# Modeling Decentralized Price Fluctuations Through Agent-Based Recognition of Scarcity

Russell Ruud, Stephen Davies
University of Mary Washington
Department of Computer Science
(rruud@umw.edu, stephen@umw.edu)

## Abstract

Since the time of Leon Walras, general equilibrium theory and the hypothetical Walrasian auctioneer have dominated market economics. Prices of commodities are assumed to reach "true" equilibrium values based on the underlying supply and demand curves of an economy, which can be represented by equations. In contrast to classical methods, the model in this paper attempts to show the behavior of an economy based on the cumulative actions and interactions of individuals in the system. Agents each produce one of ten commodities and trade with each other to fulfill their consumption needs for those commodities. They are able to change their price expectations to respond to scarcity, and may change which commodity they produce to take advantage of increased prices. The total amount of each commodity consumed is the metric by which the efficiency of a parameter configuration of the model is determined. Empirical analysis confirms that the model's prices and consumption behaved in a manner similar to how free markets are thought to operate.

## Introduction and related work

The agent-based simulation presented in this paper models a simple economy in terms of the human agents that make it up. As Axtell recently demonstrated[2], the traditional Walrasian auctioneer is not scalable to the size of actual economies, which refutes its existence. Economists have long realized this was the case, of course. The traditional equation-based descriptions of market equilibria were created not because they were thought to reflect the actual dynamics of real trading, but because they were a simple and useful method of understanding and predicting future economic events. Recently, however, new computational tools have become available that greatly lower the time required to simulate individual market transactions in an agent-based manner, promising to achieve a more detailed understanding of the economy.

According to Alfred Marshall[6], the total supply and demand for goods in an economy can be aggregated to form an equation to find what level of price and production will result in the optimal level of consumption. This rests on the idea that different agents want different amounts of goods and are willing to pay different amounts for them. The aggregate of the wants of the consumers and suppliers can be used to determine the socially optimal amount produced and the price at which it is to be sold. This traditional technique has very modest computational requirements, and has been useful for getting rough ideas of the behavior of an economy even though it was known all along that prices do not actually get established by a global auctioneer. The mantra “all models are wrong, but some are useful”[7] is certainly applicable here.

It is intuitively appealing, however, to study the economy as the interactions of the individuals who make it up. The founder of the Austrian School of Economics, Carl Menger, came to the relatively apparent, but no less important conclusion that *not all humans behave the same way*. Specifically, the realization that not all people value the same item to the same degree meant that both parties could gain from a trade and there would be more utility in the system without a physical increase in output.[5] The classical school posits that the representative agent can be substituted for the whole in order to study the effects upon the macro economy. The weakness of this hypothesis is in believing that a normal population and a single agent who is the average of that population will behave in the same way.

As Kirman stated in his critique of the representative individual, “there is no plausible formal justification for the assumption that the aggregate of individuals, even maximizers, acts itself like an individual maximizer.”[3] There is also no reason to assume that a change in the environment of the representative individual will have the same economic impact as the same change enacted upon an interacting collective. Also, a heterogeneous population (as every real society is) behaves very differently than a population composed of individuals who were all “average.” For a very blunt example, our world behaves very differently than if composed of individuals who, like the “average person,” each had one ovary and one testicle. Simply aggregating the attributes of the agents does not represent the interactions present in a system of heterogeneous agents. Kirman also states the converse: that, for these reasons, there is no reason to believe that, because a collective is observed to behave rationally, the individuals who make it up must be rational as well. It can follow that the appearance of rationality, which paradoxically provides the basis for the classical assumption that the macroeconomic behavior has similarly rational microeconomic underpinnings, may result from non-apparent results of interactions within a heterogeneous population.

It has been observed that prices change in predictable ways with regard to scarcity in the real world. When there is a political crisis in the Middle East, the price of oil and gas rises because the supply is less than the demand. People compete for the good, with the result that those who want it more (have a greater willingness to pay) obtain it and those who want it less decide they can do without it. The relative scarcity is indicated by the price level.

Axtell states in “The Complexity of Exchange” that “agents use past prices to form idiosyncratic forecasts of future prices, and trade accordingly. New prices are created. Over time forecasting rules evolve, unprofitable ones are replaced by speculative ones, and the population of agents co-evolves to one another.”[2] Distributed and uncoordinated determination of prices seems more like the real world than the metaphor of the Walrasian auctioneer. This, again, makes intuitive sense, but the exact method or methods of price determination are still waiting to be worked out.

Albin and Foley demonstrated in their “Distributed Exchange Without an Auctioneer” that agents trading from a random beginning distribution can greatly reduce inequality of utility, but fall short of the level of equality possible with the auctioneer[1]. The utility was determined by a Cobb-Douglas function of two goods. Each agent was given a random endowment of each good which added to a total of 100. They proceeded to engage in bilateral bargaining and develop searching strategies based on the acquired information for a certain number of trades to see how equitable a distribution can be reached.

The fact that agents can gather information and trade to approximate Walrasian maximum utility in a market given a finite amount of time is interesting and a necessary logical step to showing how a real economy operates. In time, however, past strategies and trades will affect future production and utility will need to be calculated again. Our model tries to see the behavior of price, production, and scarcity in a market over time and what patterns of these factors emerge over time based on consecutive attempts to maximize utility.

## Method

Our model expands the idea of a market creating an efficient allocation with multiple commodities and a larger number of trading periods. All agents live from the beginning of the model to the end and there is no increase in their number. The agents live in an economy that trades a set of ten commodities (or goods). Each agent produces a set amount of one of the goods during each time step, which is referred to as their “salary” of the good. Each agent consumes an amount of each good, which is randomly determined for each good at the beginning of the model, then applied uniformly to all the agents. To be clear: the amount of a good that each agent produces during a time period depends on the agent’s productivity, which varies across agents; by contrast, the amount of each good that agents consume depends on that good’s consumption rate, which is constant for all agents but which differs for different commodities.

Each agent wants to have enough to consume the required amount of each good at the end of each time step, and trades with others to achieve that goal. In a trade, an agent randomly selects a parameter-determined number of other agents, and attempts to buy from them those goods in which he is deficient. Each agent starts with random price expectations for each of the ten goods at the beginning of the model. When an agent A buys from another agent B, and A has too little of a commodity and B has an excess amount because he produces it, the two agents will find the average of their two expected prices and trade at that price. Each agent will then calculate the difference between their expected price and the price at which they just traded. They will divide that difference by ten and increase or decrease their expected price for that commodity by that that amount so that their expected price is closer to the trade price. In this way, agents discover other agents’ beliefs about the true prices of the various goods as the simulation unfolds, and update theirs accordingly.

If the buying agent is deficient in good 0 and the agent he approached is also deficient in good 0, the expected price of the good is increased to 1.01 times what it was for each agent. This acknowledges the good’s scarcity by increasing its expected price (In this economy, demand for all goods behaves inelastically). Likewise, if both agents are satisfied in the good, the expected price will be proportionately decreased because of the good's relative non-scarcity. If one party is deficient in the good and the other is not, the price expectations of the parties for the good is not changed to reflect scarcity.

