Application of Agent-Based Modeling to the Cost of Corporate Subsidies

Michael E. Long, Ph.D.
Research Scientist, CFC Center for Imaging Science
Rochester Institute of Technology

Thomas D. Hopkins, Ph.D.
Professor Emeritus, Department of Economics
Rochester Institute of Technology

David L. Farnsworth, Ph.D.
Professor, School of Mathematical Sciences
Rochester Institute of Technology

Email: melsch@rit.edu, thopkins@saunders.rit.edu, dlfsma@rit.edu

Abstract. The US government’s auto industry bailout was just one of many costly programs that target subsidies to particular firms. The merit of such programs is contentious, and more fundamentally, so too is the choice of a basis for their assessment. This short paper applies an agent-based modeling approach to such policy assessment. The result is an intriguingly suggestive perspective on subsidy programs, calling into questions both their efficiency and fairness. Our hypothesis is that government subsidies affect and downgrade the entire economy, and subsidized companies that undergo bankruptcy have a higher probability of its recurrence than those that have not already gone bankrupt.

Keywords: Government Subsidies, Bailout, Agent-Based Modeling

1. INTRODUCTION

Since October 2008, the federal government’s Troubled Asset Relief Program (TARP) has distributed to parts of the U.S. auto industry more than $80 billion of taxpayer funds – some $800 per American taxpaying family. While roughly $30 billion had been repaid by mid-January 2011, the Congressional Oversight Panel [1], which monitors bailout programs, concluded on January 13, 2011 that full repayment is not likely ever to occur. For the US government to break even on the rescue, the market price of General Motors stock would have to exceed $50 per share at the time that the government would decide to sell its remaining shares [2]. This is truly a potentially expensive bailout or subsidy, but the U.S. economic structure is suffused with such subsidies, both short-term and continuing. For example, from $10 billion to $30 billion annually flows from the federal budget to farmers [3]. Many other subsidies are hidden: the price paid by US consumers for sugar is far higher than the world price because the government restricts sugar imports in order to assist domestic sugar producers [4], [5].

One might enquire about the benefit and impact of these subsidies. As a result of these subsidies, has a moral hazard been created? Has the progress of stronger, non-subsidized producers, been handicapped? Has the incentive for efficient
business practices been blunted by the availability of such subsidies? The problems certainly extend beyond the auto industry into the fabric of society, by creating favored status for particular firms or other entities, complicating the prospects of non-subsidized rivals.

Of course, this is a very complicated problem with moral and economic layers compounding it. If the purpose of the short-term subsidy is to give a loan of resources to an entity that is deemed to be critical for the country, then the subsidy might be warranted. However, if the cost of the subsidy continues to be paid by society, while the subsidized entity continues to enjoy the free resources, independent of their unsubsidized rivals, then the merit of the subsidy might be more strenuously questioned.

To initiate a preliminary inquiry into this complicated issue, we developed an agent-based model. Agent-based models (ABM) are nondeterministic in that the outcome itself is not modeled and is often known. In conventional modeling, equations that fit the final state are often developed and used to model not only the final state but also the development thereof. However, in ABM individual players or agents with a set of rules are turned loose in the computer-generated landscape to perform their appointed tasks. The outcome reflects the interaction of each individual agent with other agents and with the environment that in turn acts upon the individual agent.

2. METHODOLOGY

The growth of computational power in recent decades has allowed the incorporation of a sufficient number of agents and a large enough landscape to provide interesting results by aggregating individual behavior of agents based on relatively simple rules of engagement. Relatively recently, such ABM have been developed for a number of applications such as business processes [6], epidemiology [7], segregation [8], civil violence [9], development of minority opinion [10], bank fraud [11], economics [12], tax evasion [13], and annuity policyholder behavior [14].

Agent-based models are a collection or system of computer objects (agents) coupled with methods of interaction (agent behavior). These agents are autonomous and can be adaptive to their environment, essentially learning as the model develops [15], [16]. Agent-based models use individual computer objects as players or agents. Governed by a set of rules, these agents are turned loose in a computer-generated landscape to perform their appointed tasks such as trading, segregating, spreading disease, rumors, or opinions, reacting, creating mayhem, or any number of other endeavors. Often, their resultant behavior has a remarkable similarity to observed reality and can also lead to an understanding of emergent behavior.

