Hierarchy in Management: Strategic and Tactical Behavior

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Abstract When a corporation is composed of many plants, how should it control the operation of these plants in the least intrusive way, that is, what is the minimal set of appropriate constraints the corporate level should apply? These constraints include specific operating condtions and the requirement of specific operational information. An analogy with ecology is presented and a specific example of a dynamic model of the optimal expansion of the corporation is developed.

Key words: dynamic, modeling, hierarchy, corporate, plant, operation, optimal

Consider two identical firms of the same owner. The only difference between these firms is geographic location. It is the nature of managers in each firm to optimize their own operation, whereas it is the duty of the manager at the next higher level in the ownership hierarchy to run the firms such that their combined operation is optimized. As seen from the level of the firms, individual firm optimization is a tactical process while combined optimization is a strategic process. Tactical decisions are made at your level in the management heirarchy while strategic decisions are made at the next highest level. The decision to optimize the operation of the two firms is made at the next level higher than that of the firms themselves. The decision as to how many firms this company should own is also a strategic one as seen from the firm level.

This paper is intended to shown how, in an ideal world, the tactical and strategic decisions about company expansion are most appropriately distributed across the various levels of the business environment. We model the dynamic process of industry expansion until the market is saturated and economic profits are zero. In the example below, the corporate level takes signals (constraints) from the market, including such signals as interest rates and market prices for the products being produced and the input unit costs. These corporate managers also determine the scheduling of new plants and instruct those at each of the plants to pick the best technology, build the plants at the desired rate and expand the production of each plant to maximize the profits for that period. Decisions about how to meet daily and weekly production goals are set at the plant level and achieved by those in the plant operations divsion. In this example model, the market is the highest level in the hierarchy, the corporate level is next, the plant level is the next most detailed and the plant operations division is the lowest.

Hierarchy in Nature

We can find considerable guidance on the subject of hierarchial dynamic systems in the history of ecosystem modeling to inform us here. McMahon et al. (1978) lay out a biological system of hierarchial description. They have shown three possible descriptions that span from the highest possible level to the organism. At the highest level are phylogenetic (Kingdom, Order, Species, Organism), coevolutionary (Community, Population, Breeding Population, Organism), and matter-energy exchange (Biosphere, Ecosystem, Organism). They lead to a single hierarchial description for the Organism (Organ, Cell, Molecule, Subatomic Particle). The particular branch one chooses depends on one's point of view in modeling. Allen and Starr (1982) had a critical observation on how to get results in modeling biological systems: "The limiting factor is not computational power; of that we have plenty. And it is not our ability to translate field experience into mathematical forms. A new and powerful mathematics is not what is needed; rather we are limited by a lack of familiarity with the consequences of coupling subsystems with different cycle times." Allen and Wyleto (1983) point out that unified models inevitably contain contradicions that destroy their credibility. Models representing multiple levels of the system resolve these conflicts and reveal emergent properties of the system.

Some observers will focus on the structural aspects of the system and claim it is unchanging. Others will examine the flows in a system and claim that nothing in the system is constant. Lavorel et al. (1993) demonstrate that complex systems *will* develop hierarchial structures. To us, the most useful and insighful view of hierarchy in systems comes from Johnson (1993). His claim is that hierarchy theory implies the idea of strategy and tactic are relative. One must choose the level in the hierarchy and discuss the defintions from that point of view. The dynamical behavior of the agents at specified level in the hierarchy are determined by its interactions with the next lowest level. The specified level gets the constraints on its actions from the level just above it. We say, therefore, that strategic decisions appear to those at the specified level as the result of decisions from the level above and its own tactics determine how its own dynamics will develop. From these dynamics come the constraints for the next lowest level. Johnson goes on to point out how Stommel (1963) defined the relationship between cycle times and levels in a hierarchial system. A forest, for example, can be thought of as organized by size from Landscape, to Patch, to Canopy, to Tree, to Branch, to Leaf and so on. As one moves down this hierarchial description, the cycle times become significantly shorter. Plotting these sizes versus their corresponding cycle times yields a straight line on log-log paper, indicating a power law relationship. In fact, it can easily be shown that the total biomass of any species at the Landscape level is essentially zero (Hannon and Ruth, 1997). Barring earthquakes and meteors, the Landscape level is actually defined as that level where each of the individual biomass components are steady. As one proceeds toward the small, the turnover times shorten dramatically and the predictability is diminished.

If we adapt this ecological view of hierarchial systems organization, then the process of proper constraint determination is a crucial one. The constraints must not be too general nor too specific, so as not to usurp the widest possible range of functioning of the next level down in the hierarchy. In the business world, we would say that the constaints must be set to maximize the creative response of those at the next level in the hierarchy and to engender ownership of their part of the process. The typical set of business constraints are likely to be too constraining and therefore conflicting, or too indefinite and therefore maximizing the possibility of unfufilled misson.

To those at the lower or receiving level, these constraints appear as strategic decisions while to those at the higher level, they are seen as tactical decsions. The dynamics of the higher level are the result of its interaction with the next lowest level. This view of the system is repeated down through the organization until it ceases to be useful.

We shall now develop a model of two interacting levels in a hierarchy as a way to crystalize the meaning of the proceeding rather general discussion.

A Model Demonstrating the Hierarchical Nature of an Expanding Business

Here is an example model for a hierarchical business system, a multi-plant company in a competitive market. Level 0 is the market environment. Level 1 represents the corporate management. Level 1 constrains several of its own plants at Level 2, the plant management level. The rest of the production capacity for this product lies in the hands of competitors but it is assumed they use exactly the same production technology and that all corporate managers know the expansion schedule for the rest of the industry. Our corporation will own several of the plants, but not enough for them to act differently from a competitive enterprise. In the model, Level 2 is the management of one plant as it turns a single INPUT into OUTPUT. The time constant for Level 1 is one year while the time constant for Level 2 is one month. Consequently, the meaning of time =1 for the model is one month. To improve the model accuracy, the model time step, DT, is shorter (1/8). Level 3 is the collection of production line employees in a plant. Our model focuses on the dynamics and interactions of Levels 1 and 2.

