SANDIA REPORT

SAND2004-5972
Unlimited Release
Printed November 2004

Market Disruption, Cascading Effects, and Economic Recovery: A Life-Cycle Hypothesis Model

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Market Disruption, Cascading Effects, and Economic Recovery: A Life-Cycle Hypothesis Model

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Abstract

This paper builds upon previous work [Sprigg and Ehlen, 2004] by introducing a bond market into a model of production and employment. The previous paper described an economy in which households choose whether to enter the labor and product markets based on wages and prices. Firms experiment with prices and employment levels to maximize their profits. We developed agent-based simulations using Aspen, a powerful economic modeling tool developed at Sandia, to demonstrate that multiple-firm economies converge toward the competitive equilibria typified by lower prices and higher output and employment, but also suffer from market noise stemming from consumer churn.

In this paper we introduce a bond market as a mechanism for household savings. We simulate an economy of continuous overlapping generations in which each household grows older in the course of the simulation and continually revises its target level of savings according to a life-cycle hypothesis. Households can seek employment, earn income, purchase goods, and contribute to savings until they reach the mandatory retirement age; upon retirement households must draw from savings in order to purchase goods. This paper demonstrates the simultaneous convergence of product, labor, and savings markets to their calculated equilibria, and simulates how a disruption to a productive sector will create cascading effects in all markets. Subsequent work will use similar models to simulate how disruptions, such as terrorist attacks, would interplay with consumer confidence to affect financial markets and the broader economy.

Acknowledgments

Dr. Richard J. Pryor founded Aspen and initiated our current line of research into economic confidence. I also thank Craig Jorgensen for Aspen software enhancements that enabled the simulations discussed in this report. I am also grateful to George Backus, Jennifer Nelson, and Mark Ehlen for helpful comments and suggestions.

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1.0 Introduction

Acts of terrorism have the potential to create significant economic impacts across the country and across economic sectors. For example, an attack that targets specific productive sectors of the economy could adversely affect output and employment, which could affect consumption and savings behavior and disturb financial markets.

To better understand such possibilities, we are developing a microeconomic model of economic demand and supply that is subject to terrorism-related impacts (see Sprigg et al. 2004).[1] This is the third in a series of papers describing our model and findings, and the first in this series to simulate the relationship between consumption and savings.

Our previous work [Sprigg and Ehlen, 2004] modeled how microeconomic firms and employment adjust endogenously to changes in demand and in the number of firms. We developed agent-based simulations to demonstrate that, when compared to the case of monopoly, multiple-firm economies converge toward the competitive equilibria typified by lower prices and higher output and employment, but also suffer from market noise stemming from consumer churn.

I now introduce a bond market into our agent-based model. Our goal in this paper is to demonstrate that labor, product, and bond markets converge to calculated equilibriums in accordance with a life-cycle hypothesis (LCH). I also conduct an event study (simulation) for an output disruption, and find that the disruption cascades through all sectors affecting employment, consumption, and savings. Following the event, the simulation re-converges, with all markets returning to equilibrium at about the same time.

This is an intermediate report that documents some important steps toward a model of consumer confidence and financial markets. It introduces life cycles and a simple bond market into our current line of research. Subsequent work will revisit and extend the savings model, introduce a stock market, and focus on explicit models of confidence.

This report is organized as follows. Section 2.0 describes our model of the bond market. I formulate a LCH model whereby households balance savings and consumption to maximize utility, and I describe the bond-market equilibrium.

Section 3.0 describes the design of object-oriented Aspen agents used for simulating the economy. I first describe how we are using the object-oriented concept of *inheritance* to develop in stages a complex microeconomic simulation model. Then, I describe new

[1] This work is funded by the Advanced Scientific Computing program of the U.S. Department of Homeland Security.

modifications to the rules and mechanics of Aspen household agents used in the model described herein. Finally, I describe the Aspen exchange agent, which facilitates and clears the bond market.

Section 4.0 describes two sets of Aspen simulations assuming (1) *infinite* and (2) *finite* horizons for the LCH model of households. I demonstrate that simulations under each assumption converge to calculated equilibria. I then present simulation results for an event study of an output disruption.

Section 5.0 suggests revisions and extensions to this model, such as the introduction of a stock market and explicit components for modeling consumer confidence.

2.0 Model

Our model is a three-market, multi-period, closed economy composed of *F* firms and *H* households. Each household generates utilty, either by consuming purchased goods or by generating utility at home with its own internal productivity. Goods are purchased in the goods market with wages earned by working at one of the firms. Each firm generates profits by using labor, purchased in the labor market, to produce a good and then by selling that good in the goods market.[2] Each household buys or sells from an endowment of bonds in an effort to achieve a target level of bondholdings.

2.1 Life-Cycle Hypothesis

The life-cycle hypothesis (LCH) model (see Friedman 1957, Modigliani and Brunberg 1958, Ando and Modigliani 1963) defines household behavior as an attempt to smooth consumption patterns over one's lifetime somewhat independent of current levels of income; households do this by borrowing, saving, and lending. The model is typically represented as the following constrained maximization problem:

$$\max U_{t=0} = \sum_{t=0}^{T(t)} \delta(U_t(C_t))$$
$$s.t. \sum_{t=0}^{T(t)} \rho(C_t) = B_{t=0} + \sum_{t=0}^{L(t)} \rho(Y_t), \tag{1}$$

where C_t and Y_t are respectively the levels of consumption and income in period t, $U_t(C_t)$ is the *utility* received from consumption in time period t, B_0 is an initial wealth endowment, and $\delta(\cdot)$ and $\rho(\cdot)$ are discount functions; $\delta(\cdot)$ discounts the value of future utility according to the household's internal time preference, and $\rho(\cdot)$ discounts the value of future consumption and income according to the market interest rate. Also, $L(t) \leq T(t)$, where $L(t)$ denotes the number of remaining periods in which the household can work in the labor market to earn income, and $T(t)$ denotes the number of remaining periods in the household's life cycle.

