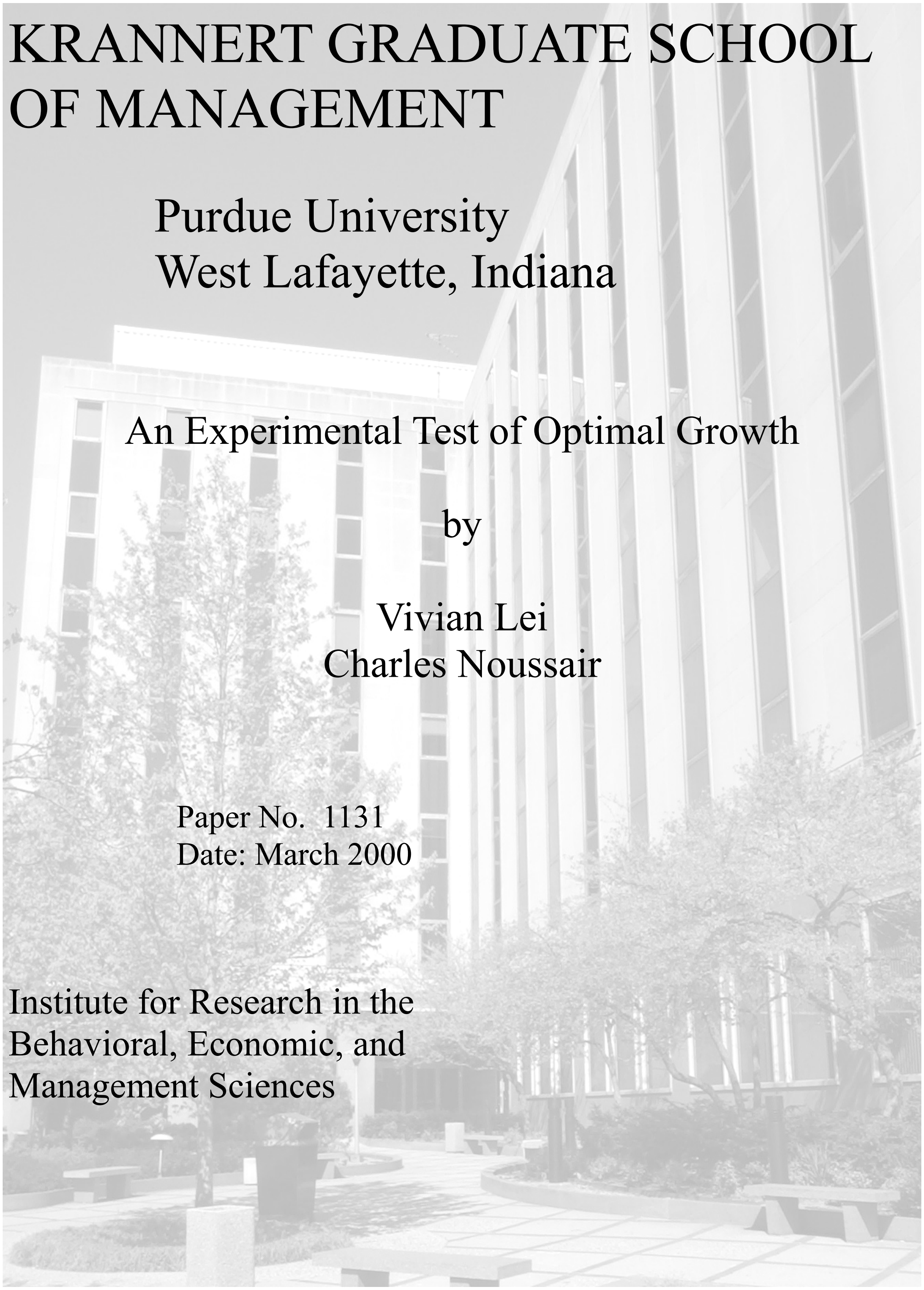

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An Experimental Test of Optimal Growth

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An Experimental Test of an Optimal Growth Model

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Abstract

This paper describes the design and behavior of an experimental economy with the structure of the Ramsey-Cass-Koopmans model of optimal growth. In the model, the levels of consumption and capital stock converge to an optimal steady state level, regardless of the level of initial endowment. The main question considered in this study is whether such convergence is observed in the experimental economy. There are two sets of parameters used in the experiment, *Low Endowment*, in which the initial level of capital stock is below the optimal steady state level, and *High Endowment*, in which it is greater. The experimental treatments consist of two different implementations of the model. In a decentralized implementation of the model with multiple agents and a market for capital, the variables in the economy have a strong tendency to converge to the optimal steady state levels. In contrast, when individual subjects are placed in the role of social planners, the economy

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is less likely to converge to its optimal steady state. These findings highlight the role of market institutions in enabling the economy to operate at its optimum.

1 Introduction

Understanding the process of economic growth is a fundamental task of modern economics. The study of the origins of changes in national incomes over time as well as differences between rich and poor countries can lead to potentially immensely beneficial policy prescriptions. Macroeconomists have certainly recognized the importance of questions of economic growth and have devised an impressive array of theoretical models which analyze the relationships between current consumption, saving, and investment decisions of agents and their impact on future economic activity (see Azariadis (1993) and Barro and Sala-i-Martin (1995) for extensive surveys of growth models). For example, in the early neoclassical growth model of Solow (1956) and Swan (1956) there is an exogenous saving rate, and current saving permits investment in physical capital which increases the productive capacity of the economy over time. In the optimal growth model of Ramsey (1928), which was further developed by Cass (1965) and Koopmans (1965), the level of investment is endogenized by modeling the economy as a representative agent who makes optimal consumption and investment choices over time given a fixed production technology. In more recent models, technological progress itself is made endogenous by, for example, assuming production functions with increasing returns (Romer, 1986), or allowing investments to be made in human capital that improve the productivity of physical capital (Lucas, 1988).

In this paper we introduce an experimental design, which we use to study some basic ideas of growth theory. We construct a simple economy with the structure of the optimal growth model of Ramsey-Cass-Koopmans. The version of the model we use is described in section two. In the model, the economy is assumed to behave like a representative agent, who can be viewed as a benevolent social planner or an "average" agent in the economy. The planner makes optimal investment and consumption decisions over an infinite time horizon, given a utility of consumption and a fixed production technology. If concave production and utility functions are assumed, there is a unique optimal steady state level of consumption and capital stock. The model predicts that consumption and capital stock converge monotonically over time to the optimal steady state level from any non-zero initial level of capital stock. The empirical prediction tested in the experiment is whether the variables in the economy do in fact converge to the optimal steady state level. We test the prediction under two different levels of initial endowment, *High Endowment*, in which the starting level of capital stock is greater, and *Low Endowment*, in which the starting level is lower, than the optimal steady state level. Under High Endowment, the model predicts that both consumption and capital stock converge to the optimal steady state from above, whereas under Low Endowment, convergence is predicted to occur from below.

The experiment is not designed to assess whether the optimal growth model is a good description of how particular *field* economies grow, nor is it designed to simulate any national economies or the world economy. Rather, the structure of the experimental economy is specified to conform closely to the model, and to allow straightforward comparisons between the numerical predictions of the model and the observed data.[1] One of the treatments of the experiment,

[1]Although this paper is the first experimental test of a growth model, there is an active literature on laboratory testing of macroeconomic models. See Duffy (1998) for a recent survey of experimental studies of monetary economics.

the *Market treatment*, does include two features which depart from the literal formulation of the theoretical model. We depart from the literal formulation of the theoretical model by: (a) populating the economy with multiple heterogeneous agents and (b) adding an institutional structure that we believed would enhance the efficient allocation of resources between investment and consumption purposes. These features are motivated by earlier research (Noussair and Matheny, 2000), which has shown that dynamic optimization problems with the structure of the optimal growth problem studied here are very difficult for individual subjects to solve when they are placed alone in the role of the social planner or representative agent.[2]

In the Market treatment, there are five heterogeneous agents populating the economy. Each subject possesses an individual utility function and production function. The economy-wide *aggregate* production and utility functions are concave. We compare the sum of the five individuals' capital stock and consumption levels to those predicted by the theoretical model under the assumption that the aggregate utility and production functions can be modeled as those of a representative agent. The five agents have the opportunity to interact in a market, in which they can exchange capital in each time period. Trade in the market follows continuous double auction rules. The market was added to attempt to promote the efficient allocation of resources. The optimal steady state in the model can be supported as a competitive equilibrium by decentralized, competitive markets in which the price of capital equals its marginal product (Barro and Sala-i-Martin, 1995). Continuous double auction markets are known to be conducive to attaining the competitive equilibrium prices and quantities exchanged in a wide

[2]Other researchers have also found that dynamic optimization problems are difficult for individual subjects to solve. See for example, Hey (1988), Fehr and Zych (1998), Gigliotti and Sopher (1997), Thaler (1981), and the survey by Camerer (1995).

class of market environments (Smith, 1962).[3]

As we describe in detail in section four, the main result we obtain from the Market treatment is that the economies have a strong tendency to converge to the optimal steady state levels of consumption and capital stock. The price of capital also converges to the optimal steady state level. This is true regardless of whether the initial level of capital is above or below the optimal steady state level. Furthermore, as we argue in section five, the existence of multiple decision makers and a market price for capital appear to be important in enabling the agents in the economy to make the proper tradeoff between consumption and investment.