The total level of consumption on a time-step would be maximized if all agents had acquired enough of each commodity to satisfy all their needs by the end of the time step. We thus recorded the total level of consumption each time period as a representation of the efficiency of the simulated market. The number of agents that an agent traded with is determined by parameter. If the number of agents producing each good were not to change, the price of underproduced goods would rise exponentially. The model thus allows agents to periodically change which commodity they produce, switching to the good that they believe has the highest expected price. This switching behavior is permitted to an agent with a certain fixed probability per time period, which is also configurable. This means that agents will respond to increases in price by increasing the supply of that good in the long run, lowering those prices in time.

# Results

We tested our model empirically with a range of parameter settings. Among them were the total number of agents created and the number of trading partners per time period; the likelihood of an agent switching to producing a different good in each time period; and the distributions of agent salaries and commodity prices. The model's responses confirmed basic expectations about price equilibrium levels, volatility, agent production choices, and consumption of goods. For the analysis below, we chose one hundred total agents, twenty trading partners per time period for each agent, normally distributed salaries (with standard deviation of 15 monetary units; the mean is varied below), and uniformly distributed commodity prices over a range of 4 monetary units (again, the mean was varied.)

Of particular interest in this initial validation step were two dependent variables: the time series of total consumption and of commodity prices.

## Measuring total consumption

Figures 1a-1f illustrate the total consumption time series, with varying levels of production switching rate and consumption-to-salary ratio. (By consumption-to-salary ratio, we mean a ratio reflecting the artificial society's ability to satisfy its members' needs. Values less than 1 indicate the fraction of the society's production power that its members actually consume, the rest being excess. Values greater than 1 reflect an ultimately hopeless situation in which the society's production is unable to keep up with its needs.)

Figure 1a depicts a “hopeless" situation, with consumption needs higher than productivity. The green line marks the theoretical consumption level; i.e., the total monetary units of goods that would be consumed if all agents had enough of each. The blue line shows the total actual value consumed by all the agents during each time period. As expected, society makes little to no progress in satisfying its members since the odds are stacked against it. In this scenario, the switch rate is kept at 25% (meaning that only about once in four time periods will an agent change the commodity it produces in response to expected price increases.)

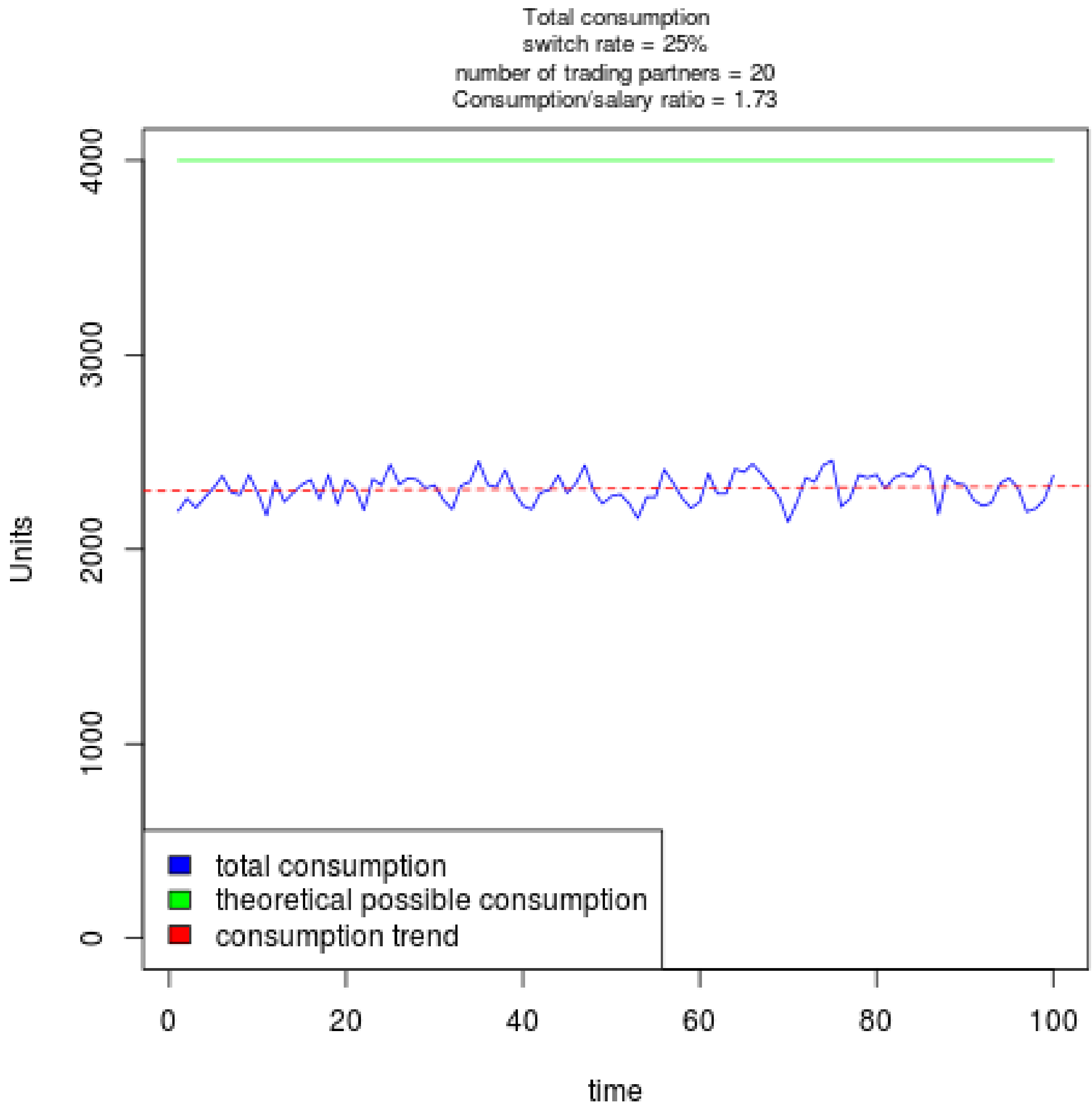


Figure 1a: High consumption vs. production ratio, with moderate switching rate.

In Figure 1b, the switch rate is increased tremendously (to 95%), which does very little good. A very slight rise in total consumption is evident among many pointless oscillations. Evidently, highly anticipatory producers are not a panacea for a consumption glut. When the consumption-to-salary ratio is increased to make the situation more manageable (Figure 1c), a switch rate of even 25% has a visibly larger impact.

