Model Economy

Design Document

Version 2.03 α

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Overview

The software will be called ModEco, which stands for "Model Economy".

This will be a laboratory in which students of complex adaptive systems can design and run a simple agent-based economic system, in which evolutionary mechanisms drive pricing of goods and services. The goal is to develop an economy which adheres to its internal physical laws, and which is sustainable, or even "restorative", in the sense described in Paul Hawken's book "The Ecology of Commerce", 1993.

There will be two types of agent: Frmrs and Wrkrs. These agents will operate in a large rectangular arena called the "township". They will compete for resources, the competition being under the mediation of price genes. The best-adapted agents will tend to survive and reproduce, while the less-well-adapted agents will tend to perish without offspring.

The township will consist of squares of land (called "lots") which produce Fresh mass/energy units (Meus) when occupied by a Frmr.

The Frmrs may hire workers, and produce, consume, buy and sell materiel. The Wrkrs will do work, and consume, buy and sell materiel.

Cash will be used to pay for work and to buy materiel. Cash will be conserved in all transactions.

All marketable mass will be measured in metabolism-based mass units (MbMus). Energy which can be (or has been) metabolized to do work will be measured in metabolism-based energy units (MbEus). When such energy is bound to a mass, such as in fresh materiel, the coined unit is metabolism-based mass/energy units (MbMEus). These form part of the metabolism-based (Mb) system of units.

For the sake of simplicity, the "" prefix will be ellided in the remainder of this document.

All mass/energy (MEus), mass (Mus) and energy (Eus) will be conserved in all transactions.

The screen will display the township, with variably colored squares representing the different status conditions of lots.

The screen will also display various graphs and panels which show the status of the economy in real time. This display is designed for a resolution of 1024 x 768, and may not display properly on smaller resolutions.

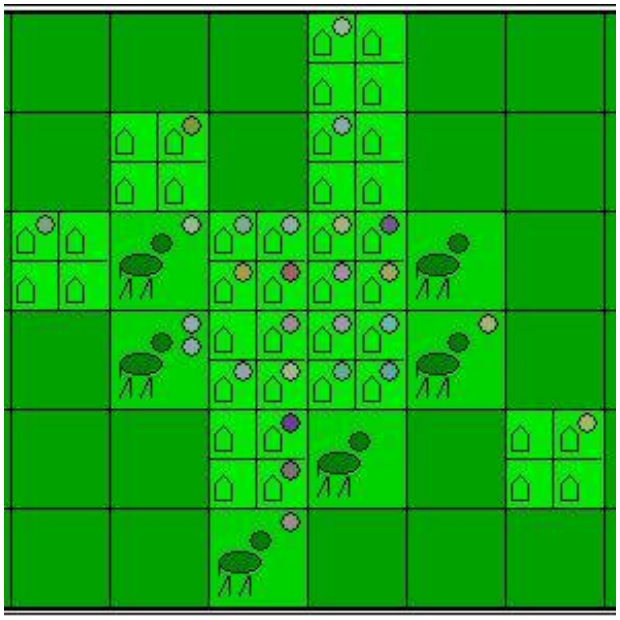
There will be features which enable the collection of data in CSV files (comma-separated value files) which allow analysis of the development of the economy, and analysis of the evolution of agents, using Excel spreadsheets.

Note that as of the current version (2.03a), there are two separate economic engines - the Short Cycle (or "B_") Engine which represents a closed cycle of energy, and the Linear (or "D_") Engine which represents an open system, with energy input from an external source (the Sun) and lost as waste heat to an external sink (bled off into space). Where they differ, this document will reflect the Short Cycle Engine. The access to the linear engine has been hidden under an "Defunct" inactive menu set.

Definitions

The ModEco application is a demonstration economy, and is not a simulation. It provides us a sample "complex adaptive system" in its own right, without reference to other systems. Nevertheless, there are analogies to real-world economies, and it is useful to be mindful of these analogies, while not demanding too much of them. I have therefore developed a lexicon of jargon and technical terms to name the parts and actions in the ModEco system. This lexicon is used to underscore the intended analogies to a real economy, but also to maintain some logical (and psychological) distance between this system and any real-world system. However, to understand any discussion of the system, one needs to learn and know the jargon. The following is a list of such terms having specific technical meaning in the discussion of ModEco.

Township – a rectangular area consisting of a grid of square lots. The township is managed by a pair of quasi-agents called the Materiel Manager (short form – MMgr) and the Estate Manager (short form – EMgr). See below for more details about the MMgr and EMgr.



A portion of the township, showing unspecified lots, farm lots (with horses), and residential lots (with four houses each.

Agent – there are two types of independent agents: Frmrs and Wrkrs, analogous to farmers and workers in a real economy. Such agents operate according to self-interest, each tending to amass greater wealth than the others to better enable the survival of themselves and their own offspring. All agents:

- Reproduce via fission. The parent disappears, and two daughters are produced. One daughter continues to live in the location of the parent, the other must move. If the second daughter cannot move, the parent cannot fission;
- Consume MEus to produce waste Mus, retaining Eus for later use in production;
- Sell waste Mus to the MMgr;
- Interact with other agents and the MMgr via the mediation of price genes.

Frmr – an agent that hires Wrkrs and purchases recycled Mus, and produces inventory MEus for sale to consumers, to become supply MEus. A Frmr is a producer, but also a consumer.

Wrkr – an agent that works for Frmrs and consumes supplies. Wrkrs live in residence lots. Wrkrs are hired (sell Eus) to do work, and produce inventory MEus for a Frmr.

MMgr – the materiel manager is an immortal non-local agent similar to a Frmr, responsible for managing the affairs of the township. However, there are these significant differences:
- The MMgr does not die of old age or bankruptcy and so is immortal;
- The MMgr does not reproduce by fission;
- It buys waste Mus from consumers and sells them as recycled Mus to Frmrs, thus closing the economic cycles for Mus and Cash, and
- Its price genes are the average of its customer's relevant price genes, so it does business at the 'going rate'.

EMgr – The Estate Manager is an immortal non-local agent similar to the MMgr. The EMgr receives the assets of dead agents in trust and returns those assets to the private sector via grants of various kinds. These 'municipal grants' involve Cash, Eus, and Mus (i.e. cash, energy and mass).

Consumer – an agent (Frmr or Wrkr) that purchases inventory MEus, consumes supply MEus, stores the energy as Eus, and sells waste Mus to the MMgr.

MEu – mass/energy unit. The plural is MEus. This is a unit of materiel representing a unit of a commodity which can be bought and sold. An MEu is composed of two parts: a mass based component called an Mu, and an energy based component called an Eu. The Mu represents the mass pulled from the environment. The Eu represents the potential energy added to that mass by the Sun which can be consumed and metabolized by a consumer.