The model used in this paper includes several simplifying assumptions; specifically, each household's utility function is constant across time (equation (2a)), utility is a concave function of consumption (equation (2b)), households do not discount the value of future consumption (equation (2c)), wages are constant across firms and across time (equation (2d)), and the market interest rate is zero (equation (2e)).

$$U_t(C_t) = U_\tau(C_\tau) = U(C) \tag{2a}$$
$$U_t'(C_t) > 0 \text{ and } U_t''(C_t) < 0 \tag{2b}$$

[2] See Sprigg and Ehlen 2004 more a detailed description of households and firms, and their participation in labor and goods markets.

$$\delta(C_t) \equiv C_t \tag{2c}$$

$$Y_t = Y \tag{2d}$$

$$\rho(C_t) \equiv C_t \text{ and } \rho(Y_t) \equiv Y_t \tag{2e}$$

The assumptions of equation (2) allow us to simplify the household's optimization problem as follows:

$$\max U_{t=0} = \sum_{t=0}^{T(t)} C_t = B_{t=0} + (L(t) \times Y) \tag{3}$$

By inspection of equation (2b), it follows that households will seek to balance their consumption equally across time periods as follows:

$$\overline{C}_t = (\ B_t + (L(t) \times Y)\ )\ /\ T(t) \tag{4}$$

2.1.1 Savings and Retirement

Households of age A for which $L > 0$ are said to be *career* households, and are able to work in the labor market to earn income. Households of age A such that $L = 0$ and $T > 0$ are said to be *retired* households, and are unable to work. Continuing from above, career households will seek to maintain a constant savings rate, as follows:

$$\overline{S}_t = Y - \overline{C}_t \tag{5}$$

2.2 Bond Market for Household Savings

In this paper, bonds are strictly a mechanism for interest-free intertemporal substitution between generations of households.[3] I model the bond market as a continuous double auction conducted by a bond exchange that takes limit orders from households. Each order includes a buy/sell indicator and the number of shares to be traded. For the purposes of this paper, bond prices are fixed at $1. The exchange will therefore clear a volume equal to the minimum volume of open buy orders or open sell orders. For example, if there are more open buys than sells, then the exchange will clear all open sells and the remaining buys will carry over to the next time step.

The aggregate number of bonds in the economy remains constant throughout the simulation. Career households accrue wealth *(B)* in the form of bond holdings via periodic saving contributions, such that

$$B_t = B_{t-1} + S_t\,. \tag{6}$$

[3] For bonds as a government-issued asset class in Aspen, see Basu et al. 1998.

Retired households cannot accrue bonds, but rather consume by selling bonds in order to purchase goods, such that

$$B_t = B_{t-1} - C_t \,. \tag{7}$$

2.3 Market Equilibrium

The market clearing conditions for the labor and product markets are described in Sprigg and Ehlen (2004). The bond market in this model is said to clear when the actual bond holdings equal the target bond holdings for either all sellers or all buyers or both; the definition for market clearing would be different if bond prices were allowed to adjust.

Bond market equilibrium is linked to equilibrium in the other markets. For example, if the economy experiences a period of recessionary unemployment, then a portion of career households will be unable to maintain their planned rate of consumption and bond purchases. Under conventional wisdom, one would expect the average household to both reduce consumption and fall behind on bond purchases, leading to a surplus in the bonds market. Furthermore, if households face a finite time horizon, then temporarily unemployed households will reduce their expected average consumption for the remainder of their life cycles, and therefore reduce their target bond holdings. I should note that if we allowed bond prices to adjust, then retired households would face falling bonds prices after a recession, leading to a reduction in both wealth and expected total consumption for the remainder of their life cycles.

3.0 Agent Design / Mechanics

The model requires two types (classes) of agent: firms and households. We design these agents in Aspen[4] as object-oriented classes. At run time, Aspen instantiates these classes as a series of objects and endows each object (agent) with its own initializing parameters. Each agent follows internal decision rules and interacts with other agents to fulfill its role in the simulated economy.

For our current line of research into terrorism and economic confidence, we are developing a hierarchy of economic models using the object-oriented programming principle of *inheritance*. For example, we began with a pair of C++ classes that we call *simple* firms and households, which contain the minimum set of variables and methods required to interact with the model's GUI and execute a simulation.

For our first model in this series, described in Sprigg and Ehlen (2004), we designed a pair of *derived* classes called *pure-market* firms and households, which inherit the basic functionality of the simple classes, but include additional functionality required for simulating competition and employment in the labor and goods markets.

For the current model, I designed two additional derived classes for households. The first, called the *bond-market* household, is derived from the *pure-market* household, and introduces basic functionality required to participate in the bonds market. This class focuses on the households' basic decision sequence and communication protocols that are pertinent to bonds trading. The second, called the *life-cycle* household, is derived from the *bond-market* household; the *life-cycle* household class introduces age and retirement components and focuses on the financial decisions that are pertinent to bond trading.

3.1 Simulation of Households

Each of the household classes derived for the model in this paper has a specific economic interpretation when used in the simulation.

3.1.1 Bond-Market Households: a Model of Infinite Time Horizons

The *bond-market* household class does not incorporate aging. Therefore, households that are instantiated from this class do not grow older or approach their life-cycle horizons. This scenario is synonomous to a life-cycle model with an infinite time horizon, which could be used to simulate a short timespan relative to the lifespan of the household.

At the start of the simulation, such households are assigned a fixed target level of bondholdings (i.e. target amount of savings); this target remains constant throughout the simulation. Each household is also given an endowment of bonds, the size of which is randomly drawn from a uniform interval centered about the assigned target bondholding. Thus, each household's endowment is either greater than, equal to, or less than its assigned target bondholdings, within a fixed variance.

[4] For details on the structure and uses of the Aspen model, see Basu et al. 1998.

Throughout the simulation, households with excess bonds submit orders to sell their excess bonds on the exchange. Households that are deficient in bonds submit orders to buy bonds as they earn income. Each household submits orders until it eventually achieves its target level of bondholdings. Once either all sellers or all buyers achieve their target bondholdings, the market is said to have cleared, and no further bond exchanges will occur.