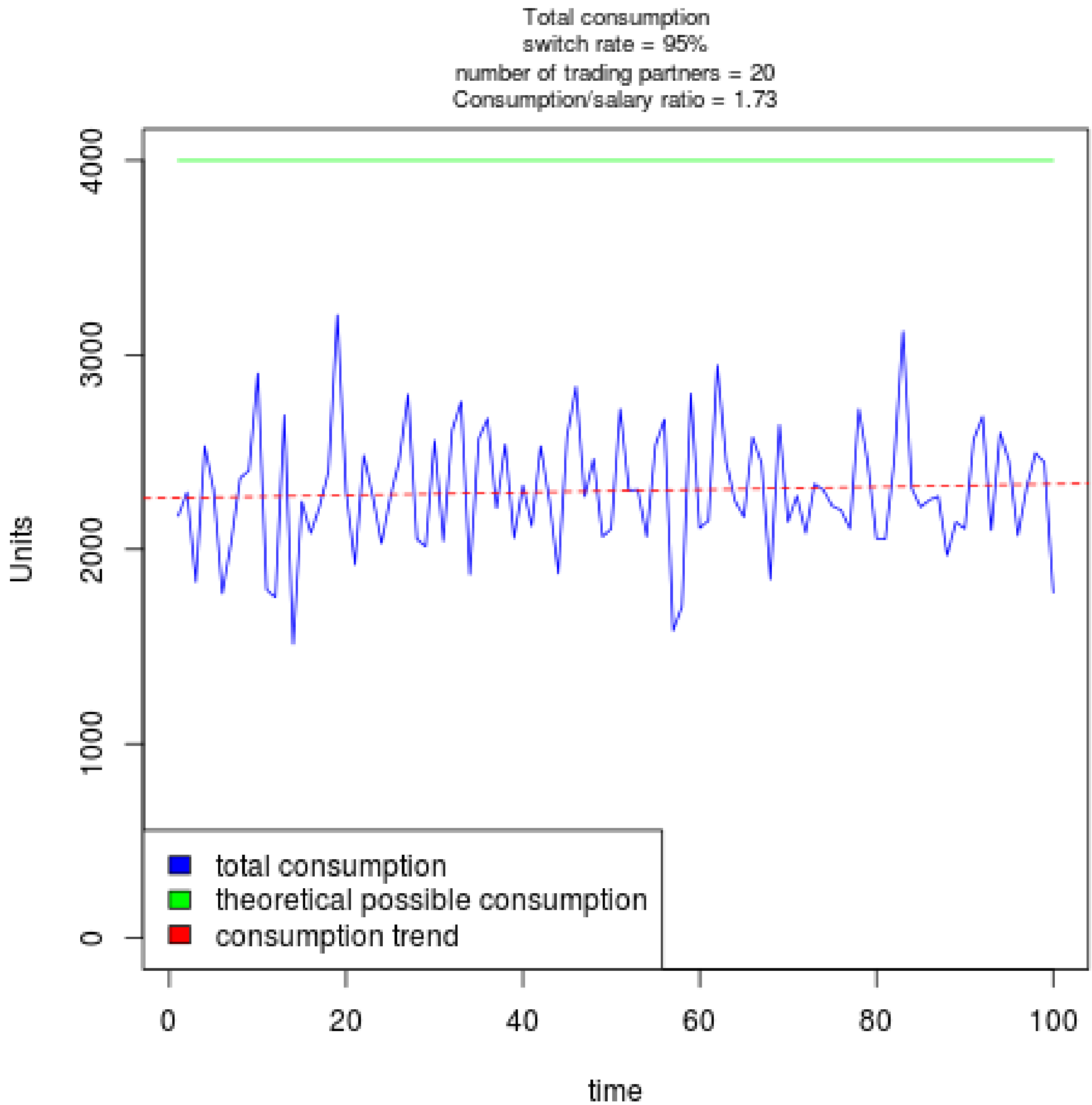


Figure 1b: A higher switch rate.

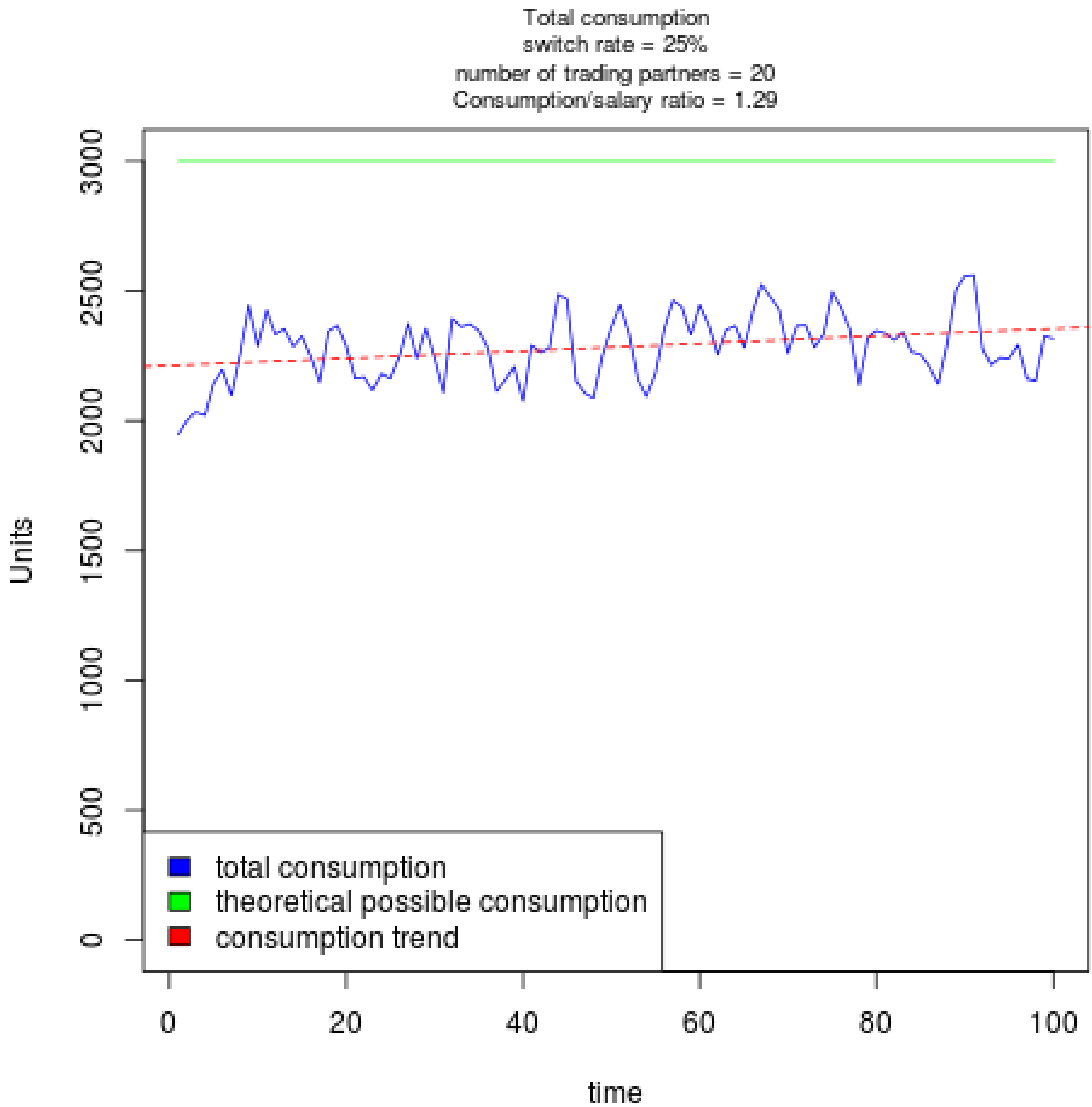


Figure 1c: Lowered consumption vs. production ratio, with moderate switching.

