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Sizing Strategies in Scarce Environments

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Abstract. Competition is fierce and often the first to act has an advantage, especially in environments where there are excess resources. However, expanding quickly to absorb excess resources creates requirements that might be unmet in future conditions of scarcity. Different patterns of scarcity call for different strategies. We define a model of interacting specialists (entities) to analyze which sizing strategies are most successful in environments subjected to frequent periods of scarcity. We require entities to compete for a common resource whose scarcity changes periodically, then study the viability of entities following three different strategies through scarcity episodes of varying duration and intensity. The three sizing strategies are: aggressive, moderate, and conservative. Aggressive strategies are most effective when the episodes of scarcity are shorter and moderate; conversely, conservative strategies are most effective in cases of longer or more severe scarcity.

Key Words: Scarcity, Interacting Specialists, Agent-Based Model, Sizing Strategies, Complex Adaptive Systems, First-Mover Advantage

1 Introduction

We conducted a study to determine the selection of sizing strategies in environments subjected to dissimilar patterns of scarcity. The study utilized a configuration of the Exchange Model developed at Sandia National Laboratories to investigate complex adaptive systems (CAS) [Beyeler et. al. 2011]. A system is defined as a set of interacting entities that together serve a common objective; an adaptive system is one in which behavior changes over time due to interactions or environmental conditions; in a complex adaptive system interactions among elements additionally produce emergent, non-linear behavior. Complex adaptive systems (CAS) may share many of the same underlying processes and characteristics. The agent-based Exchange model provides a framework in which a collection of interacting specialists, or entities, which produce and consume resources, may be described. This model can be configured to represent various biological or non-biological systems. The environment

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determines the availability of resources that entities require for survival. Entities use environmental signals to determine the amount of resources to consume and produce. First movers, entities that consume/produce aggressively, are strategically the most successful in environments with excess resources, as follows the preemption of assets advantage identified by Lieberman and Montgomery [Lieberman, Montgomery 1988]. We study environments in which resource scarcity increases in both frequency and intensity to determine if there is a point at which an aggressive strategy is no longer the most advantageous strategy.

In this paper we focus on how entities utilize rate of growth and sizing to adapt to diverse, variably scarce environments (periods of scarce resource availability followed by periods of recovery). The frequency and duration of the episodes of scarcity are differentiated to investigate how entities with different sizing strategies select their adaptation for the various environments. The growth strategies are analogous to the risk tolerance of a firm. Our goal in this research is to determine which growth strategies are most effective for different levels and durations of scarcity.

2 Model Formation

For the purposes of this study, the Exchange model is configured as a system containing six entity types which produce four resources required for survival. In the Four-By-Six model configuration (detailed in Table 1), the four resources are labeled A, B, C and D. A fifth resource required by the entities, M, is not produced by any of the six entity types; the M resource is discussed in Section 2.1. This configuration sets up a symbiotic relationship among producers and consumers within the system. Each entity type consumes two resources and produces two other resources. Each resource is produced and consumed by more than one entity making the system robust while increasing competition among the entity types. An entity's health is expressed by means of a homeostatic process involving the consumption of resources.

Table 1: Four By Six Model Configuration

Entity Type	Produced Resources	Consumed Resources
CD Maker	C,D	A,B,M
BD Maker	B,D	A,C,M
BC Maker	B,C	A,D,M
AD Maker	A,D	B,C,M
AC Maker	A,C	B,D,M
AB Maker	A,B	C,D,M

2.1 Scarcity

In order to force competition among entities, a global resource M is added to the configuration. M represents a resource needed by all entities but which the entities cannot produce. Instead M is produced by an outside process at a fixed rate. Examples of such a global resource are entrepreneurship, labor, and capital investment. Initially the system produces an amount of M required by the entities. Episodes of scarcity are introduced by reducing the rate of M production for a period of time.

M is a resource that entities must qualify to receive. We create competition for the scarce resource M, which is distributed based on a measure of merit that reflects the entity's performance. The resource M is made available and exchanged in a market. Merit is determined by an entity's ability to purchase M in an open market. Entities bid for the amount of M they want to consume. The market sets the price of M based on the availability and on entity bids for M. We use an entity's bid price for M to determine the merit of entities to receive M. Entities with less M in their stores, and with more money, will bid a higher price.

