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Growing a Market Economy

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Abstract

This report presents a microsimulation model of a transition economy. Transition is defined as the process of moving from a state-enterprise economy to a market economy. The emphasis is on growing a market economy starting from basic microprinciples. The model described in this report extends and modifies the capabilities of Aspen, a new agent-based model that is being developed at Sandia National Laboratories on a massively parallel Paragon computer. Aspen is significantly different from traditional models of the economy. Aspen's emphasis on disequilibrium growth paths, its analysis based on evolution and emergent behavior rather than on a mechanistic view of society, and its use of learning algorithms to simulate the behavior of some agents rather than an assumption of perfect rationality make this model well-suited for analyzing economic variables of interest from transition economies. Preliminary results from several runs of the model are included.

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Nomenclature

Aspen	(an agent-based simulation model)
GALCS	genetic algorithm learning classifier system
GNP	gross national product
Sandia	Sandia National Laboratories

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Growing a Market Economy

Introduction

Sandia National Laboratories (Sandia) is applying agent-based computational modeling techniques to describe the transition from a state-enterprise economy to a private-enterprise economy. Analyses of transition economies moving from socialism to capitalism, from state to private ownership, and from dictatorship to democracy provide important challenges to social scientists. Most of the tools used to analyze fully developed market economies in the democratic world are not suitable for transition economies. We are developing a new set of tools. This report describes the first step towards achieving that goal.

The model described in this report is an extension and modification of a microsimulation model, Aspen, that Sandia is developing. Aspen is an agent-based Monte-Carlo simulation that runs on Sandia's massively parallel Intel Paragon computer. Individual agents in Aspen represent real-life economic decision-makers. Aggregates of the agents' microeconomic actions generate macroeconomic variables. A prototype version of Aspen is reported in Pryor et al. (1996). An enhanced version of Aspen, which resembles the United States economy, is reported in Basu et al. (1996) [1].

Most models in economics place emphasis on *explaining* a fully grown socially observed phenomenon. Our model of the transition economy is more aligned with the work of Epstein and Axtell (1996), where the emphasis is on *growing* that phenomenon rather than explaining it. Starting from very simple rule-based microbehavior, we are able to grow a fairly complicated macroscopic market economy.

The body of this report contains five sections and a conclusion. Major topics addressed are the transition from a state-enterprise economy to a market economy, the advantages of using Aspen for analyzing a transition economy, a description of the transition-economy model, and initial results obtained from running this model. Suggestions for extending the model are also provided.

[1] There are two well-known agent-based models of the United States economy. One is the Urban Institute model developed by Guy Orcutt. See Orcutt et al. (1976). The other is Robert Bennett and Barbara Bergmann's Transaction Model (Bennett, 1986). Aspen, with its emphasis on learning and evolution, represents a second generation of these models.

Transition into a Market Economy

As defined in the World Development Report (1996), the long-term goal of a transition economy is to build a thriving market economy capable of delivering long-term growth in living standards. What distinguishes transition from reform is the degree of systematic change. To be considered a transition, reform must penetrate to the fundamental rules of the game—to the institutions that shape behavior and guide organizations. This makes reform a social transition as well as an economic one.

By 1950, one-third of the world's population had replaced a market economy with a state-planned economy that maintained centralized control of production and allocation of all resources. Since 1989, an equally radical movement had been set in motion in more than 30 countries in Eastern Europe and the former Soviet Union. Other countries experiencing such a transition include Cuba, Vietnam, China and even certain African countries like Angola, Ethiopia, and Mozambique (Fisher et. al. 1996). All these countries have their different growth paths, different histories and politics, different starting points to transition, and different speeds of transition. Despite their differences, these countries have one aspect in common—a rapidly growing private sector. The available literature on transition economies is mostly descriptive and not analytic. New approaches are needed to analyze the many aspects of transition. This report focuses on building an alternative set of tools for analyzing the emergence of a private sector in the former socialist countries. The emergence of this sector is a very important aspect of transition.

Advantages of Using Aspen

As noted previously, the microsimulation model, Aspen, was extended and modified to analyze the transition from a state-enterprise economy to a private-enterprise economy. Aspen was selected because it offers many advantages over traditional macroeconomic models in the analysis of transition economies. This section highlights some of the key features that make Aspen well-suited for this task.

Aspen uses an agent-based modeling technique. This technique allows agents and their actions to be defined at a finer level of detail than is possible in traditional macroeconomic models. This technique also supports a more general level of detail through the specification of "populations" of agents, such as households, firms, etc., rather than the single aggregate agent found in macroeconomic models. In the model of the transition economy, individuals are allowed to differ both in their productivity and their desire to become entrepreneurs. The private sector emerges as a result of interactions between the choices (or actions) of different individuals.

