



2005

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## Recommended Citation

Trailer, Jeff W. and Garsson, Kuau (2005) "A System Dynamics Approach to Assessing Public Policy Impact on the Sustainable Growth Rate of New Ventures," *New England Journal of Entrepreneurship*: Vol. 8: No. 1, Article 4.

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# A System Dynamics Approach to Assessing Public Policy Impact on the Sustainable Growth Rate of New Ventures

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Kuuu Garsson

*The growth of firms is fundamentally based on self-reinforcing feedback loops, one of the most important of which involves cash flow. When profit margin is positive, sales generate cash, which may then be reinvested to finance the operating cash cycle. We analyze simulations of a sustainable growth model of a generic new venture to assess the importance of taxes, and regulatory costs in determining growth. The results suggest that new ventures are particularly vulnerable to public policy effects, since their working capital resource levels are minimal, and they have few options to raise external funds necessary to fuel their initial operating cash cycles. Clearly, this has potential consequences in terms of gaining competitive advantage from experience effects, word of mouth, scale economies, etc. The results of this work suggest that system dynamics models may provide public policy-makers a cost-effective means to meet the spirit of the U.S. Regulatory Flexibility Act*

The buzz of the stock market bubble of the 1990s has subsided in recent years and many companies are struggling to survive. This article analyzes the classical growth of the firm and explains certain important variables in finding a level of long-term sustainable growth for a firm of any size. We use a sustainable growth model utilizing cash conversion cycles, cash required, and profit margin to instantiate our data. Although substantial research exists on the economic impact of income taxation on labor and wages, “there is a paucity of comparable information regarding the impact of income taxation on entrepreneurial enterprises” (Holtz-Eakin and Rosen 2001: 1). The brevity of research on sustainable growth within academia seems to imply that controlling production function variables has long been determined much more important for economic advancement (Matsuyama 1999). Our study examines the impacts of public policy in terms of taxation and regulation costs.

## Industrial Dynamics

Historically, success rates for new ventures have been abysmal, as “only 41.4% of new enterprises reach an age greater than five years” (Nord 1963: 1). In a more recent study, the success rate has remained about the same as, “66 percent fail within six years” (DeCastro et al. 1999). Studying this problem has proven difficult for researchers due to the dynamic complexity associated with the high number of interacting variables and their nonlinear feedback patterns and effects, which are all necessary to understand and explain firm per-

formance over time. In recent decades, many improvements in modeling firms’ growth patterns have taken place with the use of “system dynamics” mathematical modeling method, with Jay Forrester providing the first such model in Industrial Dynamics (Forrester 1961). Subsequent models have successfully revealed causal insights into the fundamental sources of corporate growth problems (Fey 1962; Nord 1963; Packer 1964; Forrester 1964, 1978; Roberts 1967, 1977; Roberts, Abrams and Weil 1968; Swanson 1969; Wright 1971; Lyneis 1975; Spencer 1978; Weil 1978; Sterman 1988, Bianchi 2002; Bianchi and Bivonna 2002, Oliva, Sterman, and Giese 2003).

## The Regulatory Flexibility Act

The results of this work suggest that system dynamics modeling may provide public policy makers a cost-effective means to meet the spirit of the U.S. Regulatory Flexibility Act (1980). “The RFA requires agencies to review their regulatory proposals and determine if any new rule is likely to have a “significant economic impact on a substantial number of small entities.” If such impact is likely to occur, the RFA then requires the agencies to prepare and make available for public comment an “initial regulatory flexibility analysis” (Whitmore and Walthall 2001: 40). Compliance with RFA currently seems to be a problem. “In monitoring agencies’ compliance with the law over the years as RFA mandates, the Office of Advocacy found that federal agencies, more often than not, failed to conduct the analyses mandated by the RFA” (Whitmore and Walthall 2001: 41). System dynamics modeling allows the isolation of single variable adjustments for assessment within complex systems. Thus, the system dynamics method offers policy-makers a means of testing alternative policies to determine their potential impact.

System dynamics models, however, must be designed to meet a specific problem. This begs the question: Which problem, potentially caused by new public policies, is most likely to result in a significant economic impact on a substantial number of small entities? In this article, we focus on limits to growth of new firms caused by public policy effects on the capability to internally generate cash.

## Internal Finance Theory of Growth

The greatest potential for causing a significant economic impact, on a substantial number of new and small firms, is arguably public policy effects on such firms’ ability to self-

finance growth. This is due to the fact that the growth of most new and small firms is limited by the available quantity of internally generated funds (Butters and Lintner 1945; Ang 1991, 1992; Petersen and Rajan 1994; Weinberg 1994; Martinelli 1997; Bitler, Robb, and Wolken 2001; Becchetti and Trovato 2002; Carpenter and Petersen 2002; Arenas 2004). An "internal finance theory of growth" (Carpenter and Petersen 2002) explains the chronic nature of this phenomenon as being attributable to several attributes that negatively affect the cost of external capital. Younger and smaller firms tend to have higher failure rates. They lack diversity in terms of both products and markets. They rely on new products or new services. They tend to have thin management expertise, and lack a documented history (Jones and Kohers 1993; Martinelli 1997). Further, agency problems of both moral hazard and adverse selection tend to be more severe with younger and smaller firms (Martinelli 1997). This is due primarily to information asymmetries, or simply the lack of information at all, that has proven difficult for small firms to overcome (Apilado and Millington 1992; Binks, Ennew, and Reed 1992; Binks and Ennew 1996; Dennis and Sharpe 2005).

In this article, we will analyze simulations of the growth of a generic new venture. Our purpose is twofold:

1. To provide an example that illustrates the potential for the system dynamics method to assess the importance of taxes, and regulatory costs in determining growth, through a self-financed, sustainable growth model.
2. To provide a generic model with parameters that can be easily modified to reflect the different assumptions associated with different industries.

## A Self-Financing Sustainable Growth Model

A company's sustainable growth rate depends on three factors: the length of time in the firm's cash conversion cycle (CCC), the amount of cash required (CR) for each operating cash cycle (OCC), and the magnitude of the profit margin (PM), or the amount of cash generated from each dollar of sales (Churchill and Mullins 2001).

The first self-financing, sustainable growth rate factor, CCC, represents the average total amount of time cash is consumed in the firm's operations: from the purchase of material from suppliers, to carrying inventory, to collection of credit sales. The longer this cycle, the longer cash is tied up, and the slower the rate at which cash may be invested for growth. The maximum length of this cycle is called Operating Cash Cycle (OCC) and is determined by the sum of days required for carrying inventory and the days required for collection of accounts receivable. The calculation of OCC days required may be represented as:

$$\text{OCC (in days)} = (\text{Accounts Receivable}/(\text{Sales}/365)) + (\text{Inventory}/(\text{Cost of Sales}/365))$$

The average cash conversion cycle (CCC) will be shorter than the OCC by the average days of accounts payable. Thus, the calculation of CCC days required may be represented as:

$$\text{CCC (in days)} = \text{OCC} - (\text{Accounts Payable}/(\text{Cost of Sales}/365))$$

The second self-financed, sustainable growth rate factor, cash required (CR), represents the average amount of cash required to finance one CCC. Cash required is a function of the magnitude of the firm's costs: cost of sales and operating expenses. As the firm finds ways to reduce costs per dollar of sales, a lower amount of cash is required to finance each operating cash cycle. The lower the amount of cash required for each cycle, the greater the growth rate for a given level of investment cash available. If it is assumed operating expenses are paid out uniformly throughout the cycle, then the cash required for each operating cash cycle may be represented as:

$$\text{CR (for each OCC)} = ((\text{Cost of Sales}/\text{Sales}) * (\text{CCC}/\text{OCC})) + ((\text{OCC} * .5)/\text{OCC})$$