2.2 Growth

Entities have the capacity to change their size over time as a function of their environment. Size is a mechanism employed by an entity to exploit or adapt to the availability of resources in an environment. Entities use size to adjust their production and consumption rates. The size of an entity is determined by the following state equation.

$$\frac{dS}{dt} = S * \frac{\left(\frac{h(t)}{h_0}\right)}{tGrowth} \tag{1}$$

Where S is the current size of an entity, $\frac{h(t)}{h_0}$ is a normalized value of health, and tGrowth is a time constant which governs the rate at which an entity can change its size. A smaller tGrowth value indicates a more aggressive sizing strategy; conversely a larger tGrowth value indicates a more conservative sizing strategy.

Initially, a size of 1 is assigned to entities. Entities can increase or decrease their size based on current health relative to nominal health. Favorable conditions cause an entity to exploit its environment and increase its size. An entity's size increases when the normalized value of health is greater than 1 causing an increase in production and consumption rates which systematically push the normalized level of health down to 1. An entity can use the same mechanism to decrease its size when the normalized level of health is less than 1. An entity strives to find equilibrium of health $\frac{h(t)}{h_0} = 1$ via size manipulations limited by tGrowth.

3. Model Configuration

The Four-By-Six configuration is suitable for three sizing strategies due to a natural pairing of entities which collectively produce all four consumed resources. Each of the symbiotic entity pairs is assigned a sizing strategy. These parings allow some entities to survive in the event that other entities pairs fail. This allows us to compare the success or failure of strategies in the model. The success or failure of entities relative to one another is reported as an aggregated statistic for each strategy. Table 2 lists the entities and their strategies. Subsequently, we will discuss strategies rather than individual pairings.

Table 2: Entity Types Sizing Strategy

Entity Type	Sizing Strategy	tGrowth
CD Maker	Aggressive	1.E+04
BD Maker	Moderate	5.E+04
BC Maker	Conservative	5.E+05
AD Maker	Conservative	5.E+05
AC Maker	Moderate	5.E+04
AB Maker	Aggressive	1.E+04

We ran each simulation for total time of 5.E+05. Five entities were realized for each entity type. The three tGrowth constants represent the three sizing strategies we are modeling. The tGrowth parameter specifies how quickly an entity can change its size by a factor of 2. The aggressive strategy has a tGrowth of 1.E+04 allowing it to change its size 500 times during the simulation. The moderate strategy has a tGrowth of 5.E+04 allowing it to change size 50 times during the simulation. Finally, the conservative strategy has a tGrowth of 5.E+05 allowing it to change size 1 time during the simulation.

We configured nine simulations to study different environments of scarcity (detailed in Table 3). Frequency describes the percent of the time entities are subjected to episodes of scarcity. Intensity is the percent reduction in the availability of the global resource M during episodes of scarcity. The model is stochastic; each simulation was run 10 times to capture the difference in outcome associated with random behavior in the model.

Table 3: Environments Configured

Simulation ID	Frequency	Intensity
1	50%	10%
2	50%	20%
3	50%	30%
4	75%	10%
5	75%	20%
6	75%	30%
7	90%	10%
8	90%	20%
9	90%	30%

3.1 Measuring Market Share

The primary output of the model is a time series of state variables describing the entities $\{e\}$ in the model [Beyeler, et. al. 2011]. There are state variables describing the health and size of entities. For comparison, we define a single value ϕ_j to measure the market share for each strategy *j* for a simulation. The following equation describes how we derive the valuation of market share for a strategy.

$$\phi_j \equiv \frac{\sum_{e \in T_j} \int_{t_f - p}^{t_f} h_{t,e} s_{t,e} dt}{\sum_{e} \int_{t_f - p}^{t_f} h_{t,e} s_{t,e} dt} \tag{2}$$

Where h_t is an internal representation of health, s_t is an internal representation of size, and T_j is the set of entities of type *j*. Multiplying health and size allows us to compare entities which have different growth strategies. For instance, an entity using an aggressive strategy may acquire a size of 5 and health of 1 whereas an entity using a conservative strategy may acquire a size of 1 and health of 5. In this case, the two entities would be considered equal. Summing h_t s_t across entities using the same strategy allows for comparisons of strategies which have different population compositions due to size. Simulation results are reported as the average market share for each strategy in a simulation over the final environmental cycle, running from time $t_f - p$ to time t_f .

