Interactive Web-based Simulations for Strategy and Sustainability:
The MIT Sloan *LearningEdge* Management Flight Simulators

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Abstract

The MIT Sloan School of Management has created a set of interactive, web-based management flight simulators to teach key ideas in business, strategy, sustainability and related fields. These simulations are freely available to anyone through the MIT Sloan *LearningEdge* portal (mitsloan.mit.edu/MSTIR/SYSTEM-DYNAMICS). Here I describe four simulations now available: *Salt Seller* (a multiplayer commodity pricing simulation); *Eclipsing the Competition* (learning curves, using the solar photovoltaic industry as the example); *Platform Wars* (competition in the presence of network externalities using the video game industry as the context); and *Fishbanks* (the Tragedy of the Commons in the context of renewable resource management, updating the classic game by Dennis Meadows). Each simulator teaches important concepts in management, strategy and/or sustainability. Each is grounded in a particular industry or firm, and comes with original case studies or briefing material describing the strategic challenges in these settings. Through these simulations, students, executives, policymakers and others can explore the consequences of different strategies so they can learn for themselves about the complex dynamics of difficult issues in a variety of important settings. I describe their purpose and use, illustrate their dynamics, and outline the instructor resources available for each.

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1. Flight Simulators for Management Education

Simulations are now an essential element in training for pilots, power plant operators, doctors, the military and many others who work in complex, high-risk settings. Management flight simulators (MFS) — simulations of complex operational and strategic issues in businesses and other organizations — also have a long history, going back at least to the Beer Distribution Game (Sterman 1989, Jarmain 1963), a board game based on the supply chain model developed by Forrester (1958, 1961).

Flight simulators in aviation and other high-risk settings are used to train personnel not merely in routine operations but in how to handle emergencies. "'Pilots don't spend their training time flying straight and level,' says airline pilot Lynn Spencer…. 'In simulator training, we're doing nothing but flying in all sorts of emergencies. Even emergencies become just another set of procedures when repeatedly trained'" (Newman 2009).

Management flight simulators also serve that function, but have a deeper purpose as well: many scholars and studies suggest that the traditional modes of instruction in colleges, universities, and professional schools, based on lecture and discussion, in which teachers play the role of "the sage on the stage" (King 1993), are ineffective, specifically in overcoming common conceptual errors, building actionable knowledge, enhancing problem solving skills and developing systems thinking abilities (the literature is massive: see, e.g., King 1993, Papert 1993, Dori and Belcher 2005, Mazur 1997, Lasry, Mazur and Watkins 2008, Kim and Pak 2002, Sterman 2000). Some scholars argue that management education, whether based on lecture or the case study method, is particularly prone to these failures (Pfeffer and Fong 2002, Mintzberg 2005).

Alternatives to the transmission model of learning are variously known as constructionism, interactive learning, learner-directed learning, or action learning, in which teachers play the role of "the guide on the side" (King 1993). Many make the case that learning and innovation in business and other organizations require similar approaches, emphasizing experimentation, simulations and "serious play" (Pfeffer and Sutton 2000, Schrage 2000, Thomke 2003, Aldrich 2009). Despite some differences, all argue that learning (only) occurs when learners (re)construct their mental models, habits, and beliefs through active engagement with the issues. Constructionists stress the importance of interaction between learners and the issues through experience and experimentation, not merely (though not entirely instead of) the presentation of facts, theory, formulae, and examples. Just as one can't become a skilled carpenter only by studying wood and tools, but must actually build things, so too one can't become a skilled pilot, surgeon, or executive without actually flying, operating, or managing. The reason is clear: from basic motor skills such as catching a baseball to sophisticated cognitive skills such as designing a circuit, there is no learning without feedback, without knowledge of the results of our actions. Transmission models provide no such feedback, while interactive, constructionist methods stress experimentation that provides rich feedback from close engagement with the material.

However, constructionist approaches face a formidable problem: we cannot directly gain experience or experiment with many important systems. In many important settings the time delays in the impacts of our decisions are far longer than the time available for learning, training, or even our career or lifespan. In others, experimentation is simply impossible—we have only one planet and cannot run experiments to determine what the impact of alternative pathways for greenhouse gas emissions will be. Even when experimentation is possible and lags are short, experience, as the saying goes, is an expensive school: in many settings (e.g., aviation, surgery, business), the consequences of mistakes can literally be fatal (e.g., crashes, medical errors, violations of safety procedures that lead to plant accidents). More subtly, in many systems, the local and distal, and short and long-term, impacts of decisions differ: what works here and now often harms the system elsewhere and later (Forrester 1969, Sterman 2011). Settings, including constructionist classrooms, in which we only experience the local, immediate consequences of our decisions may bias what we learn towards actions that may appear to be sensible, but in fact work against our own goals and values. Thus educators face a dilemma: on the one hand, one can lecture about the long-term, system-wide impacts of policies, but lecture is ineffective; on the other hand, peer instruction, demonstrations, role plays, and similar action-learning experiences that can be carried out in within the physical and temporal constraints of the classroom may systematically teach ineffective or harmful lessons. Simulations offer a resolution to the dilemma. Simulations can compress or expand time and space, allowing learners, for example, to simulate decades in the life of an airline or a century of climate change in a few minutes (Sterman 1988, Sterman *et al.* 2011a, 2011b). Management flight simulators in the system dynamics tradition have tended to address issues with long time delays and broad-scale impacts, rather than real-time tasks such as flying an aircraft or operating a power plant (e.g. Graham *et al.* 1992, Morecroft and Sterman 1994; see also the simulations available from Forio.com, iSee Systems, and Strategy Dynamics, among others). When experimentation is too slow, too costly, unethical, or just plain impossible, when the consequences of our decisions take months, years, or centuries to manifest, that is, for most of the important issues we face, simulation becomes the main—perhaps the only—way we can discover *for ourselves* how complex systems work and where high leverage points may lie.

2. The MIT Sloan Management Flight Simulators

Although some system-dynamics based MFS are freely available (e.g., the Beer Game), others are available for a fee, and some are proprietary. Simulators that are freely available are needed to enhance diffusion, particularly in the K-12 and college sectors, where funds are limited. The MIT Sloan School of Management, in keeping with the open access philosophy embodied in MIT's OpenCourseware (ocw.mit.edu) and MITx initiatives (mitx.mit.edu), established the MIT Sloan *LearningEdge* website (mitsloan.mit.edu/mstir) as a portal to provide case studies, simulations and other materials to teach management principles. All materials provided on *LearningEdge* are freely available. At present (March 2012), *LearningEdge* hosts a set of four system dynamics-based MFS, designed to teach core principles of economics, strategy, dynamics, and sustainability (more are under development).

Here I describe four simulations: *Salt Seller* (a multiplayer commodity pricing simulation); *Eclipsing the Competition* (learning curves and scale economies in the solar photovoltaic industry); *Platform Wars* (competition in the presence of network externalities using the video game industry as the context); and *Fishbanks* (the tragedy of the commons in the context of renewable resource management, updating the classic game by Dennis Meadows). Each simulator teaches important general concepts in management, strategy, sustainability, or entrepreneurship. Each is also grounded in a specific example, such as a particular industry or firm, and comes with original case studies or briefing material describing the strategic challenges faced by managers and executives in these settings. Through these simulations, students, executives, policymakers and others can explore the consequences of different strategies so they can learn for themselves about the complex dynamics of difficult issues in a variety of important settings.

Together the simulators span an array of the core concepts of competitive strategy relevant to managers, management students and anyone interested in the substantive issues, from pricing to resource management to renewable energy. Table 1 lists the simulators together with the industry and case study upon which they are based, the key concepts they address, and typical courses in which they might be used. The simulators can be used alone, or together in a sequence (as we have done at MIT Sloan, where they have been used for several years in the core MBA strategy course, and in executive education).

The most basic simulator, *Salt Seller*, gives participants the opportunity to set prices for a commodity in an important industry, but one whose cost structure and competitive dynamics are relatively straightforward: marginal production costs are constant, the product is not differentiated, and the industry is generally stable (little entry or exit, slow demand growth, slow technological change, few opportunities for cost reductions). While understanding the basic dynamics of such markets is fundamental, many products are highly differentiated, so competition takes place on other dimensions besides price. Demand is often highly dynamic, growing dramatically as new products are introduced, and as endogenous cost reductions and functionality improvements enhance the attractiveness of the products relative to alternatives. Radical, disruptive new technologies can arise and threaten the franchise of existing players. Further, many markets are characterized by various externalities, both positive and negative. Environmental damage caused by production is a negative externality; for example, emissions of CO_2 produced by firms harm human welfare by contributing to climate change, but CO_2 emitters (at present) do not pay the costs of that damage. Positive externalities arise when a firm generates benefits to others for which it is not paid: a firm's investment in fire protection to protect its assets also reduces the risk of fire to neighbors. Externalities can change the nature of competition and the optimal strategy for individual firms. The other simulators address different classes of important externalities. *Eclipsing the Competition*, based on the solar photovoltaic industry, considers competition in the presence of learning curves (also known as experience curves). In such cases, the future costs of production fall as cumulative production experience and/or investment in process improvement grow: current production generates a positive externality affecting future costs, for the firm and perhaps its rivals (when knowledge is not privately appropriable). As discussed below, the presence of such learning processes can dramatically change the nature of effective strategy.

Platform Wars expands the scope of externalities treated in the model to include direct and indirect network externalities. A direct network externality exists when the attractiveness of a product depends on the number of product users (the installed base), for example the telephone, fax, and world wide web. An indirect network externality arises when the attractiveness of a product depends significantly on the stock of complementary products or services that make the product more useful, for example, apps for smartphones, software for the Windows operating system, and Blu-Ray compatible DVDs. Competition in such markets is multi-sided; for example, a video game hardware producer such as Sony competes not only for a share of console purchases by the public but in the market for game development as it seeks to build the largest and best stock of game titles available for its platform.

The experience curve and network effects are examples of positive externalities. The fourth simulator, *Fishbanks*, addresses a pervasive negative externality: resource depletion. Fishbanks simulates competition for an open-access renewable resource. Such resources are subject to the Tragedy of the Commons (Hardin 1968); fisheries, unfortunately, offer many examples. Fishbanks offers participants an opportunity to experience the self-inflicted destruction of the resource, and the chance to negotiate and enforce self-regulation to preserve the resource and yield sustainable business success.

The simulators are all implemented in Forio Simulate (forio.com) as interactive web-sims. Users can access the simulations via any standard web-browser. Users can play as individuals or as part of a "class" – a scenario created by an instructor or workshop facilitator in which many people can play under the same conditions. The ability to create “classes” enables instructors to design a sequence of scenarios that guide participants through a structured learning sequence. For example, one can design a sequence of classes for the solar simulator that begin with the classic conditions discussed in learning curve strategy: a strong learning curve with highly elastic industry demand, myopic competitors who do not seek to price aggressively, no knowledge spillovers (i.e., all cost reductions from learning are privately appropriable and specific to the individual firm), and no possibility for the entry of radical new technologies. Other scenarios can relax these assumptions, individually or cumulatively, for example, allowing knowledge spillovers, entry of new players with radical new technologies, and/or more aggressive competitors. Instructors can also decide whether players can see the settings for a given class/scenario, and, if so, whether they can change them or not. Instructors can also access the results of the games in any class they establish, in real time as play unfolds or afterwards, to monitor and control play, present results, and download results for other purposes including research, grading or prizes. Instructors who register with *LearningEdge* also receive free access to all teaching materials for the simulations, for example, teaching notes, debrief guides, or short videos explaining how to setup and run classes and use the MFS.

3. ***Salt Seller:*** Pricing in imperfectly competitive markets

Pricing is one of the most basic decisions firms must make. Managers, management students, consumers—everyone—should understand the dynamics of pricing. Some, particularly managers and management students, have taken economics courses, mostly at the introductory level. However, few markets approximate the perfect competition described in introductory economics texts, and few firms are simple price-takers. Imperfect, or monopolistic, competition is more typical: demand at the firm level is not perfectly elastic, and many markets are dominated by a small number of firms. Price not only influences the purchasing decisions of consumers, but signals important information to the firm’s rivals. Consequently, pricing is one of the most basic strategic decisions firms must make. In imperfectly competitive markets producers have some ability to extract rents from customers, if they can signal to their rivals their willingness to focus on margin rather than market share; if successful, firms can earn abnormal returns at the expense of consumers. However, firms always face the temptation to undercut their rivals on price to gain market share. The result is often a price war that can destroy profitability for all sellers.

The Salt Seller simulation provides an interactive multi-player environment in which participants experience the challenge of setting prices in an imperfectly competitive market. Participants play the roles of salt producers in a region of North America, and bid for contracts to supply salt to customers such as counties, towns and municipalities who use salt to deice roadways in winter. The simulator is coupled with an original case study (Henderson, Sterman and Nanda 2009), which describes the salt industry, production methods, demand, and market dynamics, using the case of Compass Minerals, a salt producer on the eve of its initial public offering, to illustrate the strategic issues facing producers.

The structure and dynamics illustrated in Salt Seller are relevant to a wide range of industries, where price is a major determinant of product attractiveness and where there is either no ability to differentiate (as in pure commodities) or where imitation limits the ability to differentiate on quality, features, functionality or other attributes of the product or service. Examples include agricultural commodities, minerals, fossil fuels such as coal and natural gas, and even high-tech products such as DRAM (dynamic random access memory).

Salt is well suited as a focal case to illustrate the dynamics of pricing in imperfectly competitive markets. Salt is necessary for life and, until the 20th century, was often scarce and expensive, often more valuable than gold. Indeed, Roman soldiers were paid in salt, and the Latin word for salt, "sal" is the root of the words "soldier" and "salary" (Kurlansky 2002). Salt has played important roles in geopolitics, exemplified by the 1930 salt march, in which Ghandi and his supporters marched to the sea and made salt from evaporation of brine, in defiance of the British salt monopoly and taxes Britain imposed on salt production in India. In the 20th century, with the development of technology to mine salt from massive salt domes, the real price of salt fell, and its use increased dramatically (Figure 1). Salt today is used in a wide range of applications, including roadway deicing, water treatment, food processing, and industrial processes in chemicals, textiles, pulp and paper and oil refining. Among these, the industry and roadway deicing are by far the largest end users, together accounting for roughly three quarters of all US salt consumption (Henderson, Sterman and Nanda 2009). The largest sources of salt are rock salt and brine produced from salt domes (together approximately 80% of total production). The chemical industry predominantly uses brine, while the ice control sector is overwhelmingly dependent on rock salt.

As technology improved, real prices fell from roughly \$40-50/ton around 1900 to about \$25-30/ton in recent years (1998 dollars). However, production and especially prices vary substantially from year to year. The variations arise from both external changes in the weather and level of economic activity and from the internal responses of producers as they compete against one another.

In the deicing market, municipalities, towns, counties and others responsible for highway deicing conduct auctions each year to source rock salt in preparation for winter. As a commodity, there is little product differentiation in the salt itself. However, transportation costs constitute a large fraction of the total delivered price. Figure 2 shows the location of major salt mines in North America. There are major mines in, for example, Michigan, Ohio, Pennsylvania, Kansas, and Saskatchewan. Clearly, producers in Michigan and Ohio have an advantage relative to others with respect to municipalities in, say, Illinois, while producers in Kansas can offer lower delivered prices to cities and towns in the central states. Consequently, the market is not perfectly competitive; producers have some degree of local monopoly power based on proximity to end users.