The third self-financed, sustainable growth rate factor, Profit Margin (PM), represents the cash generated per sales dollar, or the efficiency with which potential reinvestment dollars are generated on each dollar of sales. The greater the earnings per dollar of sales, the greater the reinvestment amount, and the greater the self-financable growth rate. The profit margin may be calculated as:

$$\text{PM} = \text{Net profit after tax}/\text{Sales}$$

The self-financing growth (SFG) rate for one OCC may then be approximated as:

$$\text{SFG rate for each OCC} = \text{PM}/\text{CR}$$

The annual SFG rate is obtained from the product of the SFG rate for each cycle and the number of cycles in the year:

$$\text{Annual SFG rate} = (\text{PM}/\text{CR}) * (365/\text{OCC})$$

This rate may be compounded to obtain an annual rate: Compounded annual SFG rate =  $(1 + (\text{PM}/\text{CR}))^{(365/\text{OCC})} - 1$   
Basically, expanding operations generates cash, which may then finance a larger operating cycle, which expands operations, resulting in a self-reinforcing feedback cycle (Figure 1).

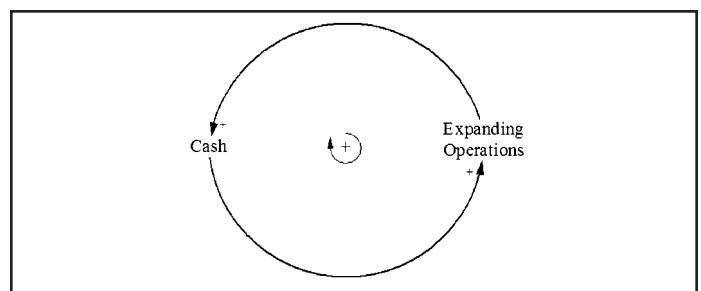
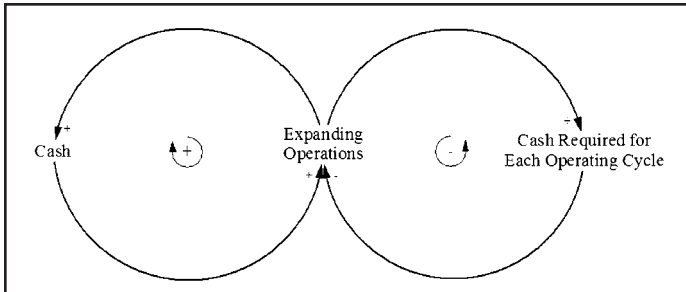


Figure 1. Self-reinforcing Feedback Cycle

However, as operations expand, the cash required to finance the operating cycle grows as well. This creates a balancing feedback effect on growth. Thus, the firm will grow only when the cash increases at the same or greater rate than the cash required (Figure 2).



**Figure 2. Balancing Feedback Effect on Growth**

The dominant variable affecting the magnitude of cash generated from operations is the profit margin. Given the dynamics of compounded returns, *ceteris paribus*, small changes in profit margin will invoke large changes in the growth experienced by the firm. The longer the time period observed, the greater the impact of profit margin on growth. The exponential growth pattern is not necessarily due to increasing profit margin as the firm grows (Murphy, Trailer, and Hill 1996), but rather to the self-reinforcing feedback cycle of increasing investment in the operating cash cycle that occurs even when the profit margin is unchanging.

Given the exponential nature of this relationship between profit margin and growth, the short-run impact may be small even though the very long-run impact will be so strong that the firm will ultimately be blocked by constraints other than cash flow issues. The availability of adequate property, plant, and equipment are not typically the dominant limit to growth; rather the availability of management talent (Schumpeter 1951; Penrose 1959; Packer 1964), negative feedback effects of delivery delay (Forrester 1961; 1978), capacity-acquisition policy (Nord 1963), and service quality erosion (Oliva, Sterman, and Geise 2003; Sterman 1988, 2000) limit growth. Even when these latter constraints are resolved, the growth rate will ultimately be limited by the market saturation (Smith 1776; Sterman 2000). Thus, profit margin may be expected to have a significant impact on potential, maximum, sustainable growth rates. However, actual growth rates should be expected to be lower than potential growth rates when the time period covers many years or decades.

## A Self-Financed, Sustainable Growth Model

In general, it is expected that policy-makers are susceptible to problems with decision making when the decisions are embedded in multiloop nonlinear feedback systems,

because the human mind is not structured in a manner that accommodates such complexity (Forrester 1961; Sterman 2001). Public policy effects on the growth of new venture firms are especially associated with such complex systems. Growth of firms is fundamentally determined by nonlinear cost and revenue functions, each with their own, multiple, dynamics inputs, many of which include delays in their impact. System dynamic models offer a means of effectively overcoming such problems of complexity (Sterman 2000, 2001). Thus, to more effectively investigate the impacts of public policy on new venture growth, we built a dynamic simulation. The model is a system of nonlinear differential equations describing:

- One competitor that sells in a competitive market; the firm represents only one of many producers and it is assumed that the output of any one firm is not sufficient to alter the market price.
- The market will purchase as many units as this firm can produce, but will pay only a single (commodity) price.
- Nonlinear cost structure, reflecting the interaction of fixed and variable costs.
- A delayed, nonlinear impact on the sustainable growth rate from accounts receivable, accounts payable, cost of sales, operating expenses, sales tax, and regulation costs.

## Model Structure

The model variables and their interactions are based on existing formulations of self-financable, sustainable growth rates (Churchill and Mullins 2001).

The model is comprised of five sectors: cash, accounts receivable, accounts payable, labor, and inventory

### Cash Sector

Cash is generated by sales and consumed by operating expenses (Figure 3). Cash from sales is reduced by both sales tax and credit sales. Collections on credit sales generate cash. Any cash accumulated determines the budget for the next weekly order from suppliers.

### Accounts Receivable Sector

Accounts receivable is generated by credit sales and depleted by collections (Figure 4).

### Accounts Payable Sector

Accounts payable is generated by orders from suppliers and depleted by payments to suppliers (Figure 5). The order decision, in terms of the size of the order, is determined by the budget relative to the cost of the material.