3.1.2 Life-Cycle Households: a Model of Finite Time Horizons

The *life-cycle* household class provides a model of continuous overlapping generations in which each household ages and saves according to equations (4) and (5). At the start of the simulation, each household is randomly assigned an age $A_{t=0}$ from a continuous uniform interval from 20 to 80. Retirement occurs at age 60 for all households. The following algorithm assigns a target level of bondholdings to each household based on its initial age, retirement age, and wage rate:

1. Compute expected average consumption per period ($\overline{C}_t$) based on equations (3) and (4) assuming $B_{t=0} = 0$ and $L(0) = max(L) = 40$.

2. Compute the expected average savings contribution per period ($\overline{S}_t$) based on equation (5) and $\overline{C}_t$ from above.

3. If the household is initially of career age $A_{t=0} < 60$, then compute the initial target bondholdings ($B_{t=0}$) as follows:

$$B_{t=0} = (A_{t=0} - 20) \times \overline{S}_t \times (\text{time steps per year}) . \tag{8}$$

Otherwise, if $A_{t=0} > 60$, then compute the initial target bondholdings as follows:

$$B_{t=0} = B_{Age=60} - ((A_{t=0} - 60) \times \overline{C}_t \times (\text{time steps per year})). \tag{9}$$

The initial *target* bondholdings increase across career households when sorted by age from 20 to 60, and decrease across retired households when sorted by age from 60 to 80.

As was also the case for bond-market households, at the start of the simulation, each life-cycle household is given an endowment of bonds drawn from a uniform interval.

Throughout the simulation, households grow older with each time step and revise their target bondholdings based on their new age and current bondholdings. Ideally, a household will purchase bonds at a constant rate from age 20 to 60, leave the workforce at age 60, and sell bonds from age 60 to 80 using the proceeds for consumption. Once a household expires at age 80, it is recycled as a new household (heir) of age 20; any bonds

held by a household upon expiration are endowed to its heir as a type of accidental bequest (for a discussion of bequests, see Abel 1985 and Sprigg et al. 2004).

At any time step, there will be roughly half as many retired households as career households, but in equilibrium the average retired household will be selling bonds at roughly twice the rate that the average career household is buying bonds. Thus, the aggregate volume of bonds being sold by retired households should roughly equal the number being purchased by career households.

3.2 The Bond Exchange

The bond market is facilitated by a bond exchange agent, which simply clears the queue of open limit orders from households. As with households and firms, we derive the *bond-market* exchange class from a base class, which contains the minimum set of class variables and methods required to interact with the GUI and execute a simulation.

The *bond-market* exchange class reads and sorts all limit orders according to limit price, matches buys and sells in such order to maximize the trading volume, and sends transaction notices to all households whose orders were executed. The bond exchange executes partial-fill transactions when the size of buy and sell orders are unequal.

4.0 Simulations

To demonstrate that labor, goods, and bond markets simultaneously converge to calculated equilibria under both finite and infinite time horizons, I adopt the same simulation parameters (Table 1) used by Sprigg and Ehlen (2004) for modeling monopolistic competition with five firms. I introduce new household parameters for modeling life cycles: *age* and *time-steps-per-year*. The *equilibrium bond holdings* is a constant in model 1, but varies in model 2 with respect to age according to equation (8). The *deviation in bonds* refers to the average percent deviation between actual and target bond holdings across households. In model 1, the equilibrium deviation *(Δ)* is constant based on the net difference between initial bond deficits and surpluses. In model 2, the equilibrium deviation *(Δ(t))* will fluctuate over time as a function of household characteristics.

Table 1. Simulation Parameters

Parameter		Model 1 Infinite Horizon	Model 2 Finite Horizon
Households			
	Number	100	100
	Internal productivity	[1.0, 2.5]	[1.0, 2.5]
	Age	----	[20, 80]
	Time steps per year	---	100
Firms			
	Number	5	5
	Productivity	2.0	2.0
	Wage rage offered	50.0	50.0
Calculated Optima			
	Equilibrium price ($\hat{p}$)	31.6	31.6
	Equilibrium employment (L^s)	59	59
	Equilibrium bond holdings	200	*f*(age)
	Equilibrium deviation in bonds	*Δ*	*Δ*(t)

The figures in this section display time-step plots of simulation variables. In each case, the horizontal axis represents time-step iterations.

4.1 Model 1: Infinite Horizon Households[5]

To investigate the impact that the bond market has on labor and goods markets, I will compare the simulation results for two cases. Case 1 refers to the case of no bond market, or a *cleared bond market*.[6] Case 2 refers to a *converging bond market* in which I initiate

[5] This model uses the Aspen *bond-market* household class.

[6] In the case of infinite horizons, once the bond market clears households have no further incentive to substitute between consumption and bond holdings; that is, *"once cleared, always cleared"*. Therefore, from the perspective of the labor and product markets, a *cleared* bonds market is synonymous with *no* bonds market at all. So, if we initialize all households such that actual and target bond holdings are equal,

the simulation with the bond market in disequilibrium. In case 2, households with a bond deficit must earn income to buy bonds; this process takes time. We track the market clearing process in Figure 1 by plotting the average percent deviation across households between their target and actual bond holdings. Since case 1 begins with a cleared bond market, the deviation for case 1 is always zero. Case 2 slowly clears until it reaches a minimum deviation at time step 2560; at which time the sellers' market has cleared, but a few buyers remain.[7]