Mu – mass unit. The plural is Mus. This is a quantity of mass which flows through the economy. Recycled Mus are sold by the MMgr to Frmrs. Frmrs hire Wrkrs to add energy and convert those Mus into MEus usable by consumers. After consumers have stripped them of usable energy, they sell the waste Mus to the MMgr.

Eu – energy unit. The plural is Eus. This is a quantity of usable energy flowing through the economy. Consumers consume MEus to store Eus. Wrkrs and Frmrs use Eus to harvest fresh Mus into supply MEus which can be sold to consumers.

Cash – the currency of the township. Cash has no intrinsic value, but it is used by agents to trade for commodities that do.

Contact Lists – Frmrs and Wrkrs maintain lists of contacts called "Contact Lists". A contact list is a list of all agents within the commuting area that could be of interest to the agent. There are union lists, supplier lists, employer lists, and customer lists.

Store – a place in which Mus, Eus, MEus, and Cash are stored. Stores are explained in more detail in the section "The Economy" below.

Conserved Quantities – In a physical system, basic quantities such as energy and mass are conserved. In ModEco, cash, intrinsic value, Eus and Mus are conserved. For more about conserved quantities, see "The Economy" below.

Cash cycle – cash is conserved in all transactions within ModEco. However, if a central agent (the EMgr or NMgr) is allowed to go into debt, this creates ficticious cash in the private sector. Cash circulates through the economy in a complicated cycle.

Mu Cycle – Mus are conserved in all transactions in ModEco. They circulate through the economy in a cycle.

Eu Cycle – Eus are conserved in all transactions in ModEco. They circulate through the economy in a slightly complicated two-route.

Estate Cycles – conserved quantities in the possession of agents revert to the control of the EMgr on the death of those agents. These estate assets are returned to circulation via estate grants. For more about estate cycles, see "The Economy" below.

Estate Grants or ***Municipal Grants*** – The EMgr transfers the estate assets of expired agents back into the private sector of the economy via the use of estate grants to "needy-but-deserving agents". These are sometimes called municipal grants. For more about estate grants, see "The Economy" below.

Quotas – Quotas are a hidden part of ModEco, and may be ultimately unnecessary. All transactions have an upper limit, defined in MEus or Mus, depending on the transaction type. For more about quotas, see "The Economy" below.

Price Gene – is a logical structure which mutates and evolves over time, and which is used to generate a quote for a unit price when an agent is negotiating the price of a commodity.

Gene-mediated Pricing – is the negotiation of a price for a transaction between agents, in which each agent consults its appropriate price gene when formulating a quote. For more about price genes and gene-mediated pricing, see "The Economy" section below.

Value – Materiel has value. Value is measured in three ways: intrinsic value, monetary value, and market value. Each store tracks both content and value. When a unit of any type (MEu, Mu, or Eu) is added to any store, the intrinsic value is added to the intrinsic value of the store, and the monetary value is added to the value of the store. These sums implicitly define an intrinsic value unit price and a monetary value unit price. The market unit price represents the price determined by the last successful negotiation. In ModEco, price negotiations may be based on the intrinsic, monetary, or market unit prices. The use of intrinsic values tends to lead to stabilized economies. The use of monetary prices leads to inflation, deflation, or wild swings.

Intrinsic value (IValue) – is determined by the number of hours of work required to produce the product, plus the value of the materiel inputs. Work (measured in Eus) has intrinsic value. Materiel or mass (measured in Mus) has intrinsic value. The intrinsic value of an MEu is the sum of the values of one Eu plus one Mu. Cash has no intrinsic value. Intrinsic value is currently measured in dollars, but should probably be measured in "days of life", or life units (Lus), or something like that.

Monetary value (MValue) – is determined by the purchase price of the unit. Monetary value is established by negotiations between a buyer and a seller. Monetary value should normally start as equal to the intrinsic value.

Market value (KValue) – is determined by the most recent successful transaction based on that pool. Both Monetary and Market value are determined by the market, but Market Value is set by a single transaction. Market value should normally start as equal to the intrinsic value. KValue is only partly implemented in the current version of the B_ engine in V2.03A.

The Economy

In this section, we look a little more closely at some of the items defined above. Note that the following discussion applies to the Short Cycle Engine.

Stores
Places in which MEus, Mus, Eus, and Cash are stored. There are many stores within ModEco, as follows:

- MMgr stores – the MMgr maintains the following stores:
  - Waste Mu store – in which the MMgr keeps the waste Mus purchased from consumers, and then from which it sells recycled Mus to Frmrs;
  - Cash store – in which the MMgr keeps the cash used to buy waste Mus and sell recycled Mus;
- EMgr stores – the EMgr maintains the following stores in trust:
  - Estate Cash store – in which the EMgr keeps the cash received on the death of agents, and from which it issues cash in the form of Cash grants to consumers;
  - Estate Mu store – in which the EMgr keeps the Mus of all types received on the death of agents, and from which it issues Mus as grants to Frmrs;
  - Estate Eu store – in which the EMgr keeps the Eus received on the death of agents, and from which it issues Eus as grants to Frmrs and Wrkrs.
- Frmr Stores – each Frmr maintains the following stores:
  - Cash store – in which the Frmr maintains its cash;
  - Recycled Mu store – in which the Frmr keeps the recycled Mus purchased from the MMgr, and from which it draws materiel to produce Inventory MEus;
  - Inventory MEu store – in which the Frmr keeps the MEus produced for sale, comprised of joined Mus and Eus;
  - Supply MEu store – in which the Frmr keeps the MEus purchased for its own consumption

  - Eu store – in which the Frmr keeps the residual Eus created during the consumption of Supply MEus;
  - Waste Mu store – in which the Frmr keeps the residual Mus created during the consumption of supply MEus, and from which is sells waste Mus to the MMgr;
- Wrkr Stores – each Wrkr maintains the following stores:
  - Cash store – in which the Wrkr maintains its cash;
  - Supply MEu store – in which the Wrkr keeps the supply MEus purchased for its own consumption.
  - Energy Eu store – in which the Wrkr keeps the residual Eus created during the consumption of supply MEus;
  - Waste Mu store – in which the Wrkr keeps the residual Mus created during the consumption of supply MEus, and from which is sells waste Mus to the MMgr;

Conserved Quantities

In any physical system, there are laws which govern its behavior, and often those laws can be expressed in terms of conservation laws. For example, energy and mass are conserved in any mechanical or chemical system. In ModEco, cash, intrinsic value, Eus, and Mus are each conserved in every transaction (purchase, death, grant). There is also a kind of parity law: the number of Mus and Eus is equal. Each conserved quantity must either cycle through the economy, or be sequestered in pools.

