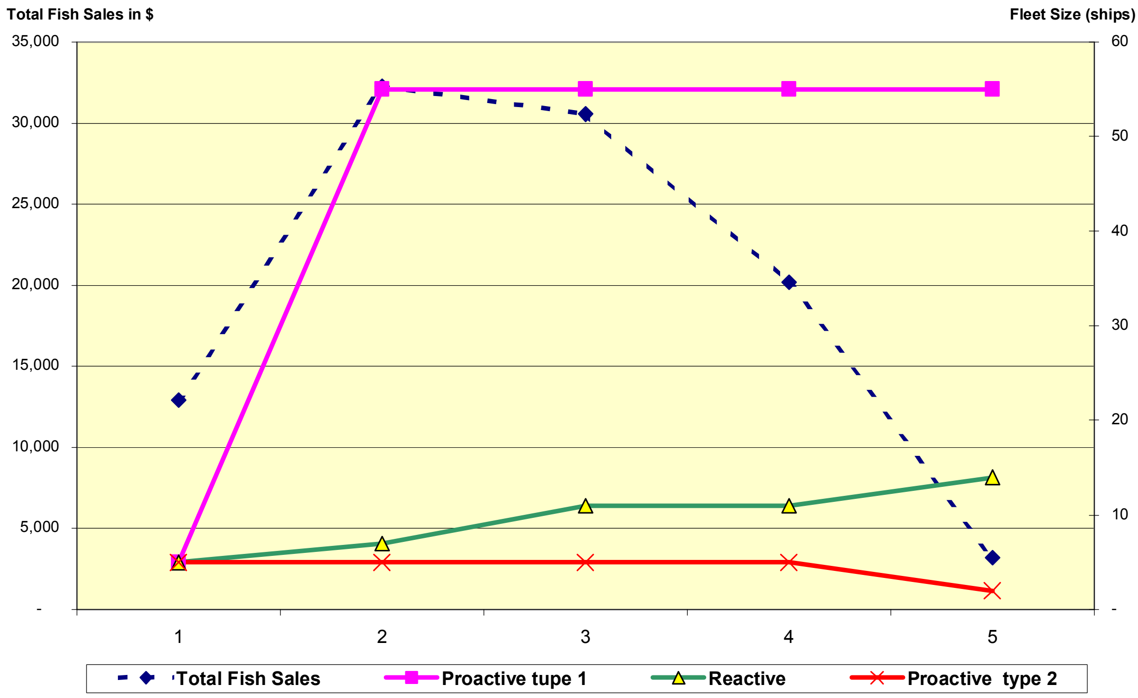


TABLE 3

Patterns of behavior: characteristics of the behavior and comments from teams illustrating their behavior

Pattern of Behavior	Characteristics of the Behavior	Examples of the Behavior
Reactive	Expanded the fleet and allocated it among the two fishing areas based on past events (changes in the volume of fish caught)	"Still plenty of fish in Deep Sea, so aggressive stance, buy more ships" (team 5 in experiment 1) "Target deep sea to start" and "relocate to coast as deep sea drops off" (team 2 in experiment 5)
	Did not foresee the effect of their decisions to build internal resources (fleet) on the external resource (fish population).	"[They will] have most boats in deep sea area whilst stocks of fish remain - so order boats early" (team 3 in experiment 4)
Proactive type 1	Set up objectives to control the effect of competitors' actions on their internal resource.	Obtain 25% of the market share of total fish caught so build the fleet to obtain 25% of the expected total number of ships. (Team 1 in experiment 2)
	Tried to guess competitors' actions, and their effect on their own internal resource accumulation (bank account)	"Pay back in 2 years, first years grow aggressively" (Team 1 in experiment 1).
	Build huge fleets in an attempt to pre-empt other teams without waiting to receive any information about external resources or competitors' actions.	"Our strategy is to build a huge fleet immediately, pillage the fishery quickly and not expand our fleet after the initial build" (Team 1 in experiment 4)
Proactive type 2	Planned ahead by inferring the effect of one of the two main uncertainties: fish population size.	"Sell ships in round 2 and be a bank afterwards/ship trading." (Team 6 in experiment 4)
	Tried to guess competitors' actions, and their effect on their external resource accumulation (fish population)	"Not to be in the business as people overfish" (Team 6 in experiment 4)
	Did not increase its fleet, or build a small fleet and allocated it for a short period in one fishing area, then moved it to a second area, and sold the fleet before the fish disappeared	Move aggressively by expanding fleet quickly because everybody would do it, go to fishing areas not exploited, and finally sell the fleet (Team 6 in experiment 6)