For simplicity with no loss of usefulness, the costs of units of all the inputs are summed into a single variable, UNIT COST. This cost includes the cost of the input, the cost of labor and energy resources, all taxes, capital cost (averaged) and the cost of depreciation and maintenance. Level 1 management has negotiated with the outside environment (another hierarchy) for the unit cost of this single input. From their analysis, they have also discovered the demand curve for their product (PRICE = 10 - 0.004*PLANTS*OUTPUT). Level 1 has also received the necessary discount rate from the market environment (Level 0). The discount rate is used by Level 1 to compare the RETURN RATES` ` ` ` ` ` ` ` `  ` ` ` ` ` ` ` ` ` ` ` of any actual scheduling of the plants.` ` ` `
` ` ` ` ` ` ` ` These are the constraints on Level 1 from Level 0.

At the beginning of each year, the corporate managers specify the number of new PLANTS they expect to see developed that year, both of their own and of their competitors. The entire industry begins with one plant and assumes new plants will be added each year as predicted by the SCHEDULE. As we shall see in the example, this schedule is a parameter that can be changed to meet specified goals. Level 1 management surveys the industry building plans and determines how many identical plants the competition is building in the coming year. They add their own building plans to that of the competitors to conform to the SCHEDULE.

Level 1 management uses the demand curve and the industry-wide building schedule to determine the PRICE. Level 1 chooses to require profit maximization on the part of their plant managers. So PRICE, UNIT COST, number of new plants to be built and the maximum PROFIT goal are the constraints Level 1 management gives to Level 2.

Level 1 management is also responsible for modeling the market and the plant simultaneously, as shown in Figure 1.

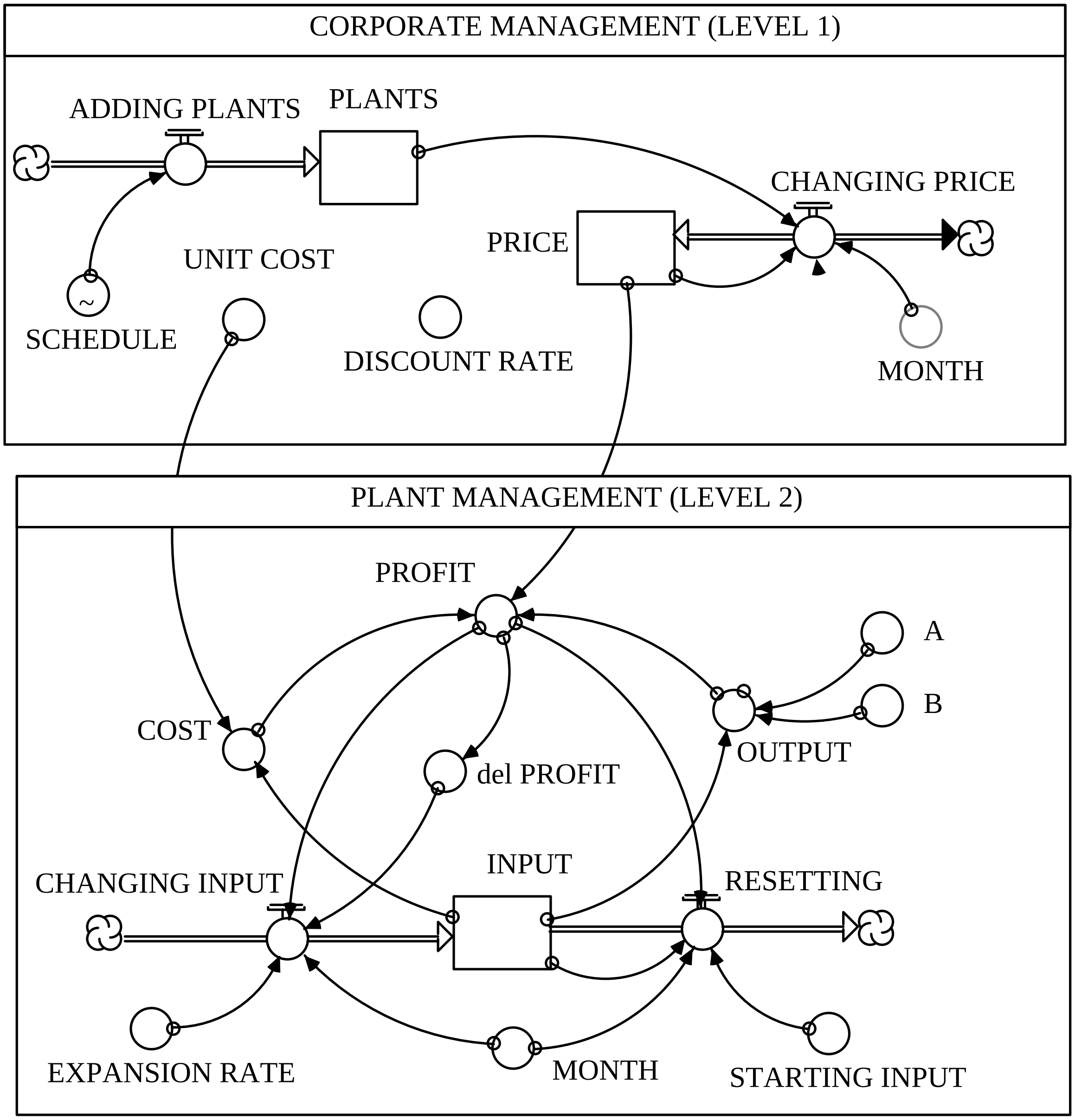

Figure 1. The model of Level 1 and Level 2 dynamical interaction. For clarity, some of the secondary control variables are omitted in this figure. All of the equations are presented at the end of the paper.

