

# A Multi-Agent Model of a Small Firm

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This paper presents a bottom-up view of industrial ecosystems by examining the interpersonal dynamics that influence corporate environmental behavior. Employees of profit-making firms don't always behave in the shareholders' best interests due to misaligned incentives, impaired information flows, and bounded rationality. Even worse, there are sometimes conflicts between shareholder interests and the broader public interest, evident in the moral struggles of people over their dual roles as employees and as citizens. Employees operate within the formal, regulative structures of the firm and government, as well as the informal, normative or cultural structures of social networks.

The paper triangulates to identify useful insights about personal networks and corporate environmental behavior, using interviews at firms, review of archival data, and a computer simulation model. Interviews and archival data provide empirical grounding, while an innovative multi-agent simulation modeling exercise supports formal theorizing. The empirical work is based on case studies of plastics processing firms in New Jersey. The simulation model characterizes production technologies, social and economic structures, and interpersonal interactions under a variety of conditions. The model may eventually prove helpful to managers interested in improving on existing organizational practices and procedures. The model could also help regulators understand corporate environmental behavior more fully.

Findings are relevant to both the eco-park and industrial ecosystem levels of analysis. This work is funded by a U.S. Environmental Protection Agency STAR grant.

The next section reviews the relevant literature. Then the paper provides an introduction to the industrial sector studied, describes case studies of four firms and findings from those cases, introduces the multi-agent simulation model and modeling processes, and draws conclusions.

## **Literature on networks and organizations**

### ***Studying organizations***

It is difficult to study organizations because they are so highly complex and adaptive. They exhibit structural complexity, having both functional and product hierarchies within whose mesh individual employees act. Organizations are also goal-oriented systems that survive by adapting to changing external conditions. The leaders of organizations work full time to change that which researchers study.

The range of organizational phenomena is rich enough that distinct disciplinary approaches to their study have developed. Often researchers talk past rather than to one another over interstitial issues such as linking structure and agency. The normal

progressive spiral of science from induction to deduction, pattern matching to hypothesis testing, evidence to theory and back again, seems to operate inefficiently. Many theories co-exist, and empirical work fails to eliminate most of these rivals. This paper attempts to get the “wheel of science” (Wallace, 1971) spinning productively by directly triangulating across extant theory, qualitative data, quantitative data, and simulation modeling.

As discussed elsewhere (Andrews, 2001), there is much useful economic theory for industrial ecologists to draw upon. It explains why firms exist (scale economies, transaction cost reductions), how they respond to changing external conditions (internal structural change, external influence projection), and how they relate to other firms (contracting, mixed-motive strategizing). Some strands of the contracting literature also assign agency to employees within a firm, typically highlighting mismatched incentives and informational asymmetries.

Prescriptive management theories have progressed over time from the efficiency studies of Taylorism, to classical management theory that emphasized commanding and controlling, to the gentler and more respectful human relations approach of Mayo, to the systems approach of Senge and others.

Classical and neoclassical economic theories provide an atomized explanation of economic actions, whereas reformist economists view economic actions as embedded within social structures. According to these theories social relations between individual actors impedes competitive markets and individuals pursue a narrow utilitarian, self-interest. This view is called “undersocialization”. “Oversocialization” is when behavioral patterns are so internalized that social relations have only a peripheral effect on behavior.

Granovetter (1985, 487) posits a middle position between over and under socialization *“Actors do not behave or decide as atoms outside a social context, nor do they adhere slavishly to a script written for them by the particular intersection of social categories that they happen to occupy. Their attempts at purposive action are instead embedded in concrete, ongoing systems of social relations.”* He furthermore rejects the neoclassical undersocialization theory arguing that *“anonymous markets of neoclassical models are virtually nonexistent in economic life and that transactions of all kinds are rife with the social connection.”* In actuality, business relations today are mixed up with social relations all the time. For example (p. 496), *“in industrial purchasing, buying and selling relationships rarely approximate the spot-market model of classical theory...and evidence consistently suggests that it takes some kind of ‘shock’ to jolt the organizational buying out of a pattern of placing repeat orders with a favored supplier.”* The reasons for this type of seemingly irrational behavior include costs associated with searching for new suppliers and establishing new relationships. These relationships are formed through trade associations, country clubs, and other social gatherings. The survival and success of small firms in the market are in part due to a dense network of social relations overlaid on top of the business relations that connects such firms and reduces pressures for integration.

### ***Social Networks***

There is a distinction between the ‘formal’ and the ‘informal’ organization of the firm with the formal represented by the organizational chart and the informal represented in the social networks within the firm. Organizational charts do not reflect the way the work gets done inside an organization. There are many actors in employees’ social networks, all of whom have the potential to influence the employee. There are two main types of actors that have this influence, and Shah (1998, p.250) call them “*cohesive and structurally equivalent actors.*” Cohesive actors or referents are individuals with close, interpersonal ties, or friends. Structurally equivalent actors are individuals who share a similar pattern of relationships with others and thus occupy the same position in a network. Shah (1998, p.249) has shown that “*employees rely on structurally equivalent referents for job related information and on cohesive referents for general organizational information and as social comparison referents.*”

Informal practices and social networks serve distinct purposes within a firm. For example, firms’ internal information is not necessarily acted upon, particularly in the context of promotion practices. According to Granovetter (1985, 499), “*internal promotions have affirmative incentive properties because workers can anticipate that differential talent and degrees of cooperativeness will be rewarded.*” Long term employees also have built up strong informal networks within the firm (Granovetter, 1985, 501), “*when many employees have long tenures, the conditions are met for a dense and stable network of relations, shared understandings, and political coalitions to be constructed.*”

Individuals are more likely to obtain general organizational information (i.e. office gossip, organizational culture, office politics) from cohesive actors, according to Shah (1998, p.252). Social comparison theory suggests that similarity plays an important role in referent selection. Demographic variables such as gender, age, tenure, and education account for different aspects of similarity within workplaces. People often select referents of the same gender, job category and education. Similarity in tenure and age may also serve as relevant dimensions for career comparisons. In the cases studies to follow, there is some evidence that long tenure and seniority on the job elicits greater influence in the work environment than simple hierarchical positions. The studies also show that there is greater cohesion in the workforce because of the similar ethnic backgrounds of the low skilled workers of Hispanic origin. This demographic trait is also a link to higher levels in the organization through internal promotions.