This last argument is based on a comparison of the data from the Market treatment with the data from another experimental treatment, the *Social Planner* treatment. In the Social Planner treatment, individual agents are given the role of the social planner and a monetary incentive to maximize the discounted sum of the utility of consumption for the economy. The Social Planner treatment is designed to correspond as closely as possible to the literal formulation of the theoretical model. Each individual's utility function, production function, and initial endowment of capital are identical to those of the Market treatment. The only major differences between the Social Planner and Market treatments are that the Social Planner treatment consolidates the entire production capability and utility function to a single agent and omits all market activity, and thus market prices, from the economy. In the data, we find that the social planner's consumption level and capital stock holdings are farther from the optimal steady state than

[3]The capital that trades in our markets has a different and more complex structure than the goods traded in previous studies, in which the competitive equilibria are observed. In previous studies, the good traded in the market typically has an exogenous value of consumption specified by the experimenter and consumption occurs at the end of the current market period. As we describe in detail in section 3, the capital traded in our markets has two possible uses, consumption and investment, so that a consumers willingness to pay is a function of the value of both uses. Calculating that value is complicated by the fact that the value of capital used in investment depends on activity in future periods. Thus, it is a priori by no means obvious from the results of previous studies that our markets for capital will operate at or near the competitive equilibrium.

the economies of the Market treatment, and lead to lower welfare. This finding underscores the role of market institutions and decentralized decision making in helping an economy to attain its potential level of output.

2 The Model

In the theoretical model corresponding to our experiment, each agent is assumed to maximize the present discounted value of the utility of consumption over an infinite horizon, as in equation (1).

$$\max \sum_{t=0}^{\infty} (1+\rho)^{-t} u(c_t) \tag{1}$$

where t indexes time period, ρ is the discount rate, c_t is consumption at time t, and $u(c_t)$ is the utility of consumption at time t. Equation (1) is maximized subject to the constraints given in equations (2) and (3).

$$c_t + k_{t+1} \leq f(k_t) + (1-\delta)k_t, \qquad \forall t \geq 0. \tag{2}$$

$$k_{t+1} \geq (1-\delta)k_t, \qquad \forall t \geq 0. \tag{3}$$

Equation (2) is a resource constraint. k_t is the capital stock at time t. Depreciation of the capital stock occurs at the rate $\delta \in (0,1]$. The capital stock at time t, can be transformed, using the production function $f(k_t)$, into output, which can be consumed in period t or used to augment the next period's capital stock k_{t+1}, as in equation (2). Utility and production functions u and f are assumed to be strictly increasing, concave, and differentiable. Equation (3) rules out negative gross investment in capital stock. We also assume that the initial level of capital stock, k_0, is strictly greater than 0.

The first order conditions of the maximization problem in (1) require:

$$u'(c_t) = (1+\rho)^{-1}\left[1-\delta+f'(k_{t+1})\right]u'(c_{t+1}), \qquad \forall t \geq 0 \tag{4}$$

and the resource constraint (2) to be binding. Under the transversality condition (5) that the discounted value of period t's capital stock approaches 0 as time approaches infinity,

$$\lim_{t\to\infty}(1+\rho)^{-t}u'(c_t)k_{t+1} = 0 \tag{5}$$

there are unique steady state values of consumption and capital stock, $c_t = \bar{c}$ and $k_{t+1} = \bar{k}$, $\forall t \geq 0$, which satisfy:

$$\bar{c} = f(\bar{k}) - \delta\bar{k} \tag{6}$$

and

$$f'(\bar{k}) = \rho + \delta. \tag{7}$$

If the initial levels of capital stock and consumption are equal to $(\bar{c}, \bar{k})$, they will remain the same in subsequent periods. If they are not equal to $(\bar{c}, \bar{k})$, the dynamics from period t to $t+1$ exhibit the properties that (a) for any given initial capital stock level, optimal sequences of consumption and capital stock are unique, (b) convergence to the steady state of both consumption and capital are strictly monotonic[4] and (c) changes in the capital stock (net investment) are larger the further k_t is from the steady state.

[4]Capital stock and consumption converge from the same direction toward the optimal steady state. That is, if $k_0 < \bar{k}$ then $\forall t, k_t < \bar{k}$ and $c_t < \bar{c}$. If $k_0 > \bar{k}$ then $\forall t, k_t > \bar{k}$ and $c_t > \bar{c}$

3 The Market Treatment

3.1 Parameters

In the experiment, the economy's aggregate production capability was a discrete function approximated by the continuous production function:

$$f(k_t) = 7.02 * (k_t)^{1/2} \tag{8}$$

and the economy's aggregate inverse demand for consumption good was approximated by:

$$D^{-1}(c_t) = 310 - 10c_t \tag{9}$$

corresponding to a utility function of $u(c_t) = 310c_t - 5c_t^2$. The approximations were chosen so that $(\overline{c}, \overline{k}) = (12, 10)$ was a solution to (6) and (7) for both the actual parameters of the experiment and the continuous functions approximating them. We set $\rho = 1/9$ and $\delta = 1$.[5]

There were two sets of parameters used. Under *Low Endowment*, the initial level of capital stock in the economy was $k_0 = 5$ and under *High Endowment*, the initial level of capital stock was $k_0 = 20$. There were no other differences between High and Low Endowment.

[5]Subjects make decisions only observing the total function $g(k_t) = f(k_t) + (1-\delta)k_t$, the total output including undepreciated capital stock. This means that a depreciation rate other than 1 could be used without changing the design of the experiment. The main impact of setting $\delta = 1$ is that it admits the possibility of capital stock of an individual to fall to 0 at any time, if he consumes all of his output. Therefore, the fact that $\delta = 1$ may make it more difficult to reach the optimal positive steady state, because it permits the economy to exhaust its entire stock of capital, at which point it cannot be reaccumulated. Of course, despite the fact that $\delta = 1$, the economy remains dynamic in structure in that positive gross investment is required in every period to assure future consumption.

3.2 Individual Production and Consumption

In each period, which corresponds to a time period t in the theoretical model, each of the five subjects was endowed with a production function indicating his ability to transform capital into output. We will denote individual i's production capability as $f^i(k_t^i)$, where k_t^i is agent i's capital stock holding in period t. $f(k_t)$, where $k_t = \sum_i k_t^i$, is the economy's production capability, as defined in section two. The production function of each agent, which is given in table 1, remained constant for each subject from period to period. In other words, there were no exogenous shocks to production. The first column of the table lists the units used in production by the individual agents for a given period.

Each of the other columns indicates the quantity that each individual agent could produce. For example, if agent 1 used one unit of capital (k_t^i) in production in a period, he could produce seven units of output ($c_t^i + k_{t+1}^i$), as indicated in the row marked 1 in the column marked agent 1. If he used a total of two units in production in a period, he could produce eight units of output, as shown in row two of the same column. The marginal product for agent 1 for the second unit of input would one unit of output. Similarly, if agent 2 used one unit of input in production in a period, he would produce three units of output. If he used two units of input, he would produce a total of five units of output, and the marginal product of the second unit of input would be two units of output.

The numbers in the table show that at the economy-wide level, the first unit of capital stock produced seven units of output, the second unit produced three units of output, the third unit produced two units of output, etc... The production capability was allocated among the five agents so that the first unit held by agent 1 produced seven units of output, the first unit held by agent 2 produced three units, the first unit held by agent 3 produced two units, etc... At the economy-wide level, the production function was an approximation to (8). Each agent knew only his own production function and did not know the production functions of other agents.

However, for the economy to produce the output given by $f(k_t)$, the particular agents who have the highest marginal product for capital must use their capital in production. It is therefore possible for the economy to produce well inside its production possibility frontier, and thus the constraint in (2) need not be binding. Under Low Endowment, each agent was endowed with one unit of capital stock at the beginning of the time horizon for an economy-wide total of 5. Under High Endowment, each agent was endowed with four units of capital stock at the beginning of the time horizon so that the total initial endowment of the economy was 20 units.

[Table 1: About Here]

The utility of consumption good c_t was expressed in terms of an experimental currency which could be converted to US dollars at the end of the experiment.[6] The marginal valuations of each unit of c_t^i for each agent i in terms of experimental currency and the conversion rate for each agent are given in table 2. The inverse demand held by each individual i was an approximation to $D_i^{-1}(c_t^i) = 300 + 10i - 50c_t^i$ implying an aggregate inverse demand of approximately $D^{-1}(c_t) = 310 - 10c_t$.[7] Each agent knew his own utility function, but not the utility functions of other agents.

[6]The conversion rate differed between agents to compensate for the higher earnings in terms of the experimental currency due to the differing production functions held by individual agents. There were eight cohorts of subjects, A - H. For cohorts A, B, D E, and H, the conversion rate was 750 units of experimental currency to 1 US dollar for agent 1 and 250 per dollar for agents 2 - 5. For cohorts C, F, and G, the conversion rate was 1000 per dollar for agent 1 and 400 per dollar for agents 2 - 5.

[7]The marginal valuations, measured in terms of the experimental currency, for c_t^i were 260,210,160,110,60 and 10 for agent 1. For agent 2, the marginal values were 270, 220, 170, 120, 70, and 20; for agent 3, 280, 230, 180, 130, 80, and 30; for agent 4, 290, 240, 190, 140, 90, and 40, and for agent 5, 300, 250, 200, 150, 100, and 50.

[Table 2: About Here]

Table 2 is read in following manner. The first column is an individual's consumption for a market period c_t^i. The remaining columns contain the marginal utility, measured in terms of the monetary payment in experimental currency the consumer receives, of each individual agent for each unit that he consumes. For example, agent 1 has a marginal utility of 260 for the first unit he consumes, 210 for the second unit he consumes, 160 for the third unit, etc... This means that he receives a payment of 260 for the first unit he consumes in the period, an additional payment of 210 if he consumes a second unit and so on. Agent 2 has a marginal utility of 270 for her first unit, 220 for her second unit, etc...

In the optimal steady state the five agents hold a total of 10 units of capital stock. There are several combinations of holdings of k_t at the individual level that are consistent with the optimal steady state, that is where $k_t = 10$, and where total output, $c_t + k_{t+1}$, is 22 per period. Two possibilities are $k_t^i = 2, \forall i$ and $(k_t^1 = 4, k_t^2 = 3, k_t^3 = k_t^4 = k_t^5 = 1)$.

Agents 4 and 5, who have the highest marginal utilities for consumption, each consume three units per period, and agents 1 - 3 each consume two units per period, for an economy-wide total of 12 units of consumption per period. For this pattern of consumption to occur, trade must take place in the capital market. At the optimal steady state level of consumption, the marginal utility of consumption is 180 - 190. 190 is the marginal utility for the twelfth (or last) unit the economy consumes and 180 is the marginal value for the 13th, or the first extramarginal unit.