Level 2 management is responsible for choosing the proper technology, building and running the plants and generating a PROFIT that each PLANT monitors constantly. PROFIT is simply revenues (PRICE*OUTPUT) less COST (UNIT COST*INPUT). ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` The OUTPUT is determined by a production function: OUTPUT = A*INPUT^2 - B*INPUT^3, with A (50) and B (15`) determined by statistical analysis of OUTPUT and INPUT data from the historical use the use of this technology. A and B represent the particular production technology chosen by the Level 2 management. The variable MONTH simply counts the months, beginning with month1, through 12, and then starts over. During each year, the plant(s) receive the PRICE signal for the year from Level 1. They are CHANGING INPUT to find their new level of OUTPUT that maximizes PROFIT, after RESETTING the INPUT to a low level at the end of each year. The technique for finding the maximum profit is quite a simple one: plant output expansion grows until the profit starts to decline. The Level 2 plant managers start their scheduled new plants at the beginning of each year with near-zero input (STARTING INPUT) and increase it slowly (EXPANSION RATE) to find their maximum profit OUTPUT value. The plants scheduled for startup that year are brought fully on line to their profit maximizing level of output in about six months and held at that level from then on. Since the market price is dropping each year as plant expansion continues, new plants must seek a new (lower) optimizing level of output each year.

For the example, the plants are scheduled as follows (see SCHEDULE in the model): 1 plant at first; 5 plants per year for years 2; 4 plants per year for years 3 and 4; 2 plants per year for year thereafter.

Corporate management would experiment to find the optimal schedule that will maximize the cumulative discounted profit. In such calculations, management would not smooth out the capital costs but assume they occurred as spikes. Here are the calculations they would have to make:

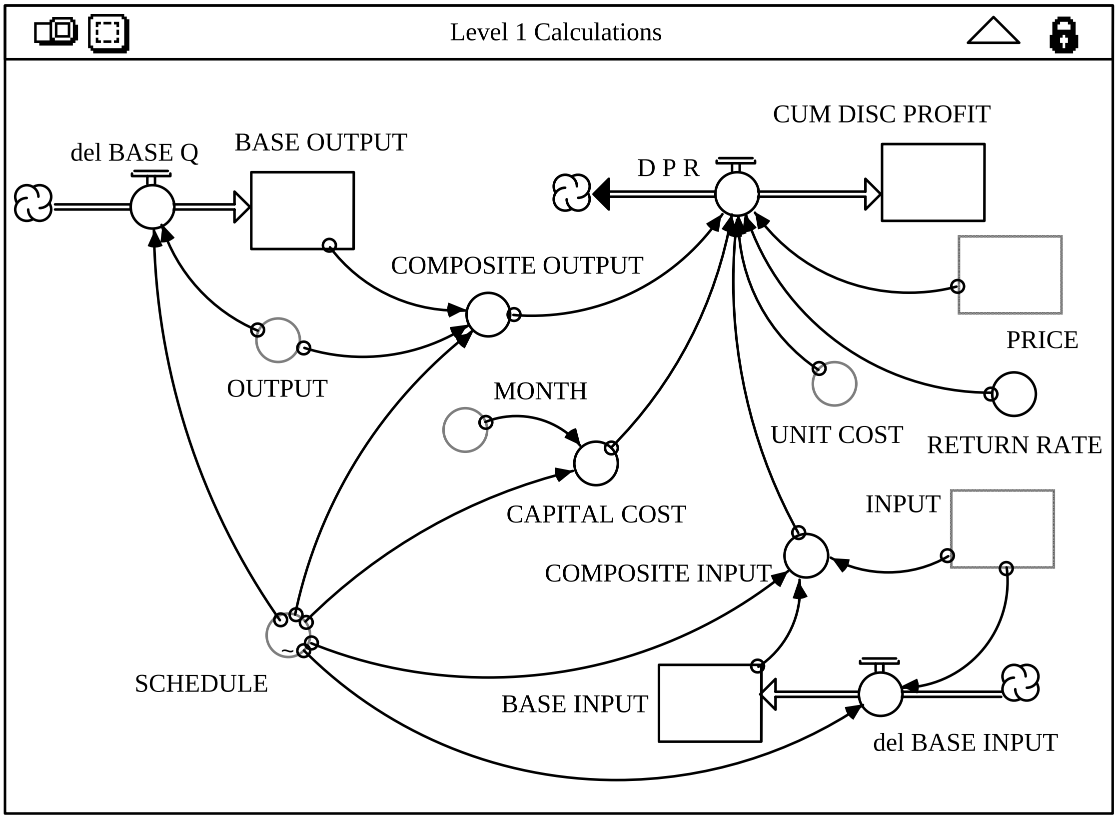

Figure 2. The portion of the model where the COMPOSITE INPUT and COMPOSITE OUTPUT are made. These values along with the periodic CAPITAL COST for initial startup and for each year's new plants, allow corporate managers to calculate the CUMULATIVE DISCOUNTED PROFIT (Cumulative discounted EVA)

In the model, plants start up each year and continue to run for the rest of the model at the optimum output rate for the price in that year.