Workplace uncertainty, socialization practices and performance ambiguity may all lead to different types of socialization within the firm. A routine, well-defined assembly line task may elicit few inquiries regarding job responsibilities and performance. More complex, loosely structured positions may generate many inquiries. The plastics manufacturing firms included in this case study would fall under the category (Toone and Jackson) of small batch production or “*job-order manufacturing for customized products in which production is done according to demand in small runs and lots.*”<sup>1</sup>

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<sup>1</sup> Toone, Roland and Jackson, Dave. 1987. *The Management of Manufacturing: The competitive Edge.* Springer-Verlag; New York, p. 22

### ***Formal vs. Informal networks***

According to Scott (2001, 153), there are two distinct features of firms today. *“First, there exists a remarkable similarity in the structural features of organizational forms operating within the same organizational field.....Second, students of organizations have long observed the presence of both a formal and informal structure, the former reflecting officially sanctioned offices and ways of conducting business, the latter, actual patterns of behavior and work routines. An uneasy tension exists between these structures.”* The formal and informal networks that frame inter- and intra-firm behavior are defined as follows by Schermerhorn and colleagues (1988, 199):

- “Formal groups are created via formal authority for some purpose. They typically have rather clear cut superior-subordinate relationships, and they often appear on formal organizational charts.” Formal groups are designated by an organizational authority and can be seen in the production pressures and technical demands of a company. Formal groups are specified by the organization chart (and by a task group in a matrix management situation).
- Informal groups on the other hand are not formally recognized but typically consist of subgroups or cliques within formal groups. These informal groups can be people within a firm that eats together or goes on breaks together. Informal groups emerge spontaneously. Informal groups consist of groups of individuals that want to achieve some mutual objective (not the organization’s but the group’s), sometimes they are merely friendship groups or people who have something in common. According to Scott (2001), “This is really where/how things get done in organizations.” Informal groups can be seen in the regulative, normative and cultural-cognitive elements of the company, including company sponsored social activities of the sort mentioned in the case study to follow.

Informal networks exist because they help individuals do their work by “offering a network of interpersonal relationships with the potential to ‘speed up’ the work flow or gain favors in ways that formal lines of authority fail to provide” (Schermerhorn et al, 1988, 200). These informal groups also help individual employees meet needs beyond what the formal groups can provide, including:

- Social satisfaction – friendship and social relations
- Security - “opportunities to find sympathy for one’s feelings and actions, especially as they relate to friction with the formal organization; opportunities to find help or task assistance from persons other than one’s superior”
- Identification – sense of belonging by associating with people who are similar

### ***Organizational life cycle***

As organizations increase in size, they typically become more heterogeneous in their orientations and in the products and services they provide. This often results in movement from a simple to a more complex structure.

<b>Organizational Life Cycle</b>		Formalization and	Elaboration of
Entrepreneurial Stage	Collectively Stage	Control Stage	Structure Stage
	Information communication and structure	Formalization of rules	Elaboration of structure
Marshalling of resources	Sense of collectivity	Stable structure	Decentralization
Lots of ideas	Sense of collectivity	Emphasis on efficiency and maintenance	Domain expansion
Entrepreneurial activities	Long hours spent	Conservatism	Adaptation
Little planning and coordination	Sense of mission	Institutional procedures	Renewal
Formation of a "niche"	Innovation continues		
Prime mover has power	High commitment		

Table 1: The Organizational Life Cycle

Source: Cameron, K. S. , and Whetten, D. A. 1983. Models of organizational life cycle: Application to higher education. *Rev. Higher Educ.* 6(4): 269-299.

Many firms, especially smaller enterprises, never reach the later stages in the organizational life cycle, either because they disappear or because they don't reach a size that requires much formalization. Nevertheless, the importance of the distinction between formal and informal social networks grows as structures become more complex.

### **Industry Background**

The industry sector studied in this project is plastics products. It was chosen because the technology is relatively simple, it has eco-efficiency and pollution reduction opportunities, there are many small and medium-sized firms available as case study candidates, and it is undergoing a dramatic transformation due to competitive pressures from economic globalization.

#### ***Plastics Product Manufacturing***

The two basic groups of plastic materials are the thermoplastics and the thermosets. Thermoplastic resins consist of long molecules, each of which may have side chains or groups that are not attached to other molecules, so they are not cross linked (SPI, 1999a). Thus, they can be repeatedly melted and solidified by heating and cooling so that any scrap generated in processing can be reused. No chemical change generally takes place during forming. Usually, thermoplastic polymers are supplied in the form of pellets, which often contain additives to enhance processing or to provide necessary characteristics in the finished product (e.g., color, conductivity). The temperature service range of thermoplastics is limited by their loss of physical strength and eventual melting at elevated temperatures.

Thermoset plastics, on the other hand, react during processing to form cross-linked structures that cannot be remelted and reprocessed. Thermoset scrap must be either discarded or used as low-cost filler in other products. In some cases, it may be pyrolyzed to recover inorganic fillers such as glass reinforcements, which can be reused. Thermosets may be supplied in liquid form or as a partially polymerized solid molding powder. In their uncured condition, they can be formed to the finished product shape with or without pressure and polymerized by using chemicals or heat.



Figure 1: New Jersey Plastics Industry Employments and Shipments  
Source: SPI (2002)

New Jersey is one of the top ten states accounting collectively for 60% of the total U.S. plastics industry shipments (SPI, 2002). Unofficial statistics suggest that both employment and shipments have dramatically declined in this industry since 2001.

***Plastic Injection Molding Industry***

Injection molding is the principal method of forming thermoplastic materials. The production process is organized around runs of product (e.g., an order for 100,000 plastic coffee cup lids). Large volume runs of simple items (like coffee cup lids) have low profit

margins because there are too many competitors for this type of simple product. On the other hand, the most profitable firms deliver high quality, complex, molded products often in smaller runs (e.g., an order for 1000 laptop computer housings). Generally, the injection molding business has a range of production specialties. At the smaller end, the precision molders make very small parts and at the large end they can make larger, more complex parts (e.g., automotive parts). There are two types of injection molders:

- Custom, contract molders make parts specific to the needs of their customers
- Proprietary, captive operations make their own products

The relevant NAICS codes that apply to this industry include:

NAICS Code	Description
326199	All Other Plastics Product Manufacturing
325991 & 3261	Plastics Product Manufacturing
32613	Laminated Plastics Plate, Sheet, and Shape Manufacturing,
32614	Polystyrene Foam Product Manufacturing
3087	Custom Compounding of Purchased Plastics Resins
325991	Custom Compounding of Purchased Resin

### ***Technology & Innovation***

Injection molding is a branch of the plastics industry that involves injection under pressure of molten plastic into the cavity of a mold followed by cooling and removal of the solidified part that retains a replica of the mold. The injection molding industry is arguably in its infancy. It was only during the 1960s that reciprocating screw technology became commercially viable. With the advent of the microprocessor, there have been significant advances in process control during the 1980s and 1990s. There have been equally significant advances in screw technology, multi-color molding, insert molding, gas assisted injection molding, and other niche processes. There have also been major advances in polymer materials, mold making, and of course, predictive analysis tools for avoiding problems before they occur and optimizing every phase of the design-to-manufacturing process.

However, in spite of all these advances, the injection molding industry continues to exhibit signs that it is still a very young industry. For example, it remains common to set up and optimize the process using time-consuming and inefficient trial-and-error methods. While molders may be able to obtain acceptable quality parts using this method, the process usually requires constant fine-tuning to maintain quality parts because it was not set up using a rigorous scientific quality control method. Failure to setup and optimize using a rigorous method normally results in a process that is not robust and therefore, is difficult to control. Beyond the setup, optimization, and control of the process, there are additional injection-molding manufacturing tasks that must be performed, optimized, standardized, and integrated across the company-wide enterprise. These additional tasks include, but are not limited to, production scheduling, preventive maintenance, process and production monitoring, statistical process control, statistical quality control, and production reporting. It is also becoming increasingly common for an injection molder's customers to demand value-

added operations such as part traceability, while simultaneously demanding per-part price decreases. Facing these challenges, injection molders must not only implement systems and processes to achieve the value-added demands, but also accomplish them cost-effectively while improving the efficiency of their existing operations.