3.3 The Market for Capital

During each period, a computerized continuous double auction market for capital operated. The market was open for a period of time, during which potential buyers could make public offers to purchase units and potential sellers could make public offers to sell units. An offer consists of a price and a maximum quantity offered for purchase or sale. For example, a buyer may offer to purchase up to 5 units at a per-unit price of 100 or a seller may offer to sell up to 3 units at a price of 300. At any time, buyers or sellers may accept offers made by agents on the other side of the market, and an acceptance of an offer means that a binding contact has occurred. Agents are not required to accept the entire quantity offered; they may accept only a portion of the total quantity offered. In this experiment, the market was computerized and used the Multiple Unit Double Auction (MUDA) computer program (see Plott and Gray, 1990, for details on the operation of MUDA).

An equilibrium market price for capital can be calculated for the optimal steady state of the economy. The marginal utility of capital good and consumption good must be equal at the economy's optimum. Because capital k_{t+1} could be substituted for consumption good c_t at a rate of 1 to 1 as in equation (2), the market price for capital must be the same as the marginal utility of consumption. Since the value of an extra unit of c_t in any period is 180, the value of a unit of investment must also equal 180. Therefore the equilibrium price for capital equals 180.

3.4 Timing

There are three notions of time in the experimental design. A *period* corresponds to a time t in the theoretical model. We use the term *horizon* to refer to the entire life of an economy, that is the entire sequence of interrelated decisions of equation (1). Finally, we use the term *session* to refer to a single day's activity in the laboratory. As described in the next two subsections and as can be seen from the instructions in the appendix, a horizon may span one or more sessions of the experiment, and a session may include more than one horizon. We use the term *cohort* to refer to each group of five subjects, who participated together as a group in a given session. There were eight cohorts of subjects, many of whom participated as a group in more than one session.

Each session consisted of a sequence of periods. The initial period of the first horizon in which each cohort of subjects participated was for practice. It was the only period during the session in which earnings did not count toward final earnings. Each subject was endowed with 10,000 units of currency and 1 (under Low Endowment) or 4 (under High Endowment) units of capital. This currency was convertible to US dollars at the end of the experiment. Purchases (sales) in the market for capital decreased (increased) this cash balance. The 10,000 units were endowed in the form of a loan from the experimenter which had to be paid back at the end of the horizon.[8] The cash balance and capital were reinitialized to the initial level after the practice period.

Within each period of the experiment, the sequence of events was as shown in figure 1. At the beginning of each period, production took place mapping input, k_t^i, to output (which would be allocated between $k_{t+1}^i + c_t^i$ at the end of the period) for each participant. Operationally, the experimenter circulated among the subjects and pressed a sequence of keys on their computer terminals. This action transformed the capital held by the agents from the amount that remained at the end of the previous period to the amount available for subjects at the beginning of the current period, according to the relationship in table 1. Each subject had a sheet entitled Production Schedule, outlining her production capability.

[Figure 1: About Here]

[8]Loaning money to the subjects in this manner creates the possibility that subjects may lose money over the course of the experiment. However in this study, the profits from consumption provided a sufficient degree of profit each period so that no subject had negative total earnings at the end of any session.

For the first two (or three) minutes of a market period,[9] subjects were free to buy and sell capital in the market. The market for capital was closed with one minute remaining in the period. During the last minute of each period, subjects had an opportunity to allocate any portion of their output to consumption, that is, to choose c_t^i.[10] Through consumption, subjects were awarded a payment which was added into their period earnings but not into the cash available for future purchases. The amount of cash bonus that subjects received from consumption was calculated based on the values in table 2. The period ended after consumption took place. The output that was not consumed became the end of period capital stock, k_{t+1}, and was transformed into output for use in the next period. Profits within a period for an agent were given by his utility of consumption for the quantity of units of c_t he consumed, as shown in table 2, plus the change in the agent's cash balance between the beginning and the end of the period. The cash balance at the end of each period was carried over to the next period. Each subject kept the same utility function for the entire horizon.

If the session was the first in which the particular cohort of subjects participated, the sequence of activity in a session was the following: (a) When subjects first arrived at the experiment, they were given approximately 50 minutes to review an interactive tutorial about using the MUDA software. (b) The instructions of the experiment were handed out to each subject. The experimenter read through the instructions for the subjects. Subjects were allowed to ask questions any time they wanted. (c) The experimenter transformed the initial capital stock of each subject based on his individual production function. (d) The market was opened

[9]To allow subjects some time to become familiar with the procedures of the experiment, the market phase in the first two periods of the first horizon in which a group participated lasted three minutes, and in all other periods the market phase was two minutes long.

[10]Operationally, consumption was accomplished by having the experimenter place an offer to buy in the market at price 0 and subjects were then asked to sell as many units as they wanted to the experimenter. This removed the units from the subjects' inventories. Subjects kept track of their consumption on paper.

for period 0 and subjects were able to trade with each other in the market during the first 3 minutes. (e) In the last minute of period 0, subjects made consumption decisions. Subjects' earnings in period 0 did not count toward their final earnings, though subjects were asked to calculate their hypothetical earnings to ensure that they understood the accounting procedure. (f) After period 0 ended, inventories of cash and capital were both reinitialized to their starting values. (g) Period 1 and subsequent periods proceeded in the same way as described in (c) - (e), except that their earnings in the period did count toward their final US dollar earnings. After period one, the cash and capital stock holdings were not reinitialized for the remainder of the horizon.

If the session represented a continuation of a previous session, the tutorial was not conducted. However, the instructions for the experiment were read. The practice period was skipped and all periods counted toward subjects' earnings. The initial values of capital stock and cash holdings were set at the values of the end of the previous session in which subjects participated. As an illustration, the timing of activity for cohort B is shown in figure 2.

[Figure 2: About Here]

3.5 Implementing the Infinite Horizon

To capture the incentive structure of the infinite time horizon in the optimal growth model, we adopted a random ending rule to determine the end of the horizons. To implement the random ending rule, the experimenter rolled a 20-sided die after each period, beginning in period 1, to determine if the horizon would continue. If the die showed numbers 1 or 2, the horizon ended immediately. Otherwise, the experiment continued to the next period within the same horizon. The ten percent probability of ending implies a $\rho = 1/9$. The infinite horizon maximization problem described in (1) - (3) is identical when there is a constant probability equal to $\frac{\rho}{1+\rho}$ of the horizon terminating in each period and no discounting of the utility of consumption from period to period.

Each session was scheduled for three hours. If a horizon ended less than one hour before the scheduled end of a session, the session was immediately terminated. If a horizon ended more than one hour before the scheduled end of the session, a new horizon began with the same group, and with the same initial capital stock as the initial level of capital stock in the previous horizon.[11] This meant that any given individual participated only in Low Endowment or only in High Endowment economies.

If the horizon did not terminate before the scheduled session ending time, the horizon continued where it left off during another session. Subjects were offered the opportunity to return for the next session. If a subject chose to return she would resume her previous role, reclaiming her previous utility and production functions. If a subject chose not to return, a substitute would be recruited to take her place. The original subject would also be awarded the amount of earnings made by her substitute. By doing so, the incentive for all subjects to make optimal decisions in each period in accordance with the theoretical model was preserved. Thus the experimenter paid out the substitute's earnings twice, once to the substitute himself and once to the original subject for whom he substituted. Substitutes were recruited from the same subject pool as other members of the group. The substitutes were required to arrive early for the sessions and go through the tutorial in the use of the software.[12]

[11]Reinitializing in this manner does not affect the optimal solution to the optimization problem in (1), because the probability of a restart is completely independent of any subject's decisions.

[12]Cohort C returned for a second session (VII) and started a new horizon, even though horizon C1 ended less than one hour before the scheduled end of session VI.

3.6 The Available Data

Some information about the 15 sessions of the Market treatment is given in Table 3. All of the sessions were conducted at Purdue University between March 1999 and October 1999. None of the subjects had ever participated in similar experiment before, though some of them had previous experience with the same computer program in other types of experiments. Each of the 15 sessions lasted between 2 and 3 hours. There were eight cohorts of subjects. Cohorts D and E consisted of graduate students in Management at Purdue University. The other six cohorts consisted of undergraduate students recruited from introductory level courses in economics at Purdue University. [13]

[Table 3: About Here]

4 Results from the Market Treatment

Figure 3 illustrates the time path of consumption in the final horizon in which each of the four cohorts in the High Endowment treatment participated. Figure 4 shows analogous data for the Low Endowment treatment. The time series labeled c^* is an approximation to the optimal sequence of consumption predicted by the theoretical model. The sequence converges to 12 as $t \to \infty$.[14]

The impression given by the figures is that after the group gains experience with the decision

[13] Any substitute subjects used are considered to belong to the cohort to which they were added. There was one substitute who participated in the second session for cohort A and two additional substitutes who participated in the third session of cohort A. There was one substitute in the second session for cohorts B and C. We were quite surprised by the very high percentage of subjects who preferred to return for another session, even though they knew that they would be paid the earnings achieved by their substitutes if they did not return.

[14] We use a shooting algorithm to compute optimal sequences of capital and consumption to six significant digits. The algorithm is similar to one used by King and Rebelo (1989, 1993). In the graphs, the values computed by the algorithm are rounded to the nearest integer.

situation, consumption is very close to the optimal steady state level.