The economic theory underlying such markets is well known. The salt market is an example of Bertrand competition, in which producers set prices (the bids they submit to end users) and then customers choose quantities from each supplier given those prices. The textbook account of Bertrand competition assumes that capacity is perfectly flexible so that producers can supply whatever customers demand, given prices; a reasonable assumption for the rock salt industry, where mines have the capacity to meet typical variations in year-to-year demand. The classic Bertrand model can be illustrated with the example of two identical producers (both with the same marginal cost). For simplicity, assume firm-level demand is infinitely price-elastic (industry-level demand has finite elasticity). If the firms could collude and had perfect information, the optimal price would be the monopoly level, which, because industry demand is not perfectly elastic, is above marginal cost; each firm would take half the market and earn the maximum margin on each ton sold, extracting rents from consumers. However, if one firm prices just below its rival, it would win the entire market and increase its profits. The other firm faces the identical incentive to undercut its rival. Consequently, each firm will undercut the other until prices fall to marginal cost, the unique Nash equilibrium for the noncooperative case.

Explicit collusion to set prices is, in the United States at least, illegal. But implicit, tacit collusion can arise through signaling. A producer may signal its willingness to maintain high prices by posting prices for its rivals to see, and by retaliating with temporary price cuts if others cut their prices. When imperfect information on costs, signaling, retaliation, and other strategic moves are introduced into the Bertrand model, pricing becomes a dynamic, multiplayer game, with outcomes including prices sustained above marginal cost, price wars that drive price down to or even below marginal cost, or periods of high prices punctuated by temporary price wars as means of retaliation to discipline producers who attempt to undercut their rivals (Green and Porter 1984).

The Salt Seller simulator creates the opportunity for participants to learn about these dynamics experientially. Salt Seller is a multiplayer simulation in which participants play the role of salt producers. Each round (simulated year), each participant enters a bid, the price at which they are willing to supply salt to end-users. Participants enter their bids independently and without knowing what the bids of others will be. After all bids are in, the simulator determines the quantity ordered from each producer, and displays industry demand, market share, firm demand, revenue, costs, profits and other key industry and financial data. Participants update their beliefs about the likely behavior of their rivals and then enter their bids for the next round.

The simulator can be played as an individual, in which case the rival is simulated by the computer using behavioral decision rules for price-setting, or in a multiplayer version, with between two and eight players (firms) competing in the market. Demand is simulated by the computer using a standard logit choice model. For simplicity, there is no entry of new firms (players), and no exit of existing firms. There are no capacity constraints and marginal production costs are constant, plausible assumptions for the salt industry over the range of variation in demand that can arise in the game.

Administrators can set a variety of parameters when creating a “class” (see above), including the industry demand elasticity, the firm-level demand elasticity (the sensitivity of market share to price in the logit choice model), the trend in industry demand, and whether demand is stochastic or deterministic (Figure 3). Instructors can select a “mystery scenario” option in which the trend in the underlying demand for salt and other parameters are not known to the players in advance.

Administrators can also set the length of the game, choosing either a fixed length or selecting a random end time (between 5 and 20 rounds). The random end time is designed to eliminate horizon effects that may arise when participants know the game is drawing to a close. For example, participants may undercut their rivals when they know there is only one or two rounds left in the belief that the game will end before their rivals can retaliate.

Finally, administrators choose how long players have to make their decisions. The default is two minutes per decision round. Testing showed two minutes to be long enough for people to deliberate and to consult with teammates (when playing in groups), but short enough to make for an exciting and fast-paced game when played in a classroom or workshop. The next round begins either when all players have submitted their decisions or when the timer expires, whichever comes first. Play typically speeds up after the first few rounds. If a player does not submit a decision before the timer expires, the prior period’s price for that player is submitted.

Figure 4 shows typical results for a two-firm game. In the top panel, the focal player, screen name “Salty Dog”, repeatedly attempts to signal an interest in higher prices, but the competitor consistently prices lower and does not respond. Salty dog is successfully exploited by the competitor: while both are profitable in the first few years, the competitor earns substantially more. In year 8, Salty Dog punishes the competitor by pricing at $19/ton, below marginal cost. The competitor responds by pricing even lower the next year, while Salty Dog raises prices to about $25/ton. As the game ends in year 10, Salty

Dog has lost a cumulative total of about $150 million, with the competitor losing roughly $300 million from year 7 through 10. In the bottom panel, the players reach a collusive equilibrium in which prices are close to equal and rise slightly each year. Market share remains approximately 50% for each, and the players resist the temptation to undercut their rival. Cumulative profits by year 11 are over $1 billion each. In the live class sessions we run, price war is far more common. One student commented, “I knew what I was supposed to do, but when [the rival firm] undercut me, I had to retaliate.”

4. *Eclipsing the Competition:* Learning Curves in the Solar Photovoltaic Industry

Competition in many of the most important industries around the world is more complex than the standard textbook model. An important class of positive externality arises from so-called increasing returns, in which costs and product attractiveness increase with the scale of production, forming positive feedbacks that can confer cumulative advantage to the market leader (Sterman 2000 provides a summary). Learning curves and scale economies are a particularly common and important class of such positive feedbacks. Eclipsing the Competition creates an interactive simulator around competition in the presence of learning curves and scale economies. Learning curves are common in a wide range of industries, and create a reinforcing feedback that can potentially confer competitive advantage on the first mover or firms that expand aggressively through low initial pricing and rapid capacity expansion.

Eclipsing the Competition focuses on the solar photovoltaic industry. The solar industry illustrates the dynamics of learning and scale well: unit costs are falling on a roughly 20% experience curve (20% cost reduction per doubling of cumulative production experience), while industry volume has been growing at 30% per year or more, doubling in less than three years (Figures 5-6). The industry is also vital to the creation of a low-carbon renewable energy system and involves significant issues of industrial policy, competition for green jobs and industry dominance among major nations, and the development of radical new technologies. Further, the solar PV industry is still in early stages of evolution. Unlike many cases used to teach strategy, the role of solar in future energy systems, and future winners and losers within the industry, have yet to be determined. The “right” strategy for producers and for governments seeking to promote their own solar industry is neither obvious nor subject to hindsight bias.

The simulator is coupled with an original case focusing on SunPower, a leading PV producer founded in the United States (Henderson, Conkling and Roberts 2007). Participants take the role of senior executives at SunPower and seek strategies for success in the presence of learning curves and scale economies. Simulation administrators can select from a wide range of settings so that participants can explore the robustness and vulnerabilities of different strategies to issues including technology spillovers, aggressive competitor pricing, and the entry of new, superior technologies.

The conventional wisdom in the popular management literature is that the presence of learning curves and scale economies favors a "Get Big Fast" (GBF) strategy. As one management book breathlessly put it, "By slashing prices below costs, winning the biggest share of industry volume, and accelerating its cost erosion, a company [can] get permanently ahead of the pack...[and build] an unchallengeable long-term cost advantage" (Rothschild 1990, 181). Similarly, in 1996 the *Wall Street Journal* noted the popularity of "the notion of increasing returns, which says that early dominance leads to near monopolies as customers become locked in and reluctant to switch to competitors. Now, dozens of companies are chasing market share" (Hill, Hardy, and Clark 1996). Aggressive strategies appear to have led to durable advantage in industries with strong learning curves such as synthetic fibers, chemicals and disposable diapers (Shaw and Shaw 1984; Lieberman 1984, Ghemawat 1984, Porter 1984), and in markets such as personal computers and e-commerce (Sterman 2000, Oliva, Sterman and Giese 2003).

The logic is captured by the feedbacks shown in Figure 7. A firm's sales (and hence production) are given by industry demand and the firm's share of that market. The greater sales, the greater the scale of operations, leading to lower unit costs through a variety of processes, from engineering scale efficiencies to greater market power in labor and factor markets (Sterman 2000, Ch. 10, notes over three dozen positive feedbacks that can lead to self-reinforcing growth of sales). Lower unit costs allow the firm to lower prices while maintaining profitability, increasing both its market share and total industry demand (the Economies of Scale loop, R1). In addition, increasing sales and production speed the accumulation of production experience, widely associated with cost reduction through learning (Argote 1999), leading to further price cuts and still greater sales (the Learning Curve loop, R2). Not all cost reduction comes from the tacit learning associated with production experience, but from investment in process improvement including explicit quality programs, better tooling and systems, partnerships with suppliers, and so on. Higher sales (and revenue) allow the firm to increase its investment in process improvement, lowering costs and prices, and further increasing sales (the Process Improvement loop, R3). To gain the initial advantage and drive these loops faster than its rivals, a firm can lower price, even below initial cost; indeed, Spence (1979) famously showed that the optimal, profit maximizing policy for a monopolist in the presence of a learning curve is to price initially at the final cost, entailing an initial period of losses. A large literature (see Sterman et al. 2007 for a summary) extends this insight to more complex situations.

However, the literature has also identified a variety of limits to the GBF strategy (Sterman et al. 2007). If know-how is not privately appropriable, spillovers from imitation, reverse engineering of rivals' products, and so on allow laggard firms to benefit from the cost advantage of larger rivals, dissipating the advantages aggressors pay so dearly (through process investment and low prices) to acquire (Ghemawat and Spence 1985). Similarly, uncertainty, including the possibility of entry by new players with better, disruptive technologies, reduces the advantage of the GBF strategy. Finally, long capacity adjustment delays and forecasting errors can lead to capacity overshoot and losses that overwhelm the cost advantage of aggressive strategies (Paich and Sterman 1993, Sterman *et al.* 2007). These processes create negative feedbacks that undermine the effectiveness of the reinforcing feedbacks created by scale and learning.

Eclipsing the Competition offers the ability to examine all these issues. Players take the role of the senior executives of SunPower and seek to maximize their profits over a twenty-year time horizon, competing against simulated rivals, including potential new entrants. Participants set the price for their solar modules and the budget for process improvement (as a fraction of their gross revenue).

The simulator includes settings that enable players or instructors to create scenarios spanning a wide array of conditions for the market, competitor behavior, cost reduction and industry demand (Figure 8). In individual mode, the player can choose the settings. When playing as part of a class, the class administrator sets these values. The settings in the box at the bottom of the list are available only to administrators when setting up a class, and determine whether players can see and/or change the settings in that scenario.

The settings provide control over the assumed price of grid power over time, including the possibility of phasing in a carbon tax, along with any subsidy available for solar PV (subsidies may be direct rebates or tax credits). The settings also provide control over competitor strategy. Each competitor sets prices based on their unit costs, adjusted by their local demand/supply balance and by the prices of the other players (see Sterman *et al.* 2007 and Paich and Sterman 1993 for the pricing heuristics used). The competitor price policy can be set with a goal of matching the player ("neutral"), or to range from Very Low, to Low, to High, to Very High relative to the player's price. Setting the competitor price policy Low or Very Low simulates the case where the competitors always seek price leadership in an attempt to pursue the GBF strategy. In addition, choosing "Competitor Always Prices Lower" ensures that the competitor always offers the lowest price, no matter what the player chooses, a useful setting to illustrate one failure mode for the GBF strategy. One can also choose the level of process investment for the competitor, (High, Medium or Low); to simulate the GBF strategy one might select High to capture settings in which competitors aggressively pursue cost reduction through heavy investment in process improvement. Settings also include the strength of the experience curve, how much of the cost reduction arises from process improvement (which requires investment) vs. tacit learning arising from cumulative production experience (which has no direct costs), and the existence and lags in knowledge spillovers (which need not be symmetric). One can also enable the entry of new players and the magnitude of the technical breakthroughs leading to new competitors, either Low, Medium, High or Very High.

Finally, when creating a class, instructors have the option of allowing players to view the settings or not, and, if allowing them to view them, whether the players can change the settings. Typically, players would be allowed to view but not change settings in their initial scenarios. In later scenarios, it is useful to hide the settings since the strength of the learning curve, strategy used by the competitor, and other key parameters are never known in advance in realistic situations.

People can play as an individual or as part of a "class" in which the faculty member chooses the settings so that all participants in the class play under the same conditions. By setting up multiple classes, a faculty member can create a sequence of scenarios that illustrate different lessons. A typical sequence for Eclipsing the Competition might begin with the default settings, in which there are no knowledge spillovers, the competitors play conservatively and do not pursue the aggressive, GBF strategy, and there are no technical breakthroughs that lead to entry of new firms with radical new solar technologies: these settings capture the classic case in which an aggressive strategy leads to durable competitive advantage. Next, one can add knowledge spillovers, or have the competitors play aggressively, or allow entry of new firms, alone or in combinations, to explore the limits to the GBF strategy. One can also examine scenarios with different paths for the price of grid power, for solar PV subsidies, and for a carbon price to explore how the market as a whole responds to changes in the overall competitiveness of solar compared to conventional power. Finally, one can challenge the robustness of player strategies to uncertainty in market and competitive conditions by choosing settings but hiding them from the players, or by enabling the "Mystery Scenario" in which the key settings are chosen randomly.

As detailed in the case study, SunPower's competitive advantage rests on their proprietary technology, which (as of the date of the case, 2006-2007), allowed them to produce the highest efficiency modules on the market. However, competitors, including Chinese producers, were pricing lower and rapidly scaling up. SunPower (and the player) must decide how aggressively to price and how much to invest in further process improvement to continue to build advantage in the performance/price ratio for their modules. The case study not only examines the strategic challenges facing firms in the industry, but also describes the PV industry, including its value chain, cost structure, electricity pricing, and the role of government incentives for solar installation. Module prices are typically given in $/peak Watt of capacity, but consumers are interested in the cost of solar per kilowatt hour compared to the cost per kWh of conventional grid power. Players learn how to determine the effective cost per kWh from module prices per peak watt together with available hours of sunlight in any location, module efficiency, installation/system integration costs, subsidies and other factors. Further, the case and accompanying slides and introductory video document the heterogeneity in both the solar resource (based on latitude and local climate), in the price of grid power, and in the patchwork of national, state and other subsidies, feed in tariffs, renewable performance standards, and tax credits that affect the final price consumers face (Figures 9-10). Heterogeneity means that there are regions in the US, and other parts of the world, in which solar PV offers a lower price to consumers than conventional, grid power, even when the average cost is higher than the average grid price. The holy grail for solar producers is "grid parity" – the point at which the cost of solar per kWh becomes equal to the cost of conventional power from the grid. At that point, solar moves from a niche technology, useful in particularly sunny locations with high power costs or solar subsidies, to a mainstream source of electric power.[1]

Figure 11 shows the main screen, with a successful strategy for SunPower in the default settings. In the default settings, learning and cost reductions are perfectly privately appropriable – there are no knowledge spillovers from one firm to another. The competitors play conservatively and do not pursue the GBF strategy, allowing SunPower to exploit their myopia. There is no entry of new players with radically superior solar technologies. These are the classic conditions in which a GBF strategy is optimal, and, as illustrated in Figure 11, by consistently pricing below its competitors and investing a higher fraction of revenue in process improvement, the player "Helios" is able to drive its costs, initially higher than the competitors, down the learning curve faster and become the cost leader by 2023, while gaining market share and earning high profits. Further, as shown in Figure 12, cost reductions and aggressive pricing lead solar PV as a whole to reach grid parity by approximately 2017, triggering explosive growth in total demand, which further speeds cost reduction.