Since the behavior of agents is probabilistic, Aspen is stochastic. Given the same set of inputs, the outcomes from any event could involve substantial variation in output. Aspen can provide a distribution of outcomes, not only the average or most likely solution.

Unlike most dynamic models in economics, Aspen does not assume an equilibrium growth path. The calculation is carried forward chronologically using different permutations of possible actions by agents. Following this methodology, the economy might emerge into a solution that is outside the bounds of possibilities normally considered by an economist using aggregate data. This property of not assuming an equilibrium growth path is extremely important in the context of transition economies and their emergent private markets where the bounds of possibilities have not been properly defined.

Economics models implicitly assume that optimizing agents act with perfect rationality. Perfect rationality in economics not only implies doing one's best given the circumstances, but generally it also implies that one has all the information available about all possible alternative scenarios, the ability to process all that information, and the ability to reach the right conclusion. These assumptions are increasingly being questioned by economists. The validity of these assumptions is even more questionable in transition economies where property, legal, and contractual rights do not have a firm foundation and uncertainties are rampant. Aspen does not require this restrictive assumption of perfect rationality because its agents use genetic algorithm learning classifier systems (GALCS) to make more realistic decisions. In the model of the transition economy, the newly emergent private firms use GALCS to determine prices. Each firm operates by trial and error to adapt to the economy, to react to each other's strategy, and to learn new rules for success.

Description of the Transition-Economy Model

This section provides a general description of the types of agents (or actors) in the new model of the transition economy and the major processes and interactions in which these agents are involved. The primary area of interest is the movement of individuals from the state to the private sector. There is a single commodity produced in the economy. It is produced by using a single input—labor.

In building this transition economy, we have produced two versions (1 and 2) of the new model. Both versions share common characteristics, but each treats selected processes in a particular way. Version 1 emphasizes only the production side. Thus, in version 1, companies are not concerned about prices or sales. In version 2, we have added another level of complexity to the economy: consumption and pricing. Hence, companies in this version are concerned about prices because they must compete on the basis of price to sell their products to individuals.

Agents

Decision makers in the Aspen economy are called agents. These agents are classified as one of three types: an **individual**, a **state firm**, or a **private firm**. One important aspect of Aspen is its flexibility. The number and characteristics of agents are easily changeable parameters or initial conditions. However, to derive the results presented in this report, we used only one state-firm agent and 1000 individual agents. Individual agents have randomly defined productivity (number of units of the commodity the individual is capable of producing) uniformly distributed between 0 and 1. At the start of the simulation, all individual agents work for the state firm. The state firm pays everyone the same wage, which is equal to 70% of the average product of its workers.

An Individual's Decision to Start a Business

The number of private firms is endogeneously determined in the model. As transition starts, individuals are allowed to start their own businesses and anyone with productivity greater than the state-firm wage has an incentive to do so. We randomly pick approximately 10% of the individuals to be entrepreneurs. In order to start a business, an entrepreneur must hire at least four individuals.

The hiring process begins as each entrepreneur sends job announcements to 10 other randomly picked individuals. If only four such individuals respond to the announcement, the entrepreneur must hire them. If more than four respond, the entrepreneur can choose among the applicants. If the entrepreneur does not acquire enough employees within 5 time cycles, there is a 50% probability that the entrepreneur will decide not to start a business. During the process of attempting to start a business, an entrepreneur can not accept any job offer from the private sector and must continue to work for the state.

The start of a business creates the third type of agent—the private firm. A newly formed private-firm (or company) consists of the entrepreneur (referred to as owner or employer as a result of this change in status) and four individual agents (alternately referred to as workers or employees of the private sector). The owner of a private firm cannot leave the company unless it goes out of business.

The owner of a newly formed private firm continues to send job announcements to 10 different randomly picked individuals for 10 time cycles after formation. Subsequently, the owner can broadcast the firm's wage to everyone. The owner is treated in this model as a worker in his own company. All employees including the owner receive a wage equal to 70% of the firm's average product. The owner also receives 30% of the total product as profit.

An Individual's Choice of Workplace

An individual will switch from the state to the private sector or change jobs within the private sector only if its current wage is less than 70% of its productivity and the offered wage is greater than the current wage. The model assumes that each individual has knowledge of its own productivity. An individual is most likely to apply for the job offering the highest wage. In the early stages of the run, when most owners have not fulfilled their input requirements, an individual is more likely to be hired. However, if an individual is rejected for five consecutive time cycles, it changes its job-application strategy. In this new strategy, the individual searches for a company that 1) pays more than the individual's current wage and 2) has a lower average productivity than the individual's own productivity. The individual will be hired by the company that meets these criteria. If there is no such company, the individual continues to work for its current employer, which could either be the state firm or a private firm. An individual that is laid off from a job can search for another job in the private sector or return to work for the state sector.