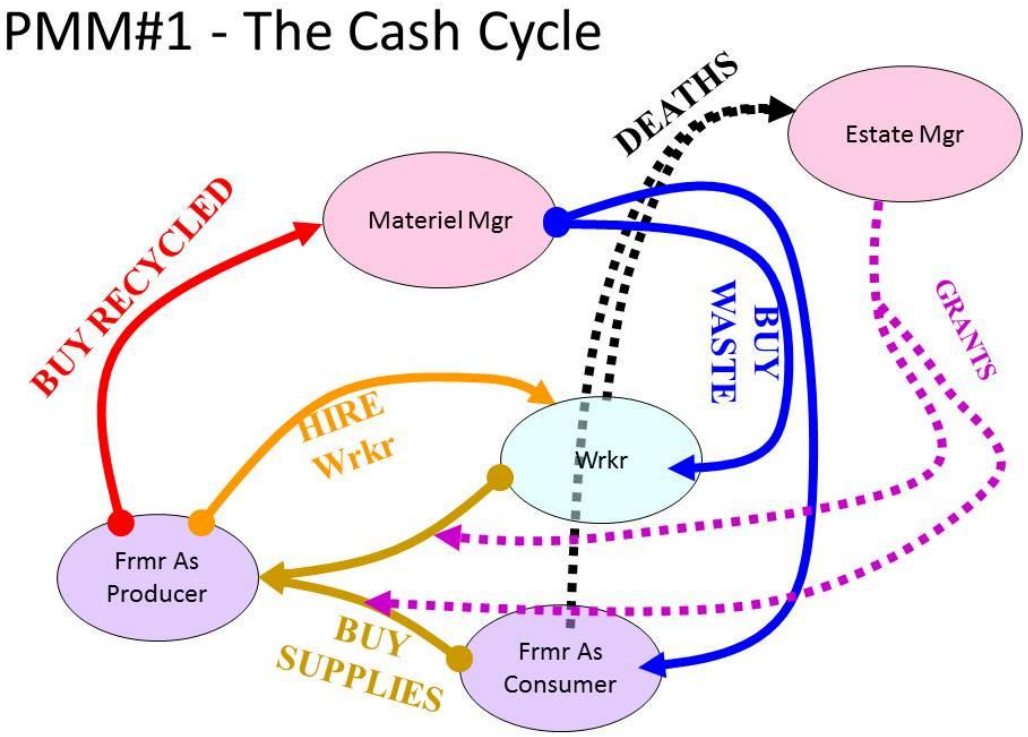
The design of an economy is the design of the flow of these conserved quantities from pool to pool. We must establish paths of flow, and we must regulate the flow of conserved quantities through these paths.

The Cash cycle

Cash is conserved in all transactions within ModEco. It circulates through the economy in a cycle having three routes as follows:

- MMgr route – a dollar:
  - starts in a Frmr's cash store;
  - is paid by the Frmr to the MMgr for recycled Mus;
  - is paid by the MMgr to a consumer for waste Mus;
  - is paid by the consumer to a Frmr for inventory MEus (which become supply MEus in the transaction);
  - is back in a Frmr's cash store.
- Wrkr route – a dollar:
  - starts in a Frmr's cash store;
  - is paid by the Frmr to a Wrkr when it hires the Wrkr to do some work (in a real sense, the Frmr purchases Eus from the Wrkr to pair with its own recycled Mus and Eus to make inventory MEus);
  - is paid by the Wrkr, as a consumer, to a Frmr for inventory MEus (which become supply MEus in the transaction);
  - is back in a Frmr's cash store.
- EMgr route – a dollar:
  - starts in a cash store of an agent, i.e. a Wrkr or a Frmr;
  - is transferred to the EMgr on the death of the agent;

- is given by the EMgr to a consumer in the form of a grant to enhance their ability to purchase inventory MEus; if the consumer has purchased an amount of inventory, but has insufficient cash to pay for all that is available, and the EMgr has the cash grants available, the EMgr will grant an amount of cash sufficient to purchase all of the inventory offered for sale;
- is back in an agent's Cash store.



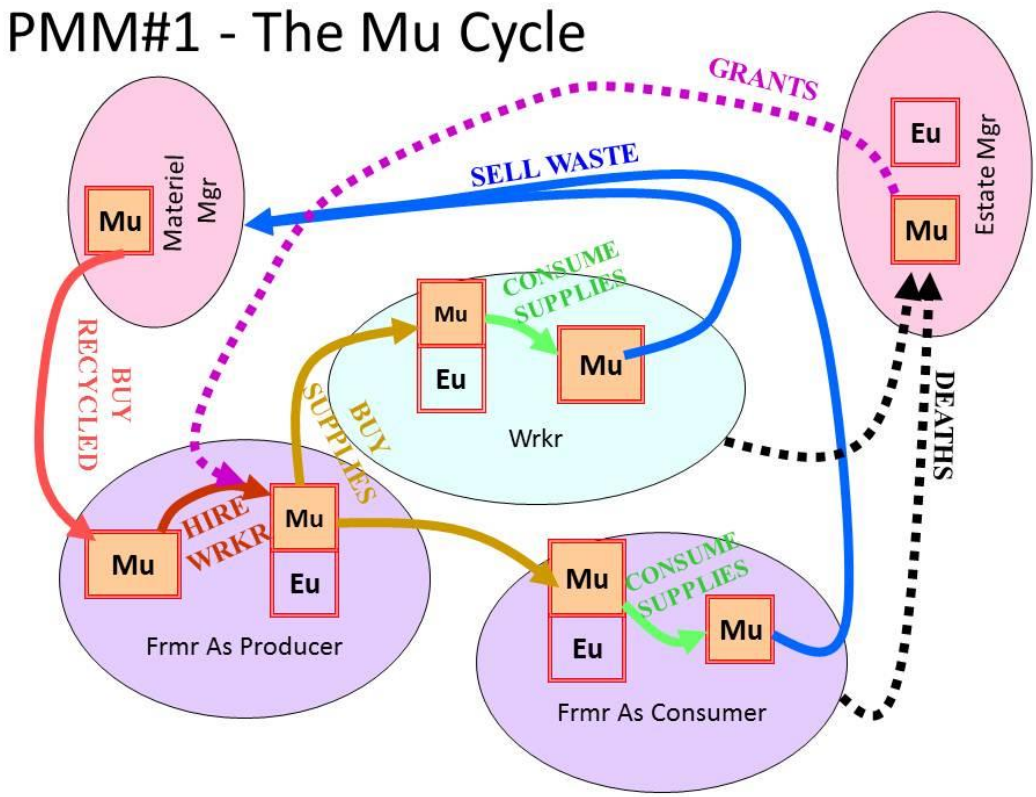
Note that, in the first two routes, value and cash flow in opposite directions for each transaction. However, in the EMgr route, cash flows without the offsetting flow of value in the other direction. The cash is 'granted' to the public sector EMgr on the death of the agents, and must be 'granted' back to the private sector agents. If we don't do this, the EMgr rapidly becomes very wealthy, and those estate pools soak up all value, causing failure of the economy.