TABLE 4

Effect on team performance of competing teams' decision-making processes.

Team's type of behaviour	Experiment	Proportion of teams by behavioural type			Performance
		Reactive	Proactive type 1	Proactive type 2	
Reactive	1	**50%**	33%	17%	Lower than proactive type 2 but better than proactive type 1
	2	**60%**	20%	20%	Lowest performance among their competitors.
	3	**80%**	0%	20%	In average good performance, with two among the best performers
	4	**20%**	40%	40%	Lower than proactive type 2 but better than proactive type 1
	5	**83%**	0%	17%	Good performance
Proactive type 1	1	50%	**33%**	17%	Lowest performance among their competitors.
	2	60%	**20%**	20%	Best performance among their competitors
	3	80%	**0%**	20%	N/A
	4	20%	**40%**	40%	Lowest performance among their competitors.
	5	83%	**0%**	17%	N/A
Proactive type 2	1	50%	33%	**17%**	Best performance among their competitors
	2	60%	20%	**20%**	Lower than proactive type 1 but better than reactive teams
	3	80%	0%	**20%**	Better performance than lowest reactive teams
	4	20%	40%	**40%**	Best performance among their competitors
	5	83%	0%	**17%**	Best performance among their competitors

FIGURE 5

Feedback view of environment-strategy-structure alignment

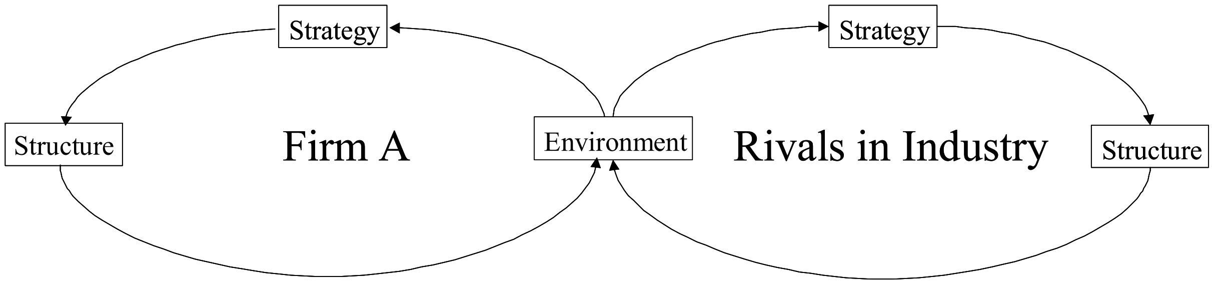


FIGURE 6

Reactive teams' conceptualisation of the resource system

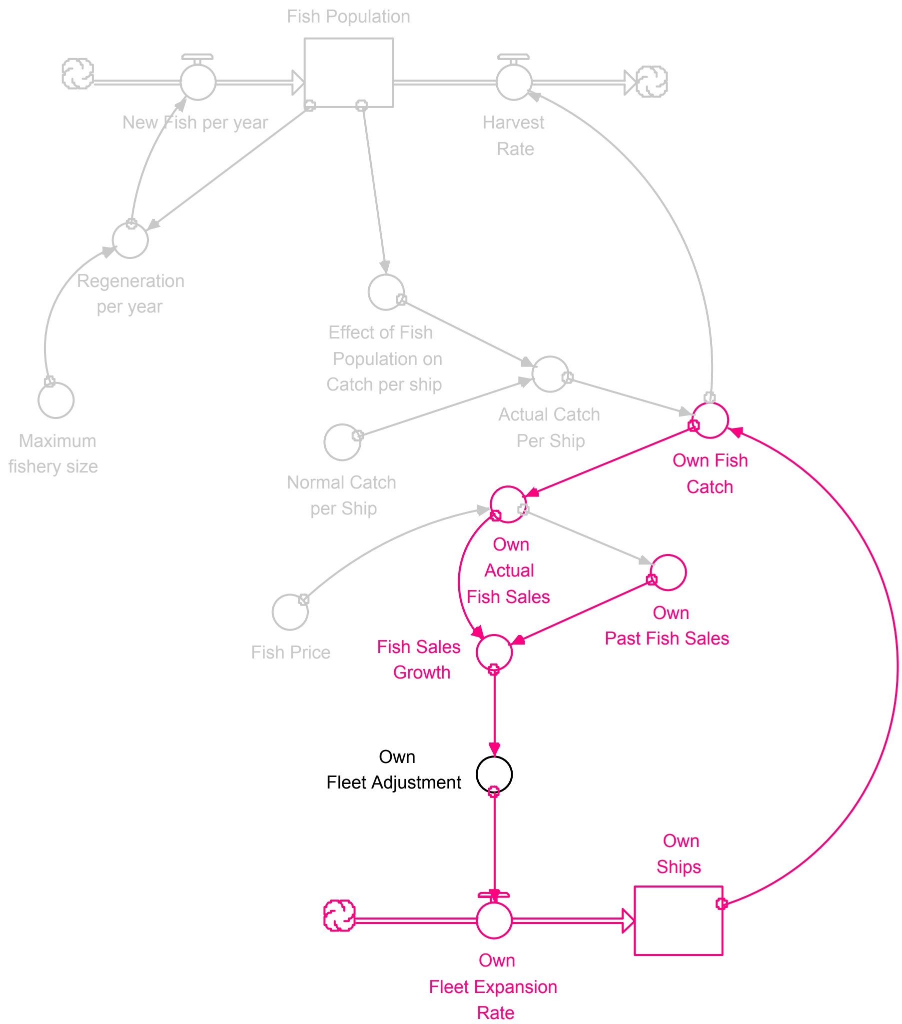


FIGURE 7

Proactive teams type 1 conceptualisation of the resource system

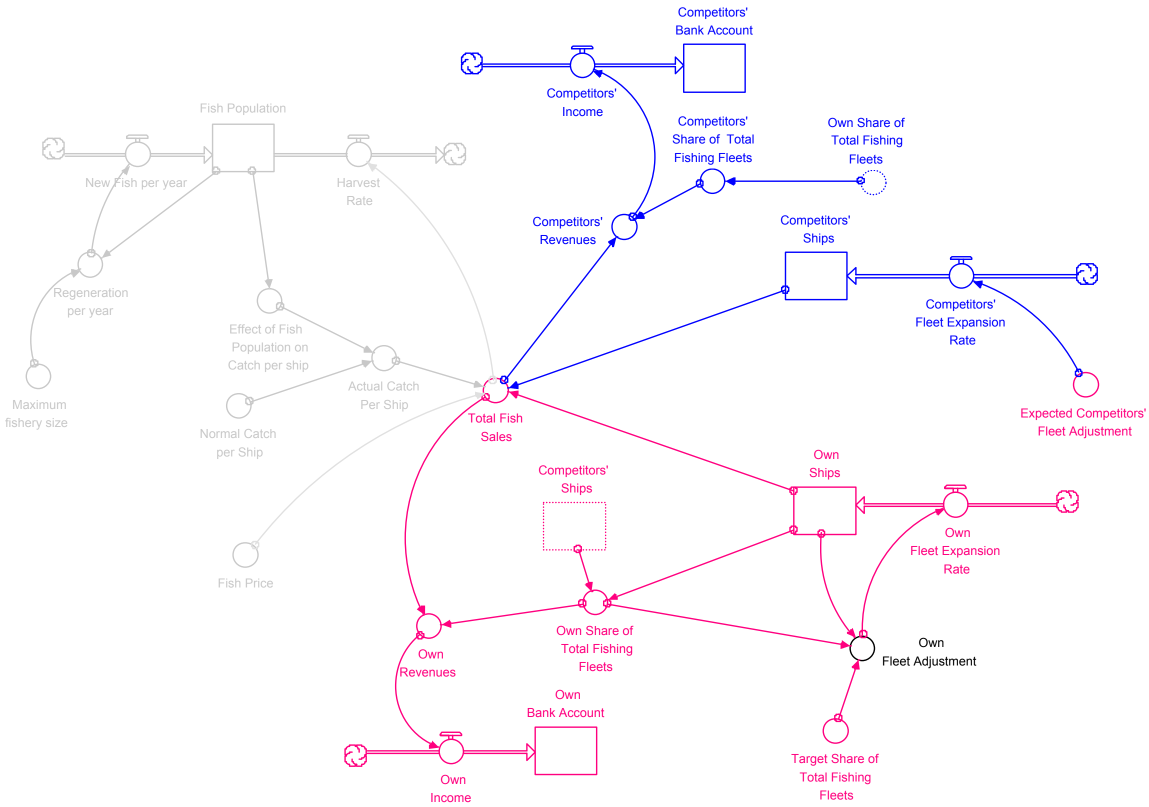


FIGURE 8

Proactive teams type 2 conceptualisation of the resource system

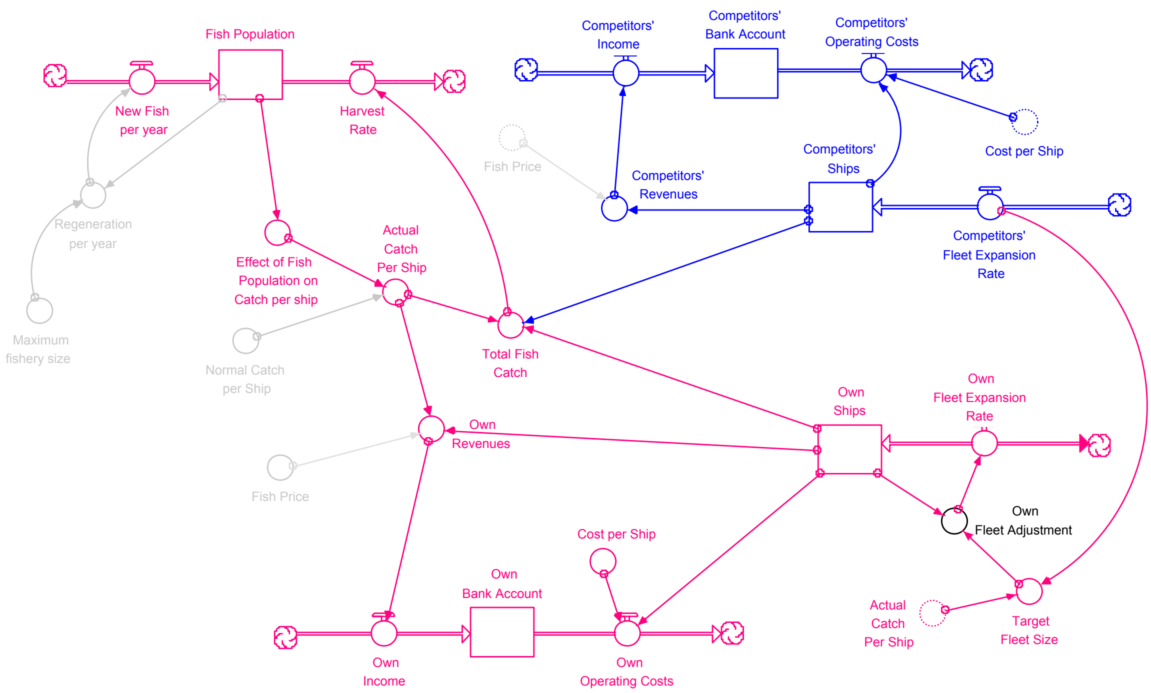
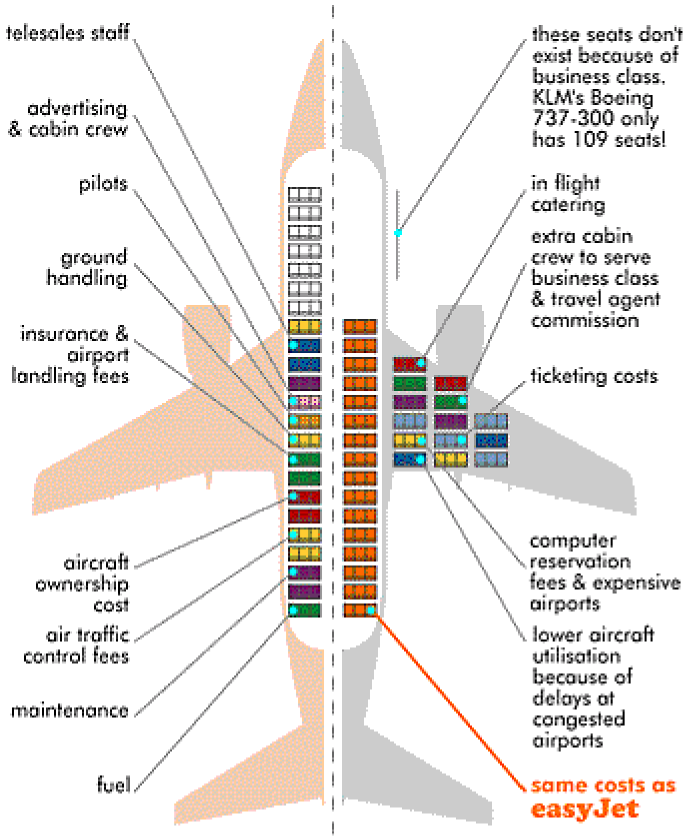


FIGURE 9