Of course the model is not intended to be predictive, and the default settings, while helping participants learn about the classic learning curve strategy, are not realistic. Figure 13 shows a scenario in which (1) knowledge spillovers allow high cost players to lower their costs towards those of the cost leader, with a lag specified by the administrator, here set to 2 years; (2) the competitors also pursue the learning curve GBF strategy by pricing low relative to their costs and investing heavily in process improvement; and (3) new players, with radical new technologies, can enter the market.[2] Under these

[1] As an intermittent power source, widespread adoption of solar PV also require a solution to the load balancing problem, either by coupling solar with complementary power sources such as hydro or gas turbines whose output can be adjusted rapidly to compensate for variations in solar inputs to the grid, through real time pricing that can adjust demand, and/or through storage technologies to buffer the difference between solar output and load.

[2] The entry of new players (when enabled) is stochastic and endogenous: each period there is some chance that ongoing research carried out by universities, governments or private firms will yield a new technology with costs far enough below current prices to form a new firm. Thus the higher the price of solar, the more likely any new innovation will be competitive and be able to attract the funding needed to enter the market. New innovations also benefit, with a lag, from knowledge spillovers from incumbents.

conditions the GBF strategy is not effective: Although the player pursues a strategy of price leadership, using the Competitive Discount mode of price setting to offer prices that are always a certain percentage lower than the average of the competitors' prices, the competitors are also pursuing the GBF strategy and so lower their prices in response, leading to an industry-wide price war that destroys profitability for both the player and the industry as a whole. Further, despite the low prices, eventually six new firms with radical new technologies enter the market. These new firms can offer prices far below those of the player and its conventional rivals. Despite aggressive pursuit of the GBF strategy, SunPower experiences massive losses (cumulatively $311 billion by 2025). Obviously, SunPower would have gone bankrupt long before. These examples provide only two examples of the rich variety of scenarios that can be explored with the simulator.

5. *Platform Wars:* Competition in the presence of network externalities

Platform Wars explores competition in the video game industry. Participants play the role of senior executives of a video game hardware maker, and seek success as they compete against other producers by setting prices for their gaming console, and by influencing the number of games design firms will produce for their platform by setting the royalty rates game designers must pay, and possibly choosing to subsidize game production.

The simulator is built on an original case, "Sony's Battle for Video Game Supremacy," (Sterman, Jekarl and Reavis 2011), which begins on eve of the launch of Sony's PlayStation 3 in late 2006:

> As Sir Howard Stringer, CEO of Sony Corporation, settled in for his flight back to Japan from New York, a number of pressing issues occupied his mind about Sony's future. At the forefront, Sony's next generation video game console, the PlayStation 3 (PS3), was set to launch worldwide on November 17, 2006, a mere week away. Despite PlayStation 2's (PS2) dominance in the last generation of gaming consoles, Stringer understood that past successes were no guarantee of future success in the intensely competitive game industry.
>
> Microsoft had launched the first volley in the last console war by releasing the Xbox 360 in the fall of 2005. Within one year, almost 4 million Xbox 360s had been sold worldwide, giving Microsoft a significant head-start in the race for market dominance. Meanwhile, Nintendo, a competitor thought to be dead due to the lackluster sales of its previous console, the Nintendo Gamecube, had generated significant "buzz" around its new entry, the Nintendo Wii (pronounced "we").

The video game industry is a prime example of a multi-sided market (Parker and van Alstyne 2005) with demand-side increasing returns, specifically direct and indirect network externalities. The direct network externality is created by the desire of gamers to have systems compatible with those of their friends: gaming is highly social, and people like to be able to play with others, either in person or online. The indirect externality is created by the desire of gamers to buy systems compatible with the widest selection of the most popular games, and the desire of game designers to write for the platforms with the largest (expected) installed base of customers. Such dynamics are critical to a wide range of technologies, e.g., personal computer platforms (e.g., Macintosh vs. Wintel), home video players (e.g. Blu-Ray vs. HD-DVD), mobile phones (e.g. iPhone vs Android), MP3 players, news media, social media such as Facebook and Twitter, and many others, including current efforts to replace automobiles powered by internal combustion engines fueled by gasoline with alternative fuel vehicles such as battery electrics, plug in hybrids and others (Struben and Sterman 2008).

The presence of direct and indirect network externalities means success in the marketplace depends as much or more on the size of the installed base and the number and scope of complementary products available for the platform as it does on price, quality, functionality and other traditional attributes of product attractiveness. Much of the literature stresses the importance of building an initial lead in installed base and complements (Arthur 1989, Katz and Shapiro 1994, Shapiro and Varian 1999, Fudenberg and Tirole 2000, Parker and van Alstyne 2005).

Consider the battle for the home VCR market (Sterman 2000, Ch. 10). Sony's proprietary Betamax technology was the first cassette-based home video technology to reach the market, some 18 months ahead of its principal rival, the VHS standard, launched by a consortium of Matsushita, JVC, and RCA (Cusumano, Mylonadis, and Rosenbloom 1992). Though Betamax and VHS technologies cost about the same, the tapes and machines were not compatible. Consumers had to choose which standard to adopt. The attractiveness of each format depends on various factors, including price, picture quality, play time, and machine features such as programmability, ease of use, size, and remote control, among others.

However, the most important determinant of product attractiveness is compatibility. To swap tapes with their friends and families people had to have compatible machines. As the installed base of machines of a given format increased, the attractiveness of that format to potential new buyers increased, which in turn increased the market share of that format and boosted the installed base even further. Even more importantly, people tended to buy machines compatible with the broadest selection of prerecorded tapes. Video rental shops chose to stock tapes in the most common format since these would rent more often and yield more profit. Movie studios, in turn, chose to offer their films in the format compatible with the most widely available format.

Sterman (2000, Ch. 10) analyzes the feedback structure of the direct and indirect network externalities and links them to dozens of other positive feedbacks that can confer cumulative competitive advantage. The key feedbacks created by direct and indirect network externalities are shown in Figure 14. Sales of any firm's product are determined by industry demand and the firm's market share. Higher sales speed the growth of the installed base of the firm's product (for simplicity, discards and obsolescence are not shown). In multi-sided platform markets with a direct network externality, the attractiveness of the product to potential customers depends not only on traditional factors such as price, quality, functionality, and so on but also on the number of others who also own that product. Thus the larger the installed base, the more attractive that firm's product, the greater market share will be, and the faster the installed base will grow (the Network Effect loops R1a and R1b). In addition, the larger the installed base of a firm's product, the larger the expected size of the market for that platform will be, as judged by producers of complementary products (video rental stores and movie studies in the VCR case, app developers in the smartphone industry, game producers in the video game industry). The larger the expected market for a particular platform, the greater the expected profits to complement producers who build for that platform, and, after a delay, the larger the installed base of complements for that platform will be. As the scope and availability of complements grows, the attractiveness of that platform rises further, leading to still greater sales (the Complementary Goods Effect loops R2a and R2b).

Competition in platform markets is rarely as simple as in the battle between Betamax and VHS, with two incompatible, proprietary platforms. In many current platform battles, complementors have the option of producing content that can be ported over to multiple platforms, with costs and production delays that can vary from case to case. If costs are low and the delays short, the indirect network externality is weakened. Similarly, hardware makers can choose to offer versions of their product that can run the software of rivals, weakening the direct network effect. The ability to run Microsoft Windows on Apple Macintosh computers through Boot Camp or third party Windows emulators such as VMWare Fusion or Parallels provides a recent example: those purchasing Macs can, at low cost, run both the Mac OS and Windows, obviating much of the installed base advantage of Windows in the PC market.

Administrators may choose settings to create a wide range of scenarios (Figure 15). The settings include determining the order of entry for the player and simulated competitor. The default is simultaneous entry with an initially level playing field, but one can allow either the player or simulated competitor to enter first. Administrators can also set the strength of the direct and indirect network effects by controlling the sensitivity of product attractiveness to the installed base of consoles and to the availability of games. Parameters governing the strategy used by the simulated competitor include whether the competitor chooses to subsidize the production of games produced for its platform, and if so, the magnitude of the subsidy, how aggressively the competitor prices its hardware relative to the player's price, the competitor's target market share (which affects competitor pricing and other decisions), and the initial royalty the competitor charges game producers for the right to produce for its platform. Parameters governing the strategy followed by game developers include whether developers can migrate their games from one platform to the other, and what the costs and delays of such migration are relative to developing a new game. If migration is not enabled the situation is much like that characterizing VCRs or Blu-Ray vs HD-DVD, with incompatible proprietary formats. If migration is enabled and the costs and delays are low enough, then all content produced by complementors rapidly becomes available for both platforms, weakening the indirect network effect. Finally, administrators, in setting up a class (scenario) have the option of hiding the settings from players (the realistic case) or allowing them to see the settings for pedagogical purposes, and, if so, whether players can modify the settings themselves to encourage sensitivity analysis and experimentation.

Figure 16 shows a typical game with the default settings. The player pursues an aggressive strategy to jump start the direct and indirect network externalities by setting the console price lower than the initial $250/unit, by cutting the royalty charged game designers from 30 to 20%, and by subsidizing the production of 20 games/year. The competitor responds by undercutting the player on console prices, but subsidizes fewer games and only slowly cuts the royalty rate. Although the competitor has a slight market share advantage for the first two years, soon the number of game titles available for the player's platform outstrips the number available for the competitor. The broader scope of titles further increases the attractiveness of the player's platform to consumers, and market share begins to rise. By year 4 the player stops lowering console prices and then cuts the number of games subsidized to zero. Although the competitor continues to undercut the player on console prices and eventually even on royalty rates, the large advantage in game titles and in the installed base of the player's platform tips the market in favor of the player, who achieves 95% market share by year 10. The player ultimately earns cumulative profits of $2.8 billion, while the competitor cumulatively loses money. The dynamics are quite similar to the results for the battle between Betamax and VHS in the home VCR market, illustrating the power of the positive feedbacks created by the direct and indirect network effects.

Competitive conditions are more complex in many platform wars today, including the Video Game industry. Figure 17 shows the result of the same strategy when the settings are changed to enable complementors (game producers) to migrate their games quickly and at low cost from one platform to another, and where the competitor pursues an aggressive strategy, including low console pricing relative to the player, aggressive game subsidies, and an initial royalty rate of 20% (matching that of the player). Now the market tips the other way, with the competitor winning 90% of the market and earning cumulative profits of $6 billion, while the player loses $2.3 billion.

A good pedagogical sequence of "classes" (scenarios) begins with the default parameters, representing the classic case of proprietary, incompatible formats without the ability to migrate content from one platform to another. Subsequent classes can relax these assumptions, introducing more realistic behavior for complementors, more aggressive competitor behavior, and variations in the strengths of the direct and indirect network effects, so that participants not only learn how the market tends to tip towards the most aggressive player, but also what the limits to such aggressive strategies are as the feedback structure of the market varies.

6. *Fishbanks:* Renewable Resource Management and The Tragedy of the Commons

Fishbanks is a simulation of an open-access fishery in which players compete to maximize the economic value of their "fishing companies". The simulation exposes participants to the Tragedy of the Commons (Hardin 1968), the dynamics of renewable resources, and the challenges of designing, implementing and enforcing policies for sustainable resource management. The web-based version described here updates and extends the classic game designed by Dennis Meadows, which is played with a board and physical pieces representing ships (Meadows *et al.* 1986). In its various forms, the game has been played thousands of times around the world, with participants ranging from elementary school students to senior business and government officials.

Fishbanks is a dynamic, multi-player game in which players seek to maximize their net worth in an open-access fishery. The simulation interface provides players with information about current market and fishery conditions. During each round, players make two types of decisions: (1) they can change the size of their fleet by buying, selling, or ordering ships, and (2) they decide how to use their fleet by sending their ships to the deep sea fishery, the coastal fishery, or keeping them in the harbor. Players can also try to negotiate agreements to manage the fishery more sustainably and equitably, and the game allows administration of fishing quotas, permits, boat buyback programs, and other policies players may wish to implement after negotiating with the other teams.

Fishbanks can be played with 1 to 10 teams (fishing companies) per "ocean"; 6-8 teams, with 2 to 4 people on each team (about 10 to 50 people in total), are best. To accommodate larger groups, multiple oceans can be played simultaneously. The author has run the simulation with 90 people in three oceans; more are possible. The facilitator monitors and paces each game. The simulation keeps track of fish stocks, recruitment (growth in fish stocks), catch per ship, profits and losses, the market value of ships, and other information. The game can be run in a workshop or classroom in a typical 80-minute class period. Fishbanks also supports an asynchronous mode in which players make decisions any time during a specified interval such as a day over the course of a week. In either live or asynchronous mode, players can be physically co-located or located anywhere in the world, as long as they have Internet access.

Instructors who register with *LearningEdge* will find additional teaching resources including a video teaching note demonstrating the game, a full teaching note with debriefing guide, and slide decks for briefing and debriefing.

Fishbanks creates the opportunity for people to learn fundamental lessons about the sustainable management of renewable resources. These lessons include:

Resource Dynamics: To be sustainable, resource extraction and degradation must be balanced by regeneration and renewal: fish can be taken no faster than they reproduce, trees can be cut no faster than new ones grow, carbon dioxide can be emitted into the atmosphere no faster than it is removed. Regeneration and renewal for many important resources, including fish and other fauna, forests and other flora, and fresh water are not constant, but depend on the state of the resource. For biological resources such as fish and forests, the level of the resource is limited by the carrying capacity of the ecosystems that support them. Prior to exploitation, the resource stock will be, on average, near the maximum level the ecosystem can support. As extraction rises, resource stocks fall, but regeneration will tend to rise as each remaining organism has more food, space and other resources it needs to reproduce. The ecosystem compensates for extraction: the more you take, the more grow back. However, when the resource becomes sufficiently depleted, regeneration peaks and falls—at some point there are simply too few fish remaining for reproduction to offset extraction. Now the dynamics shift: the more you take, the fewer grow back. The smaller the remaining resource stock, the smaller the rate of regeneration, further lowering the stock in a vicious cycle that can rapidly lead to resource collapse (Sterman 2012).

The Tragedy of the Commons: Historically, a "commons" was the common pasture on which any villager could graze their livestock. In contrast to private property, such "common pool" or "open access" resources can be freely used by anyone. If such resources are managed to maximize total profit or social welfare, extraction would be limited to no more than the maximum sustainable yield. However, common pool resources are subject to overexploitation: it is rational for each extractor to expand their take as long as it is profitable to do so. Combined with resource dynamics (see above), the result is often the destruction of the resource. The tragedy arises not merely because the resource is destroyed, but because the resource is destroyed as a consequence of each individual's rational pursuit of self-interest: the profits from taking one more fish or cutting one more tree benefit the individual extractor today while the costs of lower future harvests are borne by all (Hardin 1968). An individual who stops harvesting simply allows others to take a little more, with no change in the outcome, so it is not rational to reduce your own take.