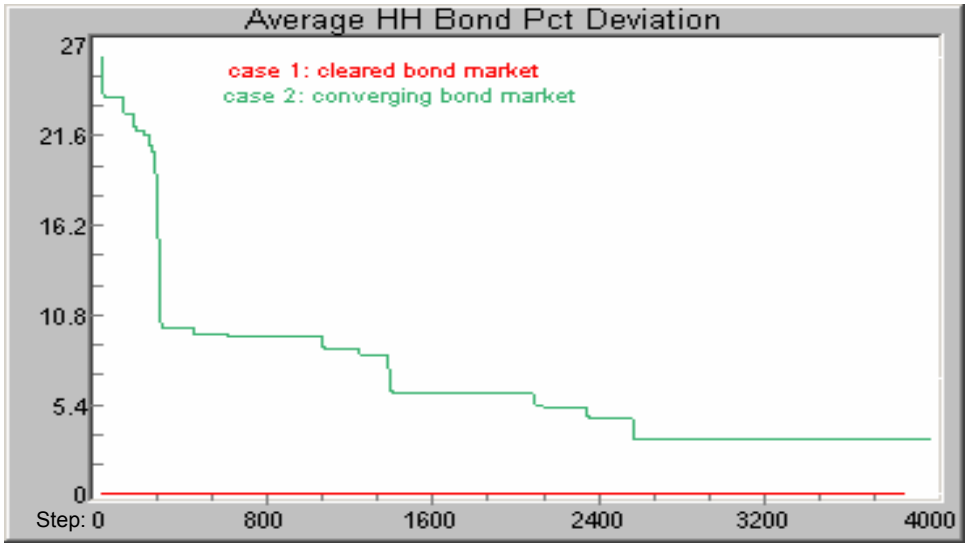

Figure 1. Infinite horizon: deviation in bond holdings.

Although the convergence process in the bond market for case 2 takes time, it does not significantly affect convergence in the other markets. For example, Figure 2 shows that the number of employees converges in both cases at roughly the same rate to slightly above the expected competitive employment level of 59. Similarly, the price converges in both cases at roughly the same rate to slightly below the competitive price of $31.60 (Figure 3).

then other variables in the simulation will converge as if there was no bonds market in the simulated economy.

[7] There are two reasons that buy orders remain in queue at the bond exchange even after the bond market clears. First, the aggregate bond deficit did not equal the aggregate bond surplus at the start of the simulation. Second, this model does not allow for time preference and bond-price adjustments; these features will be addressed in subsequent models.

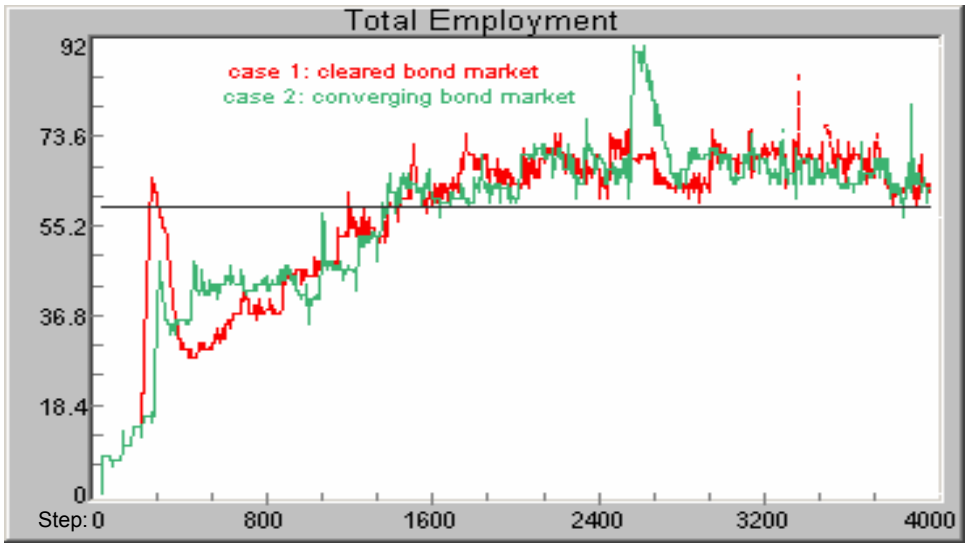

Figure 2. Infinite horizon: total employment.

Figure 3 also shows that firms searching for price in the face of a converging bond market (case 2) are more tightly constrained from raising price during the correction phase (first 1000 time steps) than when the bond market is already clear (case 2). This is true because firms in case 2 must compete against the households' demand for bonds.

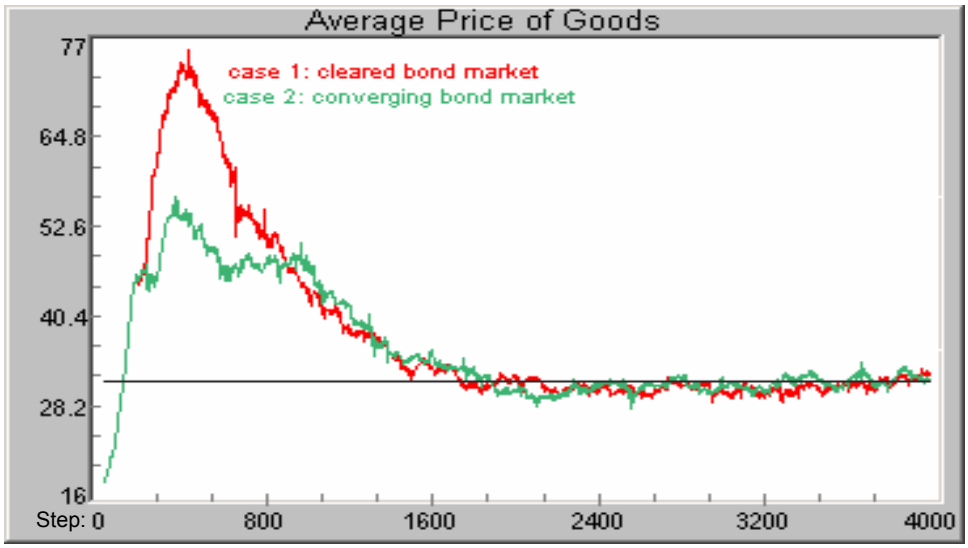

Figure 3. Infinite horizon: market price of goods.

Figure 4 and Figure 5 show that the presence of a converging bond market, compared to a cleared bond market, has no appreciable impact on firm profits or household consumption in this model.