### Labor Sector

Labor is generated by the rate at which new hires can be

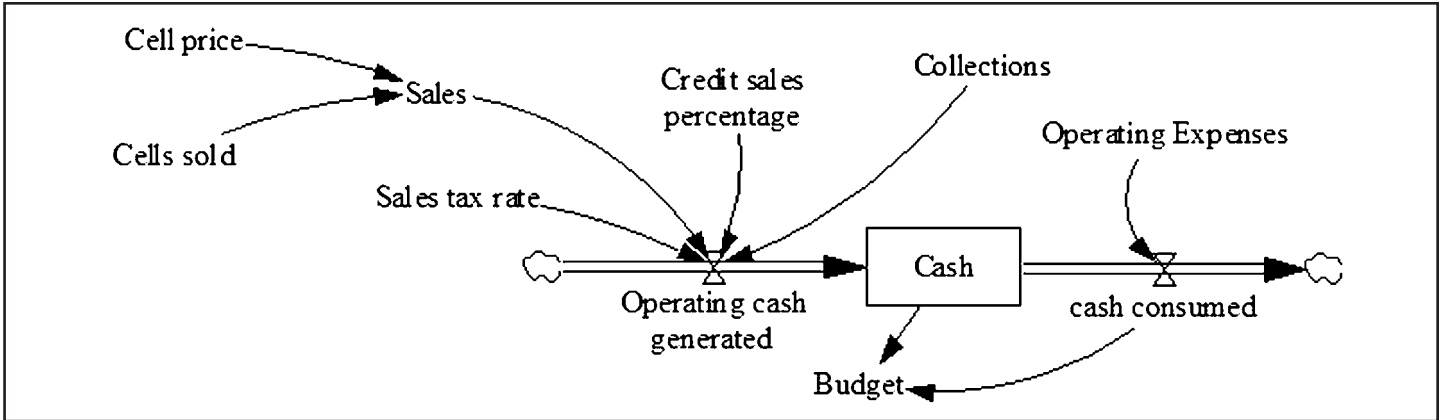


Figure 3. Cash Sector

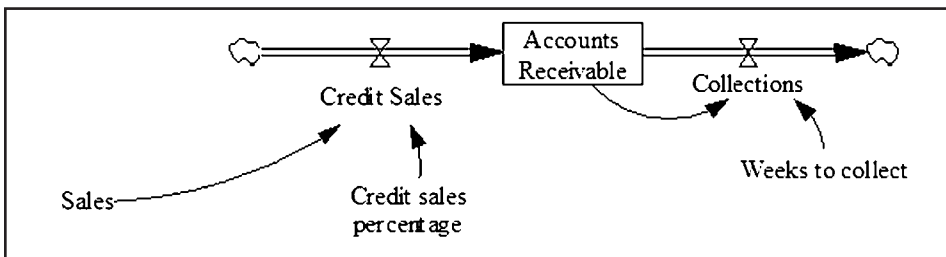


Figure 4. Accounts Receivable Sector

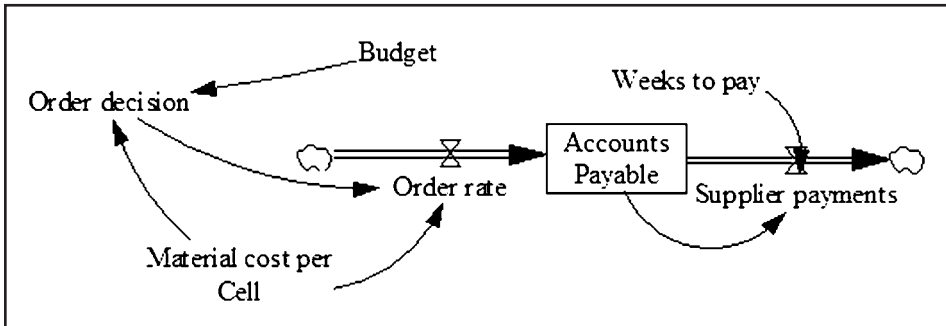


Figure 5. Accounts Payable Sector

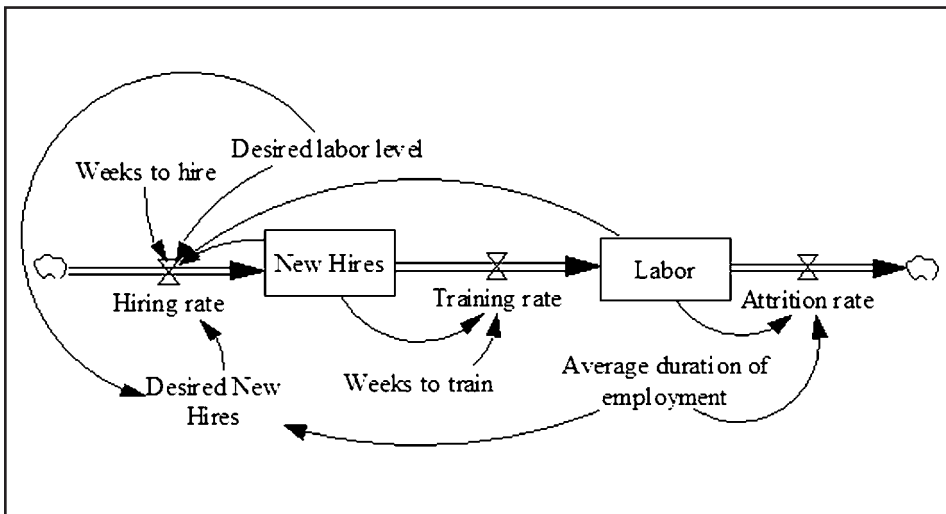


Figure 6. Labor Sector

recruited and trained, and is depleted via attrition (Figure 6). The hiring rate decision includes both the anticipated attrition rate, as well as the delay to the labor pool resulting from time in training.

### Inventory Sector

Inventory is generated by the rate at which new orders are placed and subsequently received from suppliers, and the production rate (Figure 7). Inventory is depleted by sales. Accumulated sales determine the installed base, which is expected to influence productivity due to economies of experience.

The complete model is illustrated below, showing the linkages between the five sectors (Figure 8).

### Growth Dynamics

Our growth dynamics model was used to test whether changes in public policy would have a “substantial” impact on the growth of new firms. In creating the model, the aspects of growth we considered important for public policy, were sales and jobs. Thus, our conclusions will focus primarily on these two variables.

A benefit of system dynamics modeling is that the impact of change in a single variable can be isolated for assessment. In this case, a baseline self-financable growth (SFG) pattern was generated to serve as a control for isolating the impact of alternative public policies. In this model, the growth of the firm is limited only by internally generated funds. That is, it is assumed that the firm can sell