Misperceptions of Feedback: Research shows people do not understand the basic dynamics of resource accumulation, nor the feedback processes that control extraction and regeneration (Sterman

2011). Further, extractors and policymakers often have poor knowledge of the ecological relationships governing regeneration and resource levels. Stock levels, regeneration, and even harvest rates are often known imperfectly. There are long delays in estimating and reporting resource stocks, harvests and regeneration. Thus, even if fisheries were fully privatized, thereby eliminating the incentives for overexploitation that create the Tragedy of the Commons, extractors will likely overharvest. Experiments show exactly this with simulated fisheries: participants operating a fully private fishery still overexpand their fleets, overharvest, and lose money (Moxnes 1998, Sterman and King 2011a, b). Further, there are delays in building up extraction capacity, and investments in capacity are often long-lived and largely irreversible, not least because entire communities and economies grow up around the extractive activity. Political interests in continued extraction cause opposition to and delays in the implementation of government policies or industry self-regulation to preserve the resource. Many open access resources involve extractors from different communities and nations, leading to additional delay while laws are debated and treaties negotiated. Misperceptions of the feedbacks governing resources, poor information, long delays and irreversible commitments often doom the resource and the communities dependent on it. By the time the community discovers that they are harvesting unsustainably, it is often too late.

Successful Governance of the Commons Is Possible: While the barriers to successful management of common pool resources are formidable, it is possible for communities to govern their common resources sustainably. Political scientist Elinor Ostrom has documented many examples and analyzed the conditions for successful governance, winning the Nobel Memorial Prize in Economic Sciences in 2009 for her work (see e.g. Ostrom 2009, Ostrom et al. 2010, Ostrom and Hess 2007). Successful management of the commons has been documented on a variety of scales, from local communities such as individual fishing villages to the public provision of community services such as police, firefighting, education, and libraries, to global agreements such as the Nuclear Test Ban Treaty, which bans atmospheric atomic weapons tests, and the Montreal Protocol, which limits production of halocarbons that destroy stratospheric ozone. Governance can be initiated and maintained by informal relationships among community members, but often, and particularly for larger resource systems with more and more diverse actors, requires agreements, monitoring methods, enforcement mechanisms and other policies that are institutionalized in formal laws and regulations (at local, state/provincial, national or international levels). Such agreements enable communities to act collectively to improve societal welfare.

Fishbanks provides instructors with complete control over parameters including the number of teams per ocean, number of oceans, initial fleet and cash per team, fish prices, fleet operating costs, fish stocks, recruitment and catch per boat as they depend on fish density, limits (if any) on new ship orders by individual teams, procedures for determination of ship market value, and others (the briefing guide provides full details). During play the instructor monitors the progress of the game, decides when each decision phase begins and ends, and controls the pace of play. Through the game monitor page the instructor has the option to run ship auctions and implement boat buy backs programs, permits/quotas and other policies. The instructor can also project a wide range of results on the screen for teams to see.

Each simulated year (decision round) consists of two phases. First, in the auction phase, players may elect to offer some or all of their ships for sale at auction, and may bid on ships offered by others (Figure 18). Auctions are conducted through the simulation interface. Second, in the allocation and ordering phase, players decide how many of their ships to deploy to the deep sea and coastal fisheries; they may also elect to keep some or all of their ships in the harbor. Players also decide how many new ships to order from the shipyard. The display always shows information on the player's current fleet size, bank balance, and other key data, along with information on the expected catch in the coastal and deep fisheries and the expected profit from sending a ship to each, or of keeping a ship in the harbor. Players may also use the tabs at the top of the screen to access a wide range of additional data about their fleet and financial position, auction history, ship market values, and so on. Through the chat function players can send messages to all other teams in their ocean or to individual teams. In workshop mode, with play in real time in the same room, chat is often used, though most interaction is face-to-face, as in the traditional game. In asynchronous mode, or if the players are not physically co-located, chat provides a channel for negotiation and communication among the players. In the second phase of each round, players decide where to allocate their fleet among the deep sea fishery, coastal fishery, and harbor, and how many new ships to order from the shipyard (Figure 19).

Figure 20 shows results from a session with a group of senior executives from a large multinational company. Here eight teams competed in the Atlantic Ocean. With three ships each to start, the total initial fleet is about half the maximum sustainable fleet size. However, high fish stocks mean fishing is highly profitable at the start, particularly in the deep sea. The total fleet rapidly expands. By year 4 intense fishing has significantly depleted deep-sea stocks, reducing catch per ship there and causing profits to plummet. The teams rapidly shift their fleet to the coastal fishery, quickly depleting it. By year 7 fishing is unprofitable overall, forcing the teams to lay up most of their fleet in the harbor, where the annual loss is less than the losses incurred by sending the fleet out. After rising from $300 to nearly $800 per ship, the market value of the fleet plummets after year 5. By the end, fish stocks have collapsed and the total assets of the fishers are significantly negative.

Figure 21 shows the total fleet and fish stocks for two other examples, with students at the MIT Sloan

School of Management. Here fleet growth stopped near or slightly above the maximum sustainable level, and the players, recognizing the impending collapse of their fisheries, were able, more or less successfully, to stabilize their fish stocks by negotiating an agreement in which all teams voluntarily committed to laying up part of their fleet in the harbor to limit overfishing. The players in the Pacific Ocean in this example are less successful, in part because they collectively overbuilt their fleet farther above the maximum sustainable level, forcing larger losses on each team, which increases the incentive to defect and send the fleet out to fish. The players in the Atlantic Ocean in Figure 21 are more successful and achieve positive profits, though there is evidence of some defection towards the end of the game (likely a horizon effect as players knew the session was drawing to a close).

7. Summary

Research shows that the transmission model of teaching is often ineffective, particularly in overcoming erroneous mental models and developing the problem solving skills and other capabilities needed to manage modern businesses and other organizations effectively. In response, many scholars and educators advocate a shift to learner-directed learning, emphasizing active engagement by learners with the issues and systems of concern. Simulation models are required to create the opportunity to gain experience and carry out experiments in complex systems, such as a business, market, or ecosystem, where the time lags and scope of the system extend beyond the confines of the classroom and time available for instruction. Here I described a set of interactive, web-based Management Flight Simulators designed to help students, managers and others learn key concepts in strategic management, system dynamics and related fields. The simulations, all freely available through the MIT Sloan *LearningEdge* portal, span a range of important economic and strategic issues, including pricing, learning and scale economies, competition in the presence of network externalities, and common pool resource management. Each is built around a concrete industry or firm to provide realism and context; these include the salt, solar photovoltaic, video game, and fishing industries. Playable by individuals, instructors can also design “classes”—scenarios—to guide students through structured sequences of market and competitive conditions. Each simulator comes with an associated case study and introductory and instructional material for learners and teachers.

Future work should include assessment of simulator effectiveness, but that important task must await the collection of sufficient data as the simulators are used with various audiences.

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	Salt Seller	**Eclipsing the Competition**	**Platform Wars**	**Fishbanks**
Strategic issues addressed:	Pricing dynamics in imperfectly competitive markets	Strategy in the presence of learning curves and scale economies	Strategy in multi-sided platform markets; direct and indirect network externalities	The Tragedy of the Commons; Strategy for open-access renewable resources
Industry focus/case study:	Salt Industry	Solar Photovoltaic Industry	Video Game Industry	Fisheries
Accompanying Case study:	Compass Minerals	SunPower	Sony PS3	Multiple examples
Single or Multiplayer:	Multi player or play against the computer	Play against the computer	Play against the computer	Multi-player
Simultaneous Players:	1 to 8 players in each market; simultaneous multiple markets supported	Unlimited	Unlimited	1 to 10 fishing companies per ocean; multiple simultaneous oceans supported
Useful in courses:	Economics, Strategy, Decisionmaking, Game Theory System Dynamics	Economics, Strategy, Technology Policy Energy Policy, Environmental Policy, Sustainability, System Dynamics	Economics, Strategy, Technology Policy System Dynamics	Economics, Strategy, Negotiations, Sustainability, Environmental Studies, Public Policy, Resource Economics, System Dynamics

Table 1. *LearningEdge* simulators with key attributes and uses.

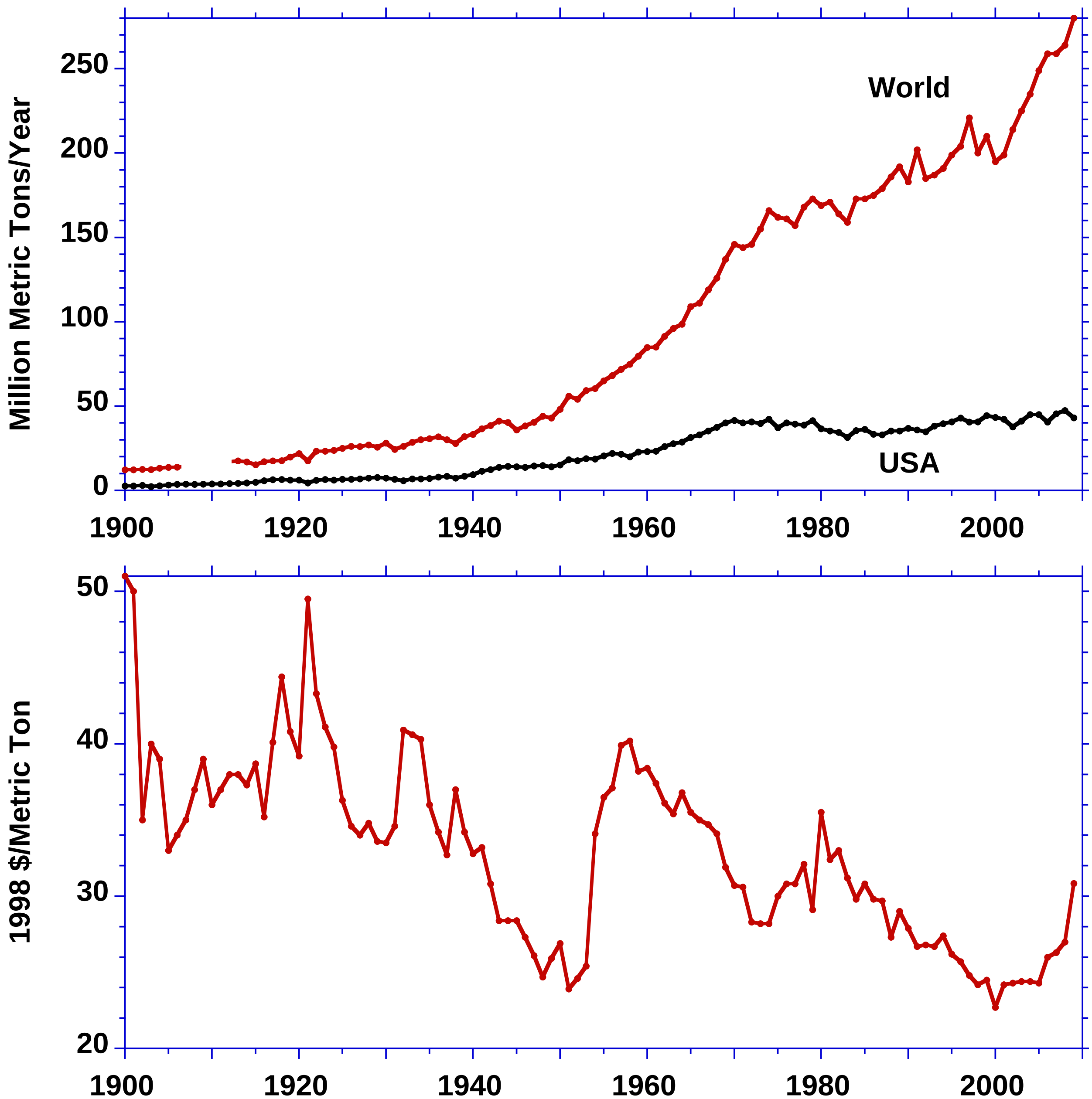

Figure 1 Top: US and World salt production, million metric tons/year. Bottom: Real US salt price, average of all production methods, 1998$/metric ton. Source: US Geological Survey, http://minerals.usgs.gov/ds/2005/140/; see also Henderson, Sterman and Nanda (2009).

Figure 2. Major salt deposits and production sites in North America. Source: The Salt Institute; Henderson, Sterman and Nanda 2009.

Sensitivity of Industry Demand to price: Low

The Sensitivity of Industry Demand to Price determines how the total demand for salt changes as the average price of salt changes.

If the price of salt rises, towns and municipalities economize by spreading less salt during winter (and hope for mild weather!). If the price of salt decreases, they spread a bit more to make the roads safer. The higher the sensitivity, the larger the change in industry demand for a given change in price, as illustrated by the graph

Sensitivity of Product Attractiveness to price: High

Towns and municipalities choose which supplier to use based on the availability and, especially, the price of salt. If your firm offers salt at lower prices than your competitor, you will receive a larger share of demand. If your competitor offers a lower price, they will receive a larger share. Because transportation costs are a significant fraction of the delivered total cost, and because customers are located in different regions relative to the salt mines you and your competitor operate, some customers will find it attractive to buy from your competitor even if your price is somewhat lower. The Sensitivity of Product Attractiveness to Price determines how responsive market share is to the changes in the prices offered by each player. The higher the sensitivity, the sharper the drop in demand for your product as you raise your price above that of your competitor, as illustrated by the graph.

Change of Industry Demand: Constant

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The total demand for salt has varied over the past few decades. Since highway de-icing is the main use for salt in North America, demand grows as the number of automobiles and lane-miles of paved roads grows. However, greater use of salt for de-icing over the past decades has caused significant environmental damage, including dieback of vegetation along highways and contamination of fresh water supplies. The demand for salt may fall as towns, states, or the federal government act to protect water supplies.

To capture the uncertainty around future salt demand you may face several scenarios for industry demand (shown in the graph):

1. **Growth:** Steady growth in industry demand, reflecting construction of additional roads and highways, with no or limited regulatory limits on salt use.
2. **Constant:** Industry demand for salt remains constant.
3. **Decline:** Steady decline in industry demand, reflecting increasing regulatory pressure to limit salt use or apply substitutes to protect the environment.

In addition, you may face scenarios in which the demand for salt varies from year to year due to random changes in the weather.

These scenarios describe how total industry demand for salt would evolve over time assuming the price of salt remains constant in real terms. Actual industry demand will vary around the scenario you select as the actual prices vary, as determined by the industry demand elasticity you set.