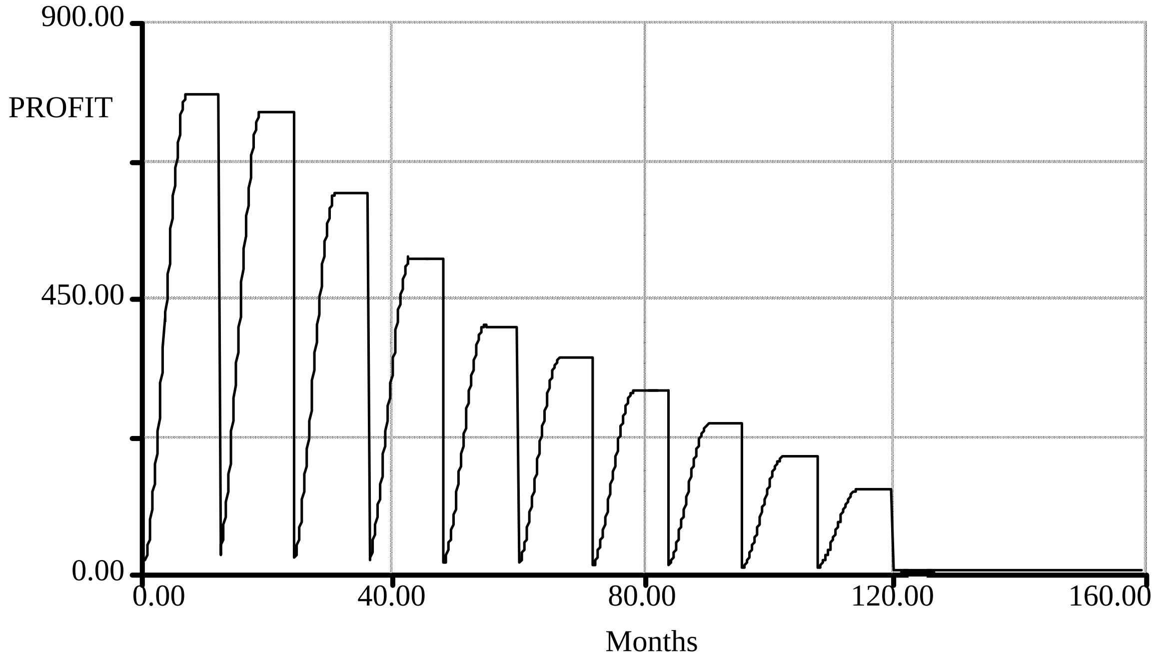

Figure 2a. The annual *additions* to profit of the new plants starting up at the first of each year. Each year's new additions (see SCHEDULE) continue to run from then on. At the end of the tenth year, additional plants cease to add any profit to the collection as market equilibrium has been reached and no further plants are built. After 120` ` months, all 26 plants continue with constant ouput (82.13 units per plant, per year) that maximize the collective (zero) profit while selling their output at the equilibrium price ($1.46).

The peak profit per plant declines as more and more plants are added. Eventually, after 120 months, the total operation has 26 plants and the addition of any more plants to this market would provide maximized but negative profits. The two levels have interacted to reveal the pattern of industry-wide profits for the particular new plant growth pattern forecast by the management in Level 1. From this point on, the production of all 26 plants is assumed to continue at the rate achieved in the last year of expansion.

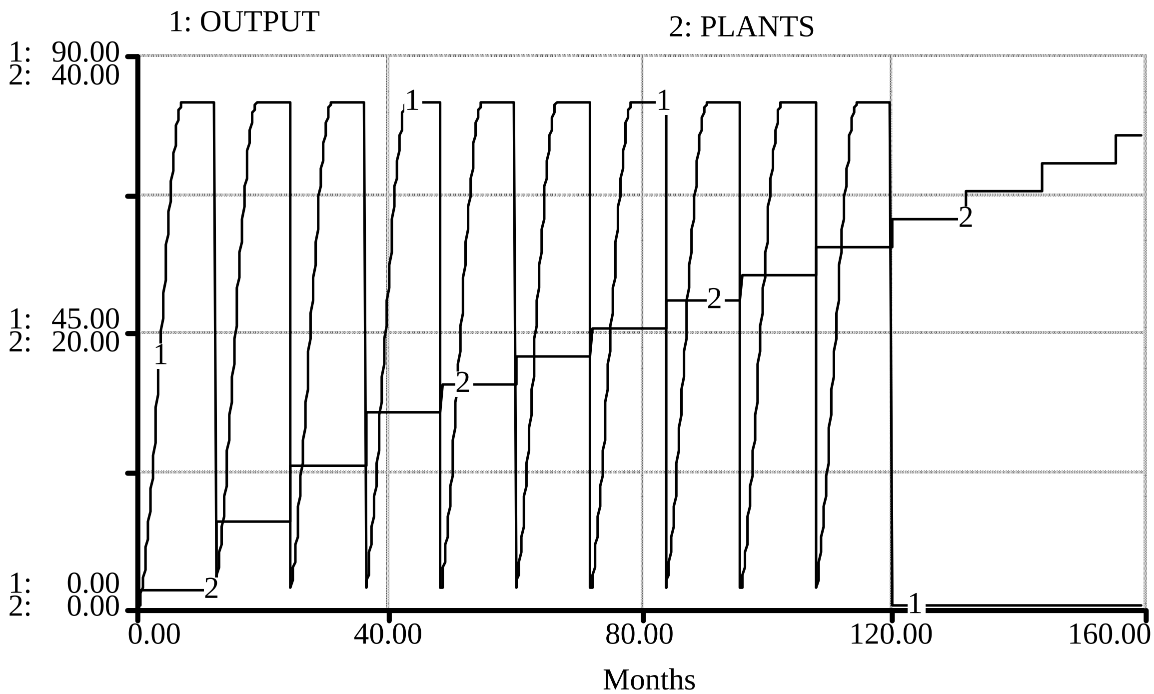

Figure 2b. The annual additions to output of the new plants starting up, and the cumulative number of plants in operaton. Each year's new additions continue to run for the rest of time. Note how little the optimum output changes for the new plants even though the profit declined continuously. This is due to the particular choice of production function.

Due to the complex nature of the startup process, it takes Level 2 slightly more than six months to get their new plants to the profit maximizing output level. This output is then fixed for the rest of that year's model run. Figure 2b shows only the first year's output of a single plant. Once each plant reaches the optimal output level, that plant continues to run for the rest of time. Each plant produces about 82 units per month.

The total output is 2140 units per year at zero economic profit. At this point we have reached the market equilibrium. The company is paying all its bills, labor, taxes and stockholders but nothing is left to invest in further plant construction.

We have imagined these plants built by a single corporation and yet our process of price-taking by the plants is a description of a competitive environment. Market information about the construction of plants belonging to other companies must be included as a part of this schedule. The industry leader corporation tries to be the first to construct new plants with the hope of causing other companies to postpone or reduce their plans. Under such circumstances, it is easy to see how an industry could become overbuilt in the sense that the optimal building schedule is exceeded. While our corporation may actually not be interested in maximizing profits for the entire industry, the process described in this model may not be too far from reality–a kind of cooperative competition–in industries where there are no exclusionary rights such as patent protection.