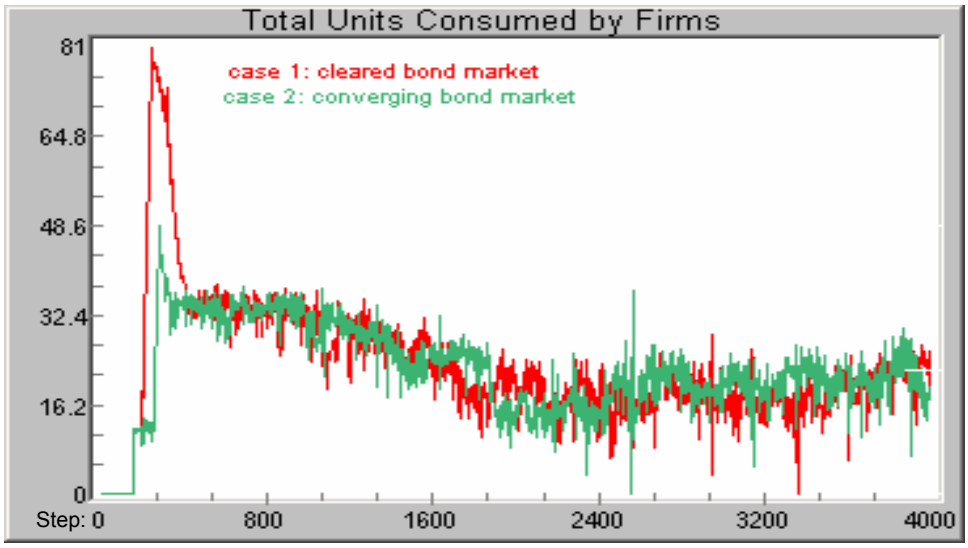

Figure 4. Infinite horizon: firm profits.

The spike in household consumption (Figure 5) at time step 2560 for case 2 occurs when the bond-sellers' market clears, thereby precluding further bond purchases and leading bond buyers to increase their consumption rate.

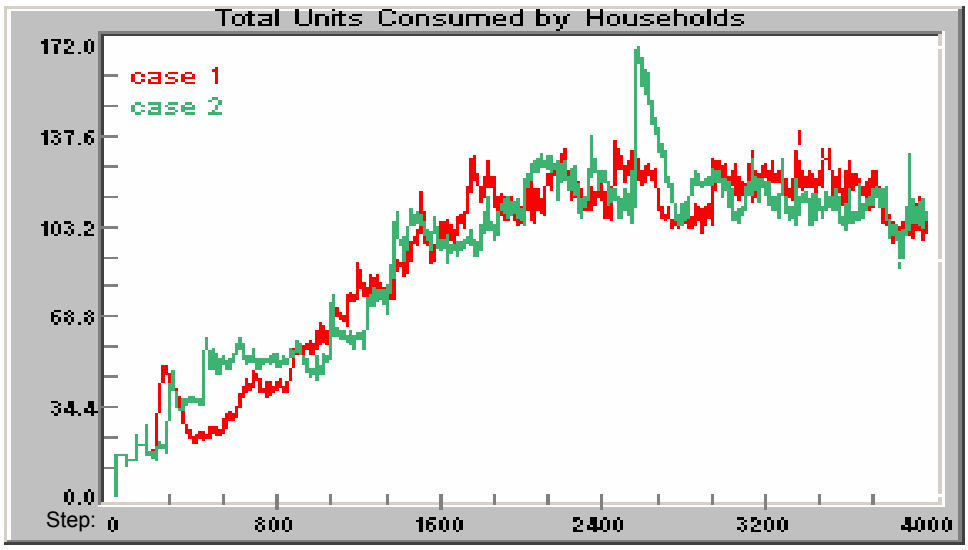

Figure 5. Infinite horizon: units consumed.

4.2 Model 2: Finite Horizon Households[8]

The finite horizon model entails continuous overlapping generations of aging households. In this model, the equilibrium conditions are not fixed. For example, the equilibrium number of jobs under monopolistic competition is not only a function of the

[8] This model uses the Aspen *life-cycle* household class.

competitive price ($31.60), but also depends on the number of households in the career phase (i.e. age less than 60), which changes over time as households age and retire and expire. Figure 6 shows that the equilibrium number of jobs fluctuates over time near 49 jobs.

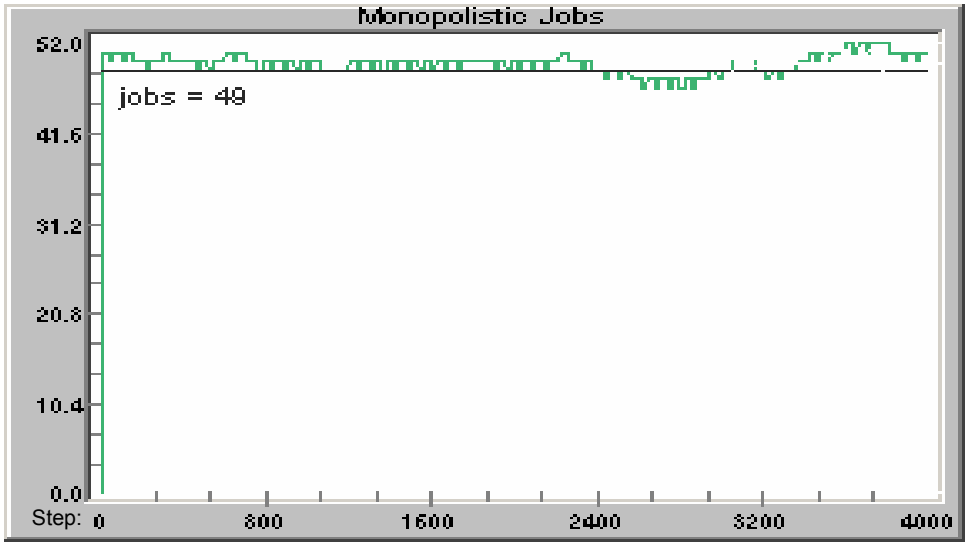

Figure 6. Finite horizon: equilibrium employment.

Nevertheless, we still find, as in previous simulations, that the number of employees converges to slightly above the expected competitive employment level of 49 (Figure 7). Similarly, the price converges to the competitive price of $31.60 (Figure 8).