When production levels exceed consumption needs, however, the ability of producers to respond to their environment is truly seen. In figures 1d, 1e, and 1f, the ratio is held steady, and only the switch rate is modified. Allowing producers to switch commodities more readily has a noticeable beneficial impact on total consumption levels, with a rate of 25% allowing the society to reach saturation within only a few time periods.

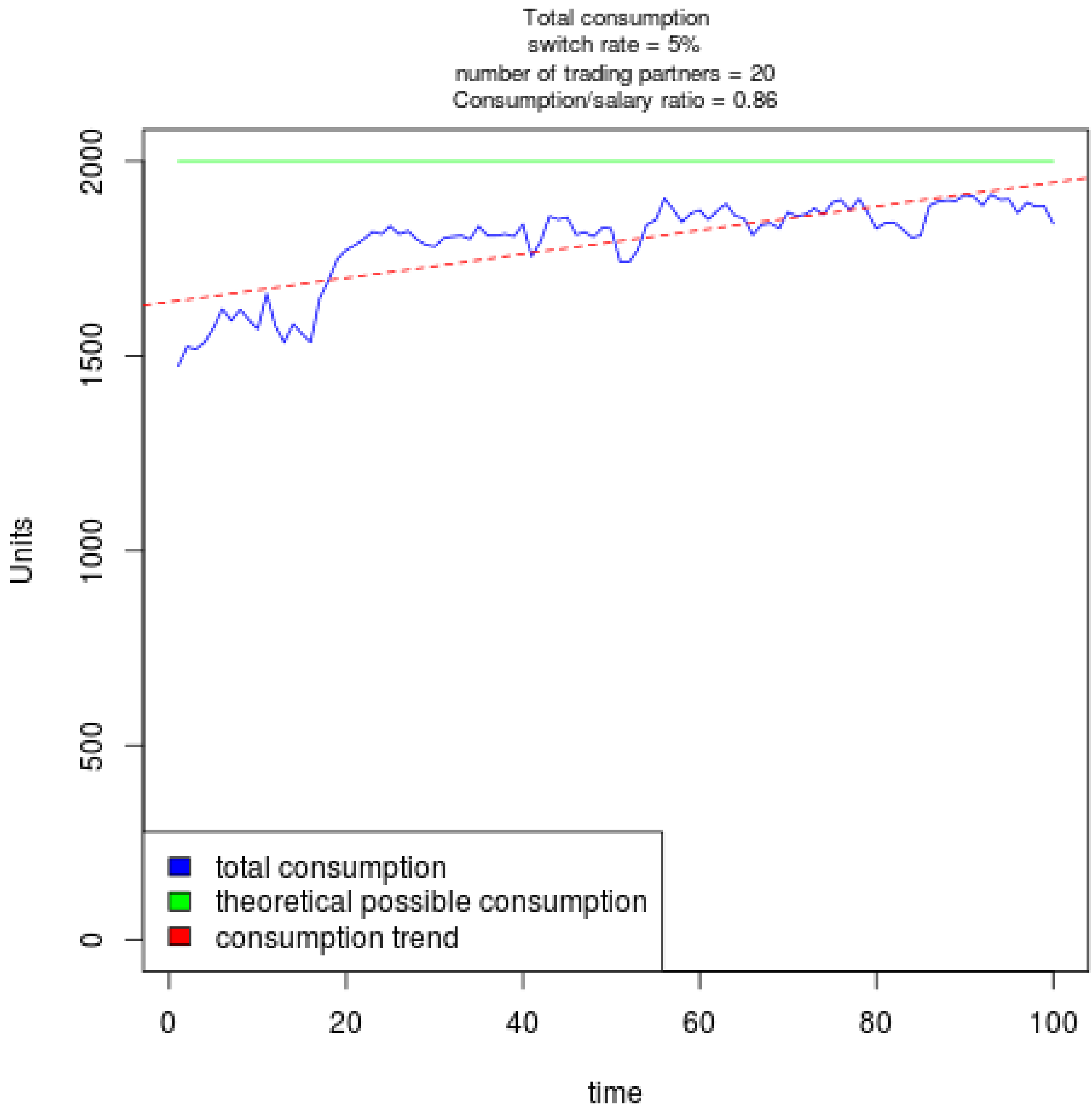


Figure 1d: Very low consumption vs. production, with low switching.