The Mu Cycle

Mus are conserved in all transactions in ModEco. They circulate through the economy in a cycle having two routes as follows:

- MMgr route – an Mu:
  - starts as a recycled Mu in the possession of a Frmr;
  - is combined one-on-one with an Eu to make an inventory MEu in the Frmr's inventory MEu store via the 'Hire Wrkr' process;
  - is sold as an MEu to a consumer (either a Frmr or a Wrkr) and placed in the consumer's supply MEu store;
  - is consumed by the consumer, and the supply MEu is separated into its constituent Mu and Eu components, at which time the Mu is placed in the consumer's waste Mu store;

- is sold to the MMgr as waste, and placed in the MMgr's waste Mu store;
- is sold to Frmrs as a recycled Mu;
- and is back in the recycled Mu store of a Frmr.



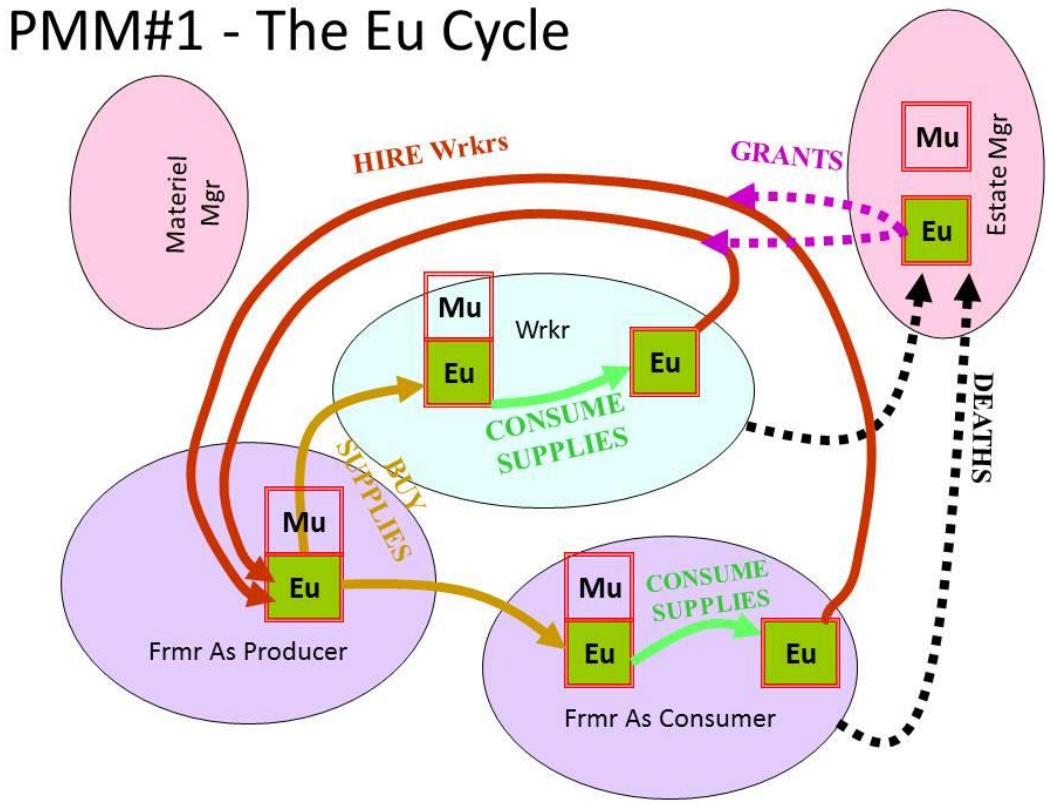
- EMgr Mu route – an Mu:
  - starts in a store of recycled or waste Mus, or supply or inventory MEus held by an agent;
  - is transferred to the EMgr on the death of the agent, where MEus are separated into Mu and Eu constituent components;
  - is given by the EMgr to a Frmr in the form of an Mu grant to enhance their ability to hire Wrkrs; if the Frmr has insufficient recycled Mus to meet a quota, the EMgr tops up the amount to quota; the Frmr does not pay for the extra Mus.
  - is back in a Frmr's inventory MEu store.

The Eu Cycle

Eus are conserved in all transactions in ModEco. They circulate through the economy in a two-route cycle as follows:

- Consumer route – an Eu:
  - starts in a Frmr's inventory MEu store as one component of a combined inventory MEu;
  - is sold to a consumer, a Frmr (not excluding itself) or a Wrkr, at which time it is placed in the consumer's supply MEu store;

  - is consumed by the consumer, at which time the combined supply MEu is separated into constituent Mu and Eu components, and the Eu is placed in the consumer's Eu store;
  - upon successful hiring of a Wrkr, an Eu from the Wrkr and another Eu from the Frmr are combined with two Mus from the Frmr's recycled Mu store to form two inventory MEus, placed in the Frmr's inventory MEu store;
  - and is back in a Frmr's inventory MEu store;
- EMgr Eu route – an Eu:
  - starts in an inventory or supply MEu store, or an Eu store, held by an agent;
  - is transferred to the EMgr on the death of the agent;
  - is given by the EMgr to a Frmr or Wrkr in the form of an Eu grant to enhance their ability to produce inventory MEus; if the Wrkr or Frmr has insufficient Eus to complete the production, the EMgr tops up the amount to quota; the receiver does not pay for the extra Eus.
  - is back in an agent's store.



Estate Cycles

The estate cycles which are part of the above-described cycles are specially devised. Conserved quantities must have special treatment on the death of an unsuccessful agent. All mass and energy units are placed into the estate stores of the EMgr. Similarly, the cash goes into the EMgr estate cash store. This represents a transfer of conserved quantities from the private sector to the public sector. Without a reciprocal transfer of these conserved quantities back into the private sector of the economy, the EMgr gradually accumulates all of the conserved quantities and the economy starves for lack of access to these key resources. (This is clearly reminiscent of the

concentration of land, wealth and power in the hands of an elite as an economy matures.) ModEco addresses this via the use of municipal 'estate' grants, as described above.

The need for these cycles arises from the intent to base each ModEco economy on a conservative and sustainable "Perpetual Motion Machine" (PMM). In the study of physics it is common practice to abstract a complicated system, removing complications through 'simplifying assumptions', and solve the simple underlying physics, before adding the complications back in. For example, when studying the simple pendulum, we first assume no friction on the fulcrum, no wind resistance, and no large angles. We can then ignore all effects of friction, and we can avoid complicated math. Our analysis then works for a pendulum which appears to run forever. To understand real pendula, we need to then, carefully, add the complicating factors back into the analysis.