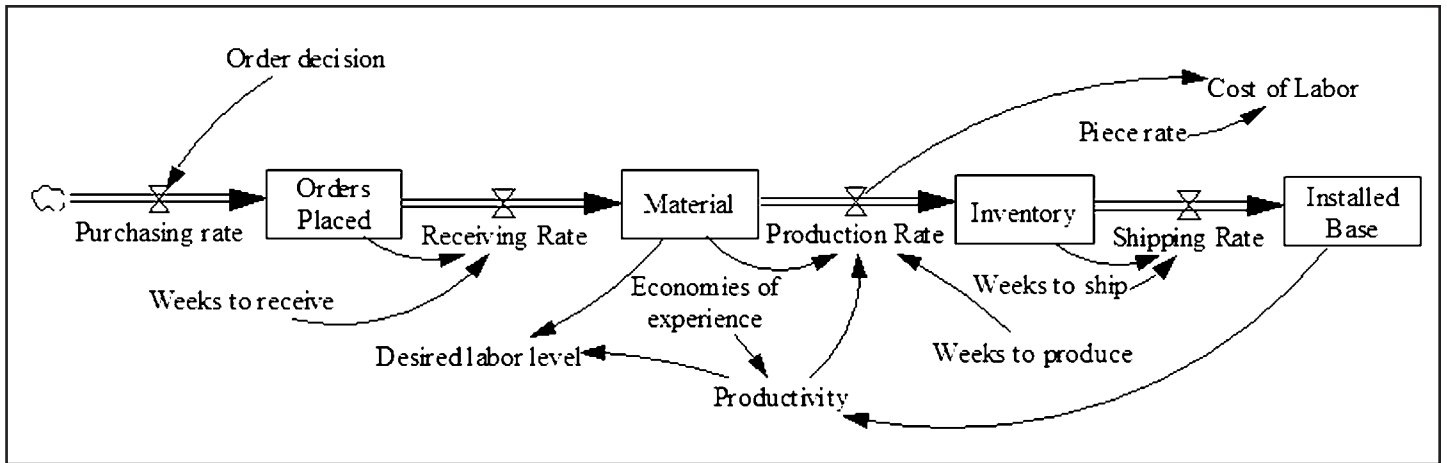


Figure 7. Inventory Sector

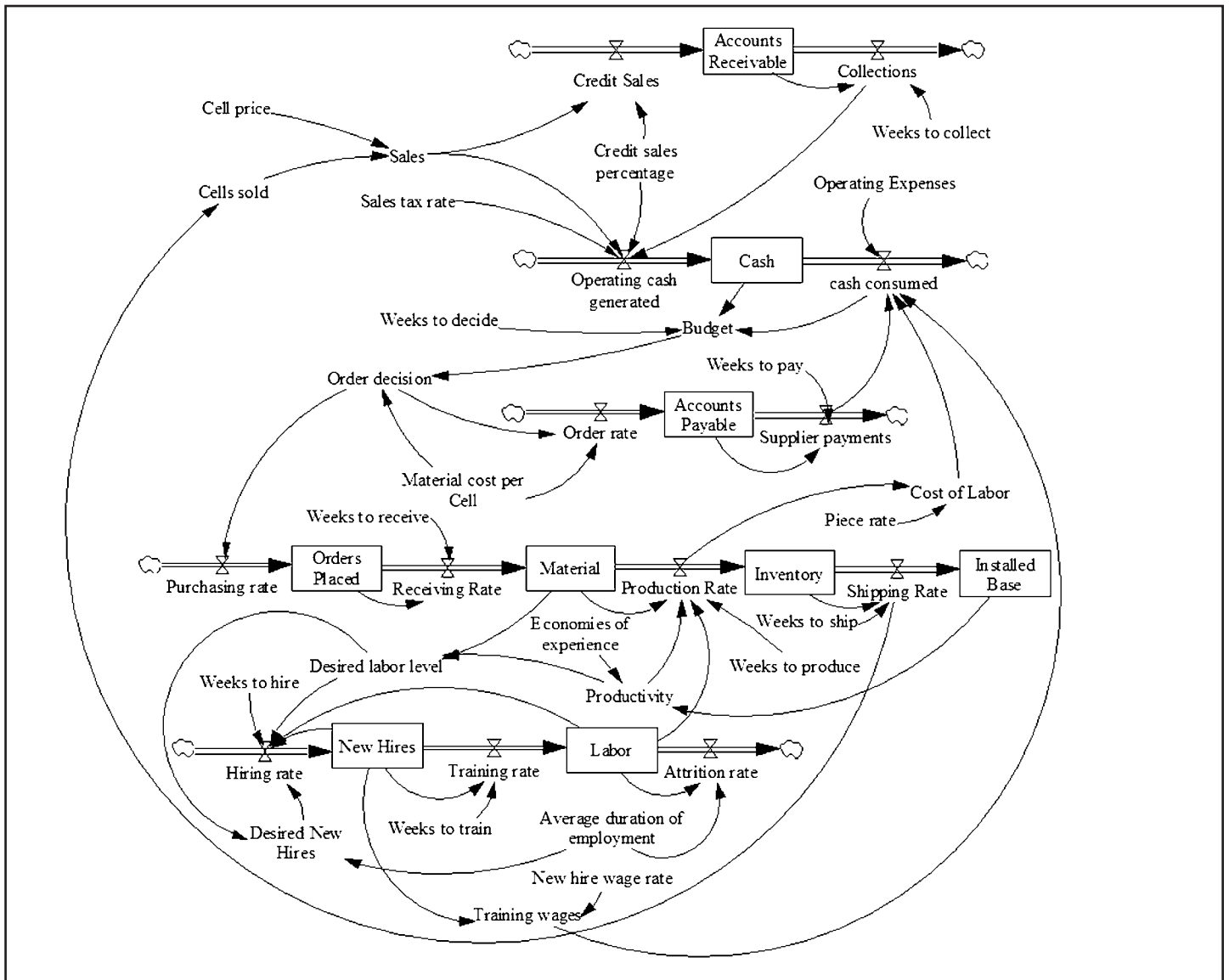


Figure 8. The Self-financing Sustainable Growth Model

as many units as can be produced, and the physical plant provides sufficient capacity for any production level over the two-year period studied. Also, labor and material are always available, although with a delay. Thus, the model generates a best-case or maximum potential growth of the new venture.

The simulation time was selected to be two years because it is generally the most restricted, for the entrepreneur, in obtaining external funding for growth. Bank managers we interviewed stated that they were reluctant to lend to firms with less than three years of documented operations. Thus, as discussed above, growth for the first couple of years is primarily dependent on the founders' own investment, and internally generated cash.

The public policies we studied were changes in the sales tax rate, and federal regulation costs. In the following sections, data is presented that show how changes in these policies affect the potential growth rate of a new venture.

### Growth Dynamics: Impact of Changes in the Sales Tax Rate

We simulated four sales tax scenarios. Sales tax was 7 percent in the baseline and we compared it to: a sales tax increase of 1 percent (total tax of 8%); a decrease of 1 percent (total tax of 6%); and the elimination of sales tax (total tax of 0%). Because the latter scenario had such a strong impact, the results for that scenario are reported separately, last.

Sales tax is typically applied only to final sales so the

model assumes the product is sold to the end consumer. Additionally, the model assumes the product is of an industry standard and sold internationally, and so the price is set by the market. Accordingly, to be competitive, the firm must pay the sales tax out of the given market price. These assumptions illustrate the comparative advantage associated with competing counties', states', or nations' sales tax policies.

The accumulating resource variables selected for presentation in this section illustrate the general dynamics of new venture growth.<sup>1</sup>

### Cash

The entrepreneurs launch their business with \$10,000 in available cash. The cash performance is presented in Figure 9. The entrepreneur runs out of cash in weeks six and seven, and accordingly requires a cash infusion of about \$1,000 for week six and \$200 for week seven. We assume the entrepreneur uses a personal revolving credit line, likely a credit card, to prevent insolvency. This seems consistent with the SBA report that about 50 percent of small businesses use credit card debt. This negative cash flow occurs because there initially are no sales to cover the costs of work-in-process. Eventually, sales occur and cash is available for reinvestment in material and labor. The erratic pattern in cash is entirely due to the firm's own internal structure of delayed feedback effects on the ordering decision.