### ***Employee Tasks***

Injection molders typically work in small independent firms with relatively few employees (5-100). Most of the employees are semiskilled workers who load plastic pellets into the injection molding machines, mixing in some recycled plastic waste as available. Once the plastic has cooled and re-solidified the mold opens and the plastic product is removed. If the machine's temperature is set too high, air pollution can result in the form of fugitive volatile organic releases. In a typical machine, every 30 seconds the machine completes a cycle, dumping a cooled molded plastic piece onto the factory floor. Injection molding machines require thorough maintenance, otherwise they become unreliable. Workers take the molded plastic pieces and break off the extra bits of plastic (little nubs and frames). The amount of plastic waste is a function of the mold design and the amount of product made.

Workers then put the waste plastic into a grinder and store it for use as recycled feedstock. Recyclability is a function of the type of plastic material used (some plastics can't be recycled once heated). Un-recyclable plastic is disposed of offsite. Workers inspect the product and reject some pieces (these get recycled) and pack the product into boxes for shipping. These boxes are shipped to customers according to a supply schedule. A process engineer supervises multiple injection molding machine lines and orders raw materials. A marketing manager solicits orders for products and a plant manager coordinates the marketing and production activities, settles employee disputes, and seeks to maintain profitability.

### ***Industry Outlook***

The injection molding business's golden era spanned the 1970s - 80s when there was less competition at the machine and process level and firms produced very high profit margins. Now there are abundant machinery manufacturers and processors inundating the market. Processors range from small family operations with a handful of machines to larger companies with hundreds of machines. Other dynamics are also lowering the margins, including increased competition from Asian imports. Asian markets have very low costs, particularly labor costs, relative to U.S. operations.

### ***Plastics Injection Molding Process***

In injection molding, plastic material is put into a hopper that feeds into a heated injection unit. A reciprocating screw pushes the plastic through this long heating chamber, where the material is softened to a fluid state. At the end of this chamber there is a nozzle that abuts firmly against an opening into a cool, closed mold. The fluid plastic is forced at high pressure through this nozzle into the cold mold. A system of clamps hold the mold halves shut. As soon as the plastic cools to a solid state, the mold opens and the finished plastic is ejected from the press (SPI, 1999b).

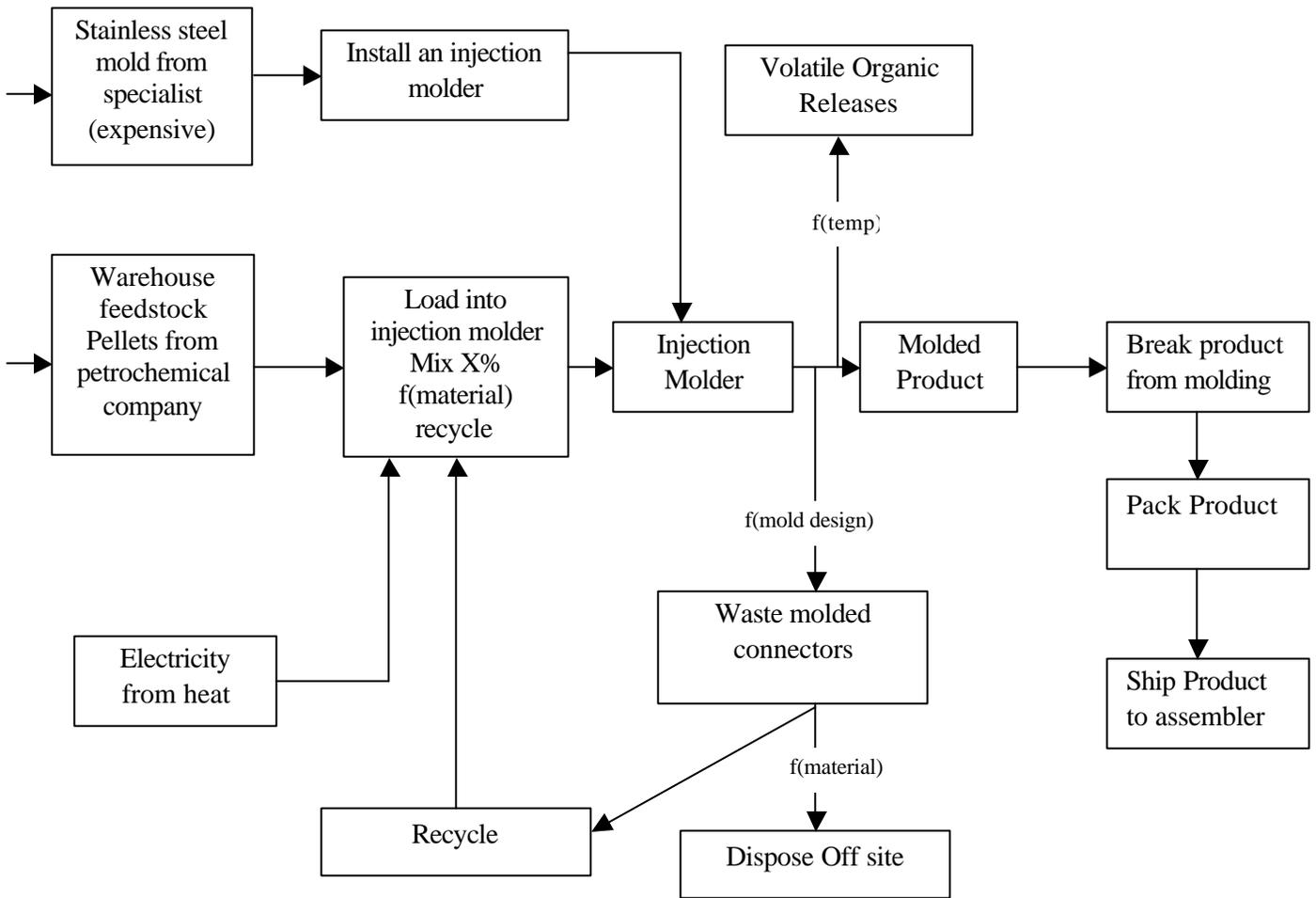


Figure 2: Plastics Injection Molding Process Diagram

**Methods**

Three plastics injection-molding firms in New Jersey and one multinational chemical corporation were selected for study. The three plastics firms were selected because they were accessible and because they have relatively simple manufacturing processes that could be more easily modeled. The multinational chemical company was studied less formally, specifically for their approach to environmental management. The case studies of the three companies include in depth interviews with the presidents or owners of each

firm, analysis of business, financial and environmental records, and site tours of the manufacturing floor. Each interviewee reviewed and signed an informed consent form and their names and the names of their companies remain confidential.