Version 1: Special Characteristics

Selected processes that are treated in a special manner in the first version of the model are described in the subsections which follow.

Individual's Loss of Job

Individuals working in the private sector can lose their jobs in the first version only if their companies go out of business.

Private Firm's Employment Decision

The consumption side is ignored in the first version. The assumption is that whatever amount is produced by either the state firm or the private firms can be sold in the market. As a result, profit is maximized when output is maximized. However, since the owner also works for its own company, the owner's income is a combination of wage and profit. Wage is decreased if the average product is decreased. It is therefore not always beneficial for the owner to increase production by hiring low productivity workers.

Private Firm's Failure

In the first version, a business can fail only if it does not have enough employees. A young private firm (less than a month old) goes out of business if for 10 consecutive time cycles it has less than 5 employees. An established private firm (more than a month old) goes out of business if it has less than 10 employees for 10 consecutive days. To protect against this possibility, a private firm tries to maintain at least 15 employees at all times. Beyond that, workers are hired only if it is beneficial for the owner to do so.

Version 2: Special Characteristics

Selected processes that are treated in a special manner in the second version of the model are described in the subsections which follow.

Individual's Loss of Job

Individuals working in the private sector can lose their jobs in the second version if their companies go out of business *or* if they are laid off by their companies.

Private Firm's Employment Decision

In the second version, employment decisions are made to maintain sufficient inventory. When a firm's inventory is greater than 1.3 times the firm's average demand, it lays off workers. When inventory is less than one days worth of demand, it hires workers.

Private Firm's Failure

A business can fail in the second version because it does not have enough wealth or because it does not have enough workers. Wealth is measured by accumulated profit. The logic to determine business failure is activated 60 time cycles after the firm is established. From this point forward, any private firm that has negative wealth for 10 consecutive time cycles or that has fewer than 2 workers (the owner and one employee) for 10 consecutive time cycles will go out of business.

Individual's Buying Decision

In the second version, individuals spend their daily income on the single commodity produced by the economy. An individual first consults a list of prices, which is compiled from price-per-unit messages that are broadcast by each firm once per time cycle. The formula for determining an individual's buying decision is

If firm f offers price $p(f)$, an individual buys from this firm with a probability $k*[p(f)]^{-q}$

where

q = a given exogeneous parameter
k = a normalizing constant.

Thus, the lower $p(f)$ is in relation to the prices of other firms, the greater likelihood the individual has of satisfying its demand by buying from f. However, the probability of buying from a firm that is not charging the lowest price is positive. A small positive probability accounts for product differentiation and cost of searching.

Private Firm's Pricing Decision

Each private firm uses a GALCS to set product prices. A private firm determines four trends daily: (a) whether product price has been recently increasing or decreasing, (b) whether sales have been recently increasing or decreasing, (c) whether profits have been recently increasing or decreasing, and (d) whether prices are higher or lower that the industry average. Based on answers to (a) through (d), the firm finds itself in one of 16 states.

The GALCS assign a probability vector (P^D, P^I, P^C) to each state,

where

P^D = the probability that the firm will decrease a given price (by a certain exogeneously specified amount)

P^I = the probability the firm will increase the price

P^C = the probability the firm will keep the price constant.

Upon entering a certain state, the private firm decides how to change a given price by using the corresponding probability vector and choosing a random number. The firm then adjusts the vector according to how the change in price affects profits. For further details on GALCS see Basu et al. (1996).