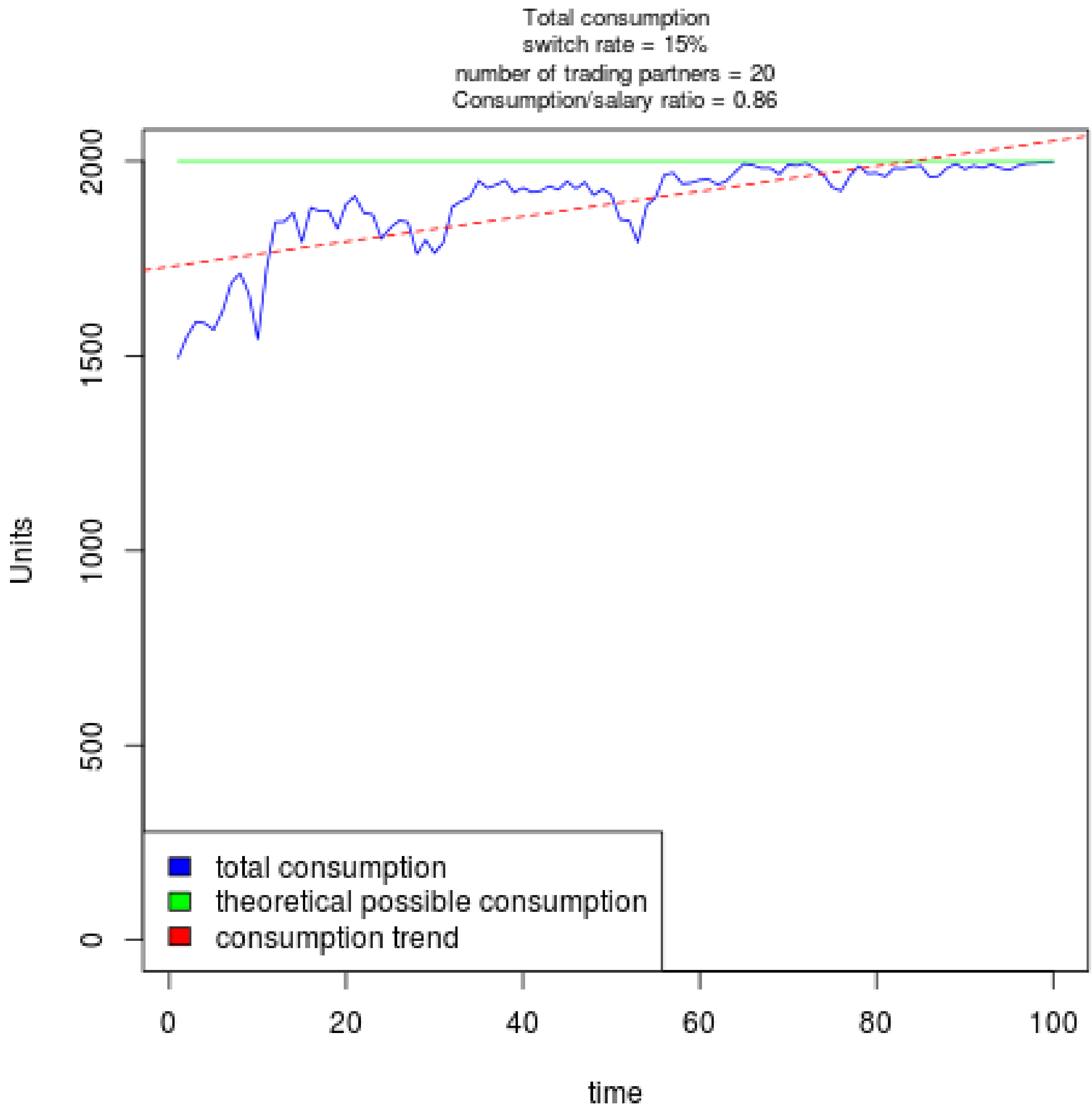


Figure 1e: A low-moderate switch rate.

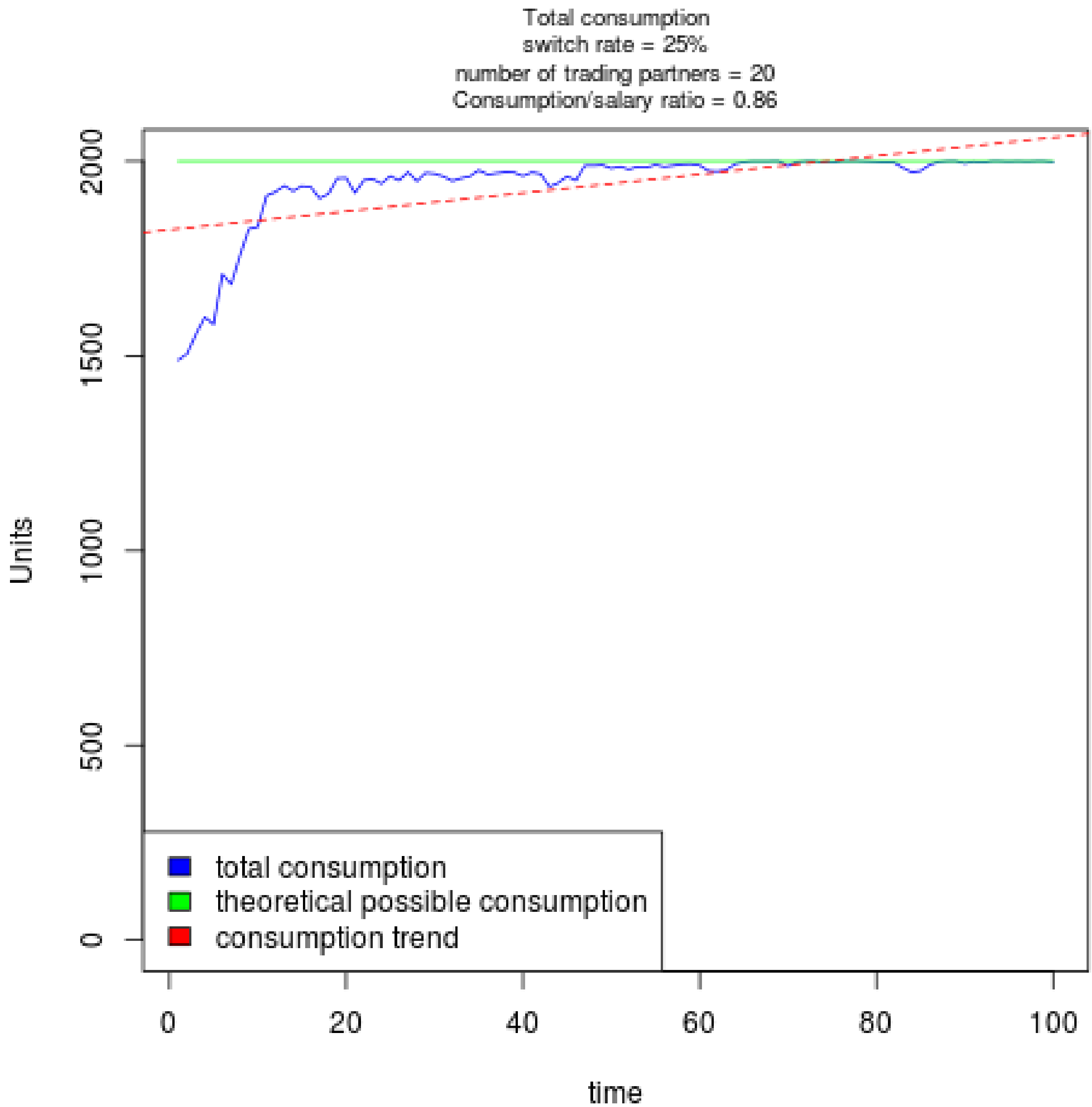


Figure 1f: A high-moderate switch rate.

## Measuring commodity price changes

Figures 2a-2b demonstrate the effects of different switching rates even more dramatically. In 2a, the harsh truth of a 0% switch rate is manifested: even if a society's production capabilities are far in excess of its needs (a ratio of only .03!) it will be doomed if its producers are unable to respond to the market. Here, one commodity (B) experienced an exponential surge in price because it was simply so rare that consumers bid up the price without limit. By vivid contrast,

Figure 2b shows that even the slightest increase in switch rate (from 0% to 1%) allows this society to manage itself quite well over time. Some commodities spike early in the simulation, but the group of sluggish (yet not totally paralyzed) producers is eventually able to shift enough to satisfy the need.