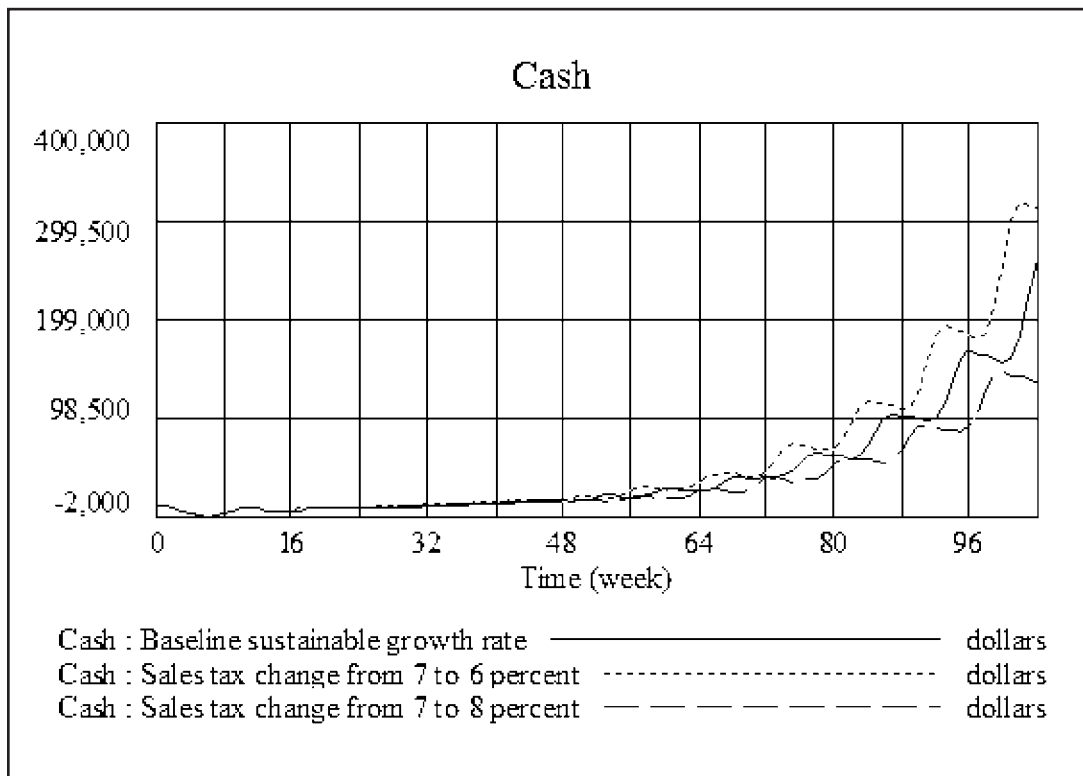
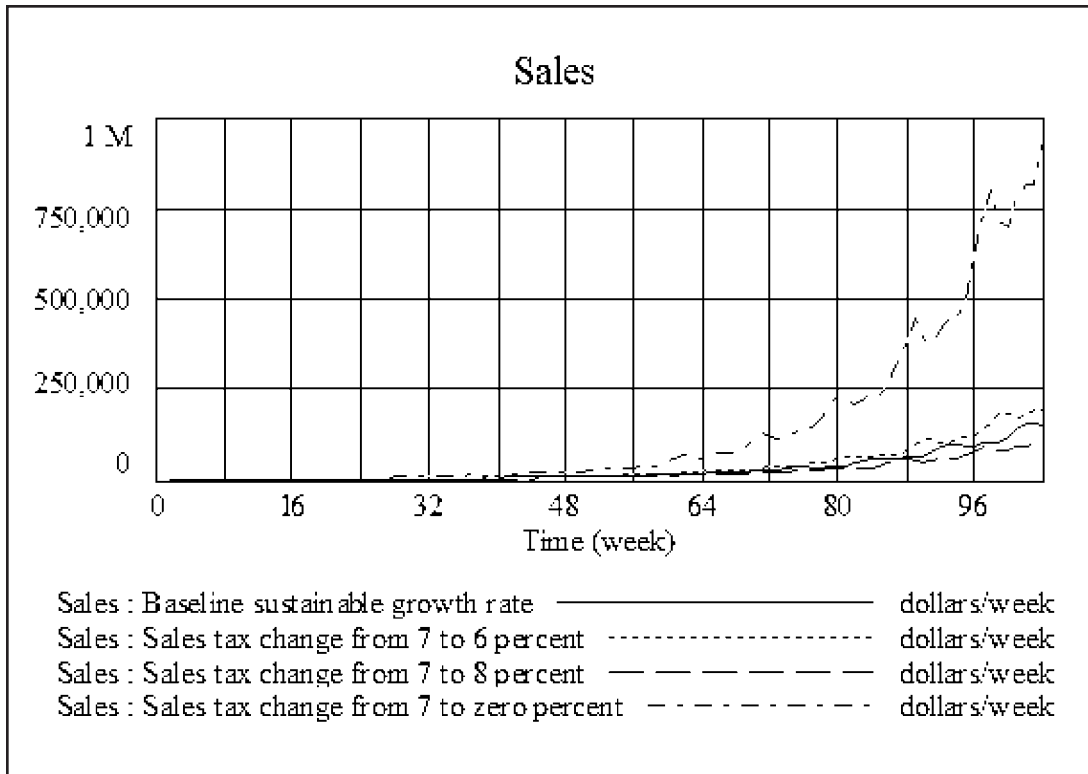


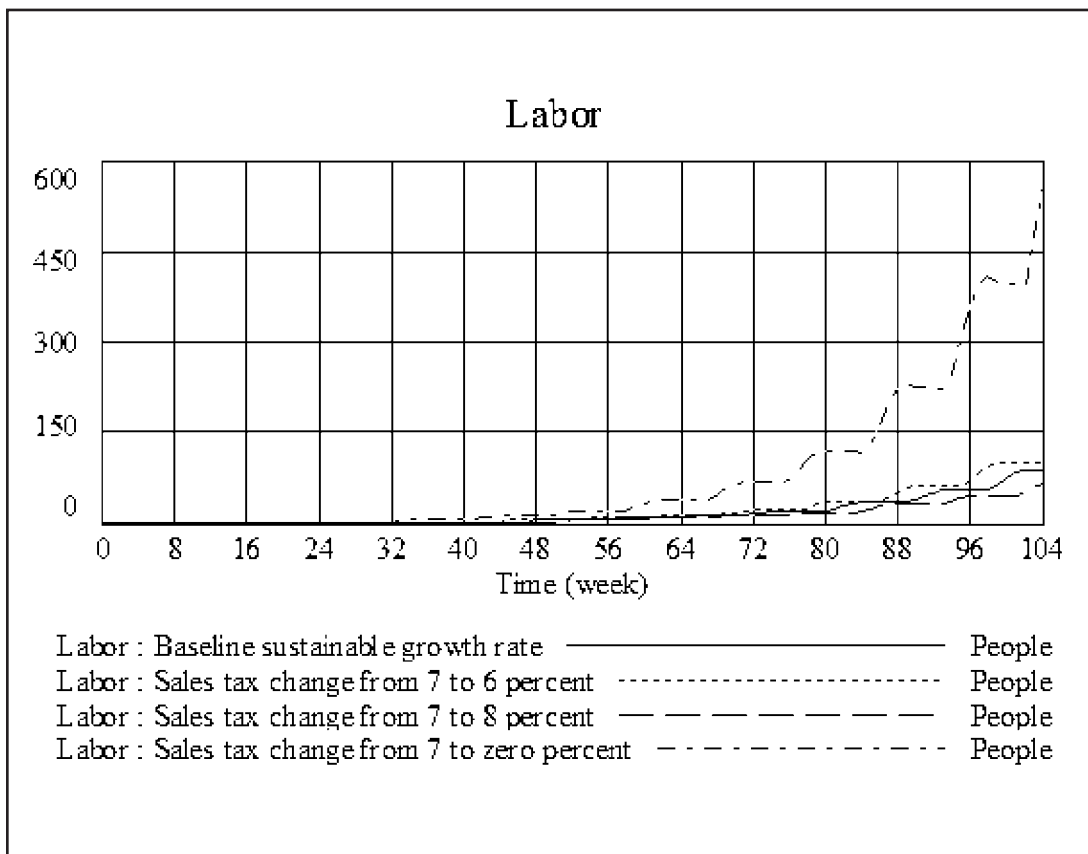
Figure 9. Cash Performance

### Sales

The rate of sales exhibits the nonlinear growth pattern typical in a new product life cycle. The seemingly erratic changes are in fact completely deterministic, not random, effects of the multiple, internal feedback loops. The impact of changes in the sales tax rate are clearly visible in the sales figure: the increase of 1 percent to 8 percent reduces the comparative sales per week almost 25 percent, at the end of the second year of operations, from \$150,335 to \$113,087; the decrease of 1 percent to 6 percent increases the sales per week more than 30 percent at the end of the second year of operations, from \$150,335 to \$196,549.