Results

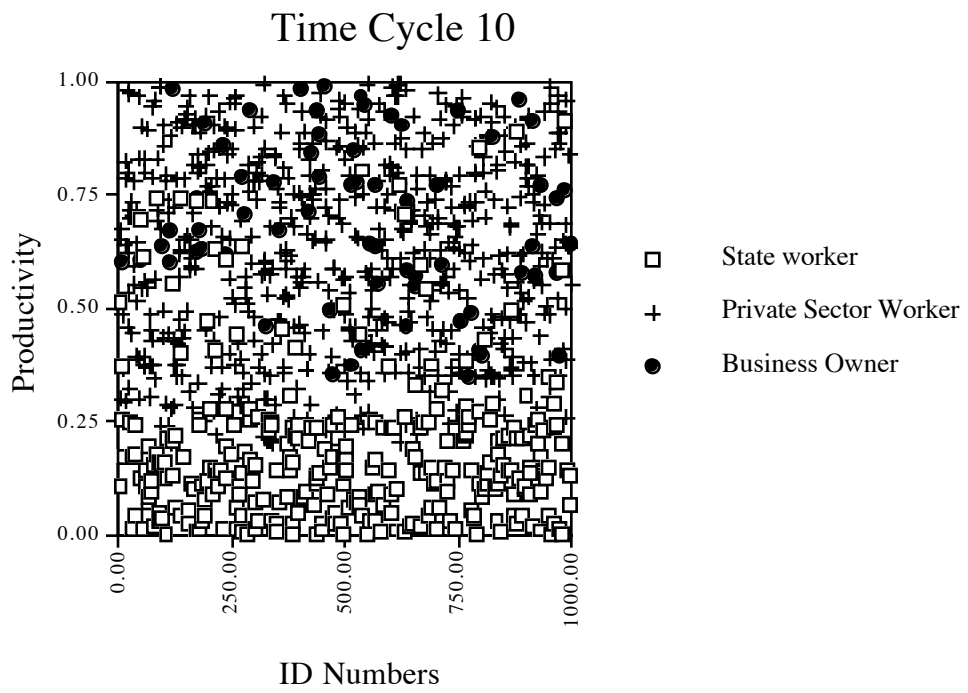
This section presents the results obtained from running versions 1 and 2 of the transition-economy model. In both versions, the simulations began with one state-firm agent and 1000 individual agents.

Primary Result

A private sector with several firms emerges in both versions as individuals exit from the state sector. As more productive workers are absorbed in the private sector, the average product in the state sector declines which makes it beneficial for more workers to leave. However, a small state sector survives.

Version 1 Results

Figure 1 shows the distribution of workers across sectors in two arbitrarily selected time cycles: 10 and 200. Table 1, which follows, presents additional details regarding the emergence of the private sector. As expected, in this framework, workers segregate themselves in the different private firms according to their productivity. By time cycle 200, only the lowest productivity individuals are employed by the state sector.



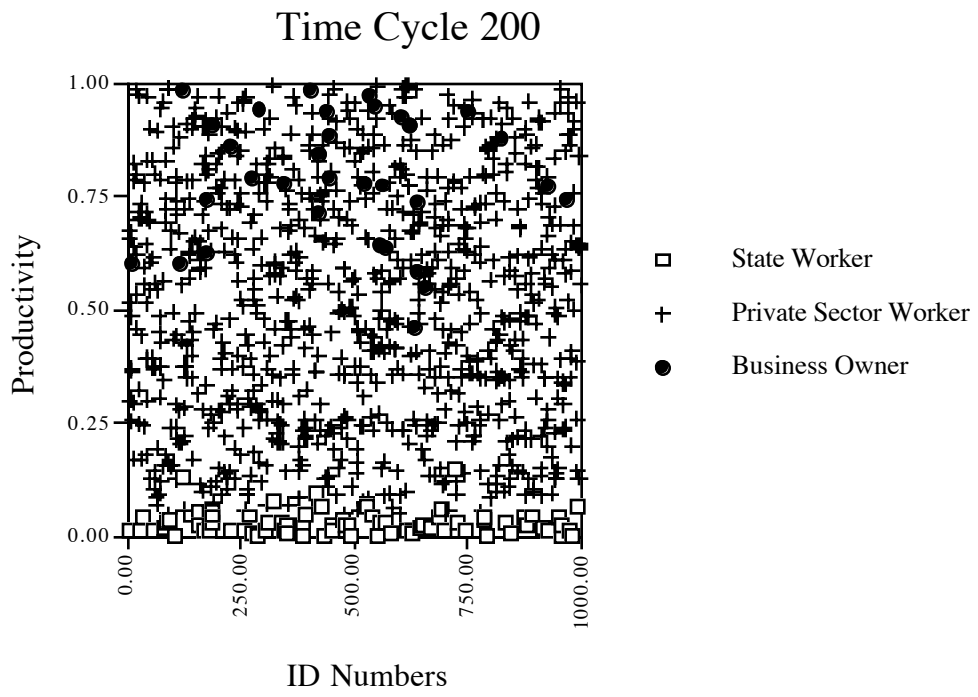


Figure 1. Workers in different sectors in time cycles 10 and 200: Version 1

Table 1. Emergence of a private sector: Version 1

Time Cycle	Number of private firms	Number of private sector employees	State sector average product
1	0	0	0.50
5	51 (0.48)	204 (1.93)	0.44 (0.001)
10	67 (0.48)	624 (1.75)	0.20 (0.002)
25	61 (1.77)	864 (2.45)	0.08 (0.002)
50	49 (1.49)	877 (3.38)	0.08 (0.001)
100	35 (1.07)	878 (3.74)	0.07 (0.003)
500	31 (0.82)	904 (2.96)	0.07 (0.001)
1000	31 (0.82)	905 (1.71)	0.07 (0.001)
5000	31 (0.82)	906 (1.55)	0.07 (0.001)

All reported results are 30-run averages. Figures within parentheses are standard deviations.