In a similar fashion, we want ModEco to be able to first produce a simplified economy which conserves all appropriate quantities, and which is also able to run forever. Once we have this 'friction-free' PMM running, we can then add the complicated embellishments that were initially abstracted away.

In an economic system, cash and value flow in opposite directions. We define a strictly conservative system as one which is conservative in every transaction, which exchanges exactly the right cash for the precise value of materiel (whether Mus, Eus, or MEus) being transferred. For every agent (Frmr or Wrkr) every transaction involves the expenditure of cash for precisely the same value of materiel. The net worth of any and all agents paticipating in the commercial cycles of the economy, including the MMgr, will never change in such a system.

So, what do we do in a strictly conservative economy when an agent dies? There is a substantial amount of cash and materiel which will be transferred to another agent without a reciprocal flow back to the dead agent.

Several options were considered:

- Let the estate assets flow to the next of kin such as a sister, or nearest cousin. This option was discarded for two reasons. First, it would be very difficult to keep track of a matrix of relationships. Second, we might be supporting the continued existence of a genetically weak agent, and thereby subverting the effects and intent of the evolution of price genes.
- Let the estate assets flow to the MMgr. Such a one-way unreciprocated flow of wealth to one agent soon causes the economy to starve for lack of resources.
- Let the estate assets flow to the EMgr, but make the EMgr keep track of the assets received in such unreciprocated flows of wealth, and let it be given back in subsequent ticks to genetically deserving agents which are momentarily short of assets.
- Redistribute the assets evenly across all surviving agents. This may dampen the effects of evolution by propping up genetically unfit agents, but it may also avoid a potential bias towards middle-class agents introduced by the previous method.

The third option was implemented by default. Genetically deserving agents are determined as follows. For almost every type of transaction there is an upper limit on the amount of materiel that might change hands, called a quota. Once two agents agree on a price, they determine whether they have sufficient cash and/or materiel to meet the quota. Either buyer or seller might

fall short of quota. They have proven that they are genetically able to compete in the free market, by reason of their agreement on a price. An agent that discovers it is short of cash or materiel may apply to the EMgr for an appropriate grant of cash, Mus, or Eus. The EMgr will then give a municipal grant, if it has the resources in its estate pools, up to the amount of the quota.

The fourth option is also available as a toggle in the Initialization Wizard, as "Even Asset Distribution" grants.

The Intrinsic Value Cycle

Intrinsic Value is conserved in all transactions of all types. In some sense, in this model, intrinsic value is analogous to energy in a physical system, as it is ubiquitous, and always conserved, even in the absence of mass. Mus are analogous to mass in a physical system. I have invented Eus to carry intrinsic value in the absence of mass. An Eu represents the health and well-being of a Wrkr or Frmr; i.e. the ability to do a day's work. This health comes from eating supplies and producing waste (feces, urine, sweat, carbon dioxide in his breath, etc.). Thus, the intrinsic value of the food is transferred to the intrinsic value of the Eu. The intrinsic value cycle is a juxtaposition of the Mu cycle and the Eu cycle, as these are the two types of vehicles that carry intrinsic value, and each type of unit is tied to its intrinsic value.

Municipal Grants

The EMgr transfers the estate assets of expired agents back into the private sector of the economy via the use of estate grants to "deserving agents". Such grants are organized into programs, and are managed as follows:

- **Frmr Recycled Mu Grants** – when a Frmr has negotiated to hire a Wrkr, and a gene-mediated price has been settled upon, but the Frmr has insufficient recycled Mus to meet the quota, the Frmr may apply for a recycled Mu grant from the estate Mu store to complete the quota. Such a grant is provided to the agent free of charge. The net worth of the agent will rise by the monetary value of the granted Mus.
- **Frmr and Wrkr Eu Grants** – when a Frmr has negotiated for the hiring of a Wrkr to do work, and a gene-mediated price has been settled upon, but the Frmr or Wrkr has insufficient Eus to meet the production quota, the agent may apply for a Frmr or Wrkr Eu grant from the estate Eu store to complete the quota. Such a grant is provided to the agent free of charge. The net worth of the agent will rise by the monetary value of the granted Eus
- **Frmr and Wrkr Cash Grants -** When a consumer (a Frmr or a Wrkr) has negotiated the purchase of a quota of supply MEus from a Frmr's inventory, and when a gene-mediated price has been settled upon, but when the consumer has insufficient cash to purchase the entire quota, the consumer may apply for a Frmr Cash grant or a Wrkr Cash grant respectively, to be drawn from the estate Cash store. Such a grant is provided to the consumer free of charge. The net worth of the consumer will rise by the monetary value of the granted cash.

Even Asset Distribution Program

This program is mutually exclusive with the other programs. Instead of allowing agents to apply for grants on successful transactions, the EMgr simply distributes all assets evenly across surviving agents when an agent dies. It is enabled in the Grants tab of the IWiz or EWiz.

Process Quotas

Process quotas are a hidden part of ModEco, and may be ultimately unnecessary. If a wealthy Frmr goes to the MMgr to purchase recycled Mus, and it buys all of the Mus, all other Frmrs are then unable to get access to necessary supplies. To spread the access to scarce supplies, quotas are put in place. When a Frmr hires a worker to produce a day's worth of inventory for a day's work, it could pay a single Wrkr to work all of the available recycled Mus. Other workers would not have access to the Frmr, and would not have access to cash. To spread the access to restricted cash, quotas are implemented here. The system of quotas is as follows:

- Recycled Mus – Frmrs may purchase a maximum of 160 Mus from the MMgr per tick;
- Daily Work Rate – Frmrs and Wrkrs may expend a maximum of 20 Eus per tick, per hire. This also limits the number of Mus a Frmr can convert to inventory MEus to 40 per hire, or 160 per tick.
- Inventory MEus – Consumers may purchase a maximum of 40 inventory MEus from a Frmr per tick;
- Supply Mus – Consumers may consume a maximum of MPT supply Mus from their supply store per tick; MPT is a life function parameter which is 16 for Frmrs and 4 for Wrkrs;
- Waste Mus – a consumer can sell unlimited waste Mus per tick;
- Minimum Quota – There is no minimum quota for sales or purchases. Partial Mus are bought and sold.

Contact lists

As mentioned above, agents maintain a variety of contact lists by which they proceed with each day's business. In summary, agents maintain the following lists:

Frmrs:

- Union list – a list of potential hires within its commuting area, all are Wrkrs;
- Customer list – a list of agents to which it can sell inventory, consisting of all Wrkrs and Frmrs within its commuting area, including itself.
- Supplier list – a list of agents from which it can purchase supplies, consisting of all Frmrs within its commuting area, including itself.

Wrkrs:

- Employer list – a list of all Frmrs within its commuting area, to which it can apply daily for work.
- Supplier list – a list of Frmrs from which it can purchase supplies, all within its commuting area.