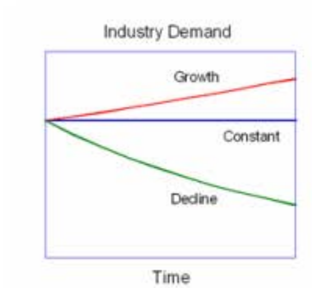
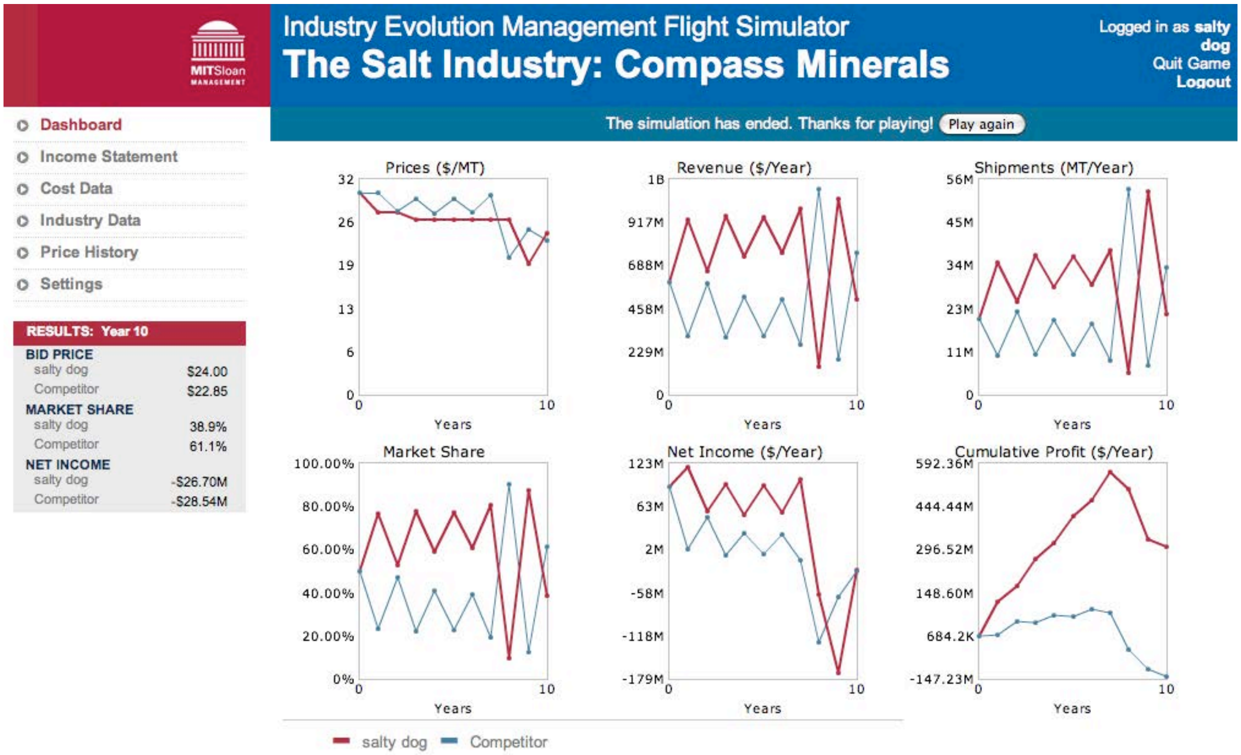


Figure 3. Scenario settings in the Salt Seller simulator. Administrators can choose a variety of values for key parameters to capture a wide range of market conditions. Administrators can also add random variation to the trend in demand.



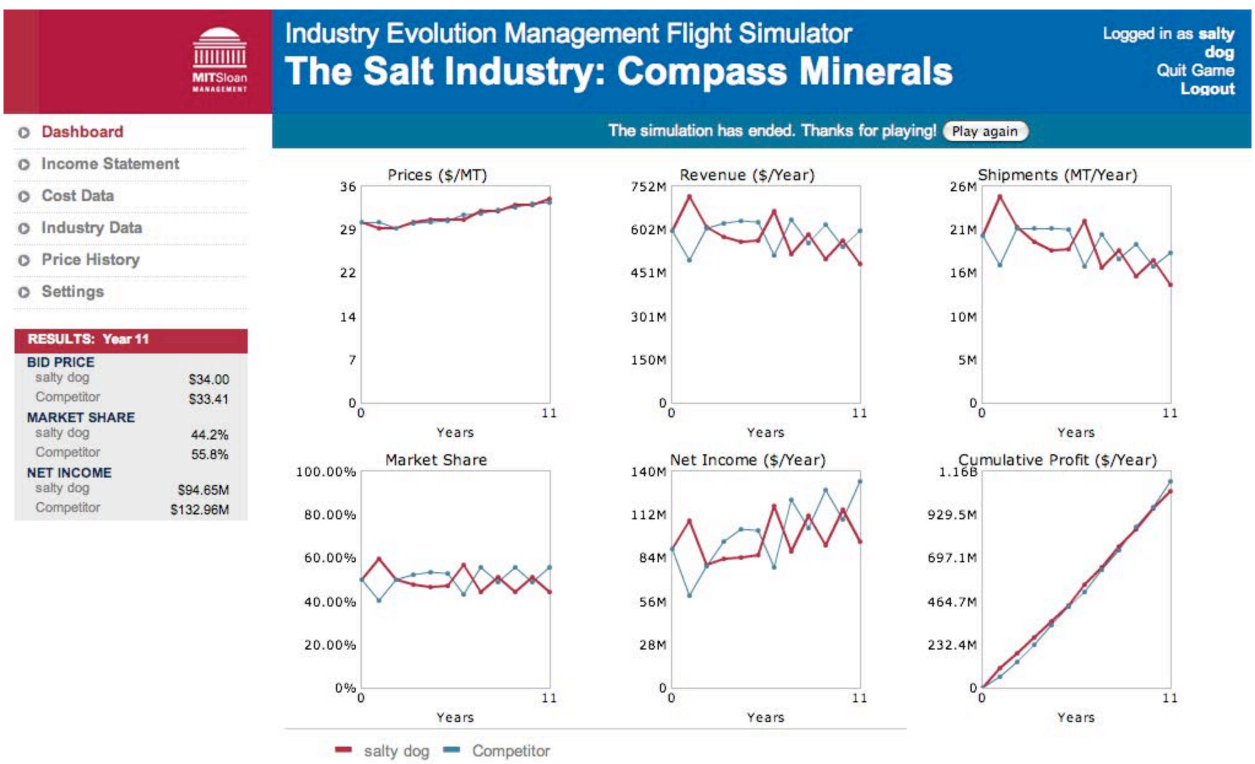


Figure 4. Top: example game illustrating price war. Bottom: Example game illustrating successful signaling and tacit collusion to achieve high profits.

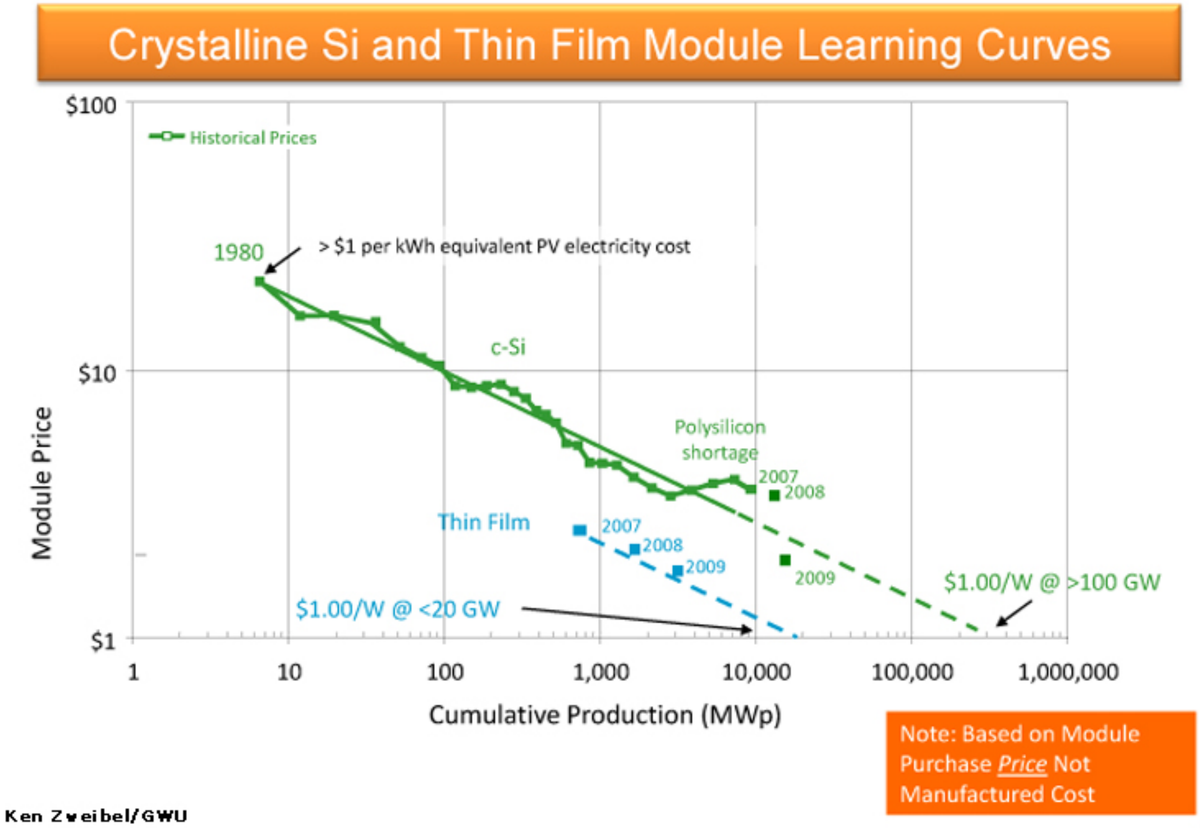


Figure 5. Solar Photovoltaic experience curve. Source: Ken Zweibel, George Washington University, http://solarcellcentral.com/cost_page.html; see also http://solar.gwu.edu/Presentations/KZSolarContract.pdf.

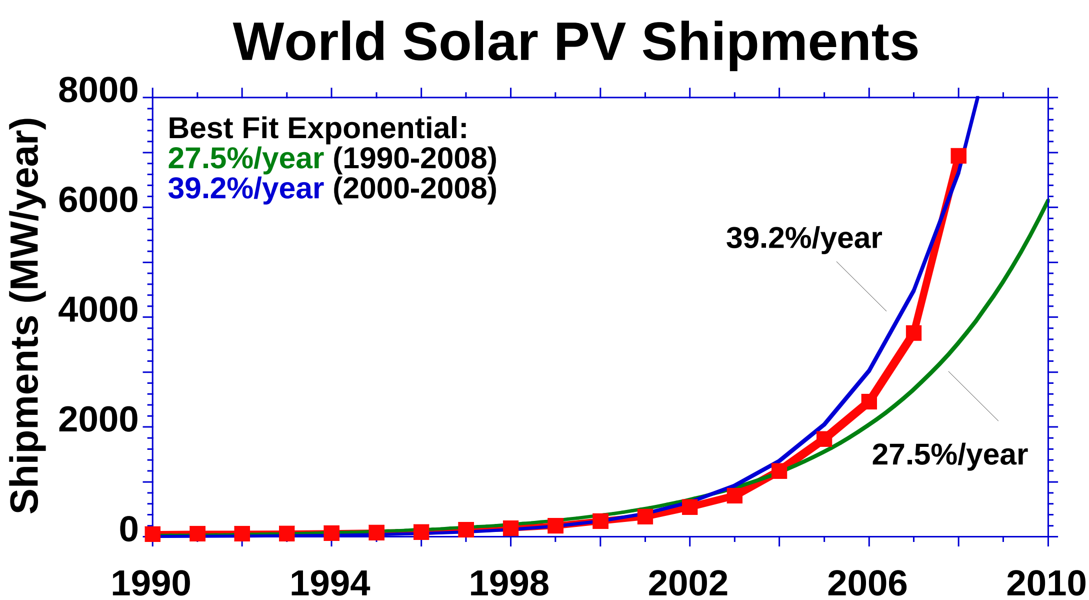


Figure 6. World Solar Photovoltaic Shipments, MW peak capacity/year. Source: PV News.

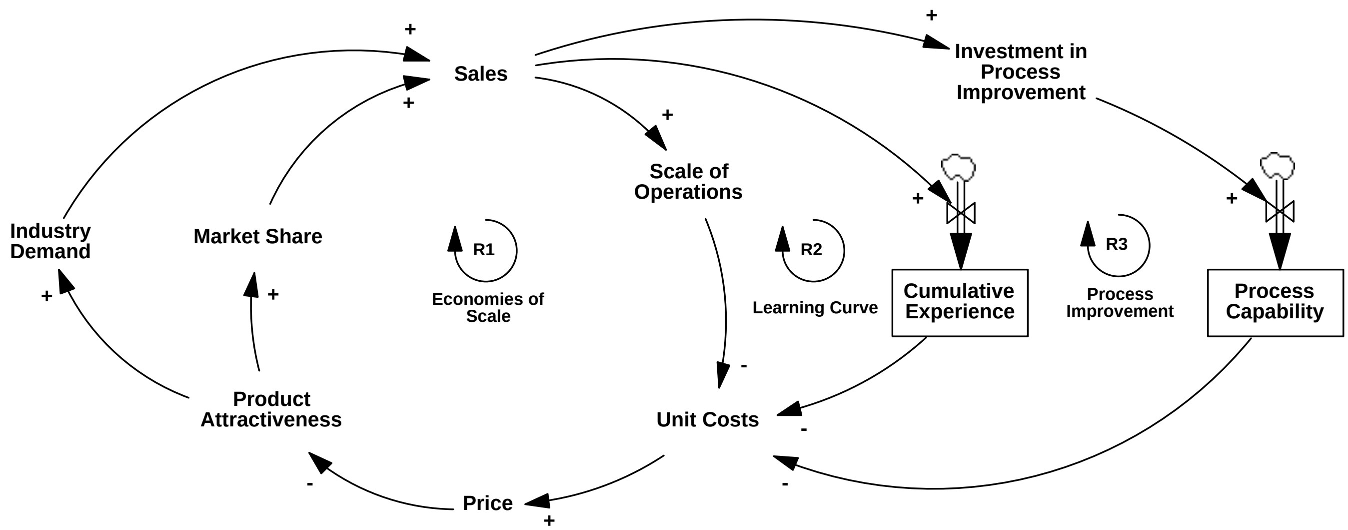


Figure 7. Principal positive feedbacks created by scale economies and learning.