It is very important to understand how the optimizations at the two levels proceed. The UNIT COST contains all the costs, including capital costs (20%). These capital costs are smoothed out and added to payable taxes and the operation and maintenance costs, per unit of input, to form the UNIT COST. Each year, Level 2 managers bring the new plants on line and up to the output level that maximizes profits, given the UNIT COST and the PRICE for that year. The Level 1 managers take a broader view. For each proposed SCHEDULE, they determine the RETURN RATE that just brings the CUMULATIVE DISCOUNTED PROFIT of the entire set of plants up to zero just as the market reaches equilibrium. For the example, that RETURN RATE for the given plant scheduling is 19% and the graph of the CUMULATIVE DISCOUNTED PROFIT is shown in Figure 3.

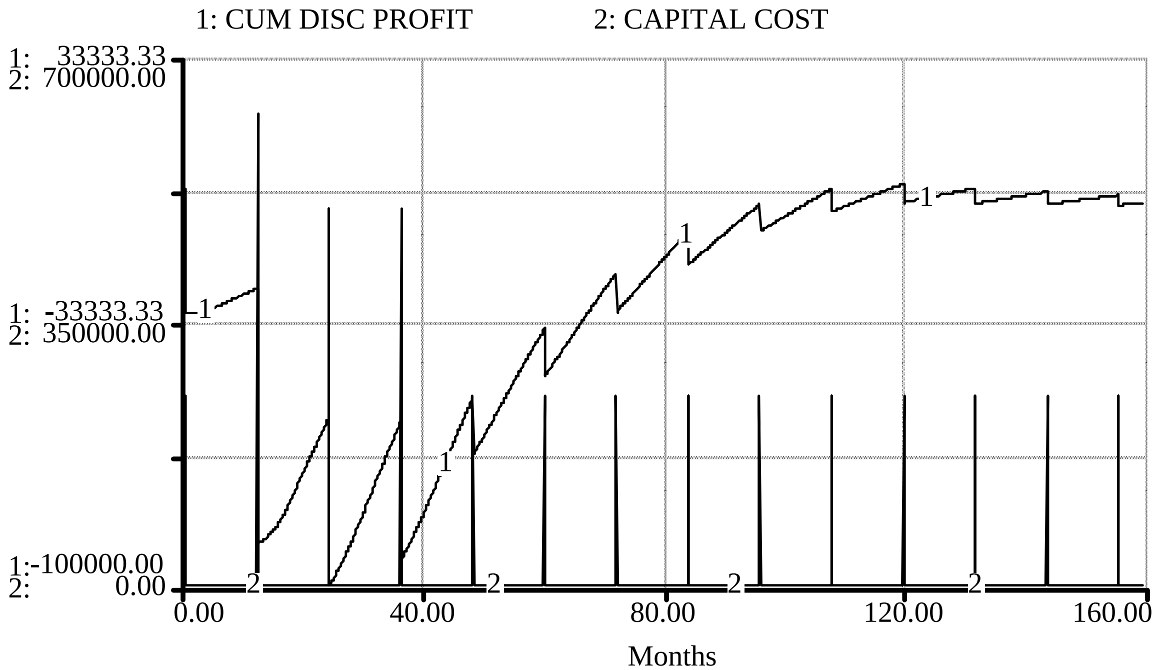

Figure 3. The CUMULATIVE DISCOUNTED PROFIT for the company is brought to zero by adjusting the RETURN RATE, just as the series of plant building has stopped (time = 120 months), for a particular plant scheduling sequence. The sequence is varied to determine the largest RETURN RATE achievable. If this rate is greater than the given DISCOUNT RATE, the plan is feasible. If this rate is the greatest of all the investment options for this firm, then the option is desirable. The CAPTIAL COSTS are shown as they occur at the beginning of each period

The RETURN RATE for this scenario is 19% and is above the given market rate of 17%. Therefore the scenario is feasible. If investment funds are available after all projects with higher return rates are satisfied, then the scenario is desirable.

According to economic theory, marginal cost should equal price when the profits are maximized. Theory also indicates that when profits are maximized at zero, the average and marginal cost should equal price. This occurs when the time = 120 months for this particular plant scheduling sequence. The sequence would next be varied to determine the largest RETURN RATE achievable.

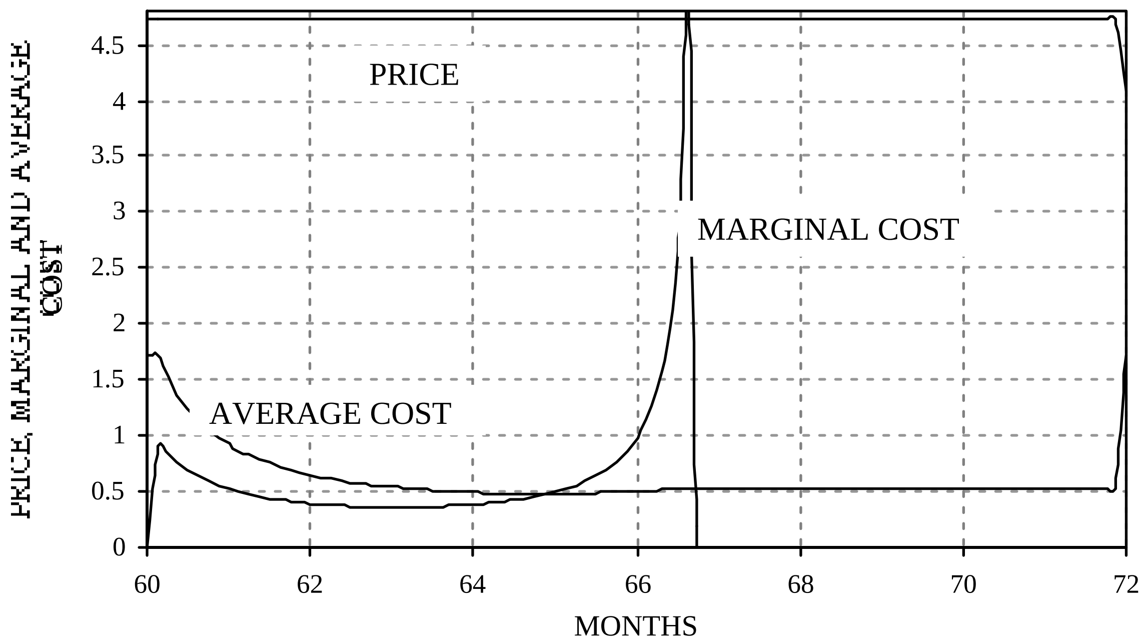

Figure 3. A comparison of Price, Marginal and Average Cost in a portion of the ninth year of expansion. Maximum profit was achieved in about 5 to 6` ` ` ` months. The exactness of the equivalency of price and marginal cost depends on the choice of DT.` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` ` AC and MC are equal when X = A/2B.