<b>Firm</b>	<b>Description</b>
Company 1	Plastics, Injection molding, Single establishment, family run
Company 2	Plastics, Injection molding, Single establishment, family run
Company 3	Plastics, Injection molding and extrusion, Subsidiary of Multinational company
Company 4	Multinational chemical firm

### **Case Study Findings**

In depth interviews with the presidents or managers of the three injection molding companies revealed a great deal of information regarding the importance of: formal and informal networks in workplace practices such as innovation and safety measures, the role of a family run vs. a corporate culture environment, external market dynamics, stable workforce dynamics. The following hypotheses reveal a rich picture of this particular industry and also highlight some important lessons more generally, regarding organizational behavior's ties to workplace practices.

***Hypothesis 1a:*** *As the external environment becomes increasingly competitive, the family-run businesses decrease the social amenities available to employees. **Supported.***

***Hypothesis 1b:*** *As family run businesses experience a generational shift, the social practices of the company also shift. **Supported.***

Interviews with all three companies revealed that there has been a shift in the business culture towards a less social work place indicated by the decrease or elimination of company sponsored social activities such as company sports teams or company picnics. In the case of the first two companies, which are run by a second generation of family members, this shift to less social activities also coincides with a shift towards a more competitive market environment and less profitability. Interestingly, the third company which operates under a more corporate culture (subsidiary of multinational company) and is not run by family members, offered many more social amenities to their employees than the first two family run companies. This difference may mean that the decrease in social activities in the first two companies may be primarily due to scarcity of resources to support such activities. On the other hand, the quality, scope and relevance of the social activities in place at Company 3 cannot be measured by this case study and therefore it is difficult to compare and contrast the activities of one company with past activities of the others. The generational shift evident in the two family-run companies was also accompanied by a downturn in the economy and increased competition in the industry. Were these social activities cut because the second generation was not as socially tied to the employees or had a different relationship with employees than their predecessors? Or is this decline a direct outcome of scarce resources to dedicate to social amenities?

According to Company 1's President, the decline of company sponsored social events might be attributable to both a generational shift and a resource allocation issue. The current owner feels that if his father were still running the business that many of the social activities he sponsored would probably still be in place. This is because part of his father's "style" was that he felt more comfortable interacting with the employees through these types of activities as opposed to more informal contact on a daily basis. The current owner thinks it was partly due to his age that he didn't relate as easily with the employees so that the social activities were a mechanism for reaching them. The owner today and his brother take a much more relaxed approach in which they feel comfortable with their employees and interact with them on a daily basis in a less structured way on the factory floor. In this case, the social activities would be nice but they are not really necessary for them to get to know the employees. On the other hand, if the current economic situation allowed for more profitability with a surplus of money available, a situation more similar to when their father ran the business, then they might well consider offering more social activities. In many ways the decision to offer company-sponsored social activities is product both of resources and personal style.

At Company 2 on the other hand, the original owners, the fathers, were very "hands on" interacting mostly on the factory floor as technical tool-makers, they were very close to the factory workers. The second generation in this company was less "hands on" and more focused on the business aspects of the company. At company 2, the owners attribute the decline in social activities more to a lack of resources and the sense that employees were not participating in the activities. In the past the company hosted several company sponsored social activities such as picnics that have since faded when they moved to a new facility a few years before, *"We used to have picnics, a company picnic. The last one was before we moved over here, but we stopped them because our business had fallen and the money wasn't really there for that or we didn't want to use it for that. I think there was also some distaste on our part that we didn't feel our employees were participating at that point."*

Company 3 offered a wide range of social activities including a bowling team, company luncheons, educational training, and other activities. Company 3's manager sees a great deal of value in sponsoring these events. The manager states, *"I would say that happens [interaction between positions] in the sports driven activities like bowling. It gets the full gamut of employees. You get staff management out there bowling and the maintenance folks and set up operators and packers, one big team."* This type of socialization is also seen as a positive contributor to company morale on the factory floor. The general manager describes the effects of such social activities on the company as follows, *"It helps on the factory floor. I don't know if I can quite put my finger on it, but when you have a crew that's been around, that's as senior as the one I've got, there's a wonderful camaraderie but there's also a totem pole."*

***Hypothesis 2: Family run businesses have strong social ties to employees, and thus may be less likely to streamline and cut labor. This theory is based on the human relations theory of organizational behavior. Not supported.***

This dynamic works well for explaining promotional or recruitment/ hiring practices but is not the driving factor in the business. Company 1, for example, relies on informal communication networks and close ties/familiarity with employees to determine promotions and even hiring or firing decisions. But Company 1's president also emphasized the need to continuously streamline and cut low skilled positions by automating these jobs, thereby reducing high labor costs allowing them to stay competitive in the marketplace. Company 2 actually detailed the difference in approach to employees with the increased competitive market, "*The biggest difference between business today and 15 years ago is that you can't stand still. Fifteen years ago you could stand still and just make product and move things along, add an extra employee here or there. If they weren't contributing too much we just let it go. Today it's to the point where you can't afford any of it. And it's hard to get business because there's so much competition.*" The second generation of owners has to consider this increased competition when making decisions about the labor force. Company 3 on the other hand, while not a family-run business, emphasizes the importance of family members working together in the company, "*It makes us a small, entrepreneurial, family run business with a push of a big organization behind us. It makes us human. Christmas parties are more fun. We don't have kids working here but we have had families over the years, a husband and wife, a 45-year employee with her son who's been here 25 years. So yes, we have families.*" Increased competition in the business is driving the streamlining of the workforce, and this raw economic factor outweighs most personal connections to workers. However, this case study was unable to document the exact pattern of hiring and firing practices conducted by each firm and had to rely on management's account.

***Hypothesis 3: Informal communication networks will be important for a variety of business management aspects for family run businesses. Supported.***

Informal networks seem to be important for how the family firms in particular (Company 1 and 2) handle issues such as: environmental and safety procedures, supplier and customer relations, promotional, hiring and recruitment practices (and termination). Informal Networks are important for recruitment, hiring, and promotional practices inside all three firms. Recruitment practices in Company 1 and 2 are also based on more informal networks or "word of mouth" from current employees. This informal mechanism of bringing in new employees is another reason why many family members work together on the factory floor. By hiring in this manner, existing external social networks are transplanted into the workplace. Seniority and tenure in the workforce matters more, in terms of stored knowledge and experience in the workplace, than formal credentials. This reliance on experiential knowledge is evidenced by the promotional practices in all three companies where promotion to higher skill levels occur from within the company as opposed to bringing in new experts from the outside. For termination, Company 3 relies on a more formal process involving the corporate human resources department, while the first two companies rely more on informal processes for reviewing individual employee behavior and performance both for promotional and termination consideration.

Companies 1 and 2 describe an incremental approach to innovation in which they try a new idea for a little while and then determine whether it is viable to go on before making

a large investment in a new product or process. This type of innovation also relies on informal information networks like trade journals and trade shows, relationships with machine manufacturers and customers and relationships with senior employees that are familiar enough with the business to develop new ideas. In Company 1 and 2, the owners were directly involved in the innovation process with no formal R&D staff in place. Company 3 on the other hand relied on corporate R&D support services for larger scale innovations in the production process. But Company 3 still developed many of its practical innovations on the factory floor with help from long term employees.