The township's MMgr maintains two master lists used for selling recycled Mus, and purchasing waste Mus:

- Frmr list – a list of all Frmrs within the township, to which it can sell recycled Mus, from which it can purchase waste Mus.
- Wrkr list – a list of Wrkrs within the township, from which it can purchase waste Mus.

No contact list is required for the EMgr, as needy agents must apply for estate grants.

Technical note: since the contact lists of agents may be small or large, and constantly changing in size and content, I have implemented a single database of contact cards. Each agent has a rolodex-like set of records (a two-way linked list) within this static database. The contact lists can be viewed by the user.

Commuting Ranges

The contact lists of the MMgr are township-wide. The contact lists of the Frmrs and Wrkrs are always limited to agents within a commuting range of (E.g.) 5 squares. The eligible area then consists of ((2*5)+1)^2 = 121 squares. Here is a table of possible commuting ranges, with associated numbers of squares.

Range	Area	Wrkrs	Frmrs
1	9	18	4.5
2	25	50	12.5
3	49	98	24.5
4	81	162	40.5
5	121	242	60.5

So, using a commuting range of 5 as an example, there are 121 squares within commuting range of each square. If we presume that half are occupied by residences full of workers, and half are full of Frmrs able to hire workers, there should be an exact match of jobs to workers. Every farm should have 242 workers on its worker list, and every worker should be on the worker list of 60 to 61 farms. This concept is drawn from the design of cellular automata in which the letter ‘k’ is used for the range, and the square so determined is called the k-neighborhood of the cell.

Similarly, workers and Frmrs will maintain a list of all sellers of produce. Such a list of sellers might have 242 workers and 61 Frmrs, for a total of approximately 303 entries.

Design issue: I expect that a smaller commuting range will result in faster evolution, as there will be a higher probability that (a) Frmrs cannot hire from their standby list, and (b) Wrkrs cannot find suitable employment. I need to tinker with the range to find the best setting. Possibly different settings will demonstrate different types of economy such as turbulent new technologies or established stable technologies. That would be cool, though unlikely. For now, the default range is 2. This is set at time of compilation, and is not user selectable.

Initiation Wizard and Economic Wizard

The Initiation Wizard allows a user to modify a number of parameters that control the behavior of the economy. (See Annex G.) These were developed with three things in mind:

- To use the experience gained from the programming of PSoup, a demonstration of an evolutionary ecology;
- To use the understanding of physical systems in which basic quantities are conserved, and for which simplifying idealizations (such as, temporarily, ignoring friction) lead to substantial insights into the dynamics;
- To build an economic system which is not just sustainable, in the common understanding of that word, but “restorative”, in line with the concepts described in Paul Hawkins book “The Ecology of Economics”.

The Economic Wizard (EWiz) is a version of the IWiz with more limited functionality allowing some of the parameters to be changed during a demonstration's run.

Some of the parameters control life functions such as birth rate, death rate, resource consumption rate, and so on. These were borrowed from PSoup and the defaults are set at those values that work well in PSoup, providing a reasonable trade-off between (a) quickness of evolution and (b) opportunity for the law of large numbers to take a necessary role.

Some of the parameters control business policy decisions, such as when to buy materiel of various types. Without these controls, materiel tends to pool in a single type of resource, and the system collapses.

There are three fundamentally different behaviors which have been identified so far, and which should be examined in more detail:

- The "Perpetual Motion Machine", in which (a) mutations are turned off; (b) all price negotiations are based on the intrinsic values, eliminating inflation; and (c) the mean of all of the price genes is set to one, and the standard deviation is set to zero, ensuring that all quotes to buy or sell are exactly equal to the intrinsic value. Such a system is analogous to a physical system which has no friction, and therefore will run forever using only its original energy.
- The inflationary system, in which prices inflate until the economy collapses.
- The deflationary system, in which prices deflate until the economy collapses.

The first of these is the 'holy grail' of sustainable economies. By examining this economy we understand how ModEco works. The other two are expected, but at the same time surprising and wonderful. I don't know why one inflates and the other deflates.

I am excitedly looking forward to analyzing these behaviors.

Gene-Mediated Pricing

When two agents negotiate a price for a commodity, they each consult their appropriate price genes, each produce a "quote", and then, if the quotes are acceptable, settle on a price. Context or prior dealings are not considered in the preparation of a quote. Gene-mediated prices proceed as follows:

- Each time a materiel unit (Mu, Eu, or MEu) changes hands, the buyer and seller negotiate a price.
- The buyer tries to minimize the price.
- The seller tries to maximize the price.
- An offer to sell is called a quote and consists of:
  - Type of unit;
  - The basis of the quote (IValue or MValue);
  - Minimum acceptable price per unit (a unit price).
- An offer to buy is called a quote and consists of:
  - Type of unit;
  - The same basis of the quote (IValue or MValue);
  - Maximum acceptable price per unit (a unit price).
- Each agent has a specific price gene for (a) that type of unit, and (b) that type of transaction (buying or selling). The buyer consults its appropriate "buy" gene for that type of unit. The

seller consults its appropriate sell gene for that type of unit. Each produces its quote independently of the other.
- If the seller's asking price is less than the buyer's offer, then both will be happy. The agreed-upon price will be the average of the two. However, if the seller's asking price is more than the buyer is willing to pay, the negotiations end, and there is no deal.
- Over time, the buyers and sellers compete for access to resources, and the best-adapted genes will prevail, giving their owners more successful transactions, and greater success in life. The least-well adapted genes will fail to complete transactions, or will result in bad (money-losing) transactions, and the owners will fail to thrive, and die of starvation or old age.
- All grants provided by the EMgr are free of charge, but can only be given as part of a successful gene-mediated transaction. This may dilute the evolutionary pressure on the genes (as a bad price results in benefits that counteract the bad price), but failure to negotiate a price, at least, is not rewarded.

Both seller and buyer generate their unit prices using a value for μ (mu; mean unit price) and σ (sigma; standard deviation of unit price) and the formula:

$$U = p(\mu + x\sigma)$$

where U is the unit price, p is the intrinsic or monetary value per unit, and x is a randomly generated variate with mean of zero and standard deviation of one. The random variate 'x' is generated using the Box-Muller formula:

$x = \sqrt{-2 \bullet \ln(x_1)} \bullet \sin(2\pi \bullet x_2)$ where x_1 and x_2 are random variates with a uniform distribution (as is produced by most computer-based pseudo-random number generators).

Both buyer and seller set the extended price P as P = MU, where M is the number of units of materiel, and U is the unit price.

The complete equation is then $P = Mp\left(\mu + \left[\sqrt{-2 \bullet \ln(x_1)} \bullet \sin(2\pi \bullet x_2)\right]\sigma\right)$.

Genetic Controls

The values of μ (mu) and σ (sigma) for buying and selling are determined via the price gene. There are eight numbers stored in a price gene as shown in the table below.

