NOTE TO FILE
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Reflections on Sustainability

ModEco is a software application built with the intent to allow students of sustainable economies to design a model economy on a desktop computer and see the economy develop in minutes as they watch. It was developed in conjunction with an enrichment program for gifted students in an Ontario high-school. The ultimate goal in the development of the ModEco application is to identify the necessary and sufficient components of a most simple but complete economy. That goal is still a distant hope.

A ModEco-based economy is a merger of two synchronized dynamic systems fashioned with a very simple post-barter agricultural economy in mind.

At the biophysical level, agents in the economy harvest grain from fields and store it in a farm's inventory bins, carry the grain home and place it in their pantries, eat it, and take the waste to the recycling depot, from which farmers collect it and put it back on the field to start the cycle over again. Agents' lives are controlled by biophysical parameters that determine things like food consumption rates, or reproductive maturity. This is the biophysical system.

Synchronized with the biophysical system is the economic system. Farmers hire workers to harvest the grain. They then sell the grain to consumers. The consumers sell waste to a central manager who, in turn, sells it back to the farmers. A single good is bought and sold in its various forms (fresh grain, inventory, supplies, waste). A single service is bought and sold (harvesting grain). All mass and energy flows in one direction, mediated by transfers of cash in the opposite direction.

Regrettably, to date, we have been able to demonstrate a simple sustainable economy only under severe constraints. The intellectual journey that has lead to the successful design of this sustainable model economy has been difficult, and full of unexpected insight. The purpose of this brief paper is to share some of those insights, and to lay on the table a challenge to others interested in agent-based modelling of sustainable economies, in the form of testable hypotheses.

This note is structured into three main parts, as follows:
1. About the PMM – the "most simple" complete sustainable economy;
2. Insights and observations derived from the search for the PMM; and
3. Hypotheses about the PMM.

1 About the PMM

As mentioned above, we have been able to establish a sustainable economy only under severe constraints, and that constrained economy has been called the Perpetual Motion Machine, or PMM, due to the inspiration derived from the vision of a friction-free bicycle wheel spinning freely forever, once set running. Clearly the PMM is a radical idealization of what most people would envisage as a "sustainable economy". However, to date, all variations from this constrained model quickly collapse. The fact that the PMM is the only "sustainable economy" achieved so far makes it of particular interest.

But before going into the details of the PMM, first one must understand the nature of a ModEco-based economy, and the arcane jargon of computer models.

1.1 Technical Characteristics of a ModEco-based Economy

Computer models – All ModEco-based economies are computer models. Each is a demonstration of a logical economy. We view them as demonstration economies, and not simulated economies. They form logical complex dynamic systems in their own right, and can be studied as such. They are internally verified to be working as intended, with over 3,500 tests, but they are not validated with respect to real-world economies, as that is not their intent. They are nevertheless able to provide some insight into the nature of economies. As computer models, each ModEco-based economy:

- Is agent-based – All economies in ModEco are agent-based. Many computer-based economic models are the embodiment of systems of mathematical equations such as supply-demand curves, utility functions, or relations between macro-economic variables such as GDP and employment rates. Those equations are used to extrapolate the values of variables over some small increment in time, one variable at a time. Gravitational models, weather models, and most economic models work this way. On the other hand, an agent-based model establishes a group of independent logical entities called agents, each of which interacts with other agents in a limited fashion. Most of those variables defined as inputs to an equation-based model are natural outputs of an agent-based model. For example, if agents negotiate for work, and negotiate for purchases of goods and services, such variables as employment rates, price indices, GDP and velocity of money are simply macro-level measurements to be made, as they are in any real-world economy, rather than controlling parameters. In an agent-based model the controlling parameters all control agent behaviour, and the economic descriptors are a derivative product of that behaviour.
- Is a finite-state-machine – A ModEco-based economy is established in an initial state from a finite list of all possible states. Then, with each tick of the ModEco clock, the economy is tranformed to a new state by a repeatable, if complex, process. Each time the economy is initialized in the same state, its future trajectory through its state space, its future evolution, is fully determined. Such logical systems are called finite-state machines, or FSMs. The standard components of an FSM are (a) the physical dimensions and construction of the unchanging structure of the machine; (b) the initial layout of the contents (the state) of the machine; and (c) the transition rule. In ModEco, the transition rule is embodied in the economic engine.