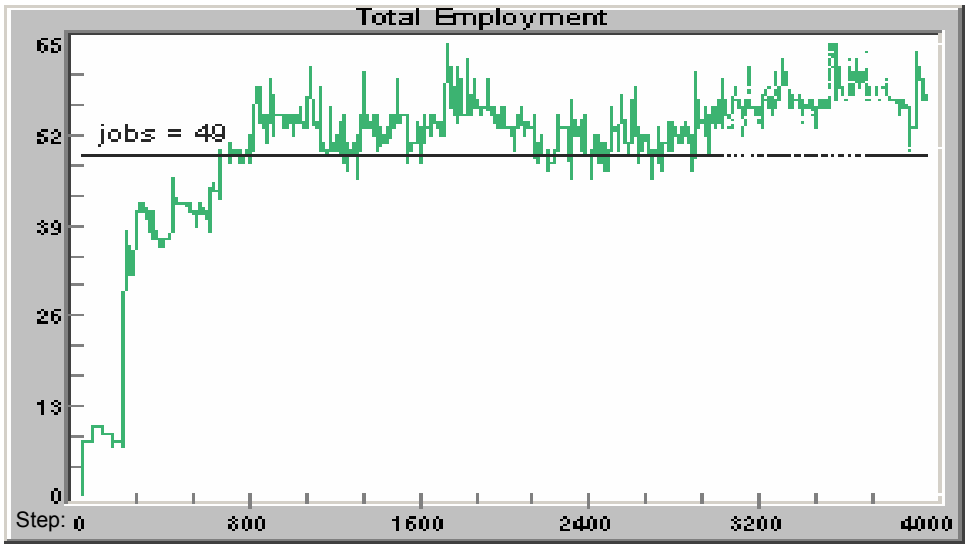

Figure 7. Finite horizon: total employment.

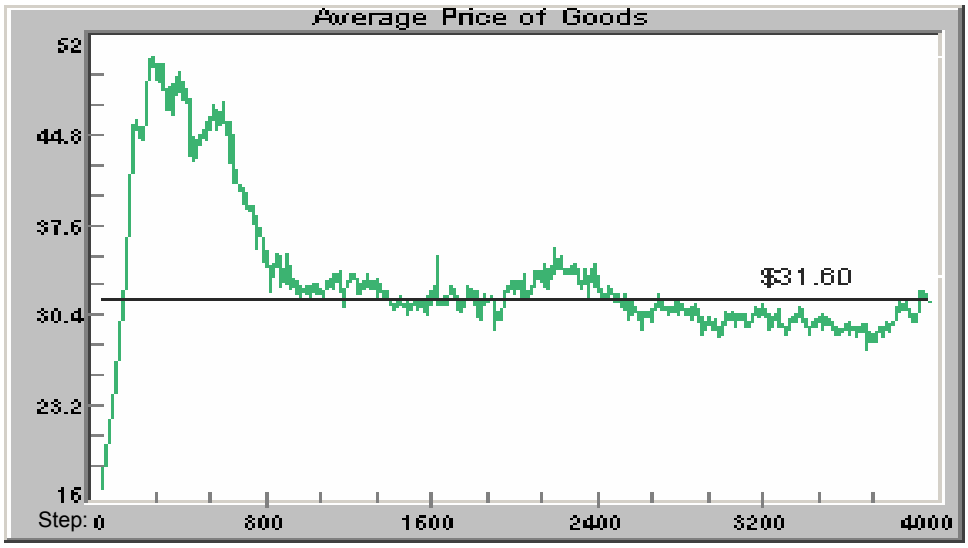

Figure 8. Finite horizon: market price of goods.

Under a finite horizon, because each household's target bond holdings are constantly changing, the average percent deviation across households between their target and actual bond holdings is not always decreasing, but rather fluctuates (see Figure 9), presumably in conjunction with the equilibrium deviation $\Delta(t)$ from Table 1.

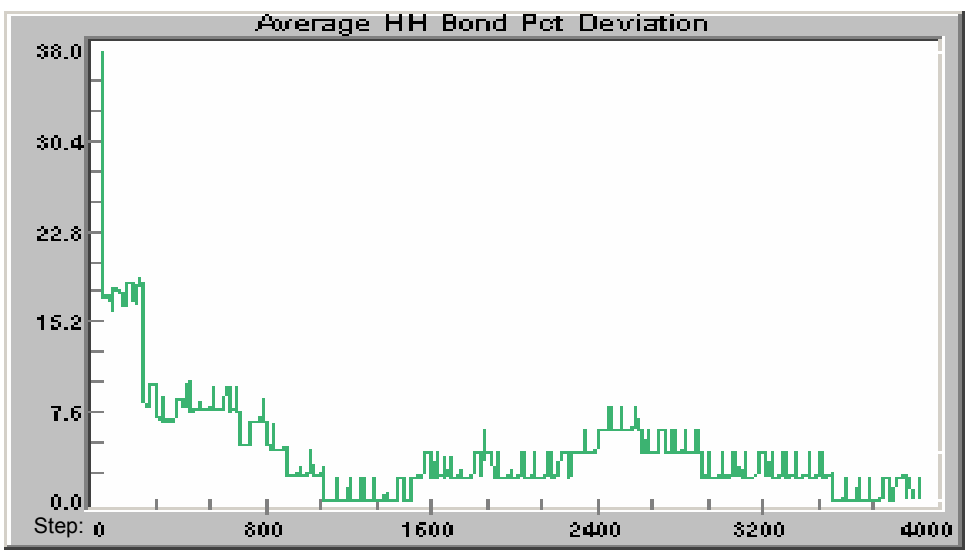

Figure 9. Finite horizon: deviation in bond holdings.

4.3 Event Study of an Output Disruption with Finite Horizons

Our underlying objective is to develop a method for estimating the expected economic impact of a terrorist event, such as an output disruption to a productive sector of the economy. To observe the effects of an output disruption, we ran two simulations assuming finite horizons. We ran a baseline simulation (case 1) with no disruption to

show baseline economic activity, and an event simulation (case 2) to show the relative effects of a disruption. We find that an output disruption has cascading effects long after the event window, and that recovery in the bonds market corresponds to recovery in the labor and product markets.

The simulation begins in disequilibrium, but converges to equilibrium after the first 1000 time steps. We imposed an output disruption from time step 2001 through step 2100, during which firms were precluded from producing goods.