[Figures 3 and 4: About Here]

The following linear regression model can be used to estimate the level of consumption toward which any convergence over time is taking place.[15]

$$c_t^j = \beta_{1A}\frac{D_A}{t} + ... + \beta_{1H}\frac{D_H}{t} + \beta_2\frac{t-1}{t} \tag{10}$$

In the above equation, c_t^j denotes the economy's consumption level in period t of one of the horizons in which cohort j participated. D_j is a dummy variable for cohort j and t denotes time period within a horizon. For example, D_A equals 1 if the data are generated by cohort A. $t = 1$ in the first period of any horizon, not only in the first one in a session nor only the first horizon in which a given group participates. The model allows for the estimation of the value of the dependent variable at the beginning of each horizon and the value to which the series is converging. In the first period of a horizon populated by cohort A the variable $\frac{D_A}{t}$ = 1 and all of the other variables equal 0. Therefore, β_{1A} is the estimated value of the time series at the beginning of a horizon populated by group A. The variables $\frac{D_j}{t}$ and coefficients β_{1j} are analogous. The specification assumes that there is a common point of origin for each horizon in which each group participates. For later periods within a horizon of cohort j the $\frac{D_j}{t}$ term decreases toward 0, while the variable $\frac{t-1}{t}$ increases toward 1. If t were projected to the infinite future $\frac{t-1}{t}$ would converge to 1. Therefore β_2 can be interpreted as the asymptote to which the time series is converging. The specification assumes that there is a common value to which the time series is converging for all horizons and for all groups. In the estimation the

[15] This model of convergence was first used by Noussair et al. (1995).

complete data from all periods in all horizons is used. We will say that we cannot reject the hypothesis that a variable converges to its optimal steady state value if the estimated β_2 is not significantly different from that value.

4.1 Consumption and Capital Stock Levels

The estimates from the regression for consumption at time t are given in tables 4 and 5 for High and Low Endowment respectively, in the rows labeled *Consumption.* The optimal steady state level of consumption is 12. The standard errors of the estimates are in parentheses. The estimated values of β_2 for economy-wide consumption are 12.09 and 11.50 for the High and Low Endowment, respectively. The optimal steady state level of consumption of 12 lies within a 95 percent confidence interval of the estimated β_2 for both treatments. Therefore, we cannot reject the hypothesis that the consumption level is converging to the optimal steady state level. The convergence occurs whether or not the initial value of capital stock is above or below the optimal steady state level. Under High Endowment, the estimated level of consumption at the beginning of each horizon, the β_{1k} term, is greater than the optimal steady state level of 12. In every horizon of Low Endowment, the estimated initial value is less than 12. Thus, for all eight groups, we observe convergence to the optimal steady state level of consumption from the predicted direction. The regression confirms the visual impression from figures 3 and 4.

The model is also estimated for the dependent variable $|c_t - \bar{c}|$, the absolute deviation of consumption from the optimal steady state level. If $|c_t - \bar{c}|$ is converging to a level different from 0, while the level of consumption is converging to the optimal steady state level, it would indicate that even asymptotically, there remains a degree of variation in consumption despite the level being on average close to the optimal steady state. The estimates of the absolute deviations are included in tables 4 and 5. For both High and Low Endowment, β_2 is smaller than any of the β_1 estimates, indicating convergence of per-period consumption toward 12. Both β_2 estimates are significantly different from 0, though small in magnitude (0.73 and 1.39 in High and Low Endowment, respectively). Thus there remains a tendency, even asymptotically, for consumption to fluctuate though it is on average no different from the predicted level.

The tables also contain the estimates for capital stock. In both of the treatments, the estimated values to which capital stock levels are converging, 10.31 for High Endowment and 9.38 for Low Endowment are not significantly different from the optimal steady state level of 10. For each of the four High Endowment cohorts, the estimated values for the beginning of the time series are all greater than 10, reflecting a depletion of capital stock levels over time as predicted in the theoretical model. Under Low Endowment the estimated capital stock at the beginning of two of the sessions is below the optimal steady state level, as predicted by the model. In two of the sessions it is above the optimal steady state level, reflecting high levels of investment in the early periods.

[Tables 4 and 5: About Here]

4.2 The Price of Capital

Tables 4 and 5 also contain the results of a similar estimation for the average price of capital by period. The estimation shows that the price of capital converges to the optimal steady state. The estimated values of β_2 are 181.8 and 178.6 for High and Low Endowment, respectively. Neither is significantly different from the equilibrium price of capital in the optimal steady state, 180. In fact both estimates are remarkably close. Under Low Endowment, in all four groups, the prices converge to the optimal steady state level from above as predicted. However, under High Endowment, we do not find that the price of capital converges to the optimal steady state level from below.

Closer inspection of the capital market sheds light on the ability of the economy to converge over time to the optimal steady state. It appears that the prices established in the market for capital provide signals which induce the economy to allocate resources between consumption and investment in a way that pushes it toward the optimal steady state. In the last horizon that each group of subjects participated in, the correlations between P_t, the average transaction price in period t, and subsequent net investment, $k_{t+1} - k_t$, were .38 for the Low Endowment data and .13 for the High Endowment data. The positive correlations indicate that the higher the price of capital, the more positive was net investment immediately following the closing of the market. The correlation between P_t and c_t, consumption in period t, is -.51 for Low Endowment and -.12 for High Endowment. This indicates that consumption increases after the price of capital falls (consumption in period t occurs after the market closes for period t). Each of the four correlations is significantly different from zero at the 5% level of significance.

4.3 Coordination of Production and Consumption Activity Among Agents

The ability of the economy to attain the optimal steady state is all the more impressive when one considers that for the economy to produce along its production possibility frontier, a non-trivial coordinating function has to be performed by the economy. To attain the frontier, at the end of trading in the market and the consumption phase, the capital stock must be held by those agents who have the highest marginal product of capital. A typical time series of Actual Production vs. Efficient Production is shown in figure 5, which illustrates the two time series for the data from group D. The Efficient Production is the production that would result if the economy's units of capital were reallocated to the agents who had the highest marginal product of capital, so that the economy would achieve the highest feasible level of output given its current stock of capital. The first horizon, which lasted only two periods, shows some inefficiency as in period 2, the capital stock in the economy could have produced 21 units of output $c_t + k_{t+1}$ if the appropriate agents held it. However only 18 units were produced. In the second horizon of the session, the actual production was one unit below the frontier in the fourth and fifth periods of the horizon, but was along the frontier in all later periods. The economy's output converged to the optimal steady state level of 22, which at the optimum would be allocated as 12 units of c_t and 10 units of k_{t+1}.

[Figure 5: About Here]

The actual production was a very high percentage of the optimal level for seven of the eight cohorts, indicating that the economies tended to produce along their frontiers. The actual production averaged 99.7 percent of the efficient production level for group A, and 97.4, 98.3, 99.7, 100, 99.5, and 99.1 percent for groups C-H. The only exception was group B, in which actual production averaged 84.2 percent of the efficient level, and was well inside the production possibility frontier until the later periods of the session. The cause of the inefficiency was that agent 0, who has a marginal product of 7 units for the first unit used in production, failed to use any input in production in 8 of the 21 periods in which he participated. This behavior disappeared over time, as he did use at least one unit in production in each of the last 6 periods.

From the individual consumption data, the *Consumption Efficiency*, a measure of welfare, of the economy can be calculated. In the optimal steady state, the total earnings from consumption for the five agents in the economy are 2940 units of experimental currency. We measure the efficiency of the economy by calculating the realized earnings from consumption each period and dividing them by 2940. In the optimal steady state the level of efficiency is 1 (or 100 percent). Using the convergence model of equation (10), we can estimate the consumption efficiency level to which the economy is converging. The estimates, shown in tables 4 and 5, in the row labeled *Realized* $u(c_t)$ *as % of Optimum*, indicate that the data are converging to levels not significantly different from 1. The economies are converging to full consumption efficiency. Not only is capital being produced by those with the highest marginal products, consumption is realized by those with the highest marginal utilities.

5 The Social Planner Treatment

In this section we consider the role that the departures from the literal formulation on the theoretical model that were included in the Market treatment played in guiding the economy to its optimum. We compare the outcomes generated in the Market treatment to the outcomes that result when individual subjects[16] are placed in the role of the social planner, and are given a monetary incentive to maximize the objective function given in equation (1), subject to the constraints (2) and (3). In this treatment, called the *Social Planner* treatment, we try to reproduce the literal formulation of the model as closely as possible.

In the *Social Planner* treatment, individual subjects were endowed with either 5 (for subjects with Low Endowment) or 20 (for subjects with High Endowment) units of capital stock at the beginning of each time horizon. There were eight subjects in the Social planner treatment, four

[16]No subject participated in both the Market treatment and the Social Planner treatment. All subjects in the Social Planner treatment were undergraduate students at Purdue University. Also, no subject was in more than one cohort of the Market treatment.

under High and four under Low Endowment.[17] At no time did any of these subjects interact with or observe decisions made by any other participants. Each individual was endowed with the entire economy's production technology $f(k_t)$ and the economy's entire utility function $u(c_t)$. The actual discrete values used for production and consumption were identical to those in tables 1 and 2.

The sequence of activities within each period was similar to what has been described in Section 3.4. However, since there was no market for exchanging capital between subjects, the procedure was simplified and did not require computerization. At the beginning of period t, production took place mapping current capital stock, k_t, into output, $c_t + k_{t+1}$. Subjects produced by filling out a form with the value of $f(k_t)$, which they could determine from their Production Schedules.[18] The experimenter then circulated among the subjects and verified that they had written down the correct quantity of output. Subjects then had three minutes to decide how to allocate the output between consumption c_t and end-of-period capital stock k_{t+1}. A subject's period earnings were equal to the cash award that he received from consumption, that is earnings were proportional to $u(c_t)$.[19] The period ended after the three minutes had elapsed. To determine if the horizon would continue, we used the random ending rule described in Section 3.5.

In sessions that were the first in which the subjects participated, the sequence of activity

[17]At first glance, using four subjects might appear to be too small a sample size. However, unlike in the Market treatment, each subject is an independent economy in the Social Planner treatment, so that the number of independent observations equals the number of agents. Furthermore, since the data conformed to our priors, which were based on the results reported by Noussair and Matheny (2000), who studied 65 similar economies. After eight observations, we had confidence that the patterns we were observing would be confirmed had we gathered more data.

[18]This had the effect of guaranteeing that the economy in the Social Planner treatment always produced along it production possibility frontier. The constraint (2) was always binding.