Figure 2 shows the relationship between productivity and wage for workers. Figure 3 illustrates the relationship between productivity and income for business owners. For workers, income is equivalent to wage; for owners, income is equal to wage plus profit. Income and personal productivity are highly correlated for workers but not for owners.

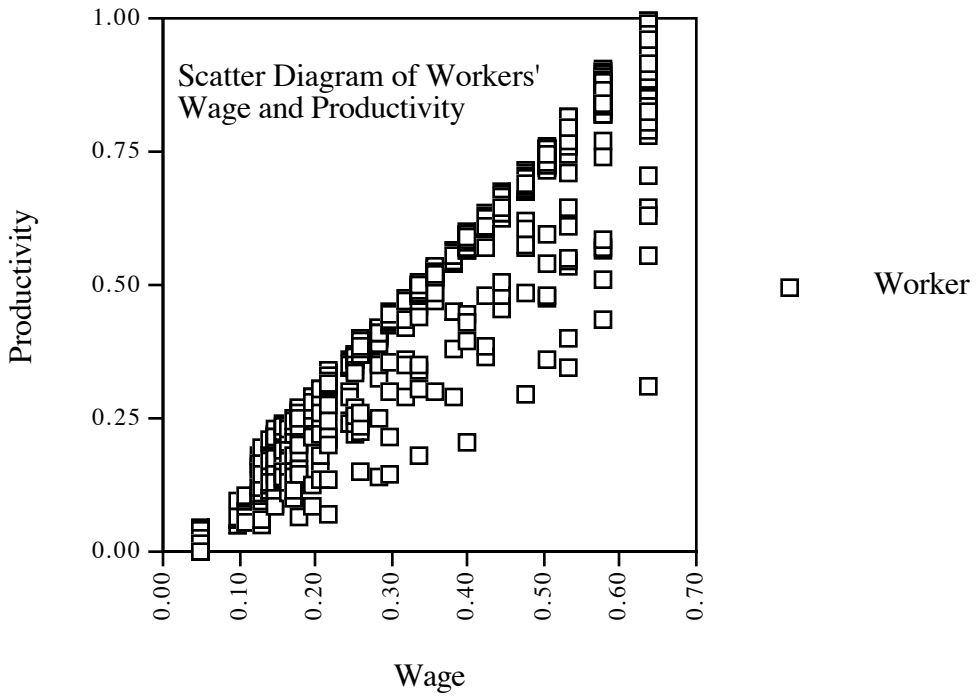


Figure 2. Scatter diagram of workers wage and productivity: Version 1

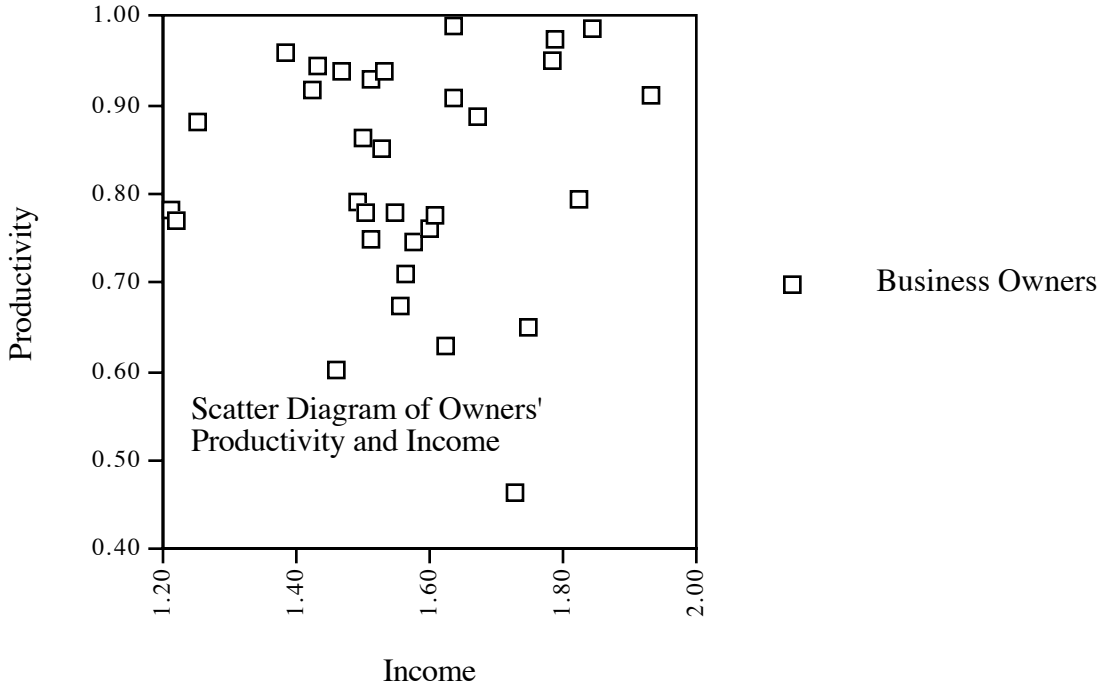


Figure 3. Scatter diagram of business owners' income and productivity: Version 1

After 500 time cycles, the following dependencies were observed:

- The correlation coefficient between worker productivity and worker income = .96.
- The correlation coefficient between owner productivity and owner income = .30.

A plausible explanation for the lack of positive correlation between an owner's productivity and income may lie in an assumption used in both versions of the transition-economy model: the owner of a private firm is not allowed to leave the company unless it goes out of business. In the early stages of the run, an owner with high productivity might end up hiring quite a few low productivity workers. The average product of the firm will be low and it is unlikely that the firm will be able to attract high productivity workers later on. If the firm manages to stay in business, the owner's income may be low. In this kind of scenario, the owner is worse off by staying in business.

Examining the Sensitivity of Version 1 Results

To examine the sensitivity of the model results described above, we changed some parameter values and the initial values of some variables. These changes are described next.

Let X_1 be the exogeneously determined percentage of the population that want to become entrepreneurs. Table 2 shows the effect of X_1 on the emergence of the private sector at time cycle 500. The data in this table indicate that there is a maximum sustainable number of private firms that can emerge in this economy. As X_1 changes from 1% to 5%, there is a rapid increase in the number of private firms created and sustained in the economy, a rapid increase in the number of people switching to work for the private sector, and a rapid decline in the productivity of the state sector as more productive workers leave the state sector. If X_1 is increased from 5% to even 100%, there is no significant change in either the number of firms or the number of individuals working in the private sector.