- Is pseudo-stochastic – An economy includes, in its initialization, a seed number for a pseudo-random number generator (PRNG) which can be used to emulate stochastic behaviour in a deterministic FSM. The PRNG used in ModEco is called the Mersene Twister. An economy with otherwise identical initialization, except for the PRNG seed, will respond to all PRNG-mediatied events as if they were stochastic events in place of deterministic events. So, for example, the PMM can be initialized with identical values many times, but with different PRNG seeds, and each will develop along its own trajectory. PRNG-mediated decisions are, for example, the order in which agents participate in the economy, or the location of new agents resulting from reproduction.
- Has two spatial dimensions – The action in the economy happens in a two-dimensional grid of squares called lots, and the rectangular collection of all lots is called the township. Agents called workers live up to four-to-a-lot in residential lots. Agents called farmers live one-to-a-lot on farm lots. Any agent can do business with any other suitable agents within a five-by-five square centred about the agent called the commuting area. For example, a worker can get a job with, or buy supplies from any farmer within its commuting area, but cannot conduct such business with farmers outside of the commuting area. FSMs with such a two-dimensional organization are usually called cellular automatons. The scope of effect of a cell in a cellular automaton is the distance, in number of cells, over which the contents of one cell can affect another cell in one tick. This distance is usually represented as k, and the square of cells within that distance is called the k-neighbourhood. A 1-neighbourhood of a cell consists of the nine cells centred on that cell of interest. So, in the language of cellular automata, the commuting area of an agent in a ModEco-based economy is a 2-neighbourhood consisting of the 25 cells centred on the agent.
- Is evolutionary – In the underlying biophysical model, agents are born, eat, and reproduce or die of starvation. Their decisions and actions are mediated by genes which mutate slightly at the moment of birth. Variations in genes cause variations in behaviour during negotiations of price. Those agents with more fortuitous gene mutations, that is, those that are better adapted, will tend to prosper and survive, while those with less fortuitous mutations will tend to perform poorly and die without issue.
- Has a joint biophysical and economic transition rule – In one tick of the ModEco clock the following activities happen in order: Setup, job offers, worker moves, sell inventory, consume supplies, sell waste, buy recycled, agent reproductions, agent deaths, cleanup. For each activity each type of agent may take an active or passive role such as offering jobs to local workers (farmers are active, workers are passive). The active agents, in random order (as determined by the PRNG) execute their activities. If the active agents are interacting with passive agents within the commuting area, the passive agents are processed in random order. This transition rule is somewhat unusual for a cellular automaton because it is organized by agent, rather than by cell, but the effect is logically the same.

More detailed technical information can be found in the design documentation.

1.2 Economic Characteristics of a ModEco-based economy

The above characteristics, however, do not describe the economies so much as the technical classification of the economies.

Every ModEco-based economy:

- Uses metabolism-based determination of value – In keeping with the philosophical perspective of biophysical economics, the biophysical needs of the agents are defined, and units of mass and energy are defined in terms of daily (i.e. per tick) metabolic requirements, and the intrinsic value of mass and energy is calibrated using metabolic needs.
- Is conservative of key quantities – During each transaction between agents key quantities are strictly conserved. These include biophysical materiel such as mass, energy and intrinsic value, and the list of conserved quantities is topped off with cash. Also, using the current economic engine (transition rule) each economy is a closed mass/energy system with no materiel flowing in or out. An open economic engine is in development, but a sustainable complete most-simple economy has not yet been achieved using this open engine.
- Is complete – The entire economy is demonstrated, as mass and energy flows from primary production on the farm, through harvest to farm inventories to consumer pantries to waste collection facilities and back to the farm where the mass is recycled for re-use. Many agent-based economic models focus on a single type of transaction that might be embedded in an economy, such as stock-trading, or the purchase of goods. However, sustainability is a characteristic of a complete economy, and not of a component of an economy, so a study of sustainability requires that the economy demonstrate complete mass and energy flows.
- Is most-simple – Every component found in a current ModEco economic engine (the transition rule for the FSM) was added to make the economy (a) complete, and (b) sustainable. The current structure of the ModEco-based economic engine is a minimal collection of operational features added in the quest achieve these two goals, with no features added for other purposes. To be clear, there are a number of additional features for code verification, for initialization, and for data collection and display, but these features are segregated from the economic engine. As such, it can be said that the current components of the economic engine are sufficient for sustainability, in the severely constrained form achieved, but they may not all be necessary for sustainability. Some components added along the way may now be redundant. The process of discovering and removing the unnecessary components has not been undertaken to date. Examples of potentially unnecessary components in the current implementation are:
    - The “move workers” function – used to enable starving workers to move, looking for work in another commuting area; in the PMM few workers move, if any;
    - Immortal central agents – used to complete the cycles for mass and energy, thereby enabling conservation laws; completion of the cycles is necessary, but the technique can vary;
    - Price averaging – used by a central agent to dampen inflation by buying and selling waste/recycled matter at the average market price; this feature is not relevant to the PMM and not used in it, but it is somewhat effective for delaying the collapse of non-PMM economies;