**Figure 10. Impact of No Sales Tax on Sales**



**Figure 11. Impact of No Sales Tax on Labor**

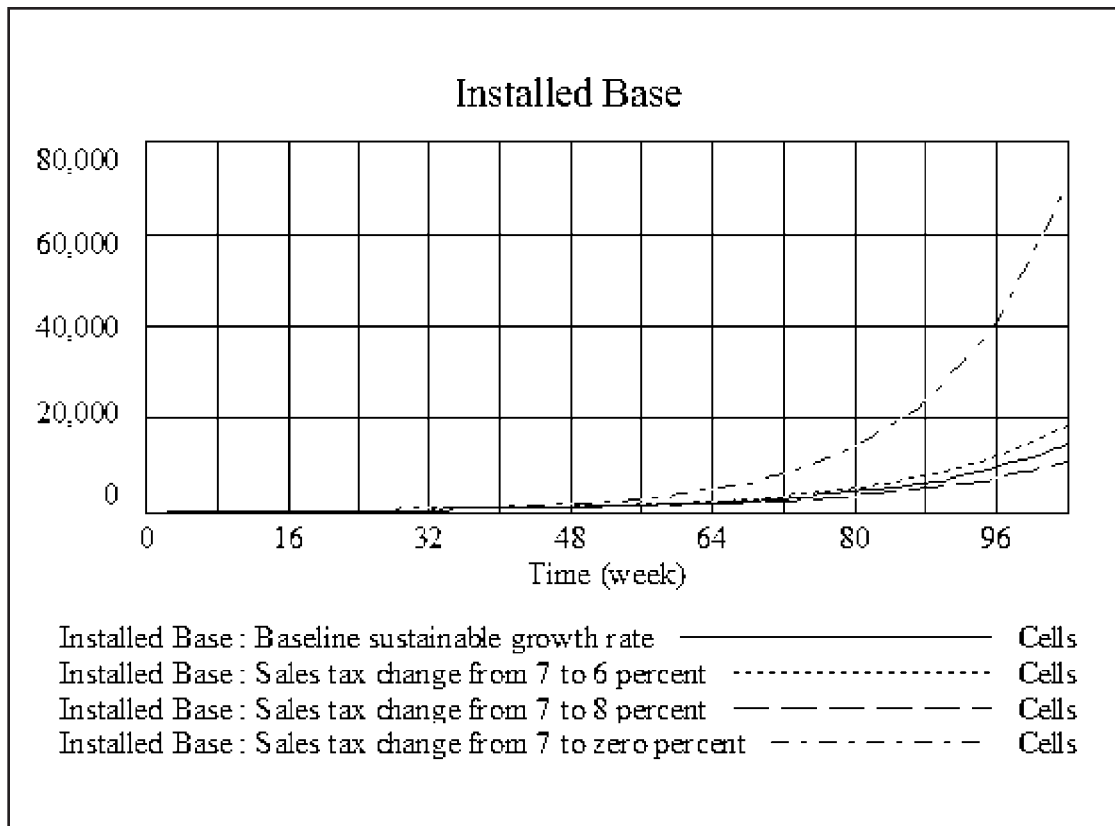
The implication for the competitiveness of firms is that higher sales tax rates reduce profit margin, which reduces cash available to be reinvested for growth. If competing firms face similar constraints in terms of credit sales, and suppliers' credit terms, new ventures operating in regions with relatively high sales tax will experience normal exponential patterns of growth, but at a slower rate. Ultimately, it has potential consequences in terms of gaining competitive advantage from experience effects, word of mouth, scale economies, etc. Eventually, when the product market matures, the firms with slower growth rates will be eliminated from the market by their larger counterparts, as the larger firms achieve cost and market power advantages. The slower growth and ultimate elimination of these firms has consequences for the employment rate for the region.

The advantage of operating in a region with no sales tax is illustrated in Figure 10. The sales per week at the end of year two is \$943,647 in the region with no sales tax, versus sales of \$150,335 in the baseline SGR. This is a 600 percent increase in rate of sales.

**Labor**

Alternative sales tax policies have very little impact on job growth over the first year of operations. The firm grows from one employee to five under each policy. By the end of the second year, however, the typical nonlin-





**Figure 12. Cumulative Sales and Installed Base**

ear growth pattern is apparent as small initial differences have large consequences. By the end of the second year, the baseline SGR has employed 87 people. Operating under the higher sales tax created only 66 jobs (25% less), and operating under the lower sales tax rate the firm created 99 jobs (14% greater).

The impact of operating in a region with no sales tax is illustrated in Figure 11. Employment at the end of year two is 560 in the region with no sales tax, versus the employment of 87 people in the baseline SGR. This is a more than 649 percent greater rate of job creation.

### **Installed Base**

Cumulative sales are reflected in the installed base figure. Under the baseline SGR, cumulative sales by the end of the second year are 14,571 units, versus 10,845 units (25% less) under the higher sales tax, and 18,659 (28% greater) under the lower sales tax, and 70,853 (486% greater) with an absence of sales tax (Figure 12).

### **Growth Dynamics: Impact of Changes in the Costs of Regulation**

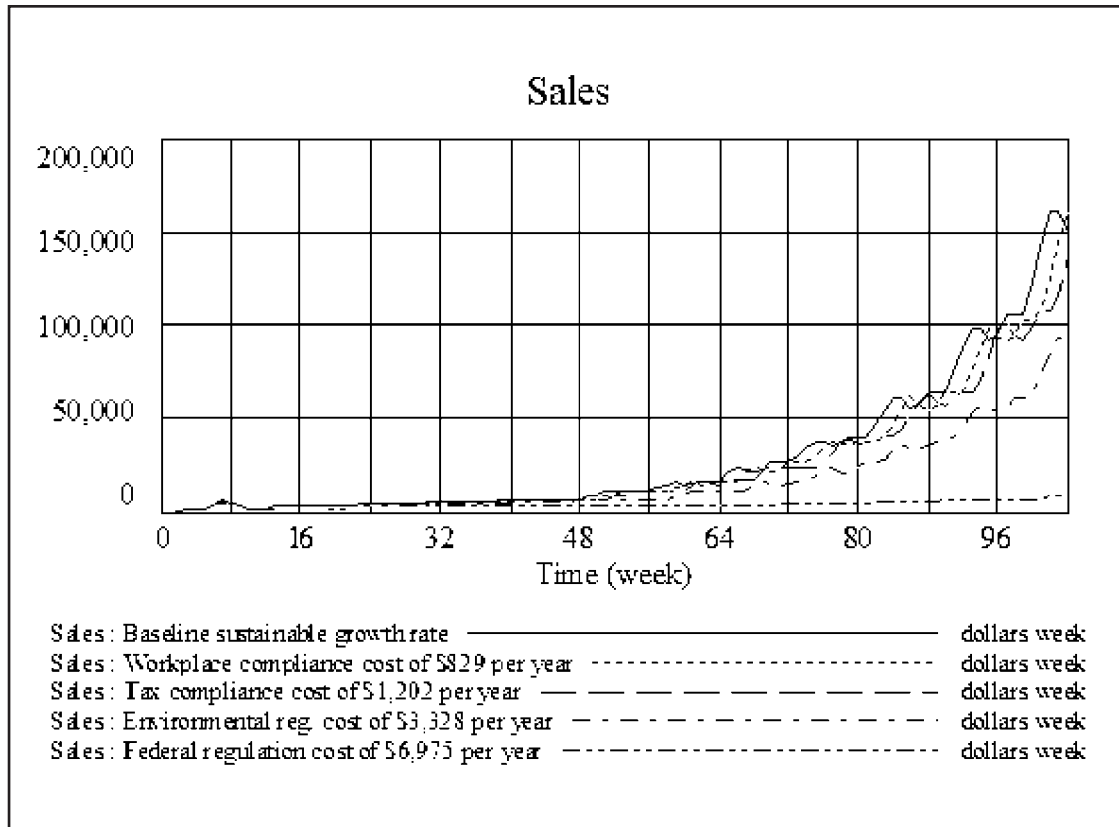
Four regulation scenarios were simulated. Regulation compliance costs were treated as a fixed expense in these scenarios. Regulation costs are not always fixed; however, the

effect of variable expenses is captured in the preceding section, so the simulations in this section illustrate the general growth dynamics associated with fixed expense impacts.