Each agent should have one price gene for each type of transaction in which they are regularly involved, such as buying supply MEus or selling waste Mus. More explicitly, agents have the following genes:

Frmrs:
- Buy Recycled (Mus) gene
- Buy Labor (Eus) gene
- Sell Inventory (MEus) gene
- Buy Supply (MEus) gene
- Sell Waste (Mus) gene

Wrkrs:
- Sell Labor (Eus) gene
- Buy Supply (Mus) gene
- Sell Waste (Mus) gene

Table of Price Gene Components

Purpose	**Initial Value**
Mu – numerator (N >= 0, N an integer)	20
Mu – denominator (D > 0, D an integer)	20
Mu – delta (an integer)	1
Mu – Strength = numerator / denominator	1.00
Sigma – numerator (N >= 0, N an integer)	10
Sigma – denominator (D > 0, D an integer)	100
Sigma – delta (an integer)	1
Sigma – Strength = numerator / denominator	0.10

MMgr
- Sell Recycled (Mus) gene *
- Buy Waste (Mus) gene *

* Note that the MMgr does not (cannot) evolve because it is immortal and non-reproducing, but nevertheless plays a central role in the economy. I have therefore decided to allow its genes to change in a manner that does not bias the evolutionary pressure on the price genes. The genes of the MMgr have the average values of all of the genes of the agents with which it must deal. So, the "Sell Recycled Mus" genes of the MMgr are the average of the "Buy Recycled Mus" genes of the Frmrs. The "Buy Waste Mus" genes of the MMgr are the average of the "Sell Waste Mus" genes of all consumers, which means all Frmrs and all Wrkrs.

You could say that the MMgr participates in the economy "at the going rate".

Mutation of Genes
A few words need to be said about the role of the eight components of a price gene and the effects of mutation.

A price gene has two main components, the mean (μ) and the standard deviation (σ), used to generate a random normal variate via a formula called the "Box-Muller Formula". Each of μ and σ has the ability to mutate independently of the other. Suppose the "probability of mutation" in the "ModEco Control Panel" is set to 0.125, then upon production of a new daughter during fission, each μ, and each σ in each price gene has a 0.125 probability of mutation.

Each of these main components is computed as a positive ratio called the strength. So the "strength" of μ is actually the number used in the Box-Muller formula, and the "strength" of σ is similarly used. These strengths are computed by dividing the correct numerator by the correct denominator.

When it has been decided that one of these two main components μ or σ should change, then:
(a) either (i) the numerator changes by delta; or (ii) the denominator changes by delta; with the condition that the numerator and denominator must remain positive integers; and
(b) the delta then changes up or down by one.

On fission, each of the price genes is processed as follows:
- A random number between zero and one is generated using the PRNG (pseudo-random number generator) and if it is greater than the "probability of mutation", then μ does not mutate, and the process jumps to treatment of σ.
- If the algorithm decides that either μ or σ or both will mutate, it then processes the numerator, denominator and delta, as may be required, as follows:
  - The algorithm decides whether the numerator or the denominator will change by an amount equal to delta, each option having equal probability. The selected value is changed by delta, and a new strength is computed.
  - Finally, the algorithm decides whether to change the delta by one (allowing for larger changes in gene strengths per mutation) or decrease it by one. A value of delta equal to zero causes it to bump back up to 1. Delta is always a positive integer.

In summary, if the first random number indicates that a mutation will happen to a main component, then:

- Its numerator or denominator will change, and
- Its delta will change, or be bumped back from 0 to 1.

I view evolution of a price gene in the following way. We start with two initial ratios, say $\mu = 10/10 = 1$; and $\sigma = 10/100 = 0.1$. Call this the initial value (μ_O, σ_O). I assume there is an ideal or optimum price gene (μ_N, σ_N). Any change which makes the agent more competitive (better adapted) will survive and replicate itself. The history of a successful price gene is a series of pairs of ratios which progressively approach the ideal. For this to happen, the denominators must be able to get large (providing a more finely grained grid of possible values) and the speed of change needs to adjust appropriately.

The deltas do not play any direct role in the economy, but, rather, govern the rate at which the means and standard deviations can change. In a very long run, the speed at which a gene races towards its ideal value will determine the winner of the race. The delta is the accelerator. Good mutations of the delta will therefore play a large role in determining the nature of the competitive landscape in the mid-term, and in the long run.

The deltas are therefore indirectly phenotypic, as a change will affect the rate of mutation of genes over generations, but will not be acted upon by the environment in this generation. The deltas should increase or decrease by 1 each time they mutate. This means the rate of change of the mu and sigma values is under evolutionary pressure. A good long-term mutation consists of a change in the mu or sigma in the right direction, combined with a change in the associated delta in the right direction, followed, a generation later, by another change in the mu or sigma in the right direction.

Let's look at a few numbers. A Wrkr has three price genes. A Frmr has five price genes. Let's focus on the Wrkr. When a Wrkr goes through fission two daughters are formed. Six new genes are formed and twelve opportunities for mutation occur (recall μ and σ are independent). If "p" is the probability of a good mutation (good ratio change and good delta change), then the probability that exactly n good mutations will occur is $C(12, n) p^{n}(1- p)^{12-n}$. A reasonable value for "p" is 0.25 times the probability of mutation. Using this formula, P(at least one good mutation) is the same as 1 – P(no mutations) ≈ 0.32. This looks good, but a good mutation might be undercut by a simultaneous bad mutation. To get a good look at the real probabilities, we will need to work out a more detailed analysis. This would be useful in finding a formula for the expected speed of evolution.

Annex A – About Counts

You can view the "counts" panel by clicking on the "S" (for status) button on the toolbar a few times.

This presents a running count of objects and events of interest as a run of ModEco proceeds. The counts have an upper limit of 999,999,999. If they exceed this number, then they revert to 1. So if you do a VERY long run, and see some anomalous statistics, then that may be the reason.

COUNTS of agents and events in the current run of the model economy.