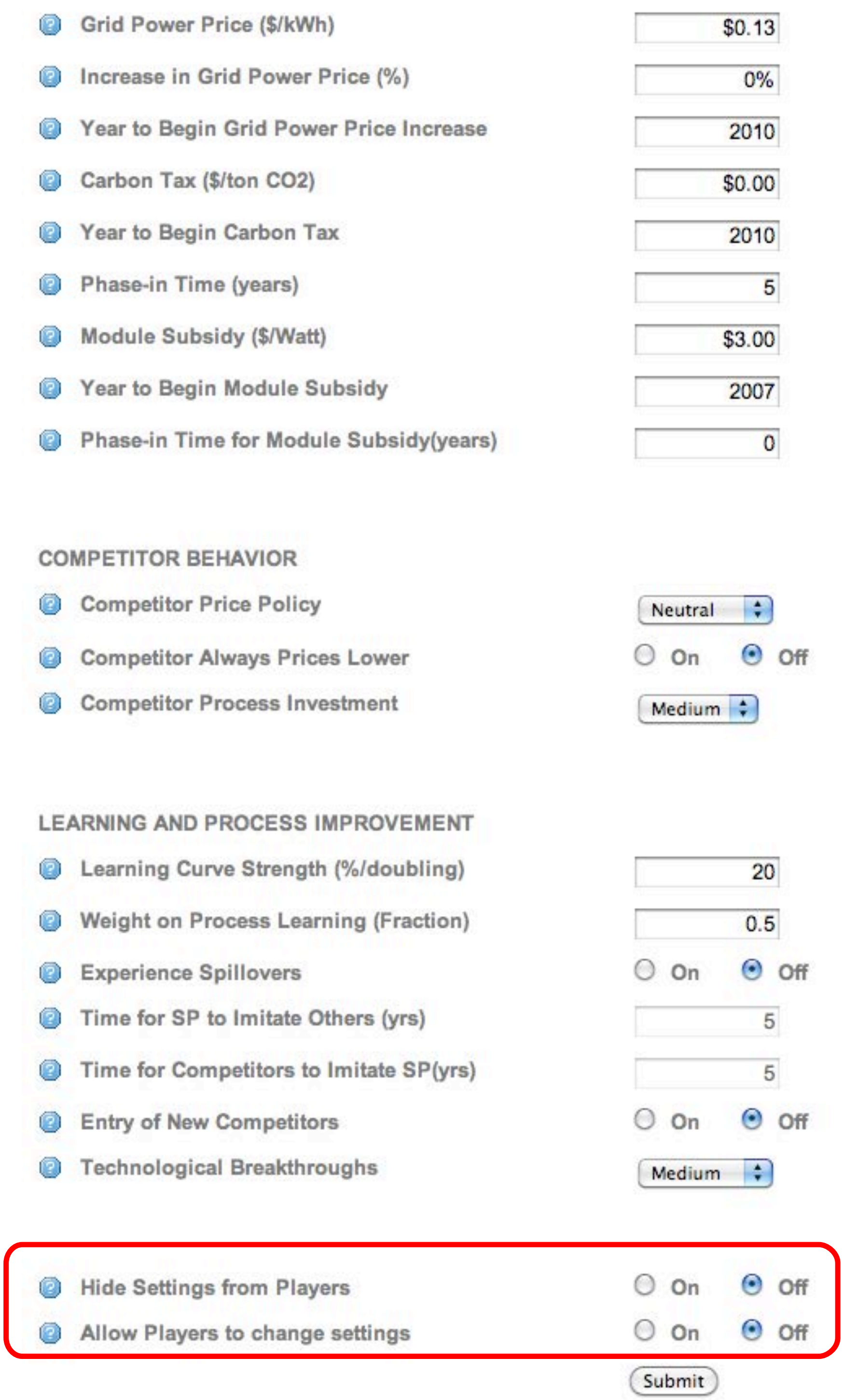


Figure 8. Settings available in the solar simulator. In individual mode, the individual player controls the settings. The settings in the box at the bottom of the list are available only to administrators when setting up a class, and determine whether players can see and/or change the settings in that scenario.

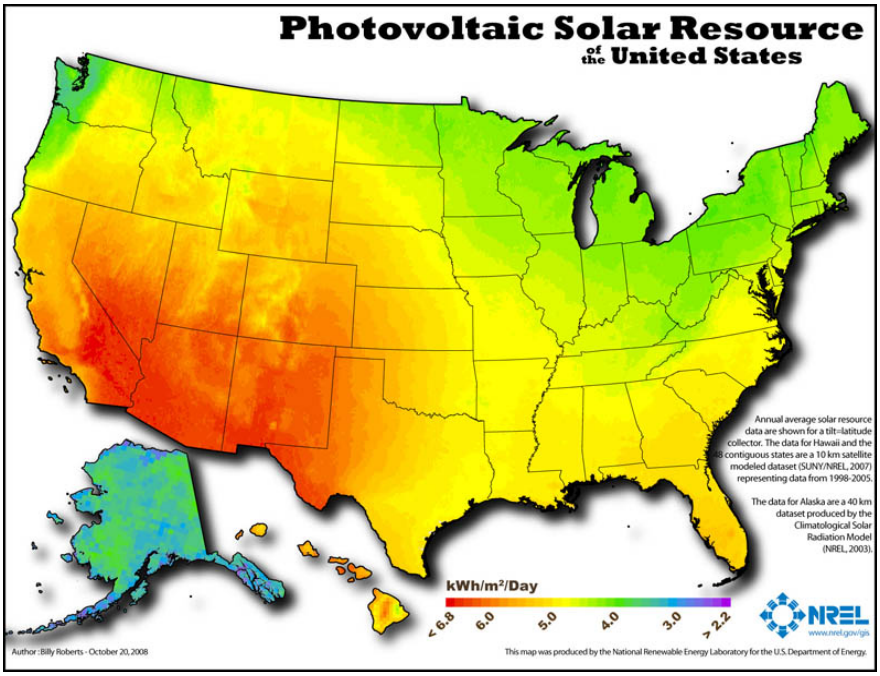


Figure 9. Heterogeneity in solar resource in the United States. Source: National Renewable Energy Lab, http://www.nrel.gov/gis/solar.html

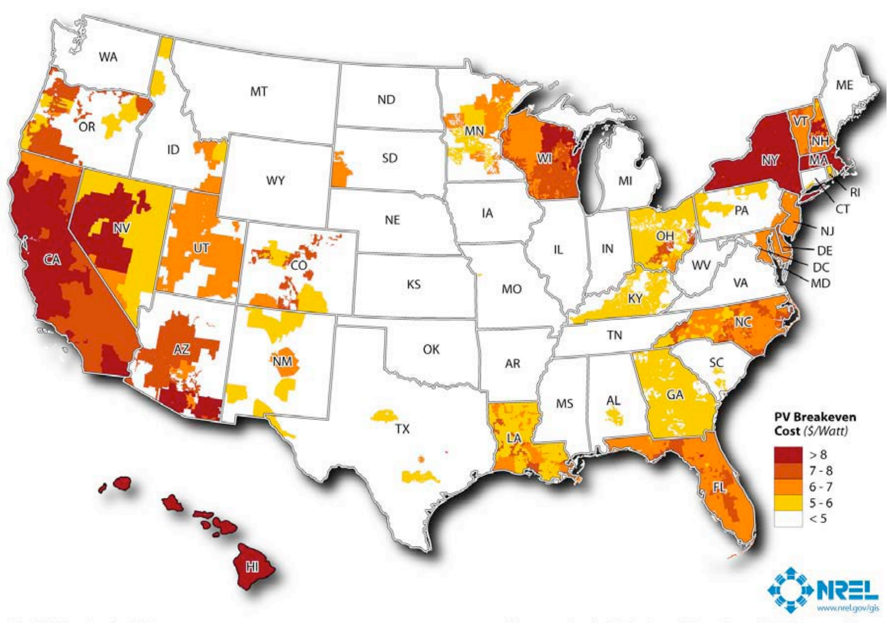


Figure 10. Heterogeneity in solar PV breakeven cost per peak watt in the United States due to variations in solar resource, local grid power prices and subsidies and tax credits for solar installation, as of 2008. Source: Denholm *et al.* (2009).

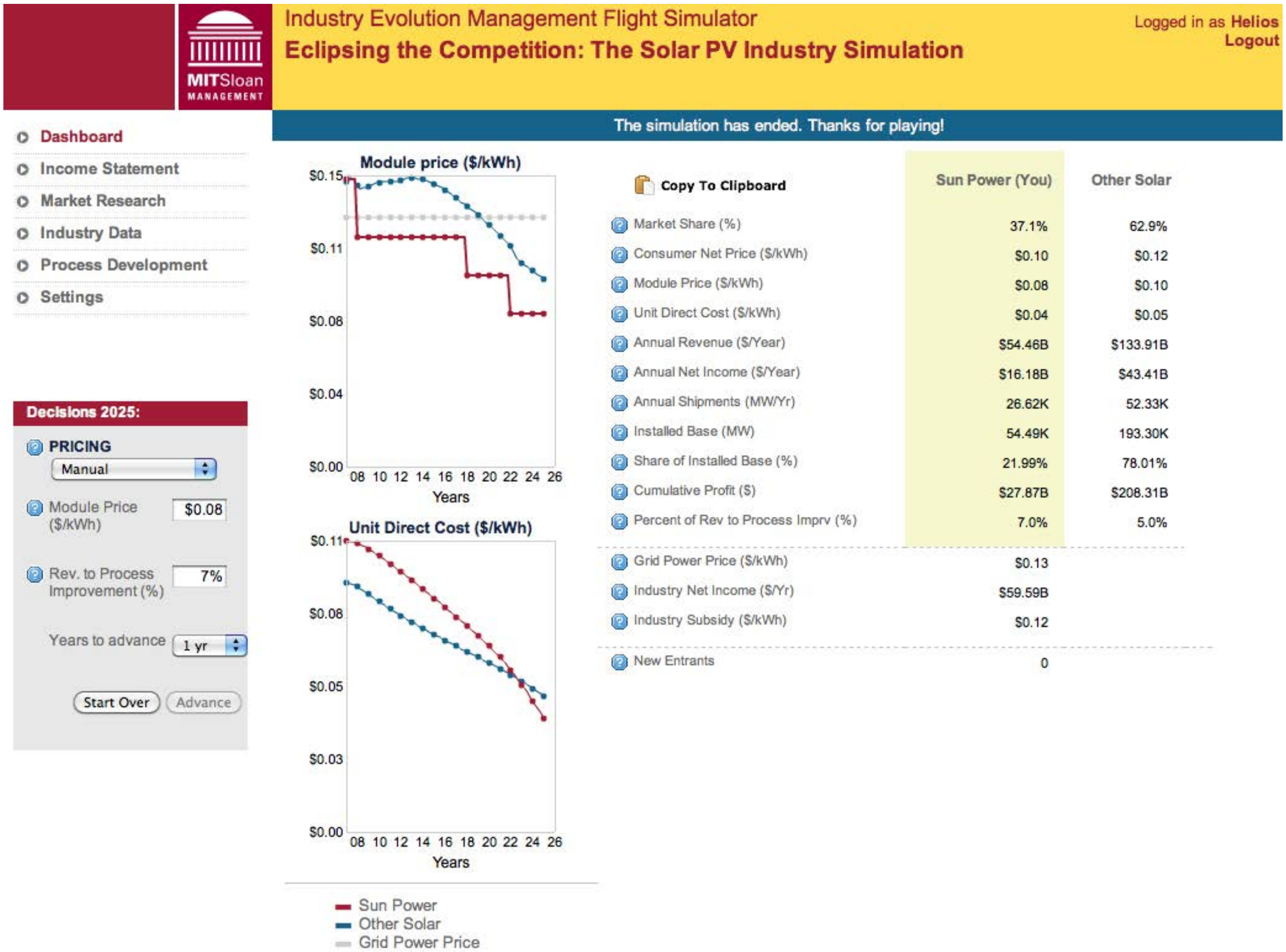


Figure 11. Main screen for Eclipsing the Competition, showing a successful strategy using the default settings. In this simulation, the player has elected to use the Manual pricing mode, in which players set prices directly, in $/kWh, each period.

Copy To Clipboard	Industry Data
Industry Sales (MW/Yr)	99.46K
Industry Revenue ($/Yr)	$232B
Average Market Price ($/Watt)	$2.29
Industry Average Capacity Utilization	1.25
Base Grid Power Price ($/kWh)	$0.13
+ Carbon Tax ($/kWh)	$0.00
= Total Grid Power Price ($/kWh)	**$0.13**
Average Module Price ($/kWh)	$0.09
+ Average Installation Cost ($/kWh)	$0.14
= Average Total System Cost ($/kWh)	**$0.23**
- Average Subsidy ($/kWh)	$0.12
= Average Net Cost to Consumer ($/kWh)	**$0.11**

Figure 12. Total solar installations and revenue, and cost calculation, for the scenario in Fig. 11.

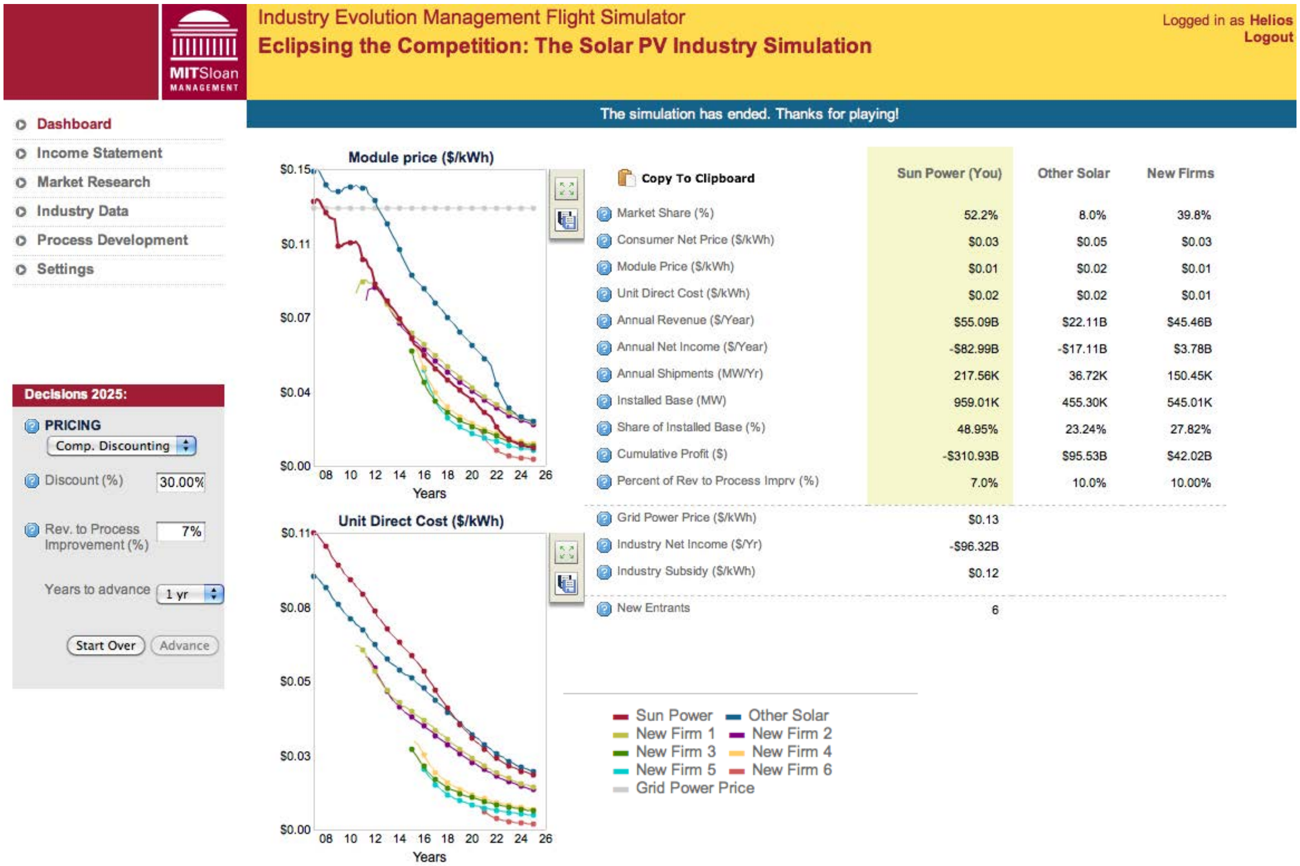


Figure 13. Failure of the Get Big Fast strategy in the presence of knowledge spillovers, aggressive competitor pricing, and entry of new firms with new technologies. In this example, the player has chosen to use the Competitor Discounting mode to enter prices. By the end of the game, the player is setting prices 30% below the average price offered by its competitors in an attempt to gain market share.