4. Model Results

First we discuss general observations of the mechanics for when entities experience alternating periods of scarcity and recovery. Second, we present the detailed results of two simulations demonstrating how the strategies selected differently for each environment.

Model results are stated in terms of the average market share gained by each strategy (detailed in Table 4). The strategy with the highest percent of market share for each simulation is highlighted. Intensity is the percent reduction in the availability of resource M in periods of scarcity. Frequency is the percent of simulation time subject to periods of scarcity.

Table 4: Aggregated Simulation Results

Intensity	**10%**			**20%**			**30%**		
Frequency	**A**	**M**	**C**	**A**	**M**	**C**	**A**	**M**	**C**
50%	59%	25%	15%	52%	35%	11%	31%	25%	23%
75%	58%	24%	17%	63%	21%	15%	26%	19%	34%
90%	31%	30%	38%	33%	33%	32%	28%	40%	31%

4.1 Entities' Response to Scarcity and Recovery

Each simulation begins with entities reaching the same equilibrium for health and size. Sufficient resources exist such that no strategy has an advantage. When the first period of scarcity is initiated, entities are not able to acquire the quantity of resources they need and their health begins to decline. Entities using an aggressive strategy respond by rapidly decreasing their size in an effort to decrease their consumption rate to a point at which health is no longer declining. Entities utilizing the moderate strategy reduce their size at a much slower rate than the aggressive entities. Entities in conservative strategy group are not able to shrink their size very much and may need to survive with unmet consumption needs. Entities' reducing their size to minimize their exposure to the resource scarcity cause consumption rates to decline, consequently lessening the intensity of scarcity.

A period of recovery begins with the restoration of the amount of the global resource to pre-scarcity conditions. Nominally this would result in entities being able to converge on the same initial equilibrium for health and size. However, entities that reduced their consumption rates via a reduction in size created a reduction in demand for the global resource at the beginning of the recovery period, leading to an environment in which there is a temporary excess of the global resource. At this point, entities using the aggressive strategy begin to absorb excess resources and rapidly expand in size. Concurrently, those using the moderate strategy are growing, but at a slower rate, and entities using the conservative strategy, although not growing, are trying to consume slightly more than normal resources to restore the health lost during the episode of scarcity.

4.2 An environment 50% scarce

The first simulation we present is configured to have 10% fewer global resources over 50% of the time (see Fig. 1). In this simulation, users of the aggressive strategy dominate their competition, capturing an average of 59% of the market share. In each simulation, aggressive strategy entities compete against only one other strategy, due to the fact that their growth during a period of recovery forced users of one competing strategy out of the market. The market share gained by users of the aggressive strategy is gained from the failure of a competing strategy.

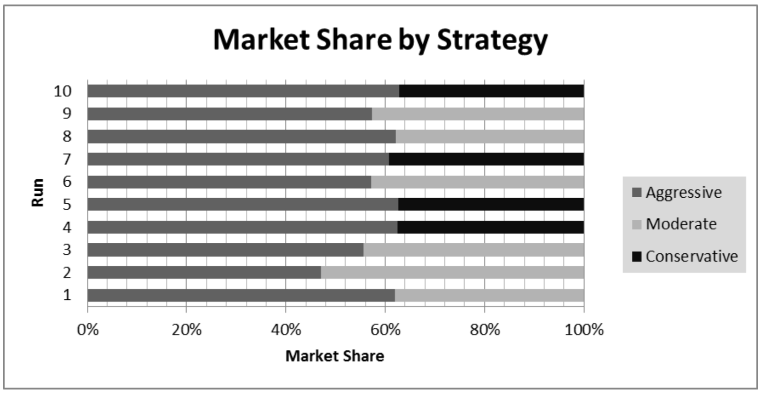

Fig. 1. Simulation Results for an environment with 10% fewer resources 50% of the time

Users of the aggressive strategy are able to take over market share by expanding during the recovery period causing the competing strategy to fail. The failure of the competing strategy occurs before the next period of scarcity begins. Once a competing strategy fails, there is more global resource availability. The increased availability of the global resource lessens the impacts of future periods of scarcity.