4.3.1 Impacts to Labor and Product Markets

We find that an output disruption occurring from time step 2001 to 2100 leads to substantial cascading effects in the labor and product markets that continue through time step 3800. Figure 10 shows that the event window is followed by an enduring period of unemployment. Figure 11 shows delayed effects on firm profits, and Figure 12 shows similar impacts to household consumption. All of these variables appear to re-converge to baseline around time step 3800.

Figure 10. Event study of total employment.

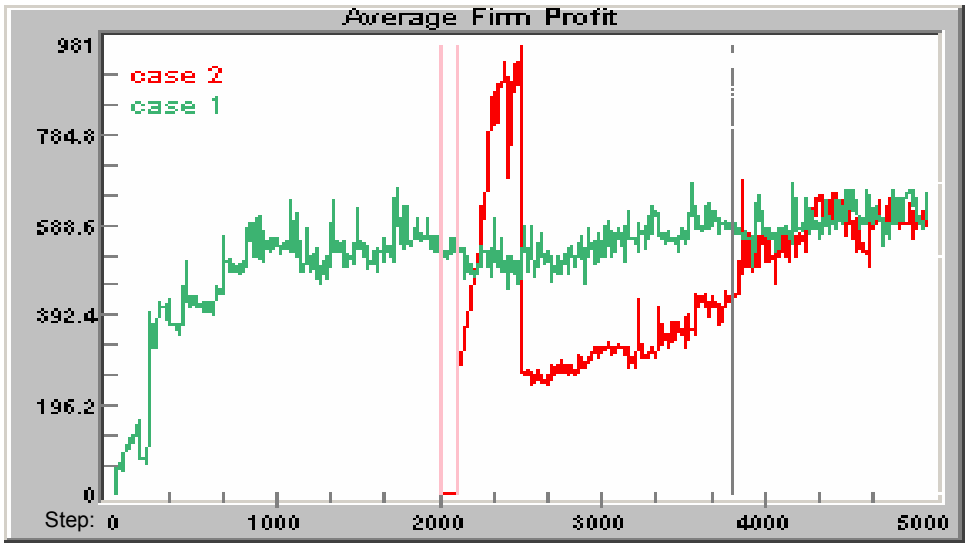

Figure 11. Event study of firm profits.

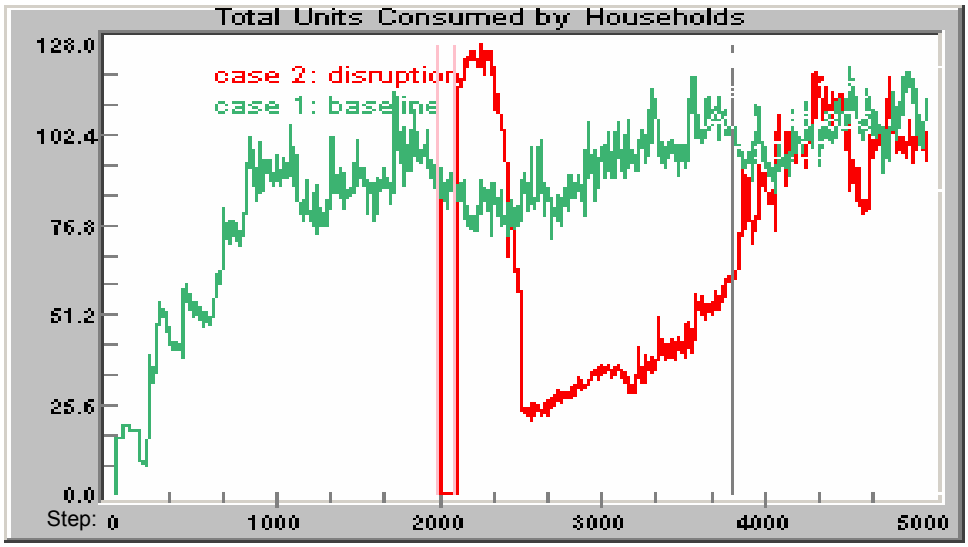

Figure 12. Event study of household consumption.

4.3.2 Impacts to Bond Market

The cascading effects from the disruption are also found in the bond market. Figure 13 shows a substantial deviation between target and actual bond holdings following disruption; these impacts enduring in the bond market for the same period as those in the labor and product markets: through time step 3800.

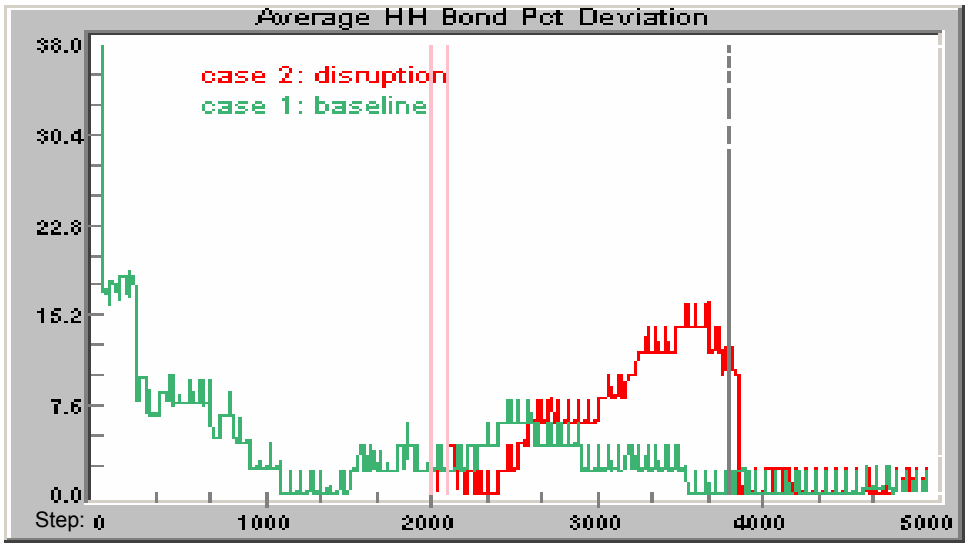

Figure 13. Event study of deviation in bond holdings.