After 120 months, the average cost switches from below to above the price. At the optimal point, price, marginal and average cost would be equal. Because the plants appear as discrete units, this equality is not precisely achievable.

In the real world, Level 1 might over or under constrain Level 2. Level 1 management could direct the plant to buy a certain technology and then insist that it be run according to a given schedule and produce the requisite profits. This could turn out to be a disaster if the corporate managers were not really good technologists or not familiar with the real history of the technology required. It is much better to put these decisions close to those who will be responsible for efficient operation of the plants. They are more likely to have the appropriate level of knowledge required for such purposes and they have the added incentive to make sure their own decisions turn out to be good ones.

Level 1 could be guilty of constraining too loosely. For example without the proper signal to stop building plants, the industry becomes overbuilt with at least some plants operating in the red.

Level 1 managers may be late in giving the signal on when to start the new plants, causing a delay in the construction schedule and ultimately in the most profitable production schedule. In fact, our model has in effect an unnecessary delay in plant startup timing in the early part of each year. This was purposely done to convey the nature of the process. However, the plants could be started in the last six months of the preceding year so that they would be fully operational at the first of the year they were scheduled to start.

Level 1 could be delayed in the gathering of information about plans of the competition. As well, the information they gather could be wrong, wrongly interpreted or largely ignored. They might direct the construction of new plants in an effort to get the "jump" on the competition. We are assuming that the competition is using a model to determine the optimal construction schedule in this industry. The question of optimal path becomes a game as to whose account the profits will actually accrue. Assuming that the profit rates are controlling the rate of plant expansion, the company with the highest rate of profit expands the fastest, constrained by the availability of investment funds. We assume that whoever this is will realize that an optimal expansion path does exist. This constraint on the rate of building new plants is not now in the model. It comes from Level 0, the (lending) market. The reader is encouraged to add it.

The Level 1 managers are faced with uncertainty, particularly with regard to the true nature of the demand curve and the intentions of the competition. What policies can they develop to cope with such uncertainty? One answer is extensive sensitivity testing of such a model to determine its response to this uncertainty. For example, what is the variation in the ultimate number of plants if the shut-off price (10) in the demand curve were really 9? The answer, with the same building schedule, is that such a change reduces the total amount of plants to 24 but lowers the return rate to only 4%, clearly well less than investment in the external market. This particular scenario is not feasible.

What about the effects of varying several such parameters at once in the hope of finding some peculiar conjunction that seriously affects the key results? Try varying the shut-off price and the slope of the demand curve simultaneously. Such sensitivity analysis can be performed efficiently using either STELLA or MADONNA.

Surely the technology will improve as we build more plants. This could be handled in the model by representing A and B, the technology parameters, as graphical functions. A would rise to an asymptote and B would decline toward one, with the rate of rise/decline based on cumulative output. This is the typical "learning curve" approach to modeling dynamic technical change.

Further modeling complications might take the form of firm behavior under conditions of a limited number of production companies (oligopoly) or a limited number of buyers (monopsony) or monopolistic collusion (Ruth and Hannon, 1997, Chapter 13).

The deeper details of the programming techniques can be found in the model documents inside the various model variables.

The entire process can be described in hierarchical terms. Level 1 receives from the market (Level 0) what they view as strategic constraints. These appear in the form of the necessary discount rate and the unit cost from the suppliers of input. Level 1 must drive down this unit cost to a point that allows them to at least make some initial level of economic profit.

Level 1 constrains Level 2 to produce at maximum profit. Level 1 also issues PRICE and UNIT COST constraints and makes the decision on how many new plants will be built and at what time. They require Level 2 to behave in such a way as to maximize profits under these constraints. These are tactical constraints in the eyes of corporate management at Level 1 but strategic constraints when seen by plant management at level 2. The distinction between strategic and tactical is in the eyes of the beholder. Level 2 issues tactical constraints, such as what technology to use and when to stop increasing output, to their production managers (Level 3). The production managers see these as strategic constraints and issue their interpretations of them as detailed instructions for plant operation. The dynamics at Level 1 are determined by their interactions with Level 2. Level 2 has chosen the technology of actual production, the startup level and rate for the plants, and they report the timing and levels of production to Level 1. The dynamics at Level 2 are determined from their interaction with those who actually run the production machinery, who face the day-to-day breakdowns and shortages that spoil their best-laid plans.

Finally, Level 2 could be two or more different types of plants in the same chain; that is, one of these two receives its input from the other one. We could elaborate the optimal production rate for each, separately considered, or we could optimize the output rate of the last plant, considering the three of them as a single plant. This is a modeling idea for the reader.

Further modeling complications might take the form of firm behavior under conditions of a limited number of production companies (oligopoly) or a limited number of buyers (monopsony) or monopolistic collusion (Ruth and Hannon, 1997).