  - Grant programs – used to distribute the assets of dead agents, and so complete the cycles for mass and energy; necessary in some form;
  - Central debt-creation programs – used by central agents to inject cash into a cash-starved economy; apparently necessary in some form;
  - Quotas – limiting the maximum size of all transfers of mass and energy; possibly unnecessary but currently untested;
  - Business factors – used to trigger participation by an agent in physical and/or commercial opportunities when they present themselves; apparently necessary in some form to control asset distribution within each agent;
  - Life function controls – used to enable the population to self-regulate its size, growing and shrinking again as needed; apparently necessary.
- Is fair – Of the two kinds of mortal agents (farmers and workers) no agent has any benefit from a process bias due, for example, to order of access to resources or to other agents, or due to location.
- Assumes mortal agents have limited knowledge of the market – All mortal agents have knowledge based only on their own experience. No mortal agents have knowledge of other agents' economic status. Unlike assumptions of perfect knowledge, agents have knowledge only of the price they paid for goods and services they have purchased from contacts they have made within their commuting area. On the other hand, the central immortal agents have full knowledge of key aspects. For example, the Materiel Manager who buys waste and resells it as recycled materiel does so at average market prices, and so must know what average market price is.

1.3 Characteristics of the PMM

When two agents interact in the above type of economy, and a price for goods and services is genotiated, one agent is almost always the winner, and the other is the loser. The goods being sold have a metabolism-based intrinsic value denominated in dollars, and those goods are priced in dollars. If the buyer does not pay exactly the intrinsic value, one agent or the other has a decrease in net worth. So, you will notice that the negotiation of price is absent from the above description of "every" ModEco-based economy. In all economies in which agents negotiate prices, the economy collapses due to inflation or deflation. Economies seem to be fundamentally unstable things. However, with the following three constraints, the PMM was produced, and was run to an amazing 20 million ticks. The specific constraints that produce the PMM are:

- Both agents must know the exact metabolism-based intrinsic value of the good or service sold. It was to enable this knowledge that the concept of metabolism-based determination of value, and intrinsic value, were introduced into the ModEco application.
- Every commercial transaction between agents must entail an exact exchange of intrinsic value (in goods and services) for value (in cash). No agent wins, and no agent loses.
- The population must be large enough to avoid the "atto-fox" problem that was described in the study of the Lotka-Volterra equation in predator-prey population studies. The births and deaths of agents of the same type become, for reasons not fully understood, synchronized, and the population size throbs like a heart-beat. Such a heart-beat is a good thing, indicating a self-

regulating negative-feedback mechanism at work, creating long-term stability. However, from time to time the decrease in population can be large enough to cause a population crash. But, if the starting population is large enough, this cannot happen.

Such a system is conservative of the net worth of its agents in every transaction. There is no room for profit and loss on any transaction. And it requires a level of knowledge that is unavailable to people in a real-world economy. Who among us knows the intrinsic value of a day's labour, in dollars. However, this highly constrained "most-simple" agricultural economy is the only sustainable economy discovered so far. And, with the inclusions of such mechanisms as biophysical and business controls for the agents, quotas, and immortal central agents, the phrase "most-simple" can certainly be questioned.

2 Insights and Observations Derived From the Search For the PMM

We started the quest for an agent-based model of a complete most-simple sustainable economy with the admittedly arrogant thought "A few farmers; a few workers; buying and selling vegetables; how hard can it be?" Well …

2.1 Lack of A Clear Definition of Sustainability

Perhaps the most disturbing observation is that there seems not to be a clear definition of sustainability. In fact, there seem to be many meanings that are not in agreement.