[19]Under High Endowment the conversion rate from experimental currency to US dollars was 3500 = 1 dollar. Under Low Endowment, the rate was 2500 = 1 dollar.

in a session was the following. (a) The instructions for the experiment were handed out to the subjects. The experimenter read through the instructions. Subjects were permitted to ask questions as the instructions were being read. (b) The experimenter transformed the subject's initial capital stock into output. (c) The subject was given 3 minutes to allocate his output between consumption and end-of-period capital stock for a practice period (period 0), which did not count toward his final earnings. (d) After the end of period 0, the inventories of capital stock were reinitialized to the starting values of either 5 or 20. (e) Period 1 and subsequent periods proceeded in a similar manner as period 0, except that the subject's earnings starting from period 1 did count toward his final earnings, and that the capital stock was not reinitialized for the remainder of the horizon.[20]

[Figures 6 and 7: About Here]

Figure 6 shows the consumption data from the last horizon for subjects in the Social Planner treatment with High Endowment. Figure 7 shows analogous data for Low Endowment. From the figures one gains the impression that, with the exception of one subject in the Low Endowment treatment, subjects' consumption decisions tend to exhibit greater absolute deviations from the optimal steady state level of consumption than under the Market treatment. There are frequent large changes in consumption from period to period. In general, the data

[20]The data for the Social Planner treatment were gathered in two sessions. In the first session, six subjects participated. Three of the six began each horizon with High Endowment and three began with Low Endowment. The session consisted of a horizon of 3 periods, followed by 20 periods of a second horizon, which did not terminate during the first session. In the second session four of the original subjects returned, two replacement subjects continued two of the horizons from the first session, and two new economies, one of which had Low Endowment and one of which had High Endowment, were started. Thus, there were eight participants in the second session. In the second session the horizon continued from the previous session lasted for 14 more periods. The two new economies experienced four horizons of 8, 5, 14, and 4 periods. The randomizing rule for ending horizons and sessions was identical to the one used in the Market treatment, though one common die was rolled to determine the end of the six original economies and another die was rolled for the two economies that began in the second session.

closely resemble those reported by Noussair and Matheny (2000).[21] The difference between the observed consumption and the optimal steady state level suggests that the overall level of welfare in the Social Planner treatment is lower than in the data from the Market treatment.

[Tables 6 and 7: About Here]

Estimation of the model of convergence described in section four for the data from the Social Planner treatment lends statistical support to above observations. The estimated coefficients of the model of convergence are given in tables 6 and 7. As before, the β_{1j} terms are the initial value for each economy, and the β_2 terms are the estimated asymptotes of the time series. For all of the variables that can be compared between the two designs, except for consumption under Low Endowment, the R^2 for the Market treatment is greater than that in the Social Planner treatment. The convergence model explains more variation in the Market treatment and the specification of smooth convergence is a better model for the Market data than for the Social Planner data. This is consistent with a comparison of figures 3 and 4 with figures 6 and 7. Figures 3 and 4 give the impression of smooth convergence to a greater extent than figures 6 and 7.

In table 6, the estimates for High Endowment are given. The capital stock converges to close

[21] In the Noussair and Matheny study, subjects were given the role of social planners in a similar manner to the Social Planner treatment. The production functions used in the study were $f(k_t) = 25.23k_t^{.2}$ and $f(k_t) = 0.884k_t^{.9}$ Under the first production function, predicted convergence to the optimal steady state is faster than under the second. δ was equal to .5. Subjects make decisions for 20 "infinite" horizons, but were not required to spend a minimum amount of time on each decision. They were required to spend a minimum of 75 minutes on the 20 horizons. Subjects averaged about 25 seconds per decision. There was no tendency to smooth out consumption. Rather, consumption was characterized by bouts of overconsumption followed by bouts of underconsumption, as in the Social Planner treatment data given here, and as illustrated in figures 6 and 7. Efficiency averaged 83.6% in treatments comparable to those of this paper. We consider as comparable treatments those using the same subject pool, Purdue undergraduates, and using the same random ending rule to implement the infinite horizon. In the Noussair and Matheny study, the results were similar if a Fixed ending rule, in which the horizon was certain to terminate after 10 periods, was used. The results also replicated in a different subject pool, undergraduate students at Waseda University in Tokyo, Japan (see Hiruma and Noussair, 1998, for details).

to the optimal steady state level, but consumption is significantly lower that the predicted level. The absolute deviations of consumption from the optimum are significantly different from 0, and the realized consumption efficiency of the economies is substantially and significantly below 100 percent. The estimates suggest that, even though the economy had on average a capital stock equal to the optimal steady state level, average consumption could not be sustained at the optimal level, due to the large fluctuations from period to period. The low and variable average consumption is reflected in low efficiency estimates.

The estimates from the Low Endowment data, displayed in table 7, exhibit a similar pattern. Though consumption and consumption efficiency converge to close to the optimal steady state level they do so on a level of capital stock that is too high. The absolute deviations of consumption from the optimal steady state level are large and significant. The fluctuations in consumption mean that to sustain an average level of consumption at the optimal steady state level, the amount of capital required is greater than the optimal level. For both High and Low Endowment, the estimated asymptote of $|c_t - \overline{c}|$ is much larger than in Market, indicating variance of consumption in Social Planner. In the Market treatment, the β_2 estimate is closer to the optimal steady state level than all $\beta_1 j$ estimates for all four dependent variables, $c_t, k_{t+1}, u(c_t)$, and $|c_t - \overline{c}|$ (32 out of 32 estimates, 4 β_{1k} terms * 4 dependent variables * 2 levels of endowment). In the Social Planner treatment, the β_2 estimate is closer in 27 of 32 cases. Convergence is more reliable in the Market treatment than in Social Planner.

6 Discussion

We have conducted an experiment to consider the ability of an optimal growth model to describe the behavior of an economy with the structure of the model. In the experiment the optimal steady state values of the variables are known and can be easily compared to the data generated by the economy. In the Market treatment, we observe a very strong tendency for the variables in the economy to evolve to the optimal levels. After a few periods, consumption, capital stock, the price of capital, and the realized utility of consumption are all very close to the optimal steady state levels. There is some variation in these variables from period to period, as one might expect in an economy in which five agents must coordinate their decisions every period. However, the model performs remarkably well in describing the state toward which the economy is converging over time.

In the Market treatment, welfare was considerably higher and departures from the optimal steady state were smaller than in the Social Planner treatment. The difference between the Market treatment and the Social Planner treatment is particularly striking when one considers that when the economy is governed by a social planner, there are no potential inefficiencies arising from the existence of multiple agents, such as the need to coordinate production and consumption among agents, and no possibility of strategic behavior on the capital market. Either of these could have resulted in insufficient or excess consumption in the Market treatment. The experiment provides an example of the role that institutions, particularly market institutions, can play in enabling an economy to allocate its resources efficiently. The market appears to compensate for the bounded rationality of individual agents that is in evidence in the Social Planner treatment.

How do the economies of the Market treatment manage to allocate resources efficiently between consumption and investment, especially in a decentralized setting in which each agent knows only his own production and utility functions? The differences between the Market treatment and the Social Planner treatment suggest that the existence of a price for capital encourages agents to make better tradeoffs between consumption and investment. The market price converges to a level at which the marginal utility of using capital for consumption and for investment is equated. Furthermore, the market price appears to serve as an informative signal of scarcity. When the price is higher than the optimal steady state level, capital stock tends to rise, and when it is lower than the optimal steady state level, capital stock tends to fall.

However, the existence of the market for capital may not be the only element of the Market Treatment that promotes efficiency. The mere presence of multiple agents in the economy may have some effect. In the Market treatment, the interaction of multiple decision makers may allow agents who make better decisions disproportionately great influence on the behavior of the economy. These agents can speculate in the capital market, or can change investment and consumption behavior in response to changes in market prices. Similarly, if the Social Planner had an opportunity to draw on the advice of four other agents, or the Social Planner was implemented as a committee who had to reach a consensus about their decisions, planners might be able to achieve outcomes closer to the optimum. This possibility could be tested in future experimental work. A Social Planner treatment could be conducted in which a group of five agents, each of whom has an incentive to maximize the total welfare of the economy, would have input into the planner's decisions.

The fact that agents are heterogeneous may also enhance the operation of the capital market. Heterogeneity of agents implies that there are potential gains from trading capital in each period. This creates an incentive to use the market for capital, and leads to the establishment of a competitive equilibrium market price, which in turn facilitates optimal decision making on the part of agents. Had our agents all been identical, the incentive to use the market would have been weaker, some of the activity in the markets might have been due to mistakes on the part of subjects, and prices might have failed to stabilize at the competitive level. In that case we may not have observed convergence to the optimal steady state.[22] The influence of heterogeneity could be isolated in a follow-up experiment in which the Market treatment would be conducted with five identical agents.

Another reason that the model works well in the Market treatment of our experiment may be that the concavity of the production function ensures that convergence toward the optimal steady state is always predicted, no matter what the current level of capital stock, as long as the economy has not depleted its entire capital stock. This means that early errors in decision making do not prevent the economy from converging to the optimum later on. Suppose that there is an initial stage of the experiment in which subjects make mistakes as they learn about the decision environment. As individuals acquire more experience in the experiment, they make better decisions.[23] In our particular experiment, if subjects begin to make optimal decisions at any time, the economy is predicted to converge to the optimal steady state level from that point on, regardless of previous history.

Future experiments can be conducted that relax the concavity assumption on the production

[22]See Kirman (1992) for a discussion of interpreting a representative agent as an aggregation of heterogeneous individuals. He suggests that assuming that multiple heterogeneous agents populate the economy circumvents many of the theoretical contradictions that arise under the representative agent assumption, and at the same time be intuitively more appealing as a descriptive model. He writes "Given the arguments presented here ... it is clear that the representative agent should have no future. Indeed, contrary to what current macroeconomic practice seems to suggest, requiring heterogeneity of agents within the competitive general equilibrium model may help to recover aggregate properties which may be useful for macroeconomic analysis."