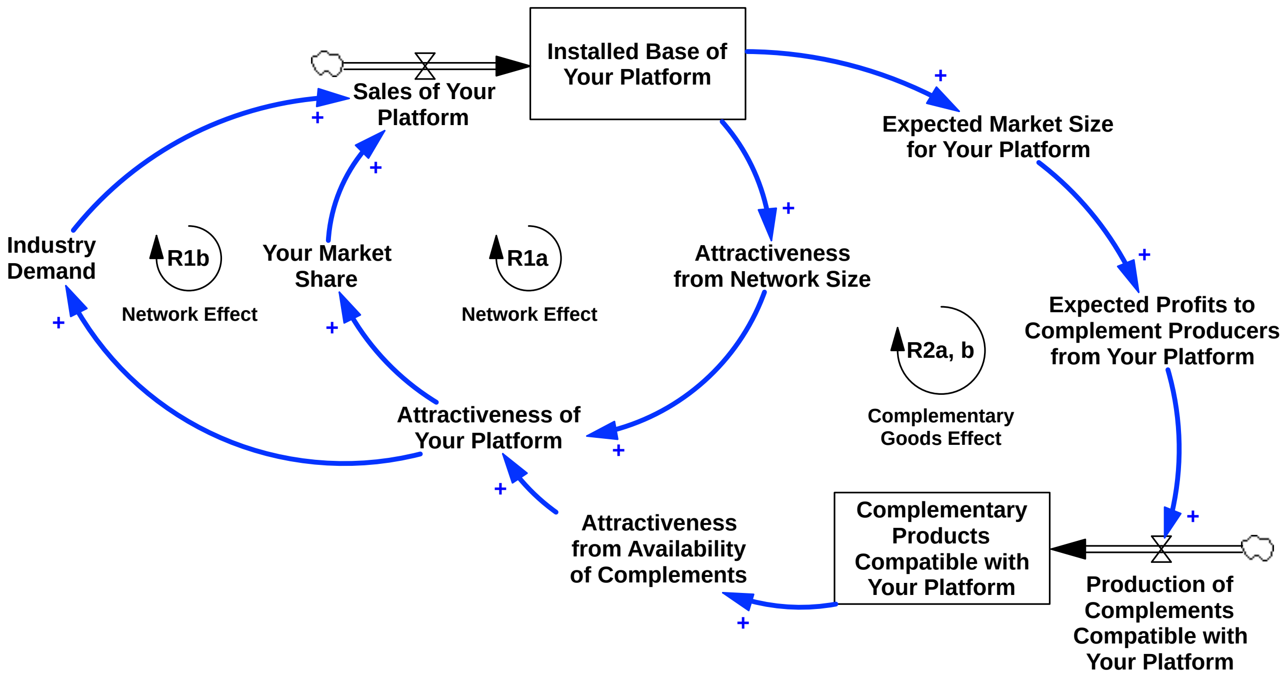


Figure 14. Positive feedbacks created by direct and indirect demand-side externalities.

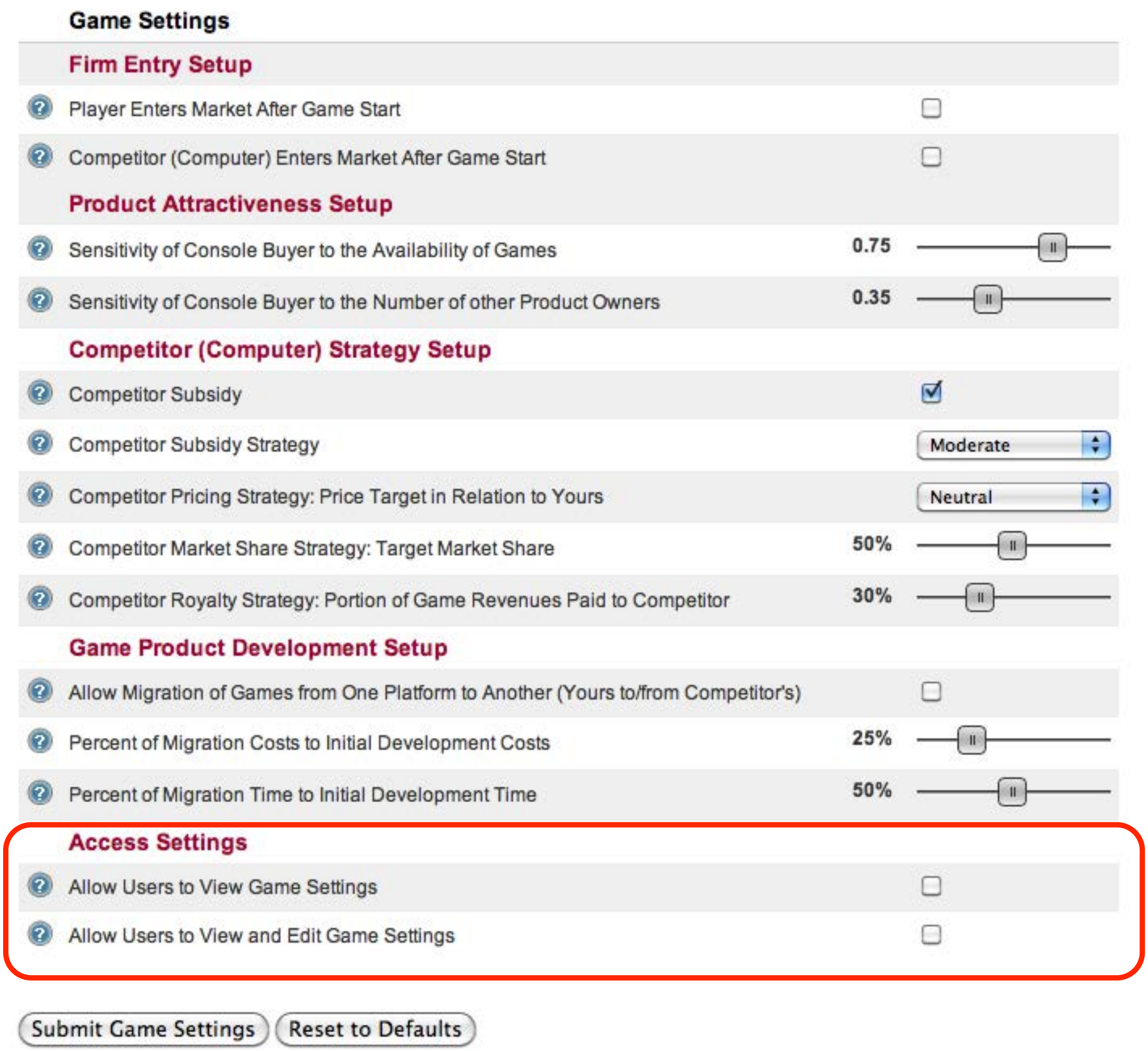


Figure 15. Settings available in the Platform Wars video game simulator. In individual mode, the individual player can set these. The settings in the box at the bottom of the list are available only to administrators when setting up a class, and determine whether players can see and/or change the settings in that scenario.

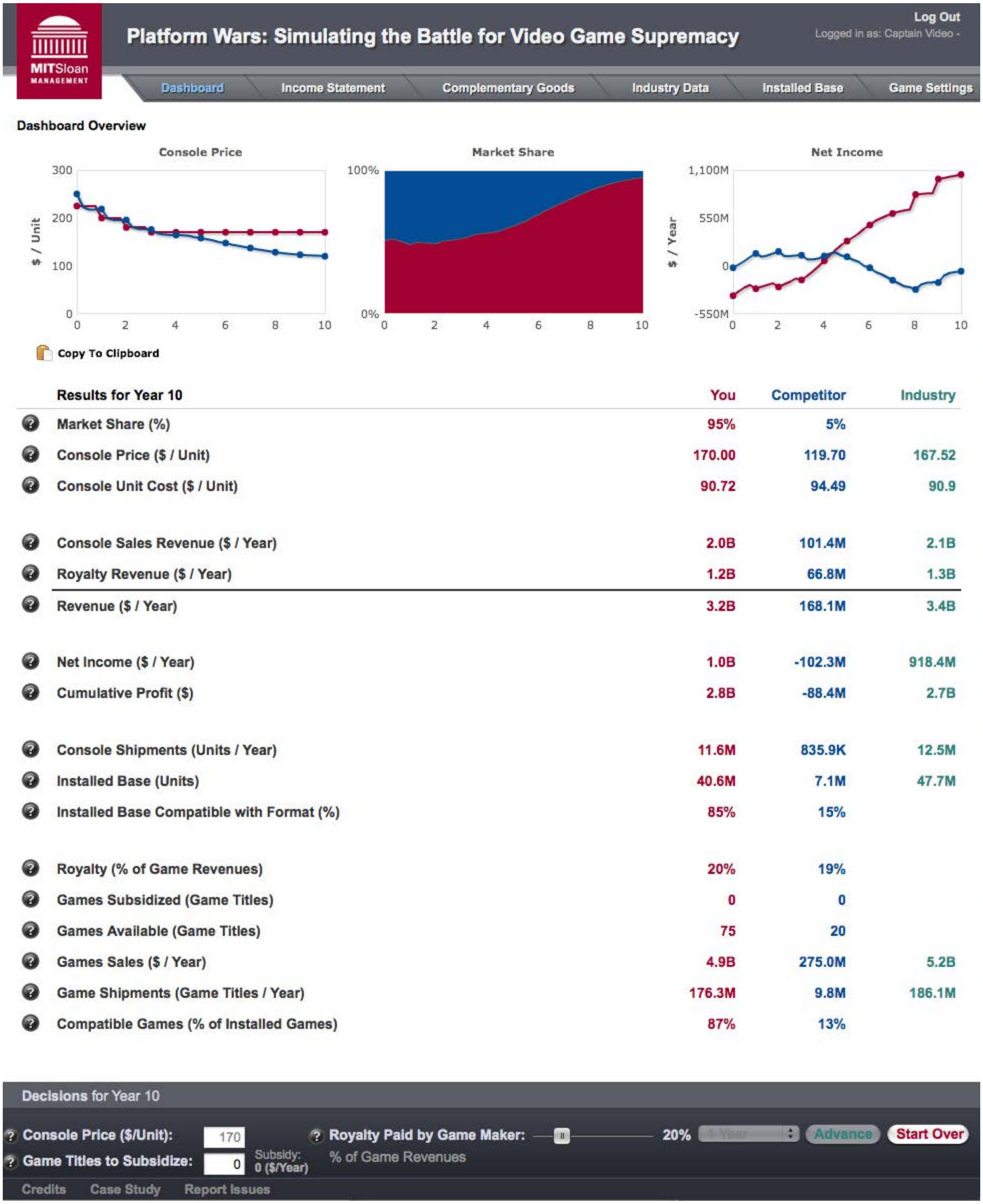


Figure 16. Main screen for Platform Wars, showing a successful strategy with the default settings.

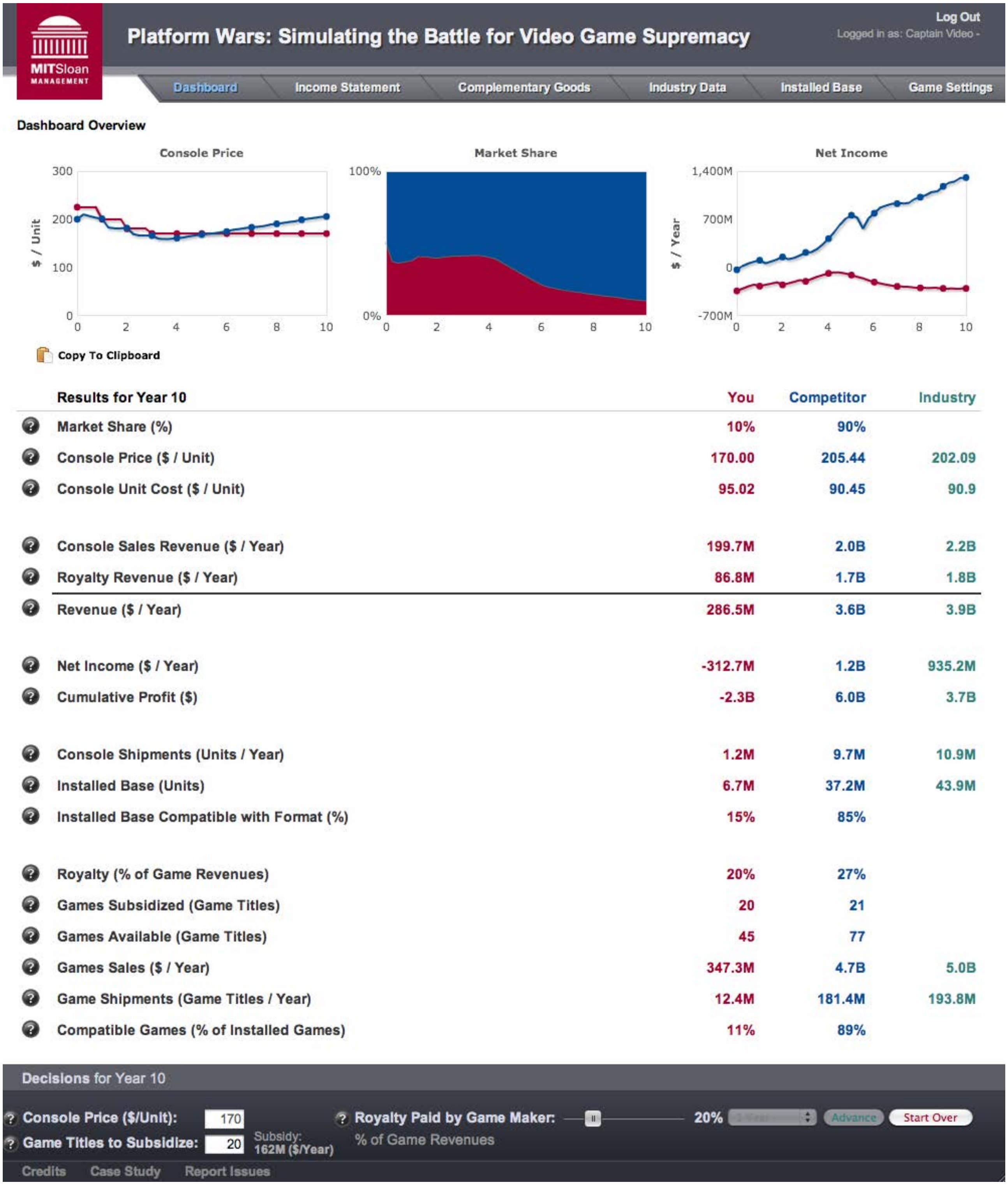


Figure 17. Main screen for Platform Wars, showing the same strategy as in Figure 16 but where games can be migrated quickly and at low cost from one platform to another, and where the competitor pursues an aggressive strategy. The competitor wins the market and profits, while the player loses $2.3 billion.