This modeling technique differs from traditional differential-equations modeling, which uses a set of top-down equations to model a system. Agent-based modeling is a type of modeling that uses individual, heterogeneous agents that are given a set of rules to follow. All of the agents follow their instructions and interact with each other and with the simulated world based on these rules. Highly complex systems [11], [17] can thus be simplified and analyzed by this simplification and style of modeling.

Agent-based models are well suited for complicated systems and have the advantage over other methods in that aggregate results are produced by modeling smaller, understandable bits and allowing the agents to sort it out. Consequently, experts can be consulted to create rules for realistic behavior of single agents. The agents can interact with each other and their environment, and their behavior can be influenced and change based on these interactions.

As recently pointed out “... economic theorists have increasingly resorted to mathematical systems of equations to model economic processes” [18, p. 76]. However, agent-based computational economics (ACE) is evolving into a powerful tool for evaluating economic policies [19] and studying complex systems that exist in economic markets [18]. Indeed, the complexity of the subsidized industry—with individual actors, personalities, and goals—led us to use an agent-based model as our modeling tool. Other modeling methods would
have had difficulties handling the complexity. However, like any modeling technique, there is a trade-off between realism vs. complexity and simplification vs. usefulness [20]. A complicated model that captures all the nuances of the situation may be realistic, but probably too complex to even execute in a reasonable time. On the other hand, a simple model with excessive assumptions is not useful either. A reasonable tradeoff is required. Although we strive for the model to be as realistic as possible, our goal is a model that can contribute to a broader study by suggesting concerns and issues warranting closer attention. With this consideration ABMs are well suited to addressing complex problems. Sometimes these super complex problems are called wicked problems [21].

2.1 Sugarscape-type Model

First, we consider a simple model of a corporate society and examine the impact of taxation as a vehicle for spreading the wealth and subsidizing weaker enterprises. Questions are: What is the effect of the level of taxation? When does over-taxation occur, and what is its effect on the corporate agents? To do this, we use the pioneering work of Epstein and Axtell [22] to develop a Sugarscape model in the computer language Python as a basic model of corporate society. We tax the agents or corporations applying a flat tax rate and redistributing the tax revenue.

In the original Sugarscape model, a 50 × 50 matrix was constructed with the cells filled with a resource called sugar in various patterns [22]. This landscape was randomly filled with agents each with a randomly generated vision (ability to sense location and amount of sugar) and metabolic rate of sugar consumption. With very simple rules—look around for the best free site; go there and harvest the sugar—for the agents and the landscape, the authors demonstrated concepts of environmental carrying capacity, coherent group structures, inequitable distribution of wealth, and evolution.

In order to assess the overall economic health of the corporate society in our model, we calculate the Gini coefficient, which is a measure of the degree of inequality in the distribution of wealth. If one entity had all the wealth and the rest of the society had none, the Gini coefficient would be 100. If all the individual agents had exactly the same amount of wealth, then the Gini coefficient would be 0.0. The median world country value of the Gini coefficient is about 40, with the US at 45 and Japan at 38. The largest value reported is for Namibia at greater than 70 and the smallest value is 23 for Sweden [23].

2.2 Corporate Model

We develop a more detailed model. The second Agent-Based Model consists of companies, workers, products, and a government. The companies employ workers and pay them a weekly salary; each company makes and sells a single unique product. The workers shop and purchase various products made by different companies, thus completing the economic cycle. The model is created with initial parameters exogenously set, as explained below. The calculations use NetLogo [24].

All agents’ behaviors in this model are created randomly from specific distributions described below.

Companies are created as follows:
1. A number of companies (agents) are created.
2. Each company is given Unit Manufacturing Cost (UMC) of their product, determined from an exponential distribution with an average value selected. For these and all subsequent exponential distributions, high and low cutoff values are set such that if a high or low value is obtained, it is discarded and a new value is generated.
3. A product cost to the customer is established by adding a mark-up value determined from a uniform random distribution ranging from 1% to 100%. Consequently, more inexpensive products are created than expensive ones.
4. Each company's product is given a unique product number, which is used to create the workers' shopping list to identify
products selected and purchased by the workers.