[23]See Plott (1996) for a detailed discussion of stages of rationality in economic experiments.

function. In particular, if the production function includes a region in which increasing returns are present, multiple locally optimal steady states can exist, with different basins of attraction. The current paper introduces a type of experimental economy that will converge to an optimal steady state level when it is unique. Questions which can be considered in future research relate to economies with multiple locally optimal steady states. For example, to which, if any, steady states will the economy converge if it has multiple steady states and will it always converge to the predicted steady state given its initial endowment? It is possible that economies organized as Social Planners may actually be more conducive to optimal equilibrium selection than those organized like our Market treatment. It may be easier for a single agent to switch from a suboptimal equilibrium to a better one, than it would be for multiple agents to recoordinate on the better equilibrium.

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Table 1: Production Function Available to Each Agent

Input (k_t^i)	Output ($f^i(k_t^i)$)				
Units	Agent 1	Agent 2	Agent 3	Agent 4	Agent 5
1	7	3	2	2	2
2	8	5	3	3	3
3	9	6	4	4	4
4	10	7	5	5	4
5	11	8	6	5	5
6	12	8	7	6	5
7	13	9	7	7	6
8	13	10	7	8	6
9	14	11	7	9	6
10	15	11	8	9	7

Table 2: Subjects Marginal Values of Consumption (in Units of Experimental Currency)

c_t^i	$u^{i\prime}(c_t^i)$				
	Agent 1	Agent 2	Agent 3	Agent 4	Agent 5
1	260	270	280	290	300
2	210	220	230	240	250
3	160	170	180	190	200
4	110	120	130	140	150
5	60	70	80	90	100
6	10	20	30	40	50

Table 3: The Sessions of the Market Treatment

Session	Cohort	Treatment	Horizon
I	A	Low	A1(2), A2(2), A3(7)
II	A	Low	A3(20)
III	A	Low	A3(13)
IV	B	Low	B1(2),B2(9)
V	B	Low	B2(10)
VI	C	High	C1(4)
VII	C	High	C2(10)
VIII	D	Low	D1(2),D2(11)
IX	E	High	E1(6)
X	E	High	E1(20)
XI	F	High	F1(3),F2(1),F3(4)
XII	G	High	G1(6),G2(20)
XIII	G	High	G2(2),G3(4),G4(7)
XIV	H	Low	H1(16)
XV	H	Low	H1(19)

Table 4: Estimates of Model of Convergence, High Endowment, Market Treatment

Dep. Var.	B_{1C}	B_{1E}	B_{1F}	B_{1G}	B_2	R^2	Prediction
Consumption	14.36	14.97	12.81	13.27	12.09	.23	12
	(0.83)	(0.82)	(0.72)	(0.60)	(0.22)		
Capital Stock	22.44	16.26	20.50	20.01	10.31	.61	10
(k_{t+1})	(2.09)	(1.47)	(1.28)	(1.06)	(0.41)		
Price of Capital	143.3	167.8	278.0	185.7	181.8	.48	180
	(19.7)	(13.8)	(12.1)	(10.0)	(3.9)		
Realized $u(c_t)$	0.956	1.125	0.910	1.082	0.980	.15	1
as % of Optimum	(0.055)	(0.055)	(0.048)	(0.040)	(0.015)		
$\|c_t - \bar{c}\|$	3.48	2.88	1.67	1.28	0.73	.25	0
	(0.57)	(0.57)	(0.50)	(0.41)	(0.15)		

Table 5: Estimates of Model of Convergence, Low Endowment, Market Treatment

	B_{1A}	B_{1B}	B_{1D}	B_{1H}	B_2	R^2	Prediction
Consumption	9.35	6.19	7.25	4.21	11.50	.18	12
	(1.31)	(1.57)	(1.57)	(2.11)	(0.31)		
Capital Stock	5.44	4.84	11.11	26.55	9.38	.27	10
(k_{t+1})	(1.92)	(2.30)	(2.30)	(3.09)	(0.45)		
Price of Capital	320.1	207.1	220.3	589.1	178.6	.36	180
	(34.0)	(40.8)	(40.9)	(54.9)	(7.9)		
Realized $u(c_t)$	0.693	0.878	0.608	0.235	0.977	.31	1
as % of Optimum	(0.077)	(0.093)	(0.093)	(0.125)	(0.018)		
$\lvert c_t - \bar{c}\rvert$	3.25	8.09	4.69	7.71	1.39	.30	0
	(0.95)	(1.14)	(1.14)	(1.54)	(0.22)		

Table 6: Estimates of Model of Convergence, High Endowment, Social Planner Treatment

	B_{1I}	B_{1J}	B_{1K}	B_{1L}	B_2	R^2	Prediction
Consumption	16.10	14.11	12.37	10.15	10.96	.05	12
	(2.28)	(2.28)	(2.28)	(1.61)	(0.41)		
Capital Stock	6.83	18.48	25.26	29.99	10.22	.33	10
(k_{t+1})	(3.56)	(3.56)	(3.56)	(1.51)	(0.64)		
Realized $u(c_t)$	1.203	1.134	1.006	.866	.906	.04	1
as % of Optimum	(.153)	(.153)	(.153)	(.108)	(.028)		
$\lvert c_t - \bar{c}\rvert$	5.40	1.10	2.92	3.49	3.07	.03	0
	(1.44)	(1.44)	(1.44)	(1.02)	(0.26)		

Table 7: Estimates of Model of Convergence, Low Endowment, Social Planner Treatment

	B_{1M}	B_{1N}	B_{1O}	B_{1P}	B_2	R^2	Prediction
Consumption	9.59	5.92	8.05	2.12	12.17	.23	12
	(2.17)	(2.17)	(2.17)	(1.53)	(0.39)		
Capital Stock	0.55	14.68	7.10	20.62	13.95	.15	10
(k_{t+1})	(3.60)	(3.60)	(3.60)	(2.54)	(0.65)		
Realized $u(c_t)$	.856	.569	.700	.251	.988	.26	1
as % of Optimum	(.145)	(.145)	(.145)	(.102)	(.026)		
$\|c_t - \bar{c}\|$	-.045	6.193	5.521	8.687	2.511	.22	0
	(1.545)	(1.545)	(1.545)	(1.090)	(0.278)		