Neo-classical economics, the dominant brand of orthodoxy in modern economic thought, includes as a fundamental concept something called the General Equilibrium Theory, or GET. One may look for the comfort of promised sustainability in the word "equilibrium" but on closer examination it cannot be found. Strangely, this brand of economics also includes a necessity for continued and everlasting growth, combined with a belief that such everlasting growth is both possible and reasonable to expect. Neo-classical economics reads like a mish-mash of pseudo-scientific quasi-religious dicta which require suspension of disbelief and verbose circumlocutions to be rendered palatable.

In corporate circles, the concern about sustainability seems to revolve around corporate survival in times of climate change and ecological degradation. The issues considered are changing business models, substitute sources of energy and materials, expansion or diversification of client bases. The issues that the economy is facing, with respect to sustainability, are much larger than this. Such a view of sustainability is narrow-minded and self-serving.

In international economic circles, the concern about sustainability seems to revolve around "sustainable development". Here neo-classical economics holds sway. It is a testament to the tenacity of our determination to believe failing concepts that this phrase is taken seriously. The implication is that

somehow we can continue to "develop" the entire planet, forever, and that this would be a good thing. This concept is rooted in the 19th century view of the world as a cornucopia of limitless resources to be harvested at our pleasure. Also, tightly tied to this concept, is the belief that economies must grow forever to be sustainable. When thinking about the small economies of the 19th and early 20th century in a big world, this belief could exist unchallenged by reality. However, in the modern small world, with wild fisheries collapsing, with forests disappearing, with glaciers melting, with wild species going extinct at high rates, and with economies in which the only real growth is found in levels of debt, it is hard to believe that major international organizations still promote sustainable development. Such a view of sustainability is seriously outdated and based on a failing paradigm.

Paul Hawken identifies a sustainable economy as one which is conservative of non-renewable resources and restorative of renewable resources. (Hawken, 1992) A sustainable economy is one which distributes resources equitably (or fairly) not just among those of the present generation, but also among different generations of people separated by time.

Herman Daly identifies as a goal a "Steady State" economy, in which growth has come to an end, and a modern market-based economy continues to thrive without growth. (Daly 1989) This theme is repeated by many modern writers. Tim Jackson, in his book "Prosperity Without Growth" presents a particularly well-reasoned and well-researched version of this argument.

The ideas of Hawken, Daly, and Jackson are more appealing intellectually than the outdated paradigm of neo-classical economics, or the self-serving world view of modern business, but there are still two problems.

First problem: It appears that the pre-1960s concept of (chemical or physical) equilibrium is implicit in Daly's concept of "steady state". A physical system at equilibrium is a closed mass/energy system and is usually quiet and unchanging. Since the 1960s there has been substantial work done in the study of dynamic systems far from equilibrium. The equivalent concept of "steady state" when applied to systems far from equilibrium is "stationary state", and it is a more complicated concept. A stationary state is found in open mass/energy systems, and can be characterized by behaviour which is turbulent and unpredictable in detail, but predictable and unchanging in large scale. The world's weather system, for example, was until recently in a stationary state, such that weather from day to day is turbulent and difficult to predict in detail, but regional climates and seasonal weather patterns are quite predictable. Economies are very clear cases of dynamic systems far from equilibrium. An economy is an open dynamic mass/energy system far from equilibrium which is not currently in a stationary state, but which we might want to bring into a stationary state. This kind of economic analysis seems to be lacking in the literature to date. Without that kind of discussion, sustainability is an empty word.

Second problem: Modern society is a dynamic system that can be characterized by mass/energy flows and entropy production, just like any other mass/energy system. Hubbert has pointed out that modern economies have risen with the consumption of fossil fuels. According to Hall, we are now running out of cheap high-grade fuel, and, as the average energy returned on energy invested (EROEI) for fossil fuels

declines, so must our society. All the talk of renewable energy sources is barely relevant, as large-scale development and deployment of renewable energy facilities will only slow the decline. With this information in mind, we must agree that economic sustainability in the short term is physically not possible. All we can really achieve now is an understanding of the dynamics of a truly sustainable market-based economy that we can bequeath to our children, and to our children's children, for them to implement.

2.2 Lack of Discussion of Sustainable Economic Process Dynamics

Science has made few real inroads, it seems, into the study of economic phenomena. We have come across a wide variety of mathematical formulae used by economists and business theorists, formulae that have a history of usage and are backed by practical how-to instructions for use. There are also economic laws such as the law of supply and demand. But we have found very few signs of scientific activity in which hypotheses are made, experiments devised, and results published for acceptance or rejection. On such a simple topic as "what is money and where does it come from" there are many positions argued, but no sign of testable hypotheses. Has the law of supply and demand ever actually been tested? Most economic laws appear to be little more than quasi-religious pseudo-scientific beliefs.