5. Each company is given a random number of employees, again determined by an exponential distribution, but independent of product cost.

Worker agents are created next:
1. An exponential distribution is used to randomly determine worker salaries.
2. With the workers’ salaries established and the number of workers per company known, each company is given cash-on-hand related to their weekly payroll commitment.

After the companies and workers are created, the simple economic environment within which the agents function is finalized:
1. A worker’s shopping list of products is created consisting of each company’s unique product number.
2. The number of times the product number appears on the list is dependent on the company’s product cost and weekly salary obligation. Hence, a company with many workers and an inexpensive product, e.g. loaves of bread, would have its product appearing on the shopping list more frequently than a company with few employees selling more expensive items, e.g. furniture sets. All workers have the same shopping list.
3. The initial cash-on-hand for each company is set at six times its weekly payroll obligation. Payroll stands in as a surrogate for all other corporate financial obligations, such as the costs of marketing, capital, material and supplies, maintenance, and so forth.

Once all the agents are created and the simple economic environment finalized, the companies manufacture products and pay the workers. The workers purchase products made by the companies. The process proceeds as follows:
1. The economic process is started in the manufacturing step with companies making product and filling their inventory.

The inventory is sufficient to support any purchases for the week.
2. Workers are paid their weekly salaries from the company’s cash on hand, which of course, is depleted by that amount.
3. Following the manufacturing phase, workers randomly select an item from the shopping list until they run out of cash. If their last purchase results in a negative balance for the week, they use a credit card and make that additional purchase. However, they start the next week with that amount less to spend. Hence, they are not allowed to carry a credit card debt beyond one week.

This produces a stable economic climate with workers randomly shopping, returning cash to the corporate environment, and getting paid weekly. However, the government now imposes a weekly tax on the workers, and therefore they have less money to spend on products. Consequently, the workers demand an annual raise to compensate for this loss and to maintain their standard of living. The lowest third of a company’s paid workers are given an annual raise. If a company runs out of money trying to meet its salary obligations, it receives a subsidy from the government. This cycle is repeated a set number of times, and the companies that go bankrupt and require a government bailout are recorded.

3. RESULTS

The simpler Sugarscape-based model illustrates the impact of taxation and support of weaker corporate identities on the environmental carrying capacity and societal wealth. The second model deals with the expected probability of repeat company bankruptcies.
3.1 Sugarscape-type Model

In the simulations with increasing tax rate via the Sugarscape type model, the initial impact is an increase in the carrying capacity of the environment—more corporations survived as the tax rate increased—as more of the less fortunate agents or companies are supported. Concomitantly, the Gini coefficient initially decreases as a function of tax rate and then levels off, indicating an initial redistribution of wealth and then lack of further impact (Figure 1). In contrast, the total wealth of the society is initially approximately constant followed by a decrease in the total wealth of the society (Figure 2). This is undoubtedly due to the redistribution of resources required to support agents with high metabolism (high consumption of resources), that is, the corporations that require subsidies to survive. Similar behavior is realized for the wealth per agent, that is, all the enterprises suffer to support the non-competitive corporations.
3.2 CORPORATE MODEL

The model’s default input parameters are shown in Table 1, although these can be varied as discussed.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Companies</td>
<td>20</td>
</tr>
<tr>
<td>Company Employment</td>
<td></td>
</tr>
<tr>
<td>Average Number of Employees</td>
<td>100</td>
</tr>
<tr>
<td>Minimum Number of Employees</td>
<td>5</td>
</tr>
<tr>
<td>Maximum Number of Employees (1)</td>
<td>200</td>
</tr>
<tr>
<td>Average Annual Salary (2)</td>
<td>$34,000</td>
</tr>
<tr>
<td>Minimum Annual Salary (3)</td>
<td>$18,000</td>
</tr>
<tr>
<td>Maximum Annual Salary</td>
<td>$150,000</td>
</tr>
<tr>
<td>Average Product Unit Manufacturing Cost</td>
<td>$8</td>
</tr>
<tr>
<td>Tax Rate</td>
<td>0.15%</td>
</tr>
<tr>
<td>Annual Worker Pay Increase</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

(1) 99.2% of US companies have 200 or fewer employees [25].
(2) The average 2008 annual personal income was $33,943 [26].
(3) The average annual minimum wage is about $15,000 based on 40 hour per week for 50 weeks [27].