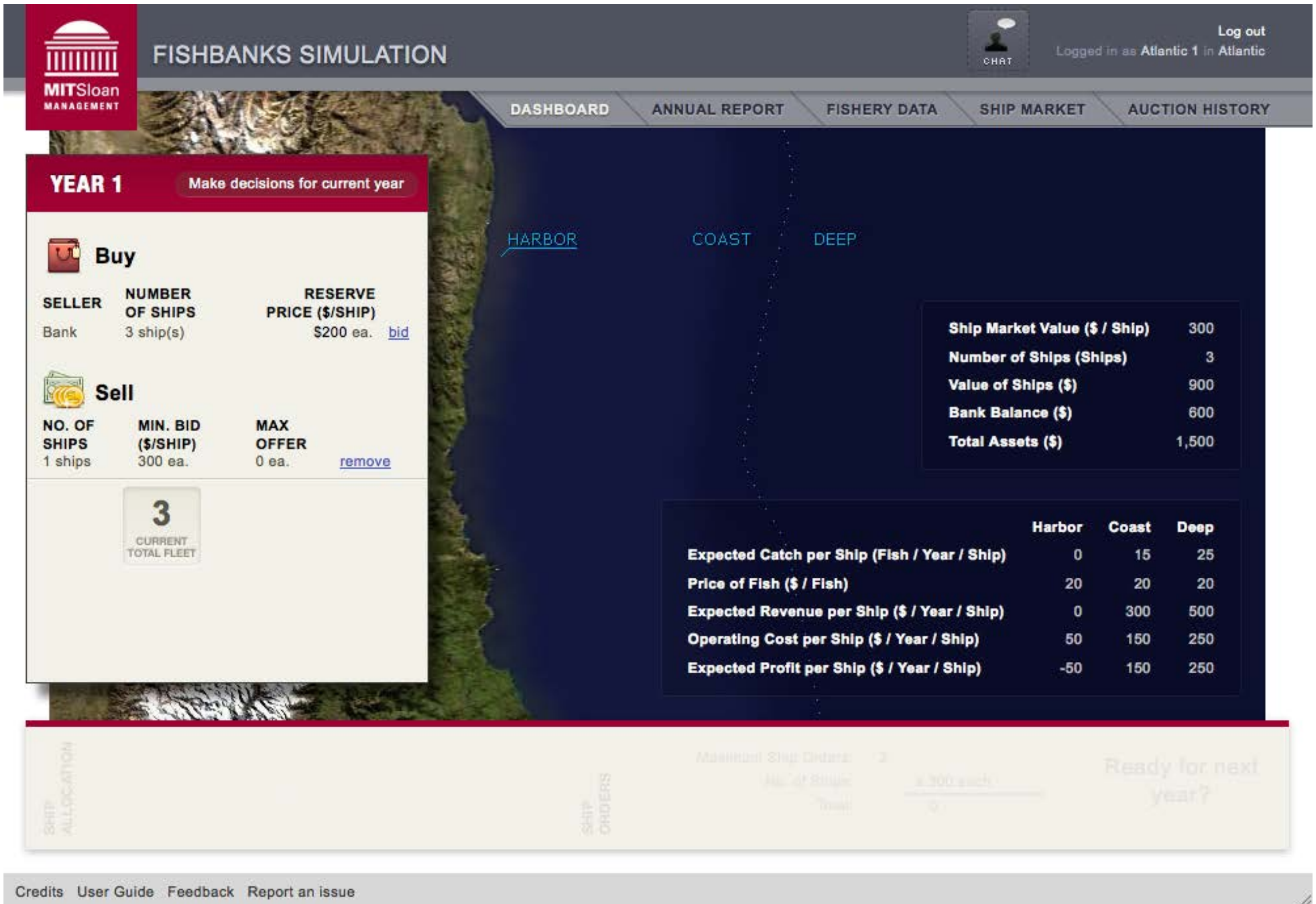


Figure 18. Player main screen, Fishbanks: Auction phase. At the beginning of each round, players may buy or sell ships at auction. In this hypothetical example, the bank is auctioning three ships, with a reserve price of $200/ship, while the player is offering one ship at auction with a reserve price of $300/ship.

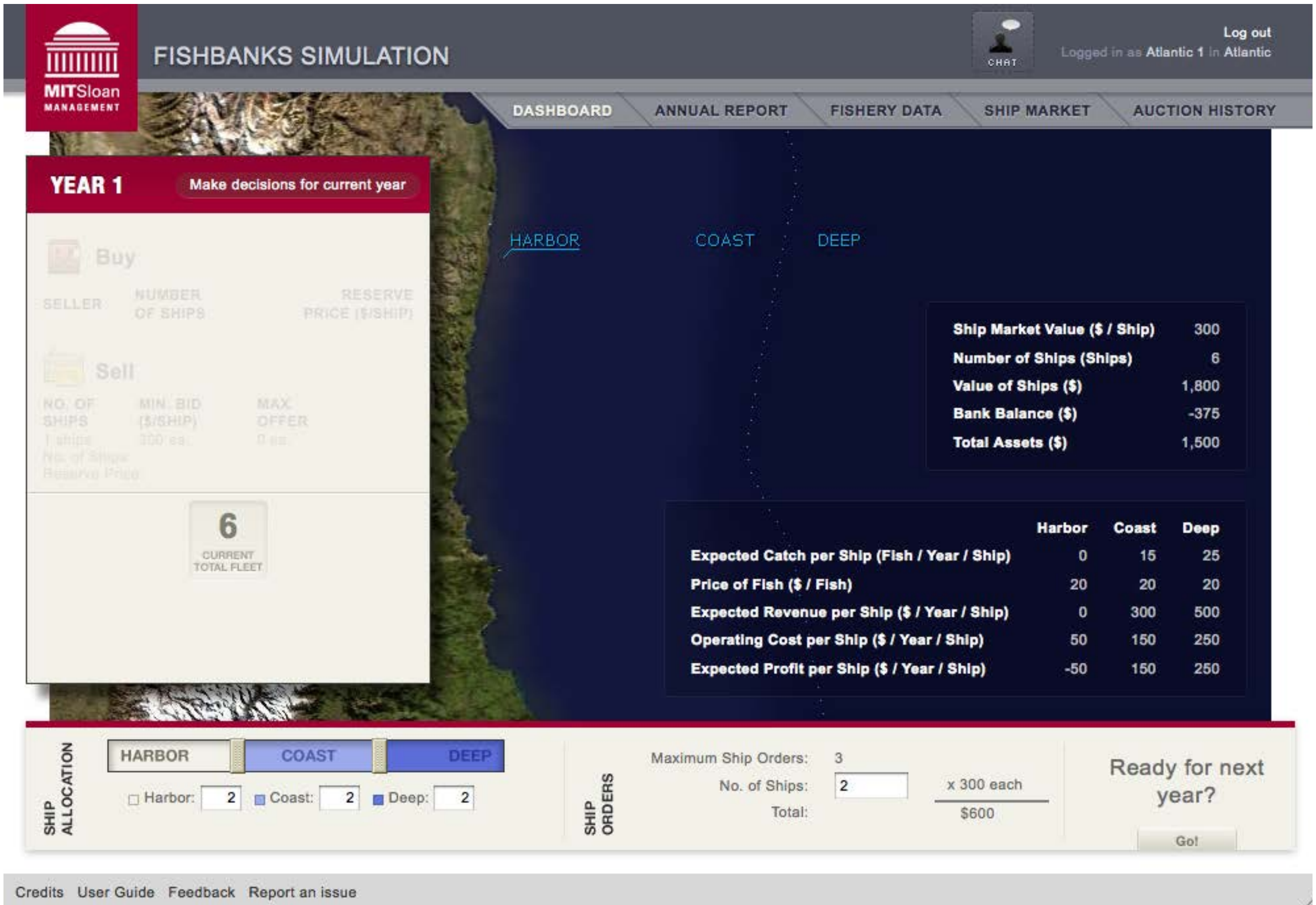


Figure 19. Player main screen, Fishbanks: Allocation phase. After the auction phase, players decide where to send their fleet and whether to order new ships from the shipyard. In this illustrative example, the player has 6 ships and allocates 2 each to the harbor, coastal fishery and deep sea, and orders 2 additional ships from the shipyard.

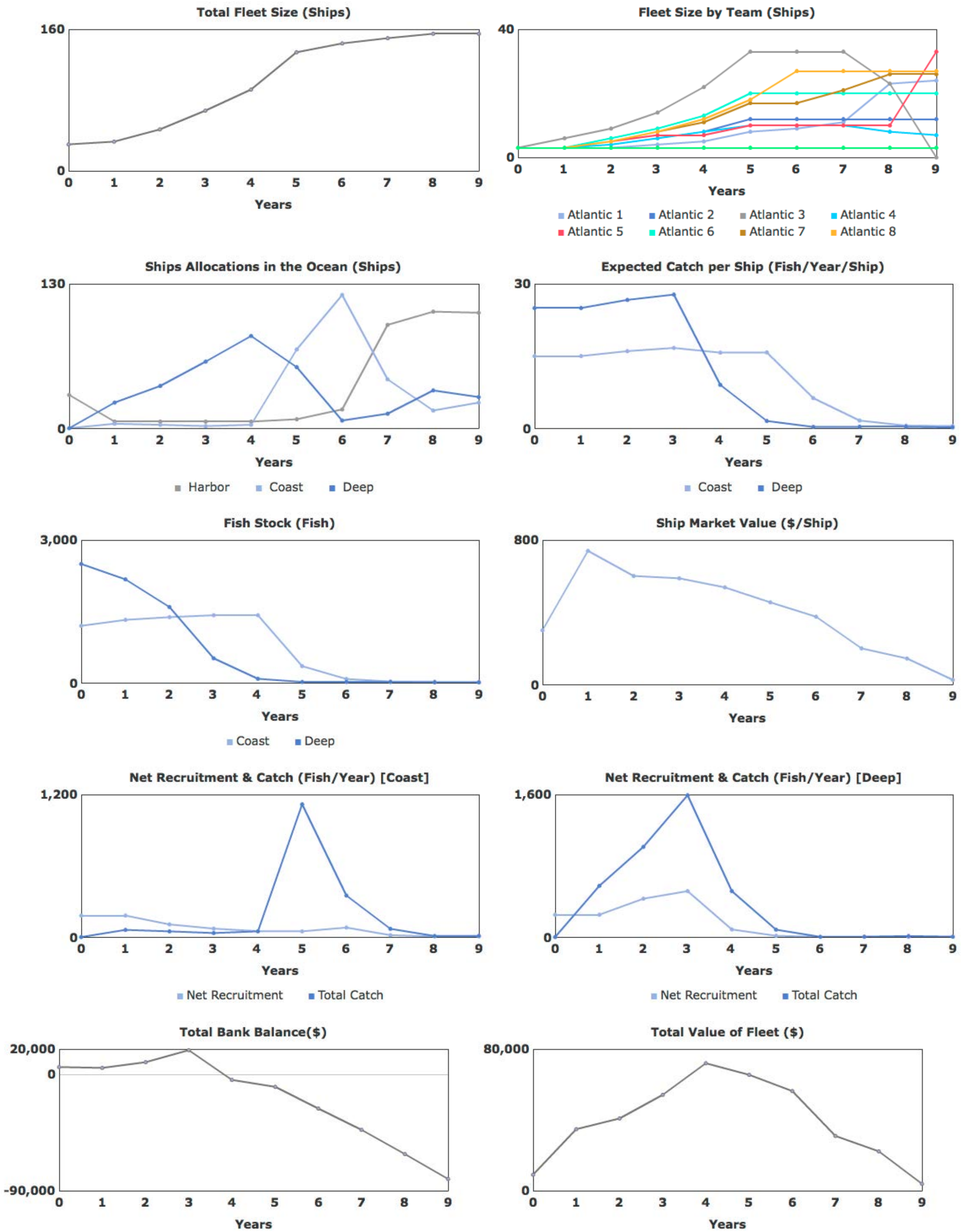


Figure 20. Typical results, with 8 teams of senior executives competing in the same ocean. Rapid expansion of the fleet quickly depletes the deep sea, and then the coastal, fisheries, causing massive losses and collapse of ship market value.

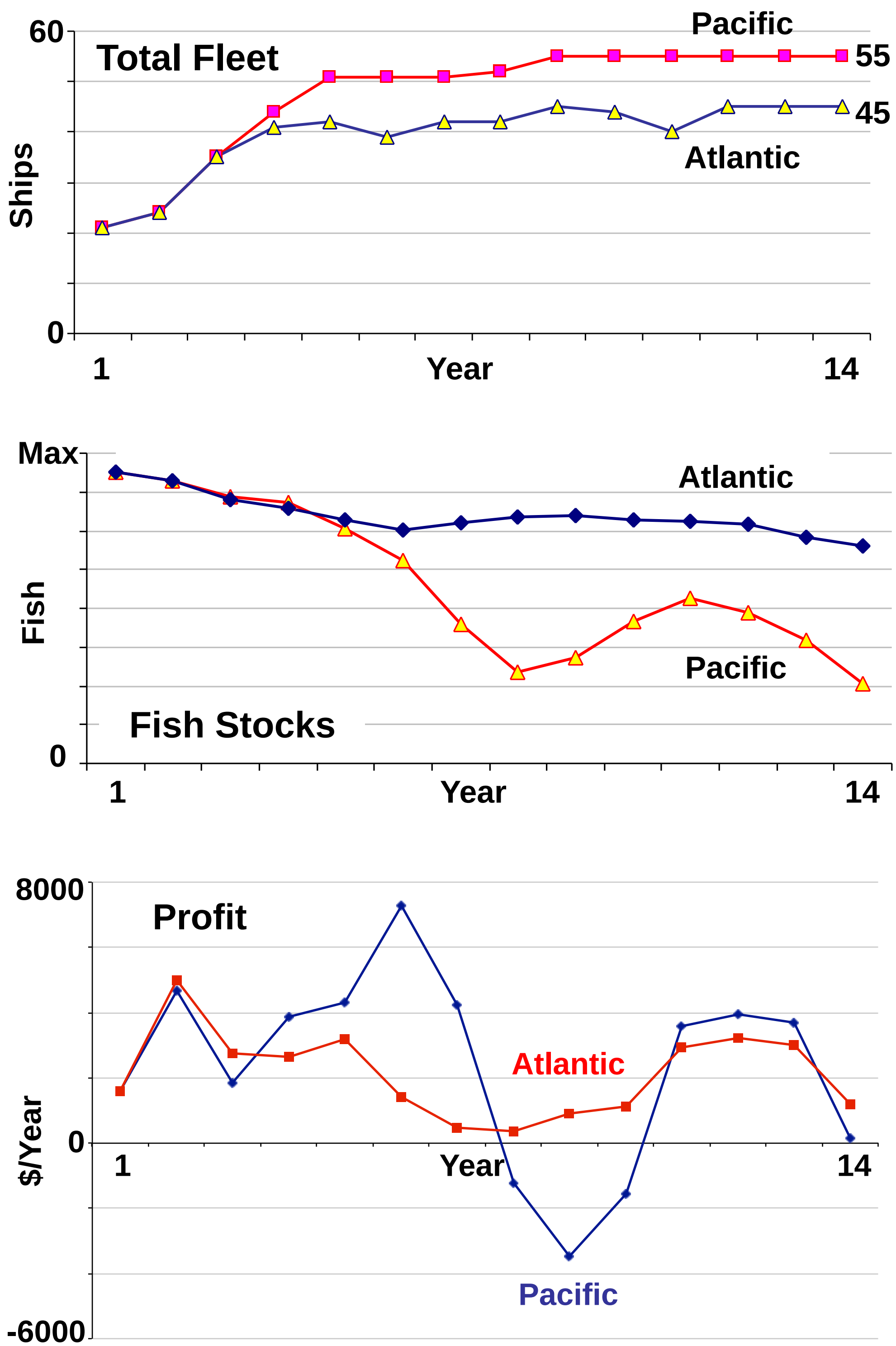


Figure 21. More sustainable policies achieved by two different groups of Fishbanks participants. The Atlantic Ocean participants were able to limit fleet expansion and fishing effort to sustain fish stocks, yielding profit each year of the game.