Frmr Repros: 114	Contacts: 12454 of 60000	Wrkr Moves: 0	Consume Supply: 76607	Sw - Percent: 100.0
Frmr Deaths: 5		Wm - Yes: 0		
Frmr Fissions: 17	Job Offers: 17814	Wm - No: 0	Buy Recycled: 3208	
Frmrs: 92 of 1200	Jo - Deal: 17814		Br - Deal: 3208	
	Jo - No Deal: 0	Sell Inventory: 14336	Br - No Deal: 0	
Wrkr Repros: 460	Jo - Percent: 100.0	Si - Deal: 14336	Br - Percent: 100.0	
Wrkr Deaths: 23	Jo - Wrkr Energy Gts: 170	Si - No Deal: 0		
Wrkr Fissions: 70	Jo - Frmr Energy Gts: 361	Si - Percent: 100.0	Sell Waste: 76607	
Wrkrs: 367 of 4800	Jo - Frmr Mass Gts: 66	Si - Frmr Cash Gts: 4	Sw - Deal: 76607	
		Si - Wrkr Cash Gts: 19	Sw - No Deal: 0	

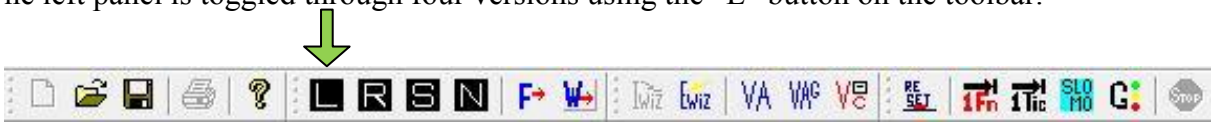
The things counted, and their meaning, are as follows:

- **Frmr Repros** – The total number of Frmrs placed into the township, including creations at initiation of the system, and daughters produced by fission.
- **Frmr Deaths** – The number of Frmrs who have died from starvation or old age.
- **Frmr Fissions** – The number of Frmrs who have been removed from the township due to fission. When a parent goes through fission the Frmr Repros grows by two and the Fissions grows by one.
- **Frmrs: xx of 1200** – The number of Frmrs currently alive in the township, being calculated as Repros – (Deaths + Fissions). There is an upper limit of 1200 Frmrs in the township. The actual number rarely climbs above 100.
- **Wrkr Repros** – The total number of Wrkrs placed into the township, including creations at initiation of the system, and daughters produced by fission.
- **Wrkr Deaths** – The number of Wrkrs who have died from starvation or old age.
- **Wrkr Fissions** – The number of Wrkrs who have been removed from the township due to fission. When a parent goes through fission the Wrkr Repros grows by two and the Fissions grows by one.
- **Wrkrs: xx of 4800** – The number of Wrkrs currently alive in the township, being calculated as Repros – (Deaths + Fissions). There is an upper limit of 4800 Wrkrs in the township. The actual number rarely climbs above 400.
- **Contacts: xxx of 60000** – The number of records in the common data base of two-way linked lists of contacts, as maintained by agents. All lists of all agents are included in the count. There is a maximum of 60,000 contact records. The actual number rarely climbs above 10,000.
- **Job Offers** – The number of times a Frmr and a Wrkr have tried to negotiate a price for a day's work.

- **Jo - Deal** – The number of such negotiations which have resulted in a successful hire.
- **Jo - No Deal** – The number of such negotiations which have resulted in failure to hire.
- **Jo – Percent** – The percentage of successful Jo negotiations.
- **Jo – Wrkr Energy Gts** – The number of hires in which a Wrkr with a shortage of Eus applied successfully to the EMgr for an Eu grant, to enable it to work through a more complete day.
- **Jo – Frmr Energy Gts** – The number of hires in which a Frmr with a shortage of Eus applied successfully to the EMgr for an Eu grant, to enable it to support the worker to work through a more complete day.
- **Jo – Frmr Mass Gts** – The number of hires in which a Frmr with a shortage of recycled Mus applied successfully to the EMgr for a recycled Mu grant, to enable it and the worker to work through a more complete day.
- **Wrkr Moves** – The number of times a Wrkr, running low on cash and supplies, has failed to find employment, and so has tried to pick up and move to another lot in the hopes of finding word.
- **Wm - Yes** – The number of moves that have succeeded.
- **Wm - No** – The number of moves that have failed.
- **Wm – Percent** – The percentage of successful Wm attempts.
- **Sell Inventory** – The number of times a Frmr has attempted to sell inventory MEus.
- **Si - Deal** – The number of times the negotiations have been successful.
- **Si - No Deal** – The number of times the negotiations have not been successful.
- **Si – Percent** – The percentage of successful Si negotiations.
- **Si - Frmr Cash Gts** – The number of successful applications for consumer grants by Frmrs for cash in support of the purchase of inventory.
- **Si - Wrkr Cash Gts** – The number of successful applications for consumer grants by Wrkrs for cash in support of the purchase of inventory.
- **Consume Supply** – The number of times a consumer (Frmr or Wrkr) has consumed supply MEus and produced waste Mus and Eus.
- **Buy Recycled** – The number of times a Frmr has attempted to negotiate the purchase of recycled Mus from the MMgr.
- **Br - Deal** – The number of such negotiations that have been successful.
- **Br - No Deal** – The number of such negotiations that have been unsuccessful.
- **Br – Percent** – The percentage of successful Br negotiations.
- Sell Waste – The number of times a consumer (Frmr or Wrkr) has attempted to sell waste to the MMgr.
- **Sw - Deal** – The number of such negotiations that have been successful.
- **Sw - No Deal** – The number of such negotiations that have been unsuccessful.
- **Sw – Percent** – The percentage of successful Br negotiations.

Annex B – Left Panel Documentation

The left panel is toggled through four versions using the "L" button on the toolbar.



The five versions are:

- Focus on Mass and Nrg Units
- Focus on Intrinsic Values
- Focus on Monetary Values
- Focus on Current Data

```
 --- FOCUS ON MASS AND NRG UNITS ---
Units: Metabolism-based MEus, Mus or Eus
FRMR AGGREGATES -
                    Current     Previous     Increase
  Energy MbEus:      6761.0       6606.0        155.0
Recycled MbMus:     14962.0      15932.0       -970.0
 Inventry MEus:     23568.0      21550.0       2018.0
   Supply MEus:     22764.0      23892.0      -1128.0
   Waste MbMus:         0.0          0.0          0.0
-------------------------------------------------------
   Total MbMus:     61294.0      61374.0        -80.0
   Total MbEus:     53093.0      52048.0       1045.0

WRKR AGGREGATES -
                    Current     Previous     Increase
  Energy MbEus:     15273.0      15110.0        163.0
   Supply MEus:     20434.0      21642.0      -1208.0
   Waste MbMus:         0.0          0.0          0.0
-------------------------------------------------------
   Total MbMus:     20434.0      21642.0      -1208.0
   Total MbEus:     35707.0      36752.0      -1045.0

MMGR AGGREGATES -
                    Current     Previous     Increase
    Mass MbMus:      7072.0       5784.0       1288.0

EMGR GRANT AGGREGATES -
                    Current     Previous     Increase
 Gt Mass MbMus:         0.0          0.0          0.0
Gt Enrgy MbEus:         0.0          0.0          0.0

TOWNSHIP OVERALL AGGREGATES -
                    Current     Previous     Increase
    Mass MbMus:     88800.0      88800.0          0.0
  Energy MbEus:     88800.0      88800.0          0.0

MbMEus=BLACK; MbMus=BLUE; MbEus=GREEN.
```