Figure 1: Timing Within Period t

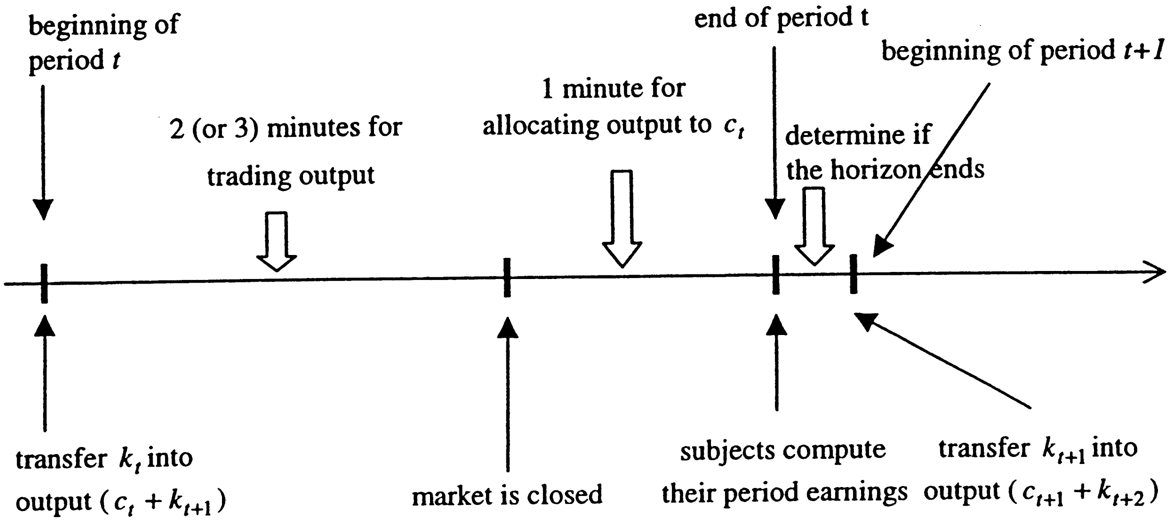


Figure 2: Activity of Cohort B

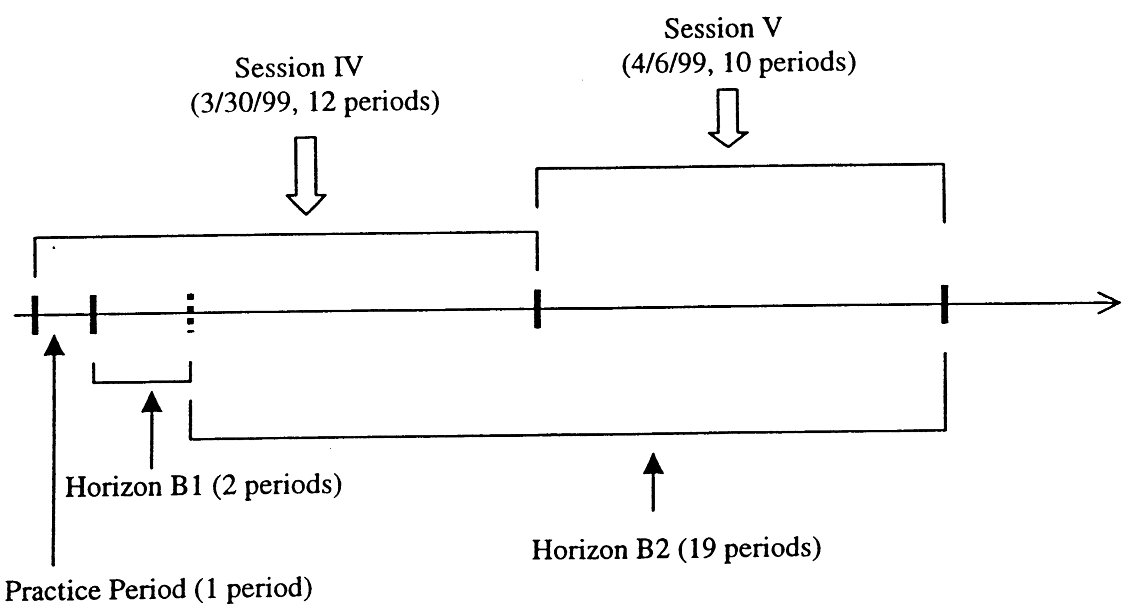


Figure 3: Time Series of Consumption: Last Horizon, All Groups, High Endowment

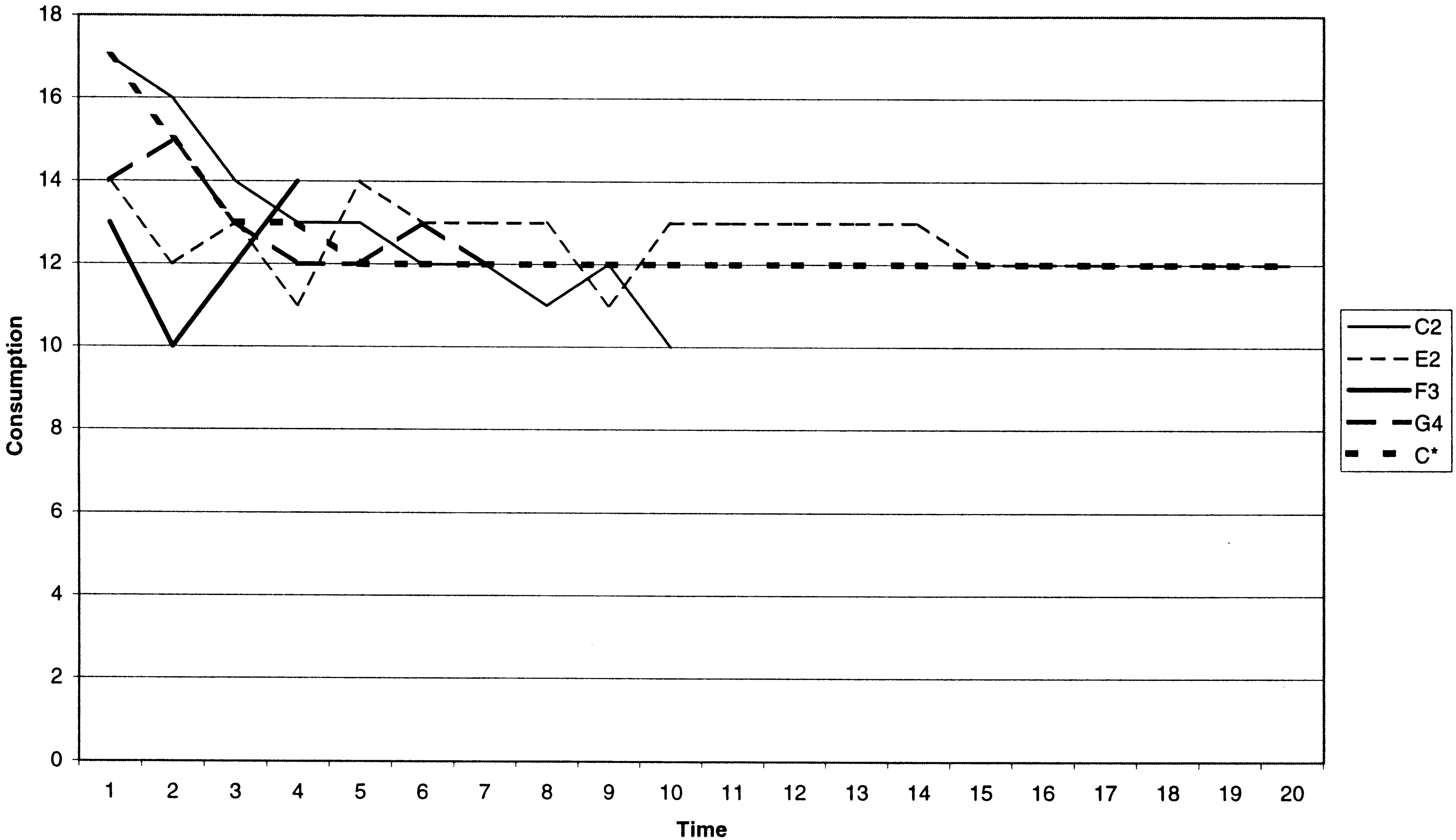


Figure 4: Time Series of Consumption: Last Horizon, All Groups, Low Endowment

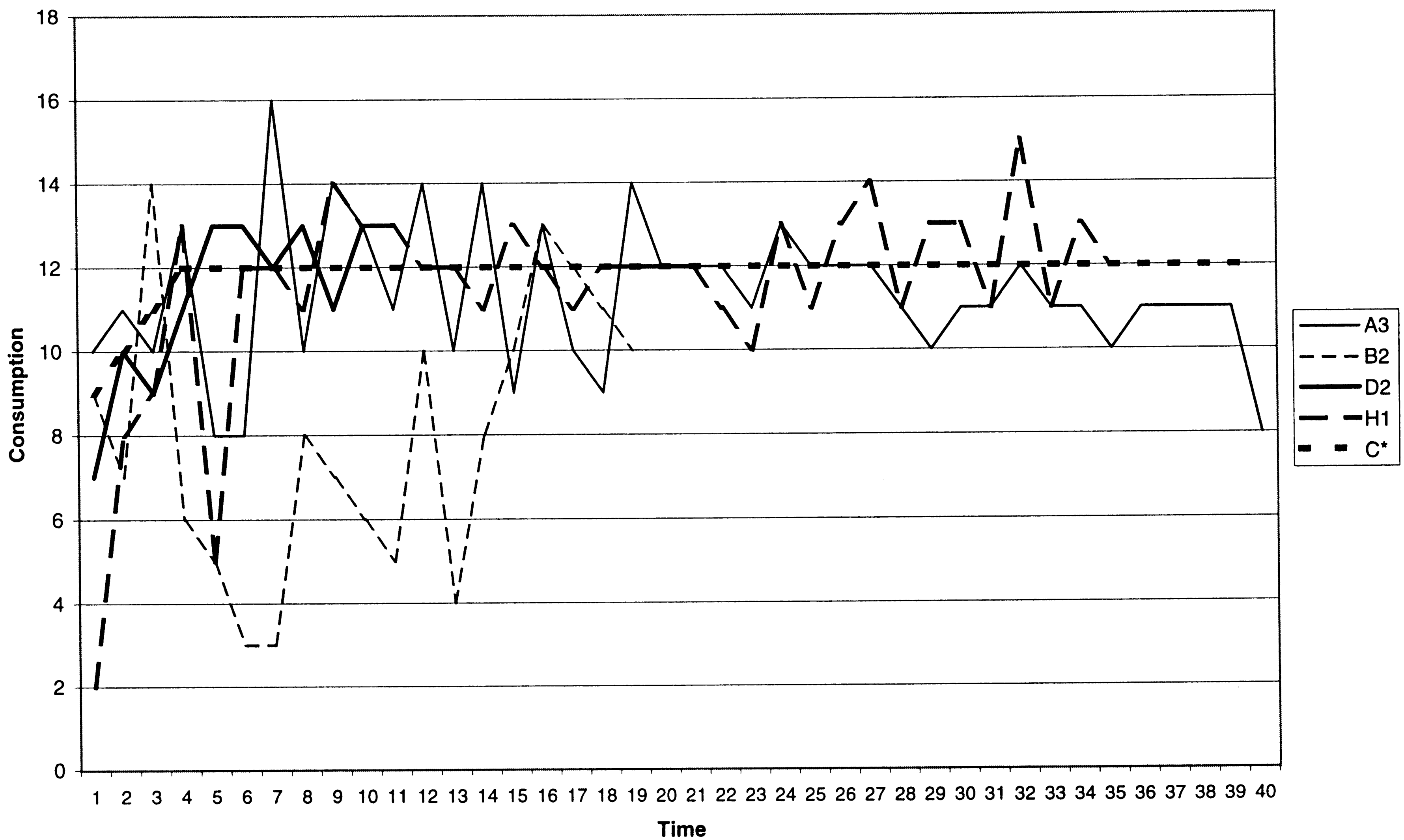