Table 2. Effect of X_1 on emergence of a private sector

X_1	Number of private firms	Number of private sector employees	State sector average product
1	8 (0.81)	487 (1.54)	0.25 (0.002)
2	11 (0.89)	548 (1.69)	0.23 (0.002)
3	16 (0.56)	611 (3.42)	0.20 (0.002)
4	25 (0.65)	848 (3.45)	0.09 (0.002)
5	31 (0.44)	897 (3.12)	0.07 (0.001)
10	31 (0.82)	904 (2.96)	0.07 (0.001)
30	33 (0.89)	900 (2.87)	0.07 (0.001)
50	32 (0.91)	900 (2.01)	0.07 (0.001)
100	30 (0.93	902 (2.05)	0.07 (0.001)

X_1 = percentage of agents who want to become entrepreneurs. All reported results are 30-run averages. Figures within parentheses are standard deviations.

For the rest of this report, we will use X_1 = 10 percent. Though there is no significant change observable from the Table 2 for ($5 \leq X_1 \leq 100$) the economy will follow different growth paths. For example, with a higher value of X_1 , the economy is likely to start transition with a higher number of private firms being created, but a higher percentage of them will not last until time cycle 500.

Let X_2 be the exogeneously determined minimum productivity required at the beginning of the run for someone to decide to become an entrepreneur. Table 3 is a snapshot at time cycle 500 for different values of X_2. Table 3 shows that there is no significant difference in the number of private firms created or the number of private sector employees as X_2 changes from 0.1 to 0.7. Only when X_2 is increased to 0.8 or 0.9 do we find fewer firms and fewer private sector employees at time cycle 500. Obviously with a lower value of X_2, there will be an increase in the number of attempts to start a business. However, most of those businesses fail before they reach time cycle 500. In most of our runs we have used X_2 = 0.35.

Table 3. Effect of X_2 on emergence of a private sector

X_2	Number of private firms	Number of private sector employees	State sector average product
0.1	32 (1.22)	906 (2.01)	0.07 (0.002)
0.2	31 (1.02)	899 (2.01)	0.07 (0.002)
0.3	31 (0.95)	909 (1.98)	0.07 (0.001)
0.4	33 (0.89)	908 (1.99)	0.07 (0.001)
0.5	33 (0.87)	908 (1.76)	0.07 (0.001)
0.6	35 (0.87)	906 (1.82)	0.07 (0.001)
0.7	32 (0.31)	890 (1.99)	0.08 (0.001)
0.8	21 (0.21)	709 (1.98)	0.15 (0.001)
0.9	12 (0.21)	531 (2.43)	0.24 (0.001)

X_2 = minimum productivity required to become an entrepreneur. All reported results are 30-run averages. Figures within parentheses are standard deviations.