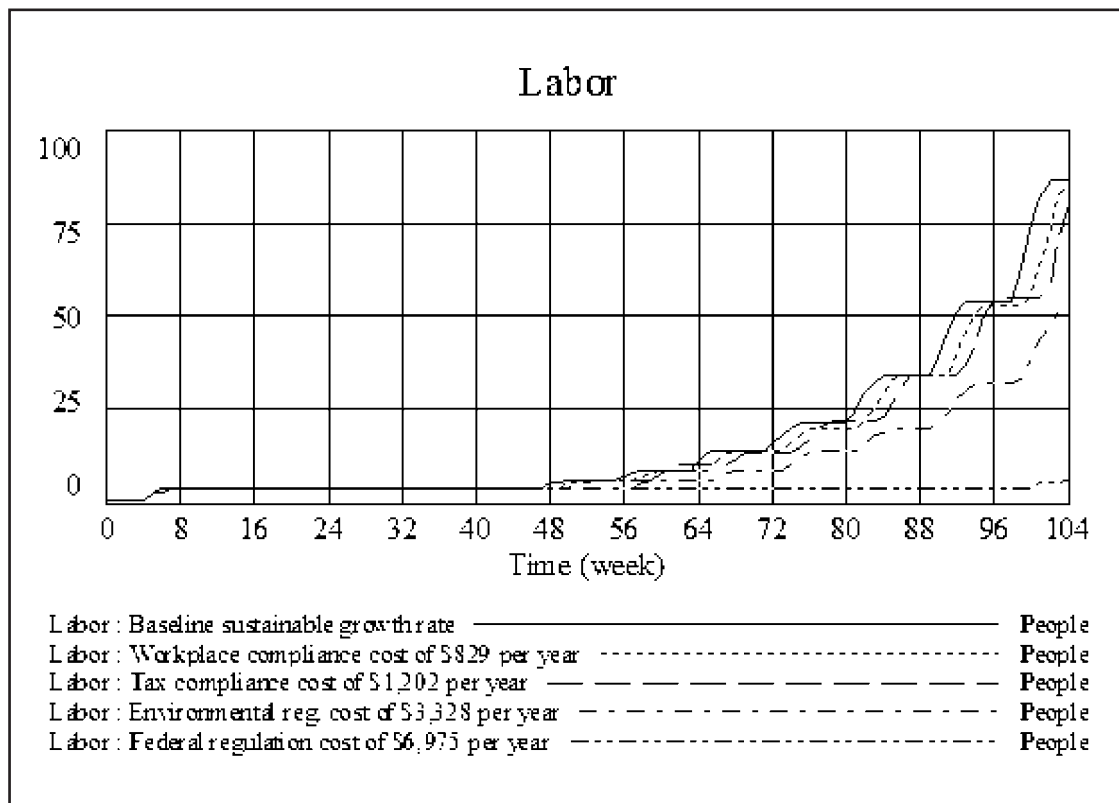
In the baseline SGR, there exist no regulation costs, so the SGR is the same as in the previous section. Those alternative regulation compliance scenarios reflect the actual, average cost(s) for firms with less than 20 employees for: environmental costs (\$3,328 annually), tax compliance (\$1,202 annually), workplace (\$829 annually), and all regulation (\$6,975 annually; equals the sum of the previous categories and includes economic costs) compliance costs (Crain and Hopkins 2001). In the model, regulation expense is assumed to be paid out evenly throughout the year, so the annual cost is divided by 52 weeks and added to weekly operating expenses.

### **Sales**

As illustrated in Figure 13, the impact of regulation expense on sales is potentially significant. The baseline SGR, in sales per week, was \$150,335. The SGR including workplace regulation costs was \$160,783, an improvement of 7 percent. This positive impact is only an artifact of the cyclic patterns of growth. The overall impact is negative, but only slightly. The SGR including tax compliance costs was \$136,996, an impair-



**Figure 13. Impact of Regulation Expenses on Sale**



**Figure 14. Impact of Regulation Expenses on Labor**

ment of 9 percent. The SGR including environmental regulation compliance costs was \$91,211 a 39 percent decline. The SGR including all regulation costs was \$9,171, a 94 percent decline. The latter indicates the potential significance of regulation costs on firm growth. In this case, the profit margin is almost entirely eliminated, and so there exists virtually no cash to reinvest into the firm.

### **Labor**

Figure 14 illustrates that the impact of regulation expense on employment is potentially significant, as noted with sales previously. The baseline SGR, in the number of accumulated jobs, was 87. The number of jobs created when including workplace regulation costs was 86, a decrease of only 1 percent. The number of jobs when including tax compliance costs was 80, an impairment of 8 percent. The number of jobs when including environmental regulation compliance costs was 51, a 41 percent decrease. The number of jobs when including all regulation costs was only 6, a 93 percent decrease. The latter indicates the potential significance of regulation costs on job growth. As mentioned above, in this case, the profit margin is almost entirely eliminated, and so there exists virtually no cash to reinvest into the firm, so production fails to grow.

### **Conclusions**

The growth of firms is fundamentally based on self-reinforcing feedback loops, one of the most important of which involves cash flow. When profit margin is positive, sales generate cash, and this cash can be reinvested to finance the operating cash cycle. As more cash becomes available, more material and labor may be employed in each cycle, generating more cash, allowing greater investment, etc. Consequently, in the absence of limits to growth, the growth dynamics of the firm are compounded returns, and *ceteris paribus*, even small changes in profit margin will invoke large changes in the growth experienced by the firm. The results of these simulations, involving both variable and fixed expense impacts from public policy, illustrate the nonlinear nature of the relationship between profit margin and growth; the short-run impact may be small and hardly noticed, but the long-run impact may be quite strong.

Both types of public policy, sales tax and regulation compliance cost, had significant impacts on the sustainable growth rate of the model firm. The results suggest that new ventures are particularly vulnerable to public policy effects, since their working capital resource levels are minimal, and they have few options to raise external funds necessary to fuel their initial operating cash cycles. Clearly, this has significant detrimental consequences in terms of gaining a competitive advantage from experience effects, word of mouth, scale economies, etc. Eventually, when the product market

matures, the firms with slower growth rates will be eliminated from the market by their larger counterparts, as the larger firms will have achieved cost and market power advantages. The slower growth and ultimate elimination of these firms have consequences for the employment rate of the region. Thus, the results seem to suggest that, in general, public policies should strive to avoid placing costs on new ventures for the first two to three years of operations. The exponential growth patterns will generate sales and jobs after the first couple of years, which may subsequently offset the initial public revenue lost.