Figure 5: Actual Production vs. Efficient Production for Cohort D

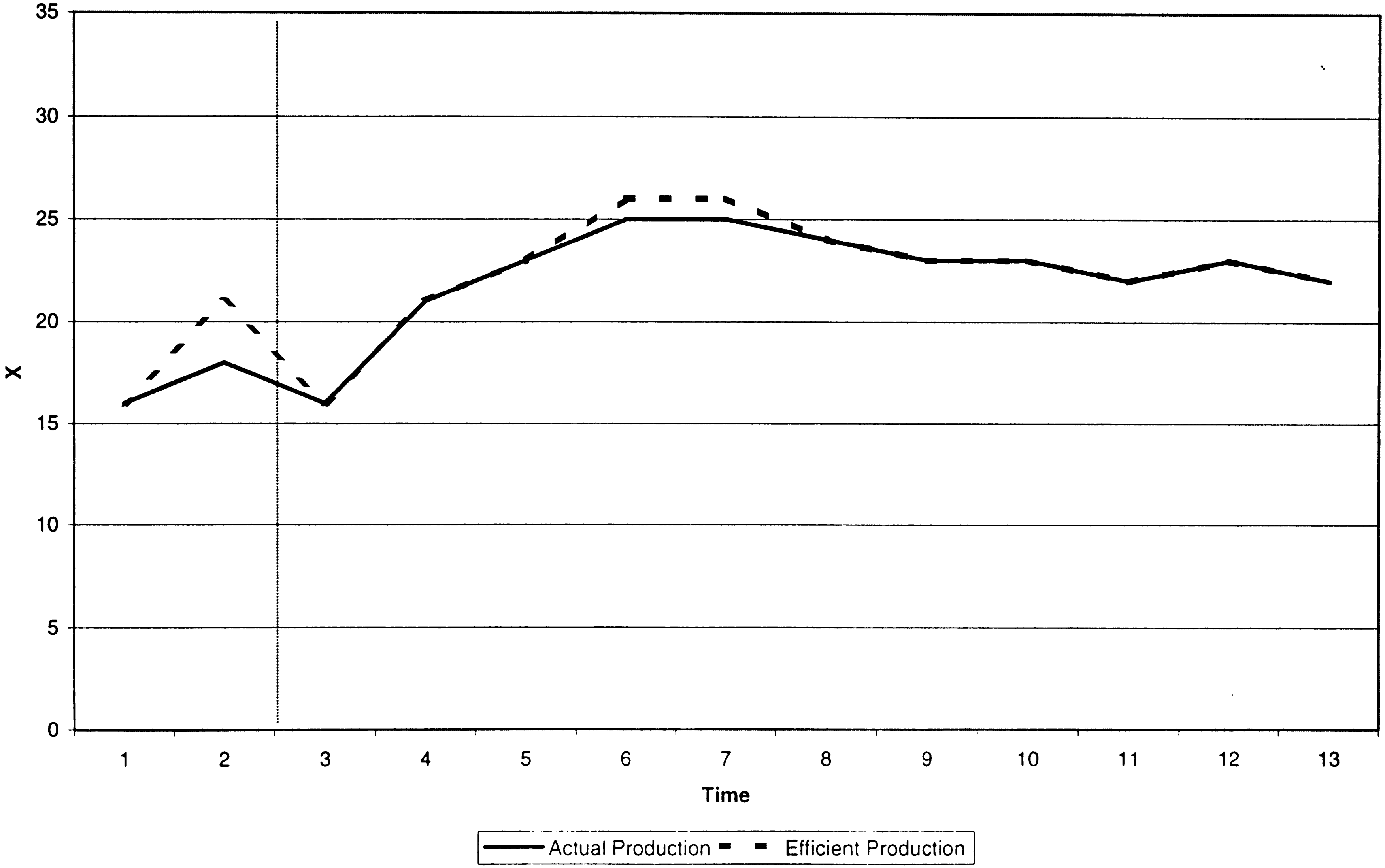


Figure 6: Time Series of Consumption: Last Horizon, All Social Planners, High Endowment

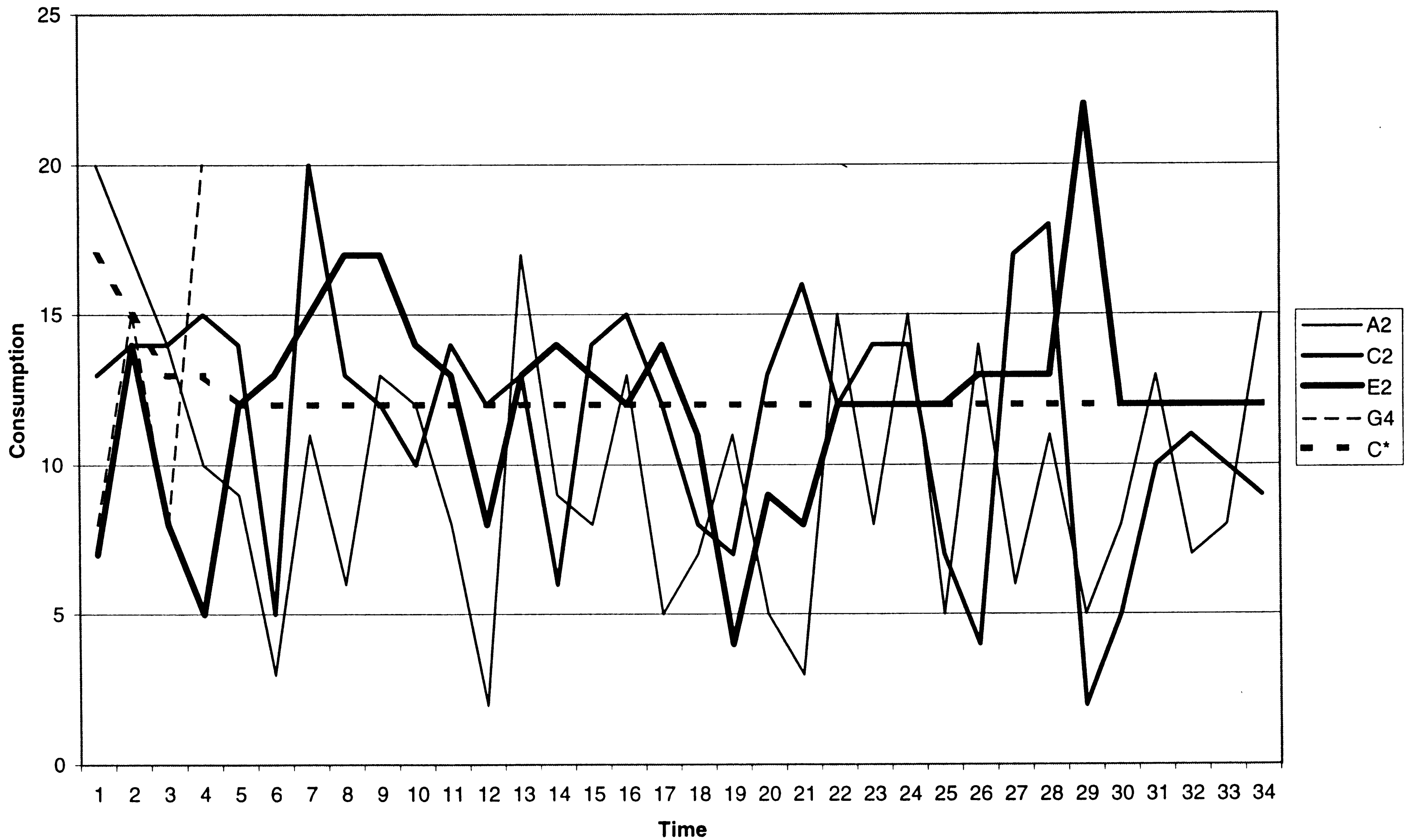
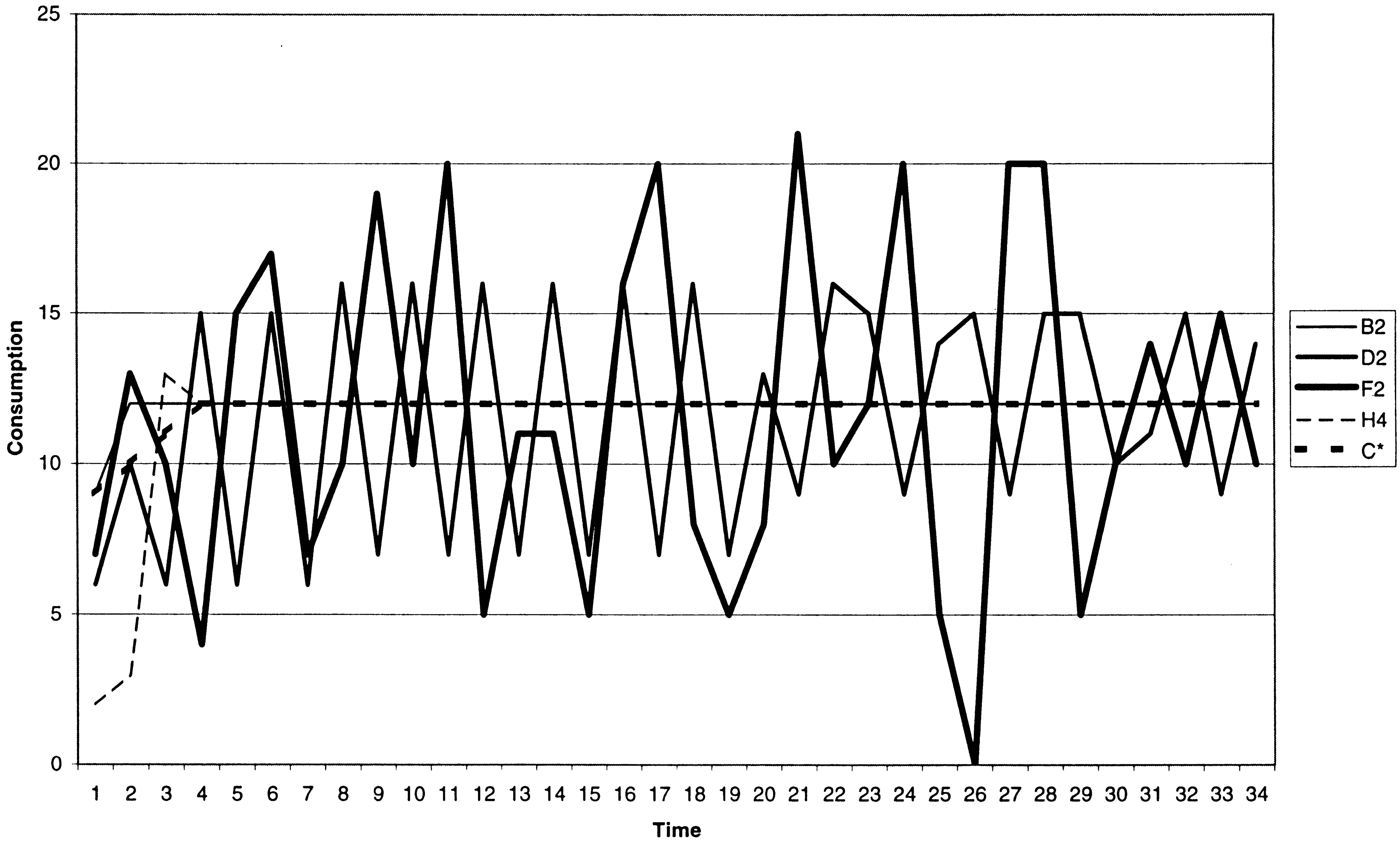


Figure 7: Time Series of Consumption: Last Horizon, All Social Planners, Low Endowment



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