The above results were obtained using the following hiring strategy by the owner. Once private firms had attained a certain size, the owner only accepted applicants with productivity higher than the current average productivity of the firm. An alternative strategy could be derived in the following manner:

Let X = the output produced by *n* employees
MP = output to be added by new employee

MP is the marginal product of the newly hired. Since the owner receives 70% of the average product as wage and 30% of the total product as profit, the applicant will be hired if $MP / X > 7 / (n * (1 + .3 * n)$. Use of this strategy leads to a different growth path for the economy. Table 4 provides details regarding the emergence of the private sector if an owner follows this strategy. Comparing the results of Table 4 with those in Table 1 (p. 17), we can see that the same number of firms were started, but that most of them fail when the alternative hiring strategy is used and that only 5 remain at time cycle 500 and beyond. Since a similar (slightly higher) number of people moved to the private sector, the remaining 5 firms are much larger in size. With this strategy, as *n* gets larger, the firm is more likely to hire employees with low productivity.

Table 4. Emergence of a private sector: Version 1, where employer uses alternative hiring strategy

Time Cycle	Number of private firms	Number of private sector employees	State sector average product
1	0	0	0.50
5	51 (0.48)	204 (1.30)	0.44 (0.001)
10	67 (0.48)	637 (1.00)	0.19 (0.002)
25	54 (2.70)	868 (4.15)	0.07 (0.001)
50	23 (1.79)	903 (4.51)	0.07 (0.001)
100	10 (1.48)	927 (1.82)	0.07 (0.001)
500	5 (0.45)	933 (1.64)	0.07 (0.001)
1000	5 (0.45)	933 (1.64)	0.07 (0.001)
5000	5 (0.45)	933 (1.64)	0.07 (0.001)

All reported results are 30-run averages. Figures within parentheses are standard deviations.

Version 2 Results

Another level of complexity was added in version 2. Firms must be concerned with the sale of their product and the resulting profit. Sale of the product is dependent on the price the firms are charging (obtained by using GALCS). The state sector charges the arithmetic average of the prices charged by the private firms, and the state sector is allowed to operate even if it is making a loss in every time cycle. This gives an advantage to the state sector, and the private sector grows at a much slower rate. Table 5 shows results from version 2. Comparing Table 5 with Table 1 (p. 17), we find that at the same time cycle, relatively fewer people make the transition to working in the private sector. This finding agrees with the view expressed by many authors regarding the pitfalls of partial reform—notably that the presence of a subsidized state sector halts the growth of the private sector (Murphy et al. 1992).

Table 5. Emergence of a private sector: Version 2

Time Cycle	Number of private firms	Number of private sector employees	State sector average product
1	0	0	0.50 (0.001)
5	51 (0.49)	204 (1.35)	0.44 (0.001)
10	66 (0.48)	524 (1.34)	0.21 (0.002)
25	66 (0.44)	656 (2.98)	0.20 (0.002)
50	66 (0.30)	565 (4.53)	0.30 (0.003)
100	36 (0.36)	463 (4.05)	0.38 (0.003)
500	20 (0.31)	506 (2.01)	0.33 (0.002)
1000	19 (0.35)	423 (1.79)	0.32 (0.001)
5000	19 (0.35)	420 (1.78)	0.32 (0.001)

All reported results are 30-run averages. Figures within parentheses are standard deviations.

Figure 4 shows total sales of the single commodity in the economy. There appear to be cyclic movements in product sales. Market economies show short-term cyclical movements in their Gross National Product (GNP). A period of decline in GNP is usually followed by an upward ascent of it. These short-term fluctuations are known as business cycles. In our single-product model, total sales of that single product can be thought of as an approximation of GNP. We need to further analyze the phenomenon to determine whether the cyclical movements shown in Figure 4 can qualify as business cycles. However the fact that we have generated this cyclic behavior, simply based on price and inventory changes by private firms, is a very important result. Since most economic forecasting models have great difficulty predicting any kind of cyclic behavior, these results are highly encouraging.