Company 3 seemed to rely on factory floor employees to improve safety measures in particular. The company set up a subcommittee and a suggestion box on the floor to encourage employees to bring their interests and innovation to bear on the issue of workplace safety. The manager of Company 3 emphasized the possible importance of employees' previous experiences or knowledge outside the firm to bring innovations and improvements to safety procedures in the workplace. The manager perceived this input from employees as a driving factor in the improvement of their safety record. Informal networks also seem to be important mechanisms for financing for the two family run businesses, Company 1 and 2. These two companies rely on long term banking relationships as their main source of financing and this relationship is based on trust in the reputation of the firm. The corporate firm, Company 3, relies on more formal mechanisms for financing through their corporate structure. Within this structure, Company 3 had to follow a formal process for justifying any new financing.

Formal networks are important for a variety of functions in all three companies although it is more prominent in Company 3. Company 3 is tied to a corporate parent that imposes a more formal structure on the firm than is evident in the first two single establishment firms. All three companies comply with federal and state environmental (EPA), Safety (OSHA) and labor standards. All three also seem to pursue environmental (recycling waste) and safety improvements according to an eco-efficiency principle in which the improvements are done independent of economic activity but the impact of the improvements are felt both in economic and environment and safety measures. While all three companies are compliant with some type of trade standards, Companies 1 and 2 are moving towards increased compliance with newer industry standards like ISO 9001 and 14001. Company 3 seems to have many of these certifications in place already, which again may be a reflection of more stringent corporate standards and more available resources to come up to compliance. All three companies describe the impacts of increased supply chain management schemes which put pressure on them to take on more of the risk. The three companies also have a flat organizational structure with manufacturing jobs representing the bulk of the employee base at the bottom of the hierarchy.

***Hypothesis 4: There will be high turnover in laborers because of low skill, low wage nature of work. Not supported.***

The low level employees in the company are generally low wage earners with pay ranging from \$6.25/hour to \$8.50/hour. While this wage seems relatively low, compared with other low skill level jobs in the service sector, these manufacturing jobs represent

better opportunities because of the accompanying benefits packages. Despite the low wages and the repetitive nature of the work, all three companies describe an extremely stable workforce with low turnover in all levels of workers. This low turnover may also be due in part to the opportunities for promotion within the company. The owner of Company 1 stated, "Everyone in our supervisory positions have been promoted from below, but she [an employee we met on the floor] was the first one to cross the picket line, so we have a special affection for her." Company 2's described promotions from lower levels, "There's a lot of that particularly with us. I think most molders are probably like that. You've got somebody who started second shift to stand by a machine, he shows a little bit of mechanical skill and interest in the job and we say well let's try him out here. If it works out well, it keeps on going. Right now our customer manager, which is probably one of the most important things we do here, he started out as an assistant foreman on second shift. He's a young guy who's going to school, he spoke good English which is important, showed a lot of energy and a lot of interest and moved up to assistant supervisor..." The manager for Company 3 also states, "We seek to grow people within the organization... we have various folks in our business who started in the plant."

Each interviewee recounted "success" stories of employees who started out in a very low level position like operator or packer and how they worked their way up the hierarchy through promotions due to good work habits, positive attitude and interest in moving up. The firms seem to reward good worker traits and reinforce this through internal promotions. The firms also did not put much emphasis on high levels of education or schooling but emphasized more the importance of experience and reliability. The Hispanic low-level workers are newer to the firms and are working their way up through the ranks. In Company 1 for example, the recent promotion of a Hispanic worker into a supervisory position is seen as a positive impact on lower level workers' morale because they feel closer to the upper ranks and they can aspire to also be promoted. This same worker was promoted because the owners of the company admired her loyalty to the company during a union strike when she crossed the picket line first. This illustrates how promotions are based on more than just efficiency or lines of command within the organization.

The interviewees described some overarching traits that are desirable for hourly, low skilled workers which include; manual dexterity and proficiency on the machines, reliability in attendance, quality of products and functions, willingness or interest to learn business, loyalty. For salaried or higher skilled workers, interviewees emphasized the level of commitment and interest in the business, accountability, reliability and positive attitude in the workplace. Free rider or shirking problems in the industries arose in one example from Company 2 when the interviewees described problems of accountability with employees. The company does not look favorably on employees who shirk responsibility for problems or mistakes on the factory floor. This shows that where there is a lack of accountability, shirking will occur and the human resources process weeds out people who tend to be unaccountable.

### ***Outlook on the Injection Molding Industry***

Company 3's business prospects for the future seem to be more secure than Company 1 and 2 due to their relationship with a larger parent corporation which provides them with greater flexibility, mobility and resources than the small family run companies. While Company 3 is small in terms of the number of employees at the facility, they can afford to be leaner (in terms of employees) because of the additional resources provided by the parent company. The drive of the plastics industry towards Asia seems to be easily accommodated by the parent company's relationship with other business units located in Asia. Both Company 1 and 2 experienced both a generational shift and a large market shift in their businesses in recent time. The plastics industry became increasingly competitive in the late 1990s while their fathers were transitioning the companies into the hands of their sons. This dual shift may account for a transition in both the business strategies employed by the firms to remain profitable and the social dynamics of the employee base. Traditionally, these family-run companies relied on long term, low skilled factory floor employees and repeat customers with little marketing or research and development efforts. Today, all three companies face increased competition from Asian companies that offer the same products but have much lower labor costs than US firms. This shift in the market has forced US firms to streamline their labor force and become increasingly automated to increase efficiency and reduce labor costs. The companies are also forced to find competitive advantages in their product marketing and innovation.

Company 1 in contrast to Company 2 is more optimistic about its future prospects in the business. This optimism is primarily due to Company 1's multifaceted strategy for surviving in the increasingly competitive market through streamlining, increased automation to reduce labor costs, horizontal integration via the acquisition of smaller operations and cornering a niche market in fire safety equipment along with a large multinational company contract. Company 2 has increasingly automated but is struggling to market their business and tap into new customer bases that they can keep long term. Company 3 is perhaps the most economically stable due to its connections to business units worldwide and their corporate resources.

One indicator for the strength of social networks in each company can be seen in the company sponsored social activities. Company 1 and 2 both experienced a decrease in the number of activities sponsored by the company at the same time that the dual generational and market shifts occurred. Interestingly, Company 3 seems to offer many more company sponsored social activities than the family run companies - suggesting that it's not just the familial nature of the company but rather the financial stability of the firm that matters a great deal in terms of supporting such social activities. Despite the drive towards automation, all three companies rely on a stable workforce characterized by low turnover and long term employees. The importance of these long-term employees in the workplace is reflected in the "totem pole" hierarchy or informal hierarchy that is established within the rank file between long term employees and new hires. According to this totem pole, long-term employees' rank overrides any professional credentials a newcomer brings to the workplace.