EQUATIONS FOR THE COMPLETE MODEL

A = 50 {Units of Q per Units of X}
B = 15
INIT PRICE = 20
STARTING_INPUT = .5
INIT INPUT = STARTING_INPUT
OUTPUT = if time <= STOP_TIME then A*INPUT^2 - B*INPUT^3 else 0
NC_UNIT_COST = GRAPH(time)
(0.00, 60.0), (30.0, 60.0), (60.0, 60.0), (90.0, 60.0), (120, 60.0), (150, 60.0), (180, 60.0), (210, 60.0), (240, 60.0), (270, 60.0), (300, 60.0)
CONSTRUCTION_COST = 19000
DISCOUNT_RATE = (1 + (.17))^(1/12) - 1
PLANT_LIFE = 140
EXPECTED_INPUT = 2
CAPITAL_UNIT_COST = CONSTRUCTION_COST*DISCOUNT_RATE/((1 + DISCOUNT_RATE)^PLANT_LIFE - 1)/EXPECTED_INPUT
UNIT_COST = NC_UNIT_COST + CAPITAL_UNIT_COST
COST = UNIT_COST*INPUT
PROFIT = PRICE*OUTPUT - COST
Profit_Lag = PROFIT - delay(PROFIT,DT)
Profit_Rise = IF Profit_Lag > 0 THEN 1 ELSE IF Profit_Lag = 0 THEN 2 ELSE 0
MONTH = MOD(TIME,12) + 1
EXPANSION_RATE = .03
CHANGING_INPUT = IF Profit_Rise = 1 OR MONTH = 1
THEN EXPANSION_RATE/DT
ELSE 0
del_OUTPUT = OUTPUT - DELAY(OUTPUT,DT)
del_COST = COST -DELAY(COST,DT)
MARGINAL_COST = IF (del_OUTPUT > 0) AND (OUTPUT >= .2) THEN del_COST/del_OUTPUT ELSE 0
INIT PLANTS = 0
SCHEDULE = GRAPH(TIME)
(0.00, 1.00), (3.00, 1.00), (6.00, 1.00), (9.00, 1.00), (12.0, 3.00), (15.0, 3.00), (18.0, 3.00), (21.0, 3.00), (24.0, 3.00), (27.0, 3.00), (30.0, 3.00), (33.0, 3.00), (36.0, 3.00), (39.0, 3.00), (42.0, 3.00), (45.0, 3.00), (48.0, 3.00), (51.0, 3.00), (54.0, 3.00), (57.0, 3.00), (60.0, 3.00), (63.0, 3.00), (66.0, 3.00), (69.0, 3.00), (72.0, 3.00), (75.0, 3.00), (78.0, 3.00), (81.0, 3.00), (84.0, 3.00), (87.0, 3.00), (90.0, 3.00), (93.0, 3.00), (96.0, 3.00), (99.0, 3.00), (102, 3.00), (105, 3.00), (108, 3.00), (111, 3.00), (114, 3.00), (117, 3.00), (120, 3.00), (123, 3.00), (126, 3.00), (129, 3.00), (132, 3.00), (135, 3.00), (138, 3.00), (141, 3.00), (144, 3.00), (147, 3.00), (150, 3.00), (153, 3.00), (156, 3.00), (159, 3.00), (162, 3.00), (165, 3.00), (168, 3.00), (171, 3.00), (174, 3.00), (177, 3.00), (180, 3.00), (183, 3.00), (186, 3.00), (189, 3.00), (192, 3.00), (195, 3.00), (198, 3.00), (201, 3.00), (204, 3.00), (207, 3.00), (210, 3.00), (213, 3.00), (216, 3.00), (219, 3.00), (222, 3.00), (225, 3.00), (228, 3.00), (231, 3.00), (234, 3.00), (237, 3.00), (240, 3.00), (243, 3.00), (246, 3.00), (249, 3.00), (252, 3.00), (255, 3.00), (258, 3.00), (261, 3.00), (264, 3.00)