### **Limitations**

For regulators to use this method to evaluate policy recommendations, rather than using a single exemplary business, some additional models would need to be developed so that together the set faithfully represented the range of actual start-up business types in the industry of concern. Further, within each type of business, the model parameters would need to be set to ensure consistency with the actual range of structural characteristics in that industry. That is, given the complex, nonlinear relationship between business profits and regulatory effects on firm growth, aggregate effects of regulation may be quite different than the effect of regulation on the average businesses.

The model developed here does not study the potential negative impacts on growth resulting from competitors' actions. Such competitive dynamics are possible to model (Warren 2002), but the inclusion of these dynamics would tend to obfuscate, rather than clarify, the potential economic impact of public policy since such models would investigate a pessimistic outlook as opposed to an optimistic one. If, however, a potential public policy is intended to alter, or steer, competitors' reactions to start-ups, then the model here would need to be extended, substantially.

### **Future Research**

There is strong belief by many of the importance of government policy in helping small entrepreneurs through subsidies such as SBA loans, micro credit programs, and "infant industry argument." However, one deduction to be drawn from this article is that the extra taxes needed for such programs will have a disproportionately negative effect on those smaller, younger firms, as they are the most vulnerable—the very ones the government intends to help. Further, such firms are the least likely to actually receive and benefit from such external government-funded finance because, like private lenders, public lenders will be frustrated by the inherent agency problems, and high risk of smaller, younger firms. Such implications are worthy of future empirical investigation.

Overall, the results of this work suggest that system dynamics modeling may provide public policy-makers a cost-

effective means to meet the spirit of the U.S. Regulatory Flexibility Act (1980). System dynamics modeling allows investigators to isolate the impact of specific variables for assessment within complex systems. In this case, a baseline self-financing growth pattern was generated to serve as a control for isolating the impact of alternative public policies.

This would seem to be, at least partially, a significant solution to the problem of assessing potential impact. Given that compliance with RFA is a problem (Whitmore and Walthall 2001), we hope the results provide a path of opportunity for public policy-makers.

## Endnote

1. The model presented in this article is available from the author. The model may be run using Vensim PLE, which is fully functional system dynamics software that is free for personal and educational use. Vensim PLE is shareware for commercial use, and comes complete with a help engine, and Adobe Acrobat format PLE User's Guide. You can download Vensim PLE at: <http://www.vensim.com/download.html>.

## Acknowledgment

We would like to thank the anonymous reviewers for their thoughtful feedback and suggestions.

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## Model Variable Definitions

*Accounts payable:* Calculated as the total accumulation of Order rate less Supplier payments. The initial value is set at zero dollars. Units in dollars.

*Accounts receivable:* Calculated as the total accumulation of Credit sales less Collections. The initial value is set to zero. Units in dollars.

*Attrition rate:* Calculated as Labor divided by Average duration of employment. Units in people/week.

*Average duration of employment:* Constant at 100. Units in weeks.

*Budget:* Calculated as the maximum of (Cash/Weeks to decide)—cash consumed, or zero. Units in dollars/week.

*Cash:* Calculated as the total accumulation of Operating cash generated less Cash consumed. The initial value was set to \$10,000. The argument for the initial amount is that the SBA reports that half of all new ventures in the United States are started with \$10,000 or less. Units in dollars.

*Cash consumed:* Calculated as Supplier payments + Cost of labor + Operating expenses + Training wages. This is intended to capture the reduction in cash due to operating expenses and the delayed expenses of cost of sales. Units in dollars/week.

*Cell price:* Constant at \$200 per cell. Units in dollars/cell.

*Cells sold:* Calculated as Shipping rate per week. Units in cells/week.

*Collections:* Calculated as Accounts receivable divided by Weeks to collect. Units in dollars/week.

*Cost of labor:* Calculated as Piece rate multiplied by Production rate. Units in dollars/week.

*Credit sales:* Calculated as Sales \* Credit sales percentage. Units in dollars/week.

*Credit sales percentage:* Constant at 20 percent of Sales. Units were dimensionless.

*Desired labor level:* Calculated as INTEGER (Material/Productivity). Units in people.

*Economies of experience:* Constant at 1. Units in cells.

*Inventory:* Calculated as the total accumulation of Production rate less Shipping rate. The initial value was set to zero. Units in cells.

*Hiring rate:* Calculated as the maximum of (Desired labor level - Labor - New Hires) / Weeks to hire, or zero. This is intended to prevent a negative hiring rate. Units in people/week.

*Installed base:* Calculated as the accumulated Shipping rate. Units in cells.

*Labor:* Calculated as the total accumulation of Training rate less Attrition rate. Units in people.

*Material:* Calculated as the total accumulation of Receiving rate less Production rate. The initial value was set to zero cells. Units in cells.

*Material cost per cell:* Constant at \$90. Units in dollars/cell.

*New hires:* Calculated as the total accumulation of Hiring rate less Training rate. The initial level was set to zero people. Units in people.

*New hire wage rate:* Constant at \$300. Units in dollars/(week\*People).

*Order rate:* Calculated as Order decision multiplied by Material cost per Cell. Units in dollars/week.

*Operating cash generated:* Calculated as Sales \* (1 - Credit sales percentage)) + Collections - (Sales \* Sales tax rate). This is intended to capture the reduction in sales-generated cash due to credit sales, and sales tax payments. Units in dollars/week.

*Operating expenses:* Constant at \$400 per week. Units in dollars/week.

*Order decision:* Calculated as IF THEN ELSE (Budget < \$10,000, INTEGER (Budget / Material cost per Cell)/2, INTEGER (Budget / Material cost per Cell)). Units in cells/week.

*Orders placed:* Calculated as the total accumulation of Purchasing rate less Receiving rate. The initial value was set to 20. Units in cells.

*Piece rate:* Constant at \$50 per Cell. Units in dollars/cell.

*Production rate:* Calculated as the minimum of Material / Weeks to produce or (Labor \* Productivity) / Weeks to produce ). Intended to limit production to the level dictated by the average productivity of labor. Units in cells/week.

*Productivity:* Calculated as  $20 + \text{LN}((\text{Installed Base} / \text{Economies of experience}) + 1)$ . This is intended to capture a learning curve effect on productivity. Units in cells/people.

*Purchasing rate:* Calculated as the maximum of Order decision, or zero. Units in dollars/week.

*Receiving rate:* Calculated as Orders placed divided by Weeks to receive. Units in cells/week.

*Sales:* Calculated as Cell price \* Cells sold. A cell is a high technology, dynamic, random access memory chip. These Cells conform to industry standard specifications, and are typically used by consumers in a wide range of hand-held electronic devices. Units in dollars/week.

*Sales tax rate:* Constant at 7 percent of Sales, unless otherwise specified. Units are dimensionless.

*Shipping rate:* Calculated as Inventory divided by Weeks to ship. Units in cells/week.

*Supplier payments:* Calculated as Accounts payable divided by Weeks to pay. Units in dollars/week.

*Training rate:* Calculated as New hires divided by Weeks to train. Units in people/week.

*Training wages:* Calculated as New hires multiplied by New hire wage rate. Units in dollars/week.

*Weeks to collect:* Constant at four weeks. Units in weeks.

*Weeks to decide:* Constant at one week. Units in weeks.

*Weeks to hire:* Constant at one week. Units in weeks.

*Weeks to pay:* Constant at three weeks. Units in weeks.

*Weeks to produce:* Constant at three weeks. Units in weeks.

*Weeks to receive:* Constant at two weeks. Units in weeks.

*Weeks to ship:* Constant at one week. Units in weeks.

*Weeks to train:* Constant at two weeks. Units in weeks.



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