The entry-level employees in all three companies are comprised of mostly Hispanic and other non-English speaking people. The similar ethnic background of the entry-level employees and the internal promotion practices creates a very close knit employee base which may also have many connections outside the workplace. It is difficult to characterize the nature or extent of these social networks because this study did not interview or study these employees directly. Company 3's manager emphasized the importance of personal and social networks in improving the safety on the factory floor in particular. Social networks, social activities outside work and the presence of family members working on the floor were perceived as a benefit to the company in terms of improvements in safety along with more general improvement in morale and productivity. But unlike the other two companies, Company 3 did not have family members running the operation, only working as lower level employees.

The competition from China is putting increased pressure on all the firms to cut back low skilled operators. At the same time, the owners seem to value company loyalty as evidenced in their respect and admiration for long-term employees. It will be interesting to see how these two forces – increased drive to streamline the workforce and a close connection with the employee base will evolve over time.

### **Model-building activity**

Researchers can productively induct theory from case studies that, like good computer programs, offer parsimony and logical coherence (Eisenhardt, 1989). This begs a question: why not express theory in the form of a computer program? Parsimony was a goal of the modeling effort, and logical coherence was a handy byproduct of the debugging process. The dual challenges with any type of modeling are to simplify reality appropriately and to communicate the results effectively (Andrews, 2002). Both challenges proved significant during the modeling process.

### ***Multi-agent simulation***

Object-oriented programming languages like Java make it possible to specify and replicate software agents relatively easily. These agents can be purposive and autonomous, and they can interact with one another and with an external environment. Multi-agent simulation modeling, so called, is an intellectual descendent of game theory, artificial life, and cellular automata, and it is gaining wide use as a social science research method (Epstein and Axtell, 1996). There is already some experience with applications to organizational behavior research (Carley and Prietula, 1998) and industrial ecology (Axtell et al, 2002).

Using the Brookings Institution's Ascape multi-agent simulation framework (Parker, 2000), a Java programmer created PolyModel, a simulation of operations at a plastic injection-molding firm. Approximately 100 employees interacted with the production technology and one another, subject to changes in the firm's external environment. The model included technology details, organizational structures, and parameter values taken from Company 1 in the case study. The model tested alternative theoretical constructs

explaining the behavior of employees, to be roughly validated against the evidence from case study Companies 2 and 3.

The current model includes 22 classes of agents, related as follows.

PolyModel contains People, the Factory, and the External Environment.

The Factory includes a Warehouse, Production Lines, and a Shipping Department.

Employee extends Person.

Owner, Plant Manager, Marketer, Engineer, Shift Supervisor, Shipping Clerk, Materials Mixer, Maintenance Technician, Machine Operator, and Janitor all extend Job. Each Employee has a Job.

Remaining Java classes serve as computational infrastructure.

The time step in the model is hourly, so the firm cycles through the workday and the work week over a period of years. Each employee assesses whether to go to work every morning, based on health, social pressures, and finances. The plant manager determines how many production lines and associated employees are needed based on pending orders for widgets. The marketer brings in orders and tries to keep ahead of production so that the capacity factor of the plant is high. The janitor keeps the factory clean, and other employees become unhappy if the factory gets dirty. The materials mixer ensures that raw materials reach the production lines, and the shipping clerk packages completed products and sends them out the door. The maintenance technician keeps the production lines in working order. The machine operators perform several sequential duties (load plastic pellets, set molder temperature, separate widgets from scrap plastic). The shift supervisor encourages machine operators to work more carefully and reports on employee performance to the plant manager. All employees are subject to worker error that affects the quality of their performance, and the probability that error will occur is a function of aptitude, experience, tiredness, and happiness.

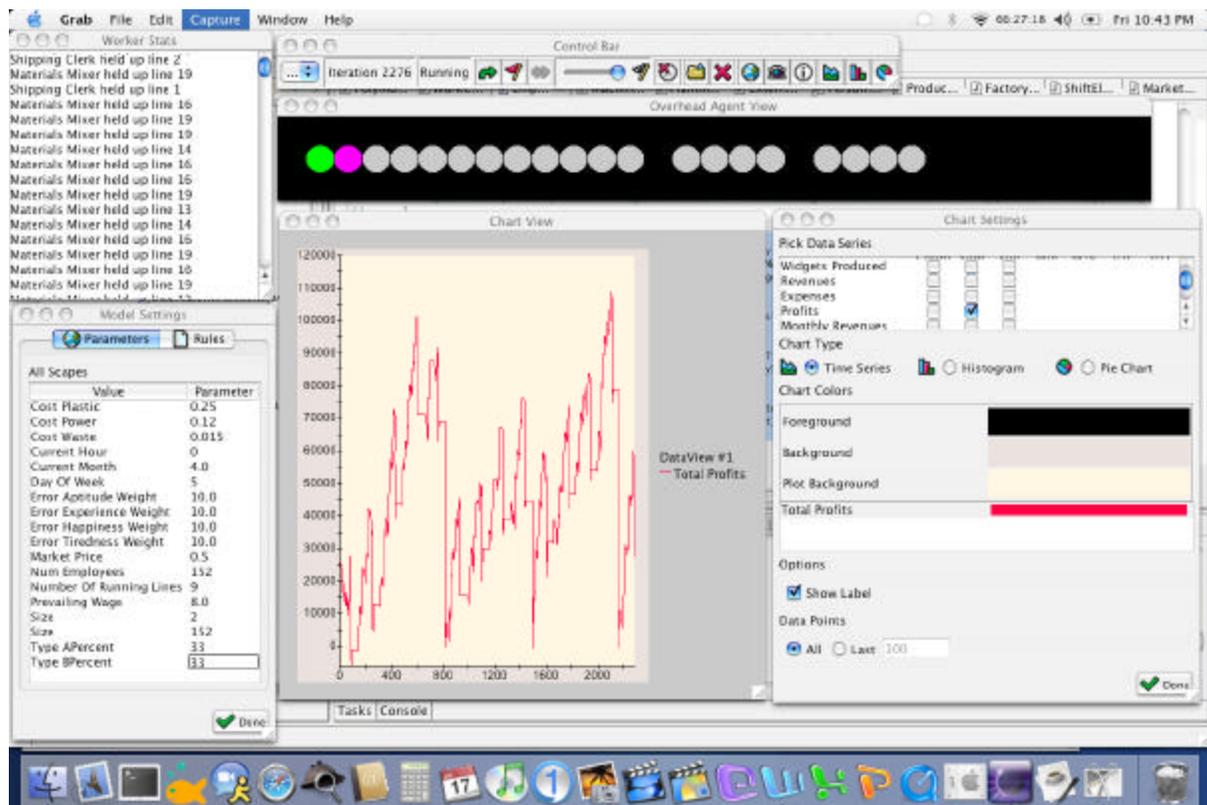
```
    }  
  
    public double getWorkerError(){  
        double aptFactor = ExternalEnvironment.getAptitudeWeight() * (100-  
this.getAptitude()) / 100;  
        double expFactor = ExternalEnvironment.getExperienceWeight() *  
(65-this.getDaysWorking())/250)/65;  
        double hapFactor = ExternalEnvironment.getHappinessWeight() *  
(100-this.getHappiness())/100;  
        double tirFactor = ExternalEnvironment.getTirednessWeight() *  
this.getTiredness()/100;  
        return aptFactor + expFactor + hapFactor + tirFactor;  
    }  
}
```

Happiness is a weighted additive function of wealth and social embeddedness.