4.3 An environment 90% scarce

The second simulation we present is configured to have 10% reduction in the availability of the global resource over 90% of the time (see Fig 2). In this environment, the conservative strategy is the most successful, holding an average of 38% market share. This strategy is successful for users due to its slow growth. Conservative-strategy entities also benefit from the fast growth of those using the aggressive strategy due to two factors.

- The difference in how strategies respond to a decline in resources. A decline in resources triggers a decline in health because the resources necessary for consumption are limited. Strategies resulting in a faster growth rate trade a reduction in health for a reduction in size, thereby decreasing their consumption rates. Strategies resulting in a slower growth rate experience a more rapid rate of health decline due to not being able to reduce their consumption rate. A steep decline in health triggers a desire in entities to consume more resources in an effort to raise their health level. Scarcity causes aggressive entities to desire fewer resources and conservative entities to desire more resources.
- Users of the aggressive strategy free up some of the scarce resource by rapid size reduction. In the 50% scarce environment, entities using the aggressive strategy were able to dominate by growing quickly during the periods of recovery and forcing one of the competing strategies to fail. In the 90% scarce environment, the period of recovery is not long enough for aggressive entities to grow and thus they remain smaller. This frees up resources needed by the users of the conservative strategy causing them to be more successful.

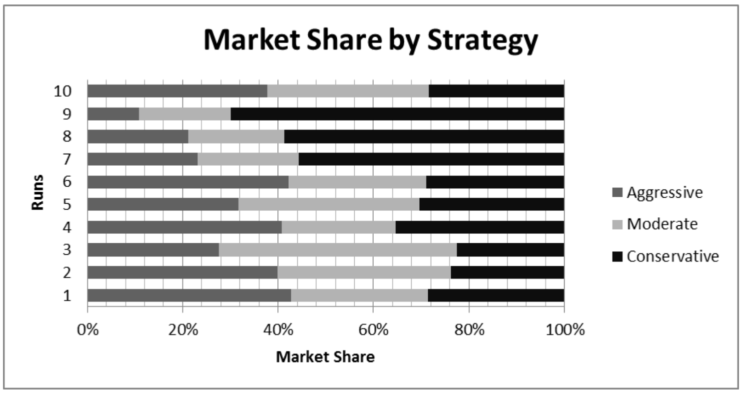

Fig. 2. Simulation Results for an environment with 10% fewer resources 90% of the time

The margin by which the conservative strategy succeeds is small; users control just over one third share of the total market. The captured market share was won from entities using the aggressive and moderate strategies, reducing their size and thus somewhat lessening the scarcity of the global resource. In order to gain a larger percentage of market share, a competing strategy would have to fail. The conservative strategy does not enable users to gain enough market share to force entities using a competing strategy to fail.

5 Conclusion

The results of the study indicate that the strategy to best select during periods of scarcity depends more on the duration of the scarcity or, more aptly, the duration of the recovery than the intensity of the scarcity. Longer periods of recovery offer entities using an aggressive strategy the opportunity to benefit from a first-mover advantage, the preemption of assets [Lieberman, Montgomery 1988]. By absorbing excess resources, users of the aggressive strategy can force entities employing a competing strategy out of the market. Once a competing strategy has failed (causing the death of those entities using it), there is more of the global resource available, enabling users of the aggressive strategy to survive future periods of scarcity more easily. Longer periods of scarcity are more advantageous for entities using a conservative strategy. The reduction in size of the aggressive entities, and subsequent decline in consumption rates, benefits entities using the conservative strategy by decreasing demand for the scarce resource. This allows users of the conservative strategy to survive the period of scarcity with a larger portion of the market share than it would otherwise have.

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