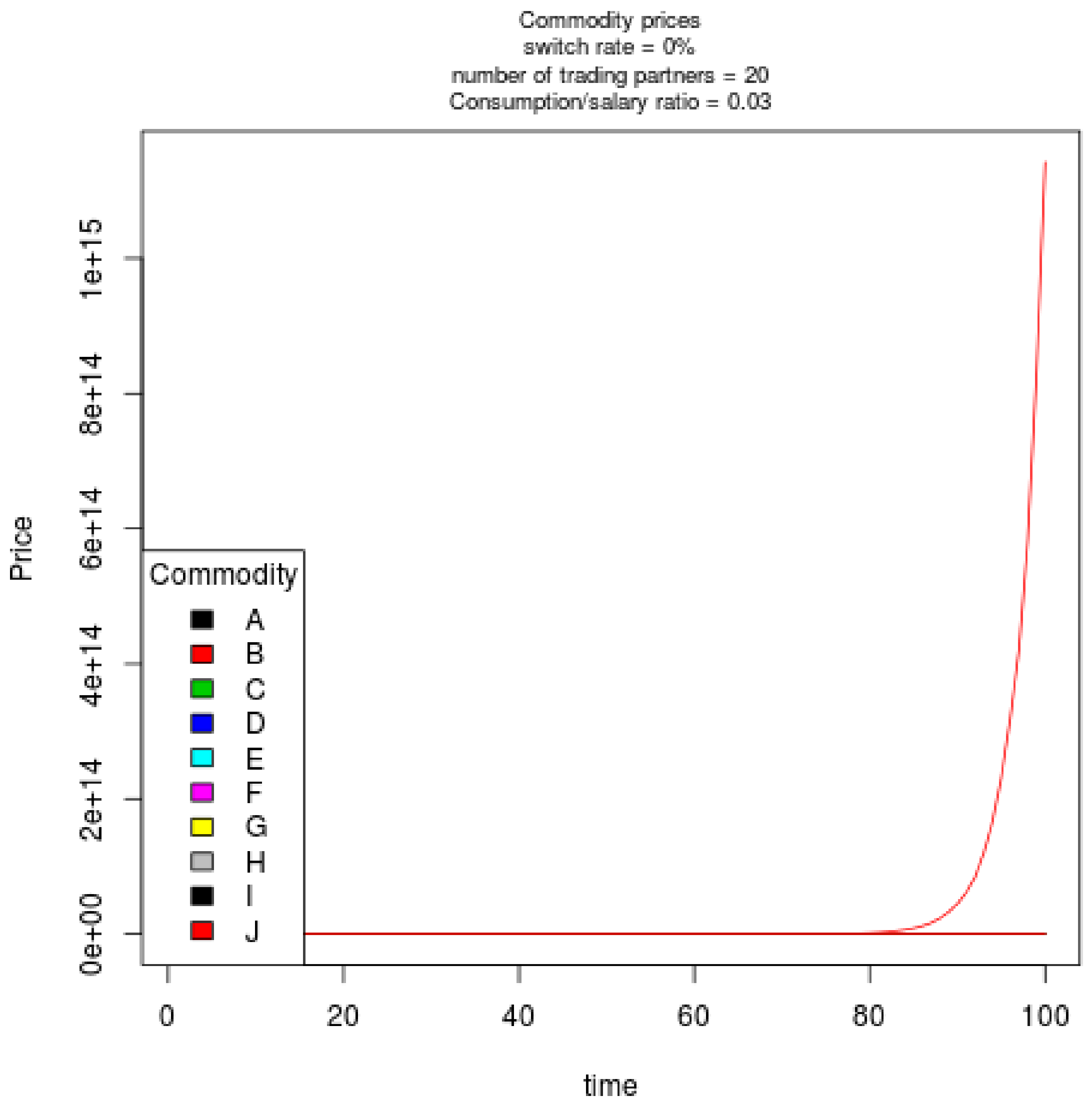


Figure 2a: Prices increase exponentially with no production switching at all.

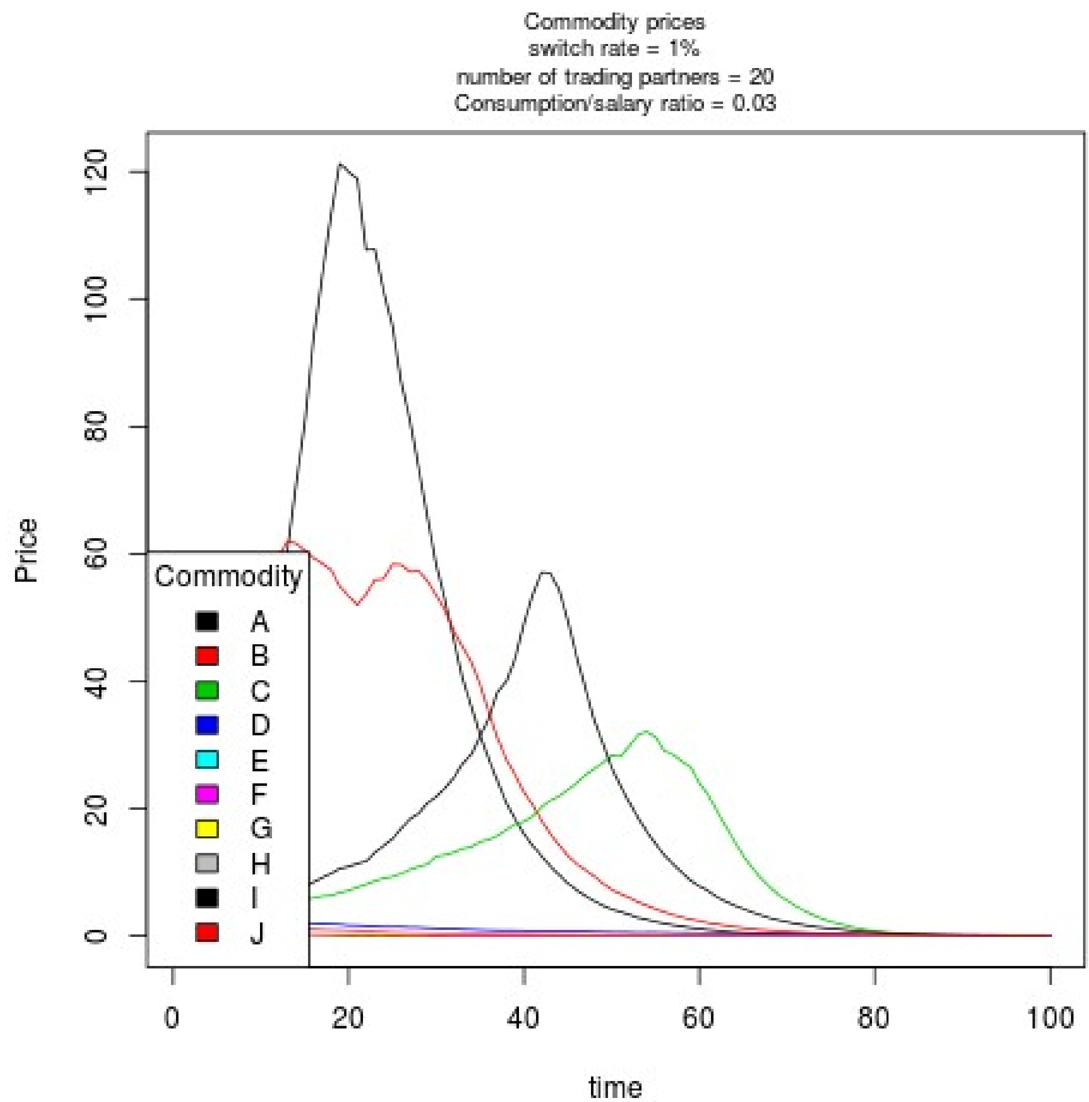


Figure 2b: Even a little switching flexibility makes prices decline to zero.