MoneyGrubbers like wealth (90, 10), SocialAnimals like their friends (10/90), and TheRestofUs are more balanced (50, 50). Wealth increases by getting paid at work, social embeddedness increases by making more friends at work and elsewhere. Friendship depends on affinity (similar intrinsic characteristics) and frequency of interaction.

As the screenshot below shows, the dynamics of these employee interactions provide realistic drama and aggregate up to firm-level performance measures of interest to

management. Parameters are adjustable on the fly, and various diagnostic tools allow the user to investigate the causes of particular dynamic behaviors.

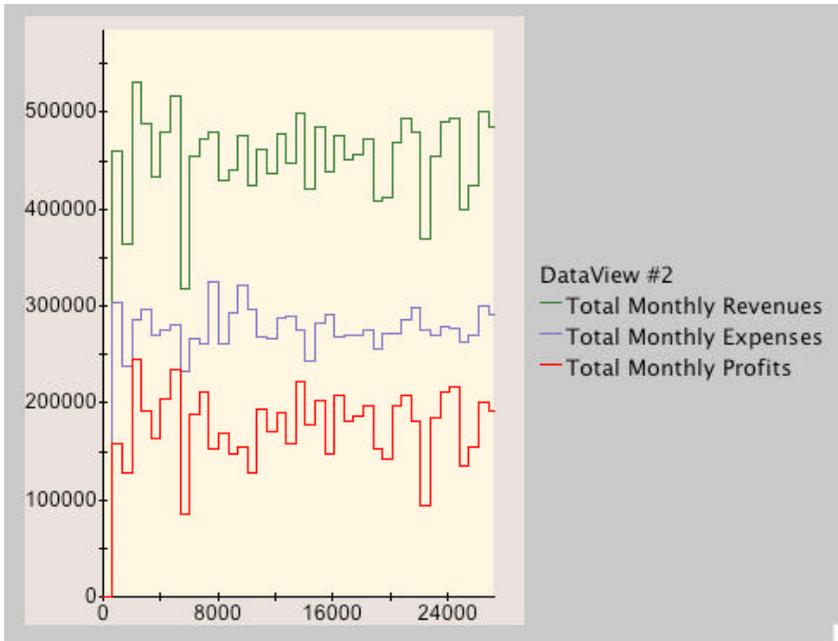


Developing the model required intense interaction between the programmer and the qualitative researchers. Much conversation centered on eliciting precisely what was the theory being formalized in the model. As the researchers played with the resulting simulations, the theoretical framework evolved.

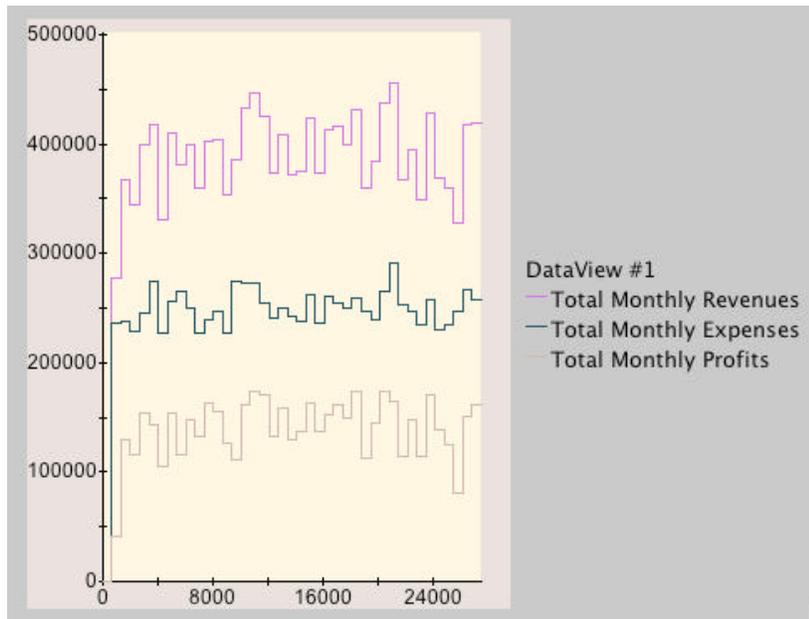
### ***Illustrative Result—Bringing in Worker Error***

This paper briefly shows one illustrative result. The project is ongoing and the model, underlying theories, and empirical evidence continue evolving. The model may eventually become robust enough to serve as a management-training simulator for the plastic injection molding industry.

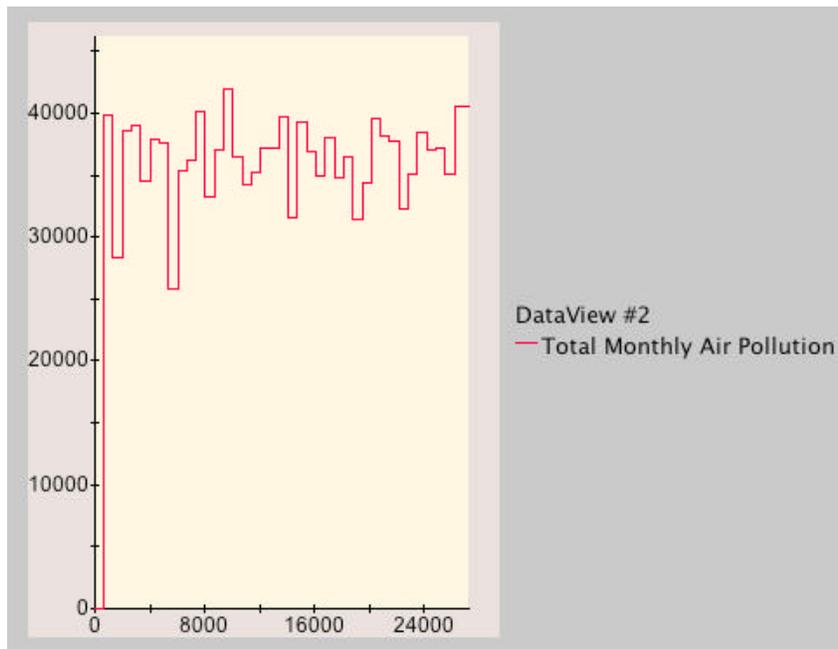
The frictionless neoclassical model of the firm typically assumes that every employee behaves like *homo economicus*, a rational, omniscient, selfish maximizer. Only principal-agent problems detract from corporate performance in that model. Our model allows us to turn worker error on and off, and thereby compare results under contrasting assumptions regarding that element of bounded rationality. As the following graphs show, a firm having imperfect (aka realistic) employees is less profitable and pollutes more. Policies to reduce worker error can now be tested *in silico*. More detailed theorizing about the determinants of worker error also becomes possible.