easyJet's, a low fare airline, conceptualisation of the usage of their main resource, airplane, compared to a full fare airline (easyJet, 2003)



ENDNOTES

[1] Similarly, the strategy field offers both industry-level (Porter 1988) and firm-level (Thompson, 1967; Hofer and Schendel, 1978) analysis to explain sustained differences in the performance and profitability of firms. In particular the resource-based view suggests that firms' unique internal resources and capabilities are responsible for differential performance (Wernerfelt, 1989; Prahalad and Hamel, 1990; Barney, 1991; Barney, 2002).

[2] But Sterman also added that aggregate decision rules may not always be appropriate in industry models, and other methods, such as direct experimentation, are needed to close the gap between micro-knowledge of individual decisions and the macro-behaviour of aggregate models and systems.

[3] Here the term frog-pond captures the essential comparative or relative effect. Depending upon the size of the pond, the same frog may be small (if the pond is large) or large (if the pond is small).

[4] It's important to be aware that we are saying a mental model is a representation of how something specific works (or is believed to work) – in this case a good way to build a fishing fleet that maximizes the asset value of the firm over the duration of the game. If one were to ask players for their mental model of fish population (i.e. what determines the fish population or how does population 'work'?) it would of course be different to their mental model for fleet expansion. The fact that players have a mental model for fish

population, and may even understand population dynamics, does not necessarily mean they use this knowledge when devising a ship purchasing strategy.