In Figures 2c-2d we return to the situation where consumption exceeds production. Interestingly, a switch rate of only 1% (Figure 2c) is enough to keep prices in check for several dozen time periods, but eventually the producers can't quite keep up. And when raised even up to a modest level (5%, as in Figure 2d) producers seem to bounce back and forth sufficiently often that outrageous price increases are kept largely in check. Note the extreme volatility here – the flexible producers are beneficial in that they help cover shortages when they arise, but detrimental in that they "overshoot" the changing scarcity levels. Too many producers rush to produce rare goods, with the result that every commodity's price becomes wildly oscillating. Clearly a managed society could seek a middle ground here, but with a free market, it is only the penalty incurred by switching industries that would keep fluctuations from dominating the system.

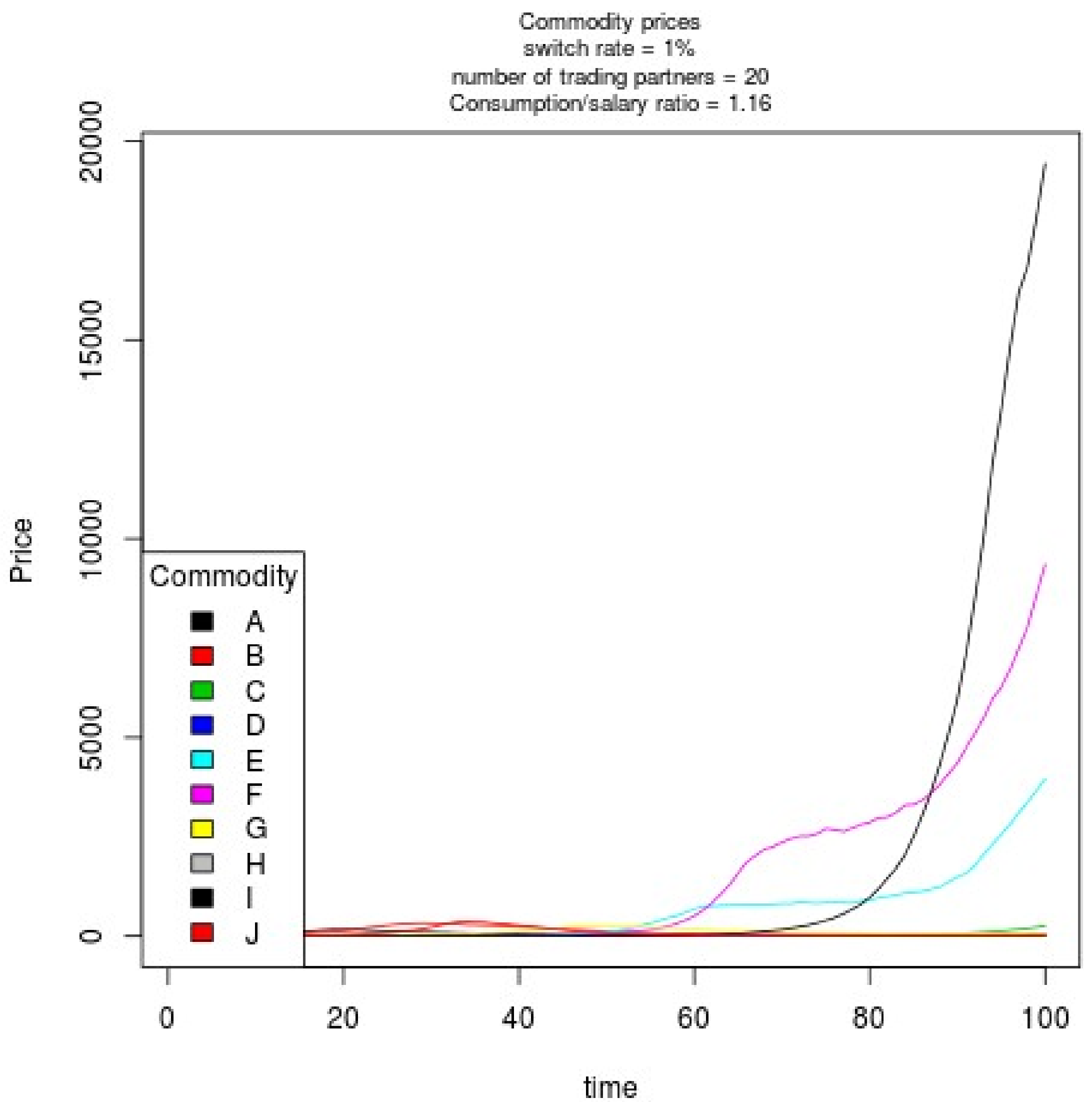


Figure 2c: Higher consumption causes an exponential increase in prices.