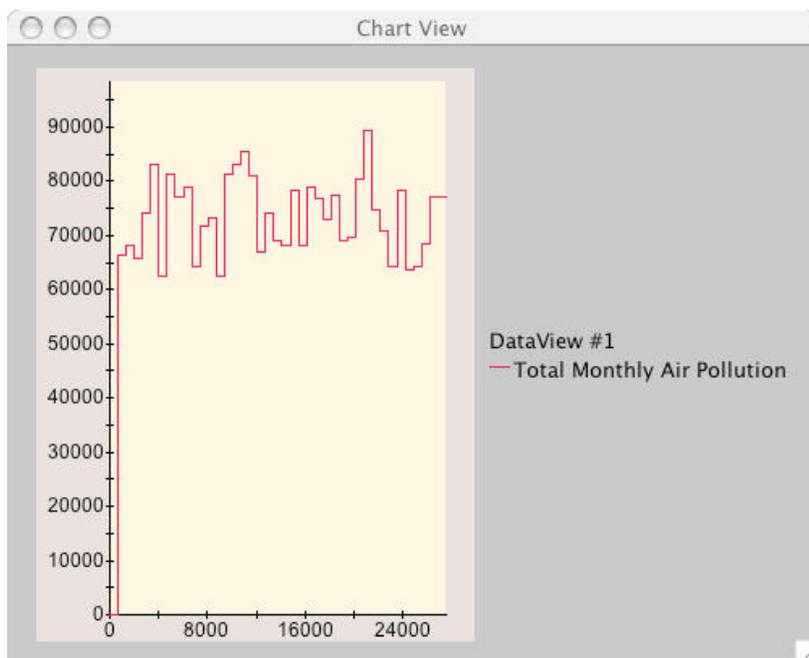
Homo economicus: Profits without worker error



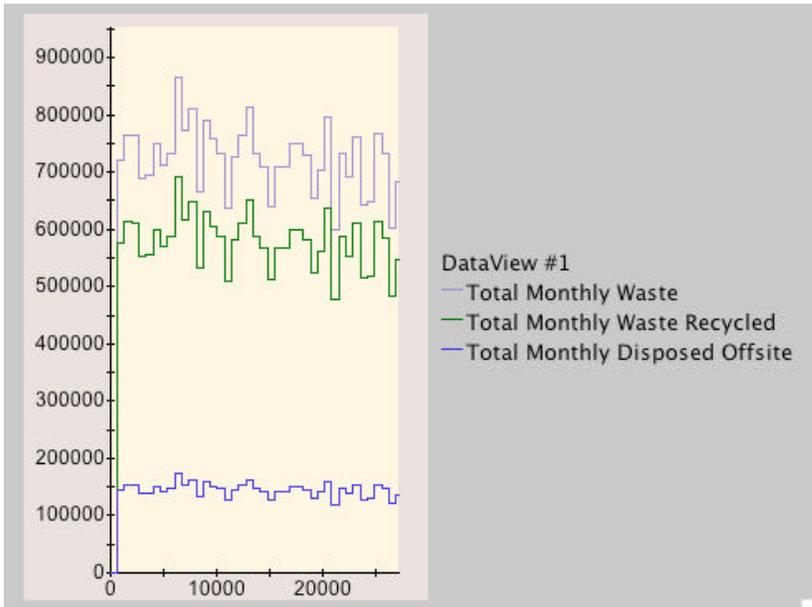
Realistic employee: Profits with worker error



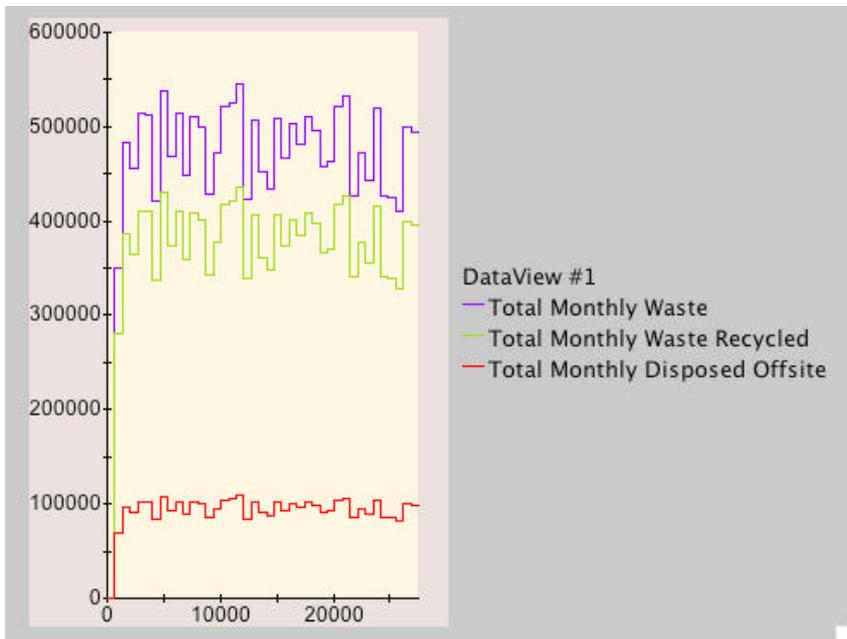
Homo economicus: Air pollution without worker error



Realistic employee: Air pollution with worker error



Theorizing worker error #1:  $\text{Error} = f(\text{experience})$



Theorizing worker error #2:  $\text{Error} = f(\text{experience, aptitude, happiness, tiredness})$

## **Conclusions**

### ***Theory building***

Regarding the motivating question for this research—what are the relative roles of informal social networks and formal regulatory structures?—the modeling and case study evidence support three insights to date. First, informal networks are very important for hiring new employees and for helping employees to decide to take job actions like strikes and sick day protests. Second, formal structures are hugely important for explaining almost everything else. In this industry there also appears to be a substantial amount of technological determinism. In other words, the type and economics of the technology explain much of the firm's overall behavior.

### ***Lessons learned***

There are two major lessons learned for researchers interested in using multi-agent simulation models and case studies in a grounded theory-building context. First, this project shows that highly diverse skill sets are needed. In fact, it is unlikely that a single individual will have the requisite range of skills, necessitating recruitment of a multidisciplinary team consisting of an interviewer, case study developer, and Java programmer. Second, iterative modeling and interviewing is crucial because new questions arise, and alternative theories need to be explored and elaborated.

The benefit of developing multi-agent simulations in this inductive way is that they appear to inform action more directly than a deductively-based model built from principles rather than evidence might. It becomes a humbler but perhaps more valuable type of social science.

Case studies are informative but static research products. By taking the next step and constructing a simulation model, this research becomes more dynamic and iterative. It becomes easier to communicate theoretical expectations and to revise them. It potentially can help with *in silico* management training and strategy development so that fewer costly mistakes get made by firms and their regulators.

### ***Future work***

There are many valuable extensions of this work that deserve future attention. First, the establishment-level model should be extended to the case of the branch plant with a corporate parent. Then the modeling effort should expand vertically to include the supply chain, and horizontally to include sectoral competitors. It would also be interesting to adapt this modeling approach to industrial clusters and eco-industrial park tenants. In addition, much more needs to be done to explore the potential for socially responsible behavior to affect overall corporate performance. Other extensions suggested by the case studies include further investigation of the special characteristics of family owned companies, and of the value and measurement of employee loyalty.

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