Further inspection reveals the source of the deviation in bond holdings. The recessionary unemployment shown in Figure 10 implies that unemployed households are unable to contribute to savings, which shrinks the aggregate bonds budget (Figure 14).

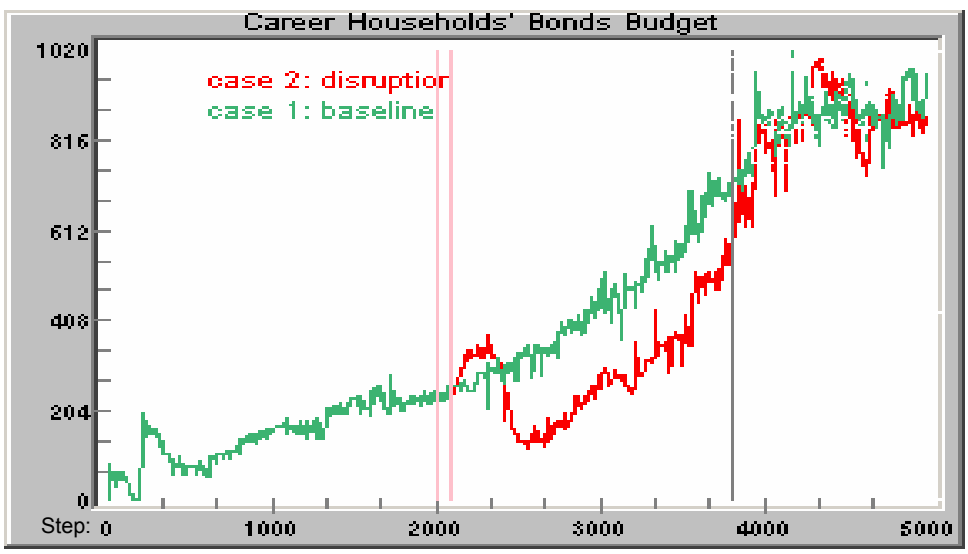

Figure 14. Event study of career households' budget for bonds.

Perhaps the most fundamental impact in the bond market is the substantial impact that recessionary unemployment has on expected lifetime income, and therefore on target bond holdings. Persistent unemployment leads households to downgrade their estimated lifetime income. Under the LCH, such downgrades reduce the unemployed households' expected retirement bundle, which reduces the present value of that bundle, which reduces the households' target bond holdings. Figure 15 shows the result of such downgrades. We see that as soon as employment returns to equilibrium near time step

3800, the target bond holdings quickly jump back to the baseline for target bond holdings.

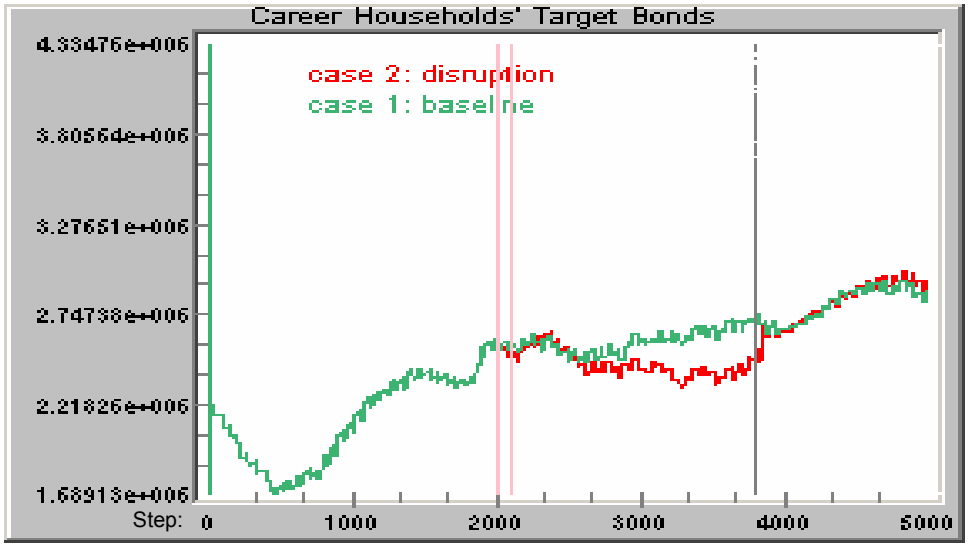

Figure 15. Event study of career households' target bond holdings.

5.0 Remarks

5.1 Summary

This is an intermediate report that documents some important steps toward a model of consumer confidence and financial markets. It introduces time horizons and life cycles into the decision process of Aspen household agents, and introduces financial markets into our current line of research in order to explore the interaction between savings, consumption, and employment.

This report demonstrates that agent-based simulations converge to calculated market equilibria in LCH models assuming infinite and finite horizons. It further models how a disruption to the productive sector can cascade through all markets, and that market recoveries are linked.

5.2 Next Steps

I used several simplifying assumptions for introducing both the LCH and the bonds market. These components should be revisited. Specifically, we intend to re-introduce household time preference and adjustable bond prices into the model. At such time, we should also explore how accidental bequests affect the bond market. Abel (1985) explores the effects of accidental bequests on subsequent generations, when the bequests occur because individuals do not know how long they will live. In our current model, households know how long they will live; bequests occur due to short-run disequilibriums in the bonds market. A proper investigation will determine whether we must introduce explicit bequests motives into the household model to proper simulated the effects of a disruption.

A focus going forward will be to extend household decision rules to employ a more explicit representation of consumer confidence, which will better model household behavior and response to terrorism-related shocks.

We have developed an Aspen stock market, which we are introducing into the model. This component will link households' saving and risk preferences to firms' capital formation; it will also add substantial complexity, requiring careful analysis and understanding of stock investments in the context of our LCH model (see Poterba 2001 and Abel 2001).

We plan to revisit the household's choice of whether to enter the labor market, and the affects of that decision on consumption and savings. Bodie et al. (1992) examine these effects when individuals can vary their work effect (including their choice of when to retire). We will investigation such model variations to determine their relevance to our line of research related to confidence and terrorism.

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