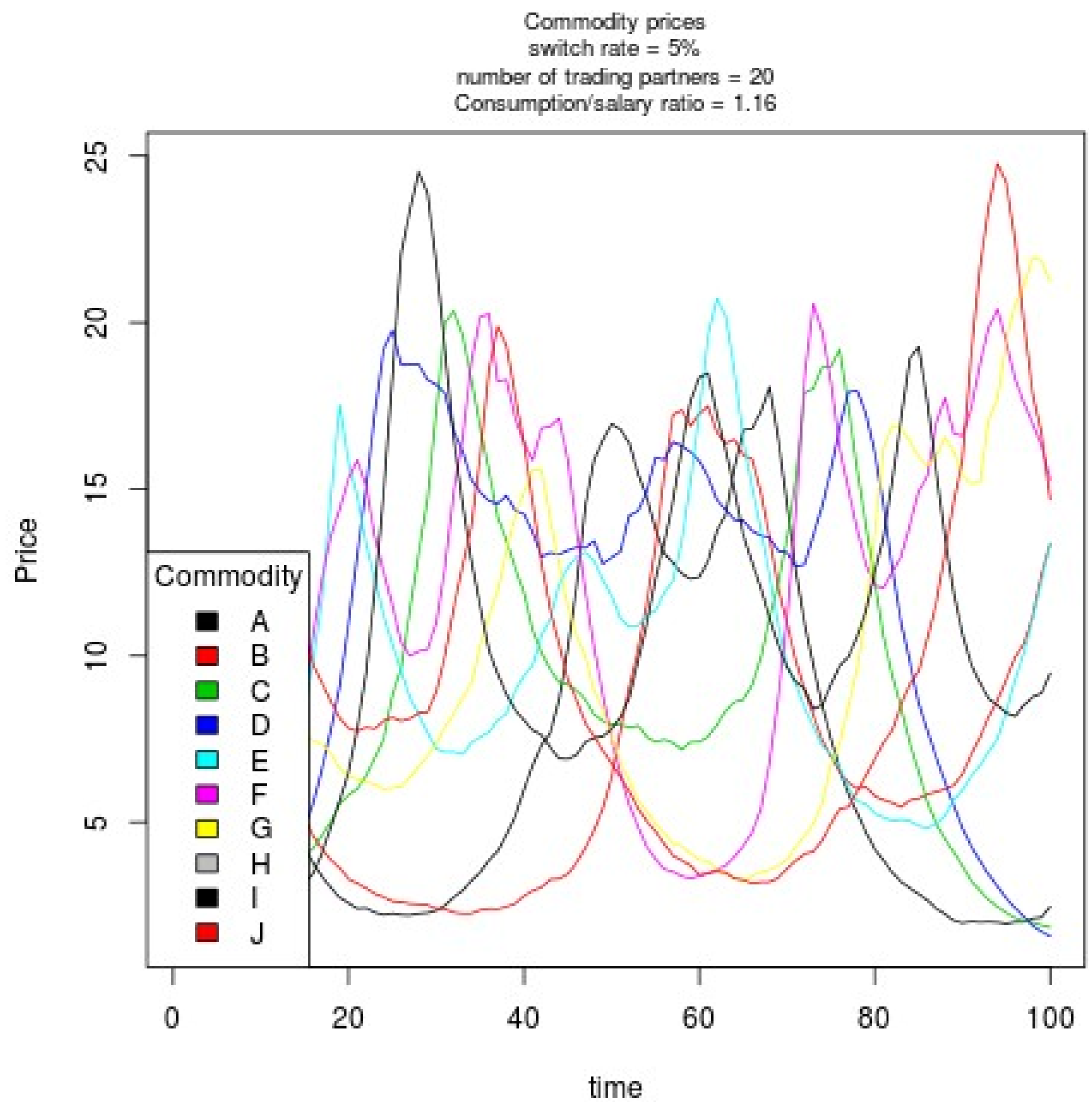


Figure 2d: A higher switch rate helps keep prices low.

## Conclusions

An increase in the rate at which agents switch which good they produce in response to price slowly moves the total consumption of the system towards maximum consumption, but only when the level of consumption is similar to the level of production.

When far more is consumed than produced, the scarcity is indicated in the prices, which continually rise. The high level of price indicates to an agent that the market as a whole needs more of the good, so they try to switch to producing that good in order to balance out the market’s needs. Unfortunately, when far more is produced than is consumed, all goods are always scarce and no arrangement of agents producing goods will lead to enough being produced that it is not scarce and lower the price. Agents will continue to switch because prices indicate that other goods are scarce and some of every good will be satisfied every time through the round.

Even in a situation of gross underproduction, fast enough switching will allow *some* agents to be satisfied in *some* good more of the time. Having more commodity holdings just over the level of satisfaction does more to keep costs down than having fewer commodity holdings far over the level of satisfaction. If switching is slow, prices (perception of scarcity) will be given more time to diffuse through the economy and there will be a slow bandwagon effect as every agent who can switch switches to produce the one scarcest commodity. While they are slowly moving, the price is rising. When enough agents have switched over to produce what was the scarcest commodity, it takes time for holdings of that commodity to rise and others to fall. The rate of production of the good gains momentum and can't turn quickly when holdings fall. When price diffusion is faster than the response mechanism to price diffusion and all goods are scarce, prices will rise very rapidly.

If, however, the economy is overproducing, no goods are terribly scarce and prices will fall to reflect this fact. If agents are able to switch what they produce more quickly, they will still be fighting to produce any good that exhibits scarcity in the economy, but in this case, they will be winning. The faster they can switch, the better all goods can be kept at an even level of holding in the economy and the faster all the prices will approach zero.

The consumption plots show how higher switch rates can cause total economy consumption to more quickly approach theoretical maximum consumption of the economy. If the economy is consuming at the maximum possible rate, this means that every agent is acquiring all the goods they need to satisfy all their needs every round. An increase of the total model consumption over time means that the allocation of commodity producers is becoming more efficient.

If consumption far outstrips production, no arrangement of producers is going to totally relieve scarcity, but it can be ameliorated by assigning the most agents to produce the commodity that is consumed at the highest rate. Even in the hopeless situations of high consumption, there is a more upward trend in total consumption with higher switching rates. When consumption is very low relative to production, an increase in switch rate allows the market to approach maximum consumption more quickly. In the middle-ground, a level of consumption that is just a bit higher than production can be brought to a markedly more equitable arrangement of production and exhibits stable or even falling prices depending on the pricing strategies of the agents.

Using these pricing strategies, we have demonstrated that a simulated economy can behave in predictable ways and allocate resources efficiently without the intervention of an auctioneer. Over time, the economy can continually adapt to the conditions it finds itself in and reflect the scarcity of goods with prices. While the rate of consumption does not respond to prices, however, prices are unlikely achieve even dynamic equilibrium because the scarcity of a good is viewed as absolute, rather than relative to others. While this is the case, prices will change at an increasing rate when they approach their extremes (infinity or zero) rather than a decreasing rate, as we see in the real world.

## Works Cited

[1] Albin, Peter, and Duncan K. Foley. "Decentralized, Dispersed Exchange without an Auctioneer: A Simulation Study." *Journal of Economic Behavior & Organization* 18.1 (1992): 27–51. *ScienceDirect*. Web. 3 July 2013.
[2] Axtell, Robert. "The Complexity of Exchange*." *The Economic Journal* 115.504 (2005): F193–F210. *Wiley Online Library*. Web. 3 July 2013.
[3] Kirman, Alan P. "Whom or What Does the Representative Individual Represent?" *The Journal of Economic Perspectives* 6.2 (1992): 117–136. *JSTOR*. Web. 22 July 2013.
[4] LeBaron, Blake. "Agent-Based Computational Finance: Suggested Readings and Early Research." *Journal of Economic Dynamics and Control* 24.5 (2000): 679–702.
[5] Menger, Carl. *Principles of Economics*. Auburn, Alabama: Ludwig von Mises Institute, 1976.
[6] Marshall, Alfred (1890). *Principles of Economics* (First Edition ed.). London: Macmillan. Retrieved 2012-12-07
[7] Box, G. E. P. and Wilson, K.B. (1951) On the Experimental Attainment of Optimum Conditions (with discussion). *Journal of the Royal Statistical Society* Series B (1):1–45.