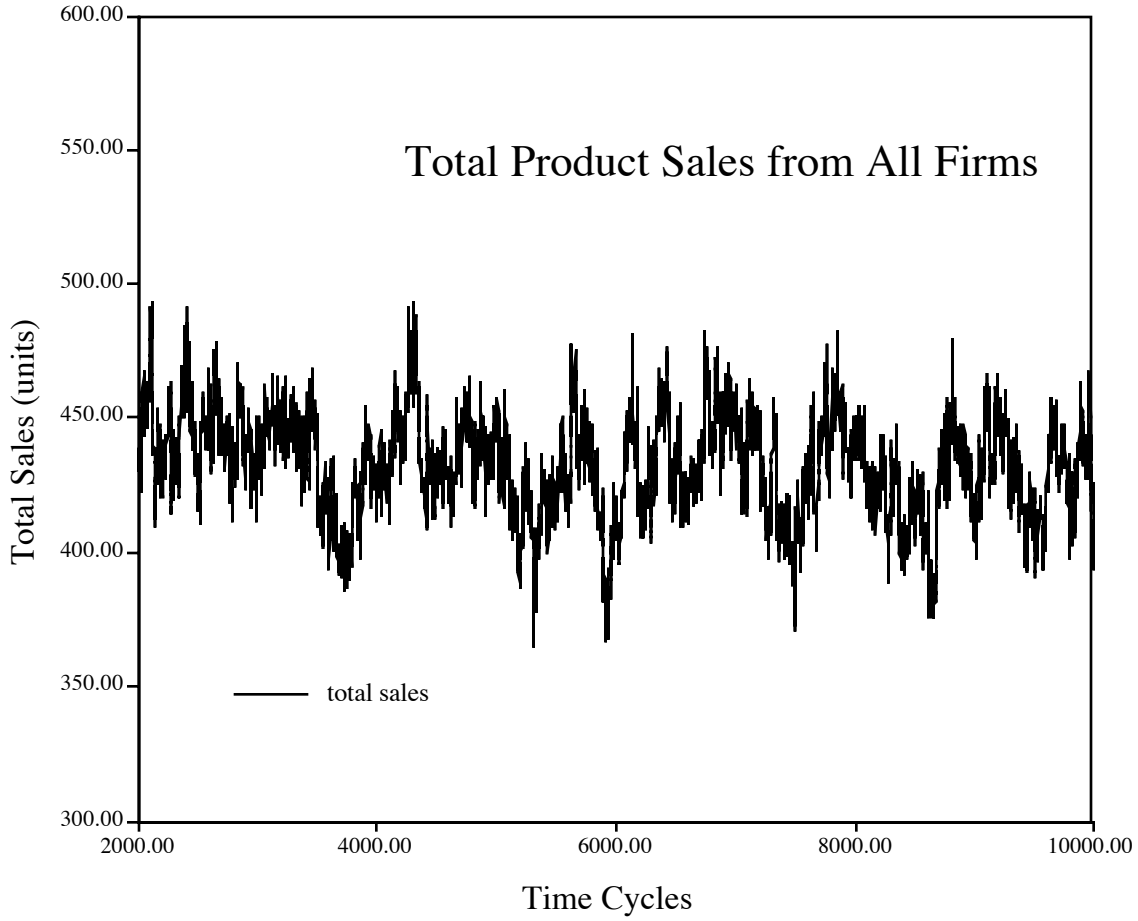


Figure 4. Total Product Sales from All Firms: Version 2

Future Extensions

The extensions proposed here are applicable to one or both versions of the transition-economy model. The most obvious extension will be to allow emergence of new entrepreneurs not only at the beginning of the run, but throughout the run. Both versions currently allow new businesses to come up later in the run, but these businesses must be owned by previous owners whose businesses have failed. Version 2 uses learning algorithms only for determining prices. A more complete version should combine pricing and employment strategies. Both versions currently place emphasis on the movement of labor between state and private sectors. The most important component omitted from the model is the possible change in productivity as an individual moves between sectors. Output capacity remains the same throughout the runs in this model economy. Future extensions of the model will incorporate changes in productivity as transition progresses.

Conclusion

Most of the tools used to analyze fully developed market economies are not appropriate for transition economies. Therefore, there is a need to develop a new set of tools. This paper describes some of the new tools we are developing to create an artificial transition economy on a supercomputer. Our model is significantly different from traditional models of the economy. Aspen is well-suited for analyzing transition economies because of its emphasis on disequilibrium growth paths, its analysis based on evolution and emergent behavior rather than on a mechanistic view of society, and its use of learning algorithms to simulate the behavior of some agents rather than an assumed perfect rationality. We have also reported preliminary results from the model. The results are along the expected lines but interesting. Since the intent was not to get new results but to grow commonly observed phenomena from very simple assumptions, the preliminary results suggest that we have taken a step in the right direction.

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