With these input parameters, eventually, a company can run out of cash. The question is: Why, in the model, do companies go bankrupt? The following possible non-random conditions or dependencies might cause bankruptcy.
1. Time dependence, for instance, occurrence after a particular elapsed time.
2. The number of employees, for instance large or small companies might be more likely to run out of cash.
3. Particular salary obligations.

4. Product cost, such as a more expensive or inexpensive product.

Table 2 shows the results of 14 simulations addressing the number of weeks before the first company ran out of cash. The simulation was stopped at the first bankruptcy or at an arbitrary duration without a bankruptcy. The results are for the default values in Table 1, but without taxation and subsequent corporate subsidies. With repeated simulations, there does not appear to be a set time that companies go bankrupt or a simulation time after which bankruptcy occurs.

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Weeks of Operation</th>
<th>Bankruptcy Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>15</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>260</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>380</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>400</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>450</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>473</td>
<td>Yes</td>
</tr>
<tr>
<td>1</td>
<td>721</td>
<td>No</td>
</tr>
<tr>
<td>12</td>
<td>764</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>791</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>795</td>
<td>No</td>
</tr>
<tr>
<td>13</td>
<td>888</td>
<td>Yes</td>
</tr>
<tr>
<td>14</td>
<td>1900</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>3000</td>
<td>No</td>
</tr>
<tr>
<td>11</td>
<td>9580</td>
<td>No</td>
</tr>
</tbody>
</table>

The four simulations shown in Tables 3 and 4 address the questions of bankruptcy caused by number of employees and salary obligations. Each simulation was stopped at the first bankruptcy and the employee information recorded. There does not appear to be a dependence on the number of employees or a preponderance of lower salaried employees on the company payroll. One might have incorrectly reasoned that bankruptcy is more likely for companies with more lower-paid employees because they are receiving the annual...
raise and thus increasing the company’s weekly salary obligation.

Table 3: The Number of Employees for Bankrupt Companies

<table>
<thead>
<tr>
<th>Number of Employees of Bankrupt Company</th>
<th>Minimum Number in Simulation Run</th>
<th>Maximum Number in Simulation Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>10</td>
<td>131</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>656</td>
</tr>
<tr>
<td>17</td>
<td>3</td>
<td>129</td>
</tr>
<tr>
<td>69</td>
<td>69</td>
<td>133</td>
</tr>
</tbody>
</table>

Table 4: The Number of Employees with Salaries below the Simulation Median

<table>
<thead>
<tr>
<th>Number of Employees of Bankrupt Company</th>
<th>Number of Employees with Salaries below Median</th>
<th>Median Salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>21</td>
<td>$33,135</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>$31,280</td>
</tr>
<tr>
<td>17</td>
<td>8</td>
<td>$30,749</td>
</tr>
<tr>
<td>69</td>
<td>40</td>
<td>$41,142</td>
</tr>
</tbody>
</table>

Figure 3 considers the question of the dependence of bankruptcy on weekly payroll obligations and product costs. The instances of bankruptcies in seven simulations (runs as denoted in Figure 3) are indicated with a circle. For bankrupt companies, the company’s weekly payroll obligation does not appear to have any relationship to its consumer product’s cost.

Simulation runs were also performed looking at other possible dependencies, such as frequencies of and time intervals between multiple bankruptcies and repeating the above summary of results for 10, 20, 40, and 50 companies. One hundred simulations of the model explored different standard causes of bankruptcy, but none of the resultant bankruptcies’ patterns showed any dependence on model input parameters.

Consequently, we conclude that the occurrence of bankruptcy in the model is a random event dependent on the overall company configuration, as defined by the model and input parameters, and not a simple dependency on a single model input parameter. Multiple simulations over longer time periods followed this test phase. The policy of government subsidies to bankrupt companies at the rate of five times their weekly salary obligations was instituted allowing them to return to operation. Certainly, the amount of the subsidies could conceivably affect future financial outcomes for a struggling company. However, the government subsidies for bankrupt companies are intended as a financial seed and are usually considerably less than the company’s market capitalization.