In our search for insight into the economic processes of a sustainable economy we did find a few signs of growing interest:

- Econophysics – Yakovenko et al published a study of the "Statistical Mechanics of Money" which lead us to the relatively new branch of heterodox economics called Econophysics. We found both insight and inspiration in many articles published in this field, leading to a better understanding of the nature and cause of distribtions of wealth.
- Ecological Economics – Herman Daly, continuing with the work of Roegen, has injected a more realistic understanding of steady-state economics based on physical systems. Based on readings of his work we began a redesign of the economic engine of ModEco to more correctly represent a mass/energy cycle or flow-through. This work is in progress.
- Biophysical Economics – Charles Hall, continuing with the work of H.T.Odum, has greatly elaborated an understanding of the role of entropy production in economic processes. Based on readings of his work we moved to a metabolism-based determination of value, and have added accounting hooks for contained, embodied, and expended energy. This work is still in progress.

That being said, we were unable to find any writings, backed by scientific studies or otherwise, which looked seriously at the necessary and sufficient characteristics of even a simple sustainable economy.

2.3 Lack of Examples of Agent-based Models

Agent-based modelling is a relatively new and rapidly growing method of study of economic systems. (name articles)

However, no guidance could be found with respect to how to construct a sustainable society for study.

The Association for Computational Economics (ACE) has a subgroup focused on agent-based economic modelling. They maintain a website on which researchers may announce new models with an abstract of capabilities, and, in many cases, the ability to download a working copy. Review of this website failed to turn up any models designed to study complete sustainable economies.

The Journal for Agent-based Simulated Societies (JASS) publishes a quarterly journal with a focus on agent-based computer models. A review of past articles failed to turn up any studies of sustainable economies.

The Journal for Ecological Economics has published many studies based on agent-based models. A review of past articles, however, also failed to turn up any studies of sustainable economies.

In fact, we were disappointed to discover that we could not find any models of complete economies, whether sustainable or not.

2.4 Collapse – The Dark Side of Sustainability

In our search for an understanding of sustainability, we, of course, inevitably, discovered the growing literature about collapse. There were several significant signposts along the way:

- Tainter proposes that societies become more and more complex as they mature until, eventually, they collapse under the weight of their own unsustainable complexity. However, he pulls back from the suggestion that overloading or exhaustion of ecological resources is a primary cause. (Tainter, 1988)
- Diamond, on the other hand, proposes that the ultimate cause of societal collapse is biophysical rather than social. The inability of the land to support the complex society is the primary cause of collapse. (Diamond, 2005)
- Changing the view from the study of the collapse of past complex societies to the predictions for our own society, The Club of Rome, and others are predicting a significant change from growth to decay starting about now. These studies are not sociological in nature, but tend to be founded in the biophysical sciences. (Meadows; Hubbert; Hall).
- For a different perspective, Greer looks not at the possibility of collapse, but at the probable process by which collapse happens. He proposes a process of "catabolic collapse" by which society progressively becomes more simple and smaller through a cascading series of minor collapses and recoveries.

To understand sustainability, do we not need to also understand economic collapse. Under the present circumstances, we can define "sustainability" to mean controlled catabolic collapse to an ultimately sustainable but desirable economy and society.

2.5 The Impact of a Price/Value Gap

To date we have achieved only one economy which is complete, sustainable, and very simple, and we call it the Perpetual Motion Machine, or PMM. It was inspired in part by Paul Hawken's writings about

restorative economies. However, to achieve sustainability we had to build in a variety of constraints such as quotas or limits on flow rates, controls on distribution of assets across asset classes within each agent. We also had to build in flexibility in population sizes, and flexibility in amounts of cash available in the economy. Nevertheless, with all of these constraints and flexibilities, the economies were unstable and ungovernable. The last and most important constraint added was the elimination of the price/value gap in every transaction.

A ModEco-based economy does not include interest on debt. All inflation or deflation of prices comes from the difference between the value of dollars paid and the intrinsic value received. We call this the price/value gap. Agents negotiate prices for each commercial transaction. The basis of an agent's price negotiation is memory of prices paid in previous trades. If all prices paid are at exactly the intrinsic value, inflation or deflation cannot occur, and the economy will run forever.