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ADDING_PLANTS = if Time <= STOP_TIME then (PULSE(SCHEDULE,0,1000) + PULSE(SCHEDULE,12,12)) else 0
INIT BASE_OUTPUT = 0
COMPOSITE_OUTPUT = BASE_OUTPUT + OUTPUT*SCHEDULE
CHANGING_PRICE =   IF MONTH = 13-1*DT and time < STOP_TIME
         THEN (20*exp(-.001*COMPOSITE_OUTPUT) - PRICE)/DT
              ELSE   0
Positive_Profit = If PROFIT <= 0 then 0 else 1
RESETTING =  IF MONTH = 13 - DT
      THEN (INPUT - STARTING_INPUT)/DT
           ELSE IF Profit_Rise = 2 AND Positive_Profit = 0
              THEN INPUT/DT
                  ELSE 0
AVERAGE_COST = If  OUTPUT > .2 then  COST/OUTPUT else 0
INIT BASE_INPUT = 0
del_BASE_INPUT = If MONTH = 13- DT then (PLANTS*INPUT - BASE_INPUT)/DT ELSE 0
del_BASE_Q = IF MONTH = 13 - DT
    THEN (PLANTS*OUTPUT - BASE_OUTPUT)/DT
        ELSE 0
INIT CUM_DISC_PROFIT = 0
CAPITAL_COST = IF MONTH = 4 and PROFIT > 0  and TIME < STOP_TIME
   THEN CONSTRUCTION_COST*SCHEDULE
      ELSE 0
COMPOSITE_INPUT = BASE_INPUT + INPUT*SCHEDULE
RETURN_RATE = (1 + (.21))^(1/12) - 1
D_P_R = (PRICE*COMPOSITE_OUTPUT - CAPITAL_COST/DT - NC_UNIT_COST*COMPOSITE_INPUT)*EXP(-RETURN_RATE*TIME)
PRICE(t) = PRICE(t - dt) + (CHANGING_PRICE) * dt
INPUT(t) = INPUT(t - dt) + (CHANGING_INPUT - RESETTING) * dt
PLANTS(t) = PLANTS(t - dt) + (ADDING_PLANTS) * dt
BASE_OUTPUT(t) = BASE_OUTPUT(t - dt) + (del_BASE_Q) * dt
BASE_INPUT(t) = BASE_INPUT(t - dt) + (del_BASE_INPUT) * dt
CUM_DISC_PROFIT(t) = CUM_DISC_PROFIT(t - dt) + (D_P_R) * dt
OUTPUT =  if time <= STOP_TIME then A*INPUT^2 - B*INPUT^3  else 0
NC_UNIT_COST = GRAPH(time)
(0.00, 60.0), (30.0, 60.0), (60.0, 60.0), (90.0, 60.0), (120, 60.0), (150, 60.0), (180, 60.0), (210, 60.0), (240, 60.0), (270, 60.0), (300, 60.0)
CAPITAL_UNIT_COST = CONSTRUCTION_COST*DISCOUNT_RATE/((1 + DISCOUNT_RATE)^PLANT_LIFE - 1)/EXPECTED_INPUT
UNIT_COST = NC_UNIT_COST + CAPITAL_UNIT_COST
COST =  UNIT_COST*INPUT
PROFIT =  PRICE*OUTPUT - COST
Profit_Lag = PROFIT - delay(PROFIT,DT)
Profit_Rise = IF Profit_Lag > 0 THEN 1 ELSE IF Profit_Lag = 0 THEN 2 ELSE 0
MONTH = MOD(TIME,12) + 1
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CHANGING_INPUT = IF Profit_Rise = 1 OR MONTH  = 1
   THEN EXPANSION_RATE/DT
      ELSE 0
del_OUTPUT = OUTPUT -  DELAY(OUTPUT,DT)
del_COST = COST -DELAY(COST,DT)
MARGINAL_COST = IF (del_OUTPUT > 0) AND (OUTPUT >= .2) THEN
del_COST/del_OUTPUT ELSE 0
SCHEDULE = GRAPH(TIME)
(0.00, 1.00), (3.00, 1.00), (6.00, 1.00), (9.00, 1.00), (12.0, 3.00), (15.0, 3.00), (18.0, 3.00),
(21.0, 3.00), (24.0, 3.00), (27.0, 3.00), (30.0, 3.00), (33.0, 3.00), (36.0, 3.00), (39.0, 3.00),
(42.0, 3.00), (45.0, 3.00), (48.0, 3.00), (51.0, 3.00), (54.0, 3.00), (57.0, 3.00), (60.0, 3.00),
(63.0, 3.00), (66.0, 3.00), (69.0, 3.00), (72.0, 3.00), (75.0, 3.00), (78.0, 3.00), (81.0, 3.00),
(84.0, 3.00), (87.0, 3.00), (90.0, 3.00), (93.0, 3.00), (96.0, 3.00), (99.0, 3.00), (102, 3.00),
(105, 3.00), (108, 3.00), (111, 3.00), (114, 3.00), (117, 3.00), (120, 3.00), (123, 3.00),
(126, 3.00), (129, 3.00), (132, 3.00), (135, 3.00), (138, 3.00), (141, 3.00), (144, 3.00),
(147, 3.00), (150, 3.00), (153, 3.00), (156, 3.00), (159, 3.00), (162, 3.00), (165, 3.00),
(168, 3.00), (171, 3.00), (174, 3.00), (177, 3.00), (180, 3.00), (183, 3.00), (186, 3.00),
(189, 3.00), (192, 3.00), (195, 3.00), (198, 3.00), (201, 3.00), (204, 3.00), (207, 3.00),
(210, 3.00), (213, 3.00), (216, 3.00), (219, 3.00), (222, 3.00), (225, 3.00), (228, 3.00),
(231, 3.00), (234, 3.00), (237, 3.00), (240, 3.00), (243, 3.00), (246, 3.00), (249, 3.00),
(252, 3.00), (255, 3.00), (258, 3.00), (261, 3.00), (264, 3.00)
ADDING_PLANTS =  if Time <= STOP_TIME then (PULSE(SCHEDULE,0,1000) +
PULSE(SCHEDULE,12,12)) else 0
COMPOSITE_OUTPUT = BASE_OUTPUT + OUTPUT*SCHEDULE
CHANGING_PRICE =   IF MONTH = 13-1*DT and time < STOP_TIME
         THEN (20*exp(-.001*COMPOSITE_OUTPUT) - PRICE)/DT
               ELSE   0
Positive_Profit = If PROFIT <= 0 then 0 else 1
RESETTING =  IF MONTH = 13 - DT
      THEN (INPUT - STARTING_INPUT)/DT
           ELSE IF Profit_Rise = 2 AND Positive_Profit = 0
              THEN INPUT/DT
                  ELSE 0
AVERAGE_COST = If  OUTPUT > .2 then  COST/OUTPUT else 0
del_BASE_INPUT = If MONTH = 13- DT then (PLANTS*INPUT -
BASE_INPUT)/DT ELSE 0
del_BASE_Q = IF MONTH = 13 - DT
    THEN (PLANTS*OUTPUT - BASE_OUTPUT)/DT
        ELSE 0
CAPITAL_COST = IF MONTH = 4 and PROFIT > 0  and TIME < STOP_TIME
   THEN CONSTRUCTION_COST*SCHEDULE
       ELSE 0
COMPOSITE_INPUT = BASE_INPUT + INPUT*SCHEDULE
D_P_R = (PRICE*COMPOSITE_OUTPUT - CAPITAL_COST/DT -
NC_UNIT_COST*COMPOSITE_INPUT)*EXP(-RETURN_RATE*TIME)
```

References

Allen, T. F. H. and T. B. Starr, 1982, Hierarchy As a Context for Mathematical Modeling, in: Hierarchy, University of Chicago Press, Chicago, Illinois, Chapter 10.

Allen, T. F. H. and E. P. Wyleto, 1983, Journal of Theoretical Biology, 101: 529-540.

Hannon, B. and M. Ruth, 1997, Modeling Dynamic Biological Systems, Springer-Verlag, New York, Chapter 32.

Johnson, A. R., 1993, Spatiotemporal Hierarchies in Ecological Theory and Modeling, 2nd Intn'l Conf. On Integrating Geographic Inform. Systems and Environmental Modeling, Breckenridge, CO.

Lavroel, S., Gardner, R. H. and R. V. O'Neill, 1993, Analysis of patterns in hierarchically structured landscapes, OIKOS, 67:521-528.

MacMahon, J. A., Phillips, D. L., Robinson, J. V. and D. J. Schimpf, 1978, Levels of bioloigical organization: an organism-centered approach, Bioscience, 28-11: 700-704.

Ruth, M. and B. Hannon, 1997, Modeling Dynamic Economic Systems, Springer-Verlag, New York, Chapter 13.

Stommel, H., 1963, Varieties of oceanographic experience, Science, 139: 572-576.