The simulation was stopped after 5 companies went bankrupt and bankrupt companies were noted. This simulation with 20 companies was repeated 25 times. If our hypothesis that a company that goes bankrupt once has a higher probability of going bankrupt again is true, then a high rate of repeat bankruptcies would be expected from the corporate model compared to a random process.

For the random process, consider the following probability model for bankruptcies. Consider 20 companies that are vulnerable to bankruptcy over a given number of years. Designate by \( k \) the total number of bankruptcies in a simulation where repeat bankruptcies by a company are counted. To compare with the model’s outcomes, we require the probability \( P(k) \) that within the \( k \) bankruptcies that one or more companies will repeat the act of going bankrupt one or more times.

This probability model is the same as the following for a container of 20 objects, labeled 1 through 20. An object is selected randomly, the number of the object is recorded, and the object is replaced in the container. This process of selection, recording, and replacement is repeated a fixed number of times, \( k \). The probability that among the objects selected there are any repeats is \( P(k) \).

The solution to this problem for \( k = 5 \) is \( P(5) = 0.4186 \), which can be found as follows. In the first selection, the probability of not getting a match is 20 out of 20. For the second selection, the probability of not getting a match is 19/20 because one has already been selected. The probability of not getting a match on the first and second selection is \( (20/20)(19/20) \). The probability of getting a match is the complement of the probability of getting not getting a match. Consequently, the
probability of finding one or more duplicates in k = 5 draws from 20 objects is
\[ P(5) = 1 - \frac{20! \times 19 \times 18 \times 17 \times 16}{20 \times 20 \times 20 \times 20 \times 20} = 1 - \frac{20!}{20^5 \times 5!} = 0.4186. \]

This technique is used to solve the birthday problem, which asks the question: How many people must be at a party in order to have at least a 50-50 chance that two of them share a birthday, but, perhaps, not a birth year? The answer is 23 individuals [28].

For 20 companies and 5 bankruptcies, the null hypothesis is \( p = 0.4186 \) from the probability model with the alternative hypothesis \( p > 0.4186 \). For twenty-five simulations of the corporate model, 17 had one or more repeated bankruptcies. The standard normal value for this proportion is
\[ z = \frac{(17 - 0.5) - (25)(0.4186)}{\sqrt{25(0.4186)(1 - 0.4186)}} = 2.4466, \]
which gives the p-value 0.0072. The probability of getting by chance the proportion of 17 successes or more in 25 trials is only 0.0072, which is quite small. Consequently, it is safe to conclude that repeat bankruptcies in the corporate model are not random events.

The key parameters used here (see Table 1) include realistic values for variables that most might agree are of central importance in understanding business conditions. The results derived have sufficient plausibility to warrant further inquiry into the consequences of bailouts.

4. SUMMARY

These results by no means prove that the auto bailout, or any other of our myriad subsidy programs, has produced analogous damage to either the level or distributional equality of societal wealth, but they are intriguingly suggestive. There is a common tendency for observers and advocates of subsidies to point to the survival of the subsidized firm(s) as evidence of the merit of the subsidy. That the new General Motors is developing a solid record of sales and profits is undeniable. But, this is not sufficient grounds for declaring the bailout a success. Although the auto bailout may be at least a limited success in that it reduced the country's despair during a difficult time and eliminated a possible financial domino effect, it certainly is too early to be sure of its true impact. Nevertheless, other bailouts remain questionable in their cost to the consumer and their effect on US manufacturing competitiveness on the world market.

What would occur in the absence of such bailouts, while difficult to discern, is the critical comparison state. US bankruptcy laws provide an orderly means for failing companies to be dealt with in the absence of subsidies. When we prevent their operation, as subsidies do, we open the possibility that neither efficiency nor economic-equality interests are well served.

References


http://www.candyusa.com


Figure 3: Weekly Company Payroll vs. Product Cost for Bankrupt Companies