If you can picture a bicycle wheel mounted on an axle. If you start the wheel spinning, it may spin for a while, depending on the quality of the bearings and the alignment of the wheel. But, eventually, it will run down and stop. We view the constraints and flexibilities that we built into the PMM as metaphors to the axle, wheel, bearings and other design and installation considerations of a bicycle wheel so mounted. But, to make the motion sustainable, we had to eliminate the friction.

In the language of dynamic systems, the PMM is a closed mass/energy system located at an unstable equilibrium point (not a stationary state) in state space. But the situation is a little more comples. On dimensions such as population size and money supply, the PMM wanders away from average values from time to time and returns again. It behaves as if in a stable equilibrium state, and any movement away from the average state is turned by negative feedback, and it returns to the average state. However, on the dimension of price of goods and services, the PMM behaves as if it is on an unstable equilibrium point. Any slight movement of price away from the exact intrinsic value immediately set in motion a cycle of positive feedback that leads ultimately to collapse of the economy.

In order to allow price negotiations within the PMM and remain sustainable, we need to devise a form of negative feedback on price inflation, such that prices never wander too far away from average prices. We have not yet succeeded in that effort.

When considering open mass/energy economies, even the elimination of the price/value gap fails to establish sustainability. That effort, also, is ongoing.

This raises an interesting question: Does profit have a positive role to play in a sustainable market-based economy, or is an economy that allows for profits and losses by definition unsustainable? It is difficult to imagine a market-based economy without profit and loss.

2.6 Sustainability verses Libertarianism

It was originally the intent and design of the ModEco economic engine that all agents would be mortal and would come to an end by reproduction (fission), by starvation (biophysical dynamics) or bankruptcy (economic dynamics). However to achieve the goal of sustainability it was necessary to create two additional immortal central agents that have access to all agents and have perfect knowledge of key aspects of the economy.

The role of the Materiel Manager (MMgr) is to ensure that all agents can easily sell waste mass and all farmers can easily purchase recycled mass for use on the farm. This completes the mass cycle in the PMM (remember, the PMM is a closed mass/energy system) in a way that is least restrictive to the volume of flow. So, the MMgr is both immortal and has full access to all agents, and is not limited to action within a commuting area. Without the MMgr, each farmer would be required to buy recycled mass from consumers within their own commuting area. That did not work. With the introduction of the MMgr, farmers can always buy from the central (i.e. non-localized) agent.

The MMgr has two additional roles. It buys and sells at the average market price for waste/recycled mass, and so must be aware of this market-based price. This significantly dampens the rate of inflation in non-PMM economies. Also, the MMgr can go into debt to purchase waste mass with dollars it does not have. This removes one constraint (conservation of cash) making the system open in this important dimension. Versions of the PMM without this feature require a larger population to avoid collapse before steady state is achieved.

The role of the Estate Manager (EMgr) is to distribute the assets of dead agents fairly among those who are still alive. Assets given to the EMgr are not value-for-value transfers, but, rather, represent free gifts to the EMgr. These assets must be gifted back into the economy. The EMgr is special because it has access to all agents, and is non-localized, and therefore considered a central agent like the MMgr. The means by which the EMgr chooses agents as recipients of these free grants form a kind of public welfare policy. Within the PMM, these grants (variously called estate grants, municipal grants, or welfare grants) are the only means by which an agent can increase its wealth. The distribution policies therefore become very important public policies.

The characteristics of the immortal agents are:

- They do not die, or reproduce, nor do they have biophysical requirements, and, as such, can be viewed as metaphorical to a township bureaucracy;
- They are non-local, and their actions are not limited to any commuting area, nor to any number of agents per tick; that is, they can address the needs of all mortal agents in every tick;
- They complete the mass cycle in a closed mass sytem in such a way that the flow of mass is not hampered by two-dimensional access issues;
- They provide a flexible money supply;
- They execute a public policy for the redistribution of wealth of dead agents.

Libertarian ideals value small government and minimal regulation. The PMM is, on the other hand, a highly regulated society in which quotas are applied to every commercial transaction, prices are strictly controlled, scarce resources (waste mass) are managed by central authorities, and wealth is redistributed by public policy with sustainability goals in mind.

Question: Is any form of economic sustainability compatible with libertarian ideals?

2.7 Sustainability versus Social Justice

However, there is a radically more disturbing observation. In almost all organizations devoted to sustainability, the goals are closely aligned with goals of social justice. Like motherhood and apple pie, these two utopian dreams are both warmly desired and inseparably intertwined in the language of most modern ecological activists. A sustainable society is one which fairly shares the wealth with present and future generations. A just society is one which fairly shares the wealth between members of the present generation.

In addition, most modern utopian thinkers hope to see a future in which the standard of living is substantially above the hard-scrabble subsistence-level of existence that we see in many third-world poverty-stricken countries today.

Unfortunately, in the PMM, these goals are utterly at cross purposes to each other. In the PMM life tends to be short and brutal:

- Fifty percent of every generation die of starvation. In an evolutionary biophysical system it is the evolutionary compulsion of every organism to produce more offspring than have a reasonable chance of survival, to ensure replacement of not only themselves, but others, with their own offspring. Since ModEco agents reproduce by fission, only one of two daughter agents can survive, on average.
- Poor agents must distribute what wealth they have among several mass/energy/cash asset stores. For example, a farmer must maintain stores of cash, recycled mass, inventory, supplies, and waste. A shortage of asset in a particular store (e.g. an amount below quota) may constrain the ability of the farmer to participate in commercial opportunities that come along. The result is, poor agents have radically reduced opportunities to participate in the economy, even though it is a “fair” economy in which they can never lose net worth.
- Those born to wealth get richer, and those born to poverty die young and their wealth, such as it is, is largely transferred to the wealthy offspring of wealthy parents. Since net worth is conserved in commercial transactions, the net worth of agents is decreased only by fission (each daughter gets half) or death (the EMgr gets it all), and the net worth of agents is increased only by grants from the EMgr. In the current implementation, grants are given to agents who have sealed a commercial deal, but have insufficient assets to meet quota. This was intended to give the poor a helping hand, but in effect it propels the middle class into higher wealth brackets. The very wealthy produce

middle-class daughters who climb the ladder back to wealth. The middle class agents produce poor daughters who starve at a young age.

Question: How might you modify the PMM to inject social justice?

- Population control – Enact a policy that limits the offspring per agent. However, this removes the automatic response of the system to the heart-beat throb of a rising and falling population, and the policy would have to be applied unevenly across different generations of agents.
- Divert welfare grants from the middle-class to the poorest – these agents will always be disadvantaged and needing support, creating a welfare class. The middle-class will degrade and the population will rise until all are poor, living mostly on grants.

In even this most simple ModEco-based economy, it is difficult to imagine an acceptable way to merge the goals of sustainability and social justice.

3 Hypotheses About Sustainable Agent-based Model Economies

There are several variations on the scientific method in use in the modern world. The classic method is consistent with the use of agent-based computer models as testing tools. In that method, an hypothesis is made, an experiment is designed to test the hypothesis, and it is either supported or refuted. Scientific laws are merely those hypotheses that have stood the test of time and have not yet been refuted. And failed hypotheses lead to better, more accurately formulated hypotheses that are harder to refute, and may ultimately be viewed as laws.

We believe that further research focused on the nature of simple sustainable economies is needed if we, the human race, are to truly implement economic policies that will craft a sustainable future for our children and our grandchildren. We further believe that the construction and study of agent-based models such as are implemented in ModEco are the most effective way to undertake these research studies. There are many ecologically-minded modelers and researchers around the world who already work with agent-based models, and it is to these people that the following hypotheses are addressed.

Hypothesis #1: We hypothesize that the PMM as found in ModEco is the most-simple complete agent-based sustainable economic model that can be constructed and run to 20 million ticks.

Testability – To disprove the hypothesis, one only needs to build a more simple model which meets the description. The model must still meet the definition of a complete sustainable agent-based economy, i.e. it must have two types of agents (farmers and workers), it is a closed or open mass/energy system, food is harvested, given to consumers, eaten, and the waste is returned to the fields, and all goods and services are exchanged for cash. To be judged more simple, it must remove one of the complicating mechanisms found in ModEco, such as (a) quotas on transactions; or (b) central agents.

Hypothesis #2: It is not possible to construct a complete sustainable agent-based model economy in which all negotiated transactions allow for the possibility of profit and loss.

Testability – To disprove this hypothesis, one only need to build a complete sustainable agent-based model in which prices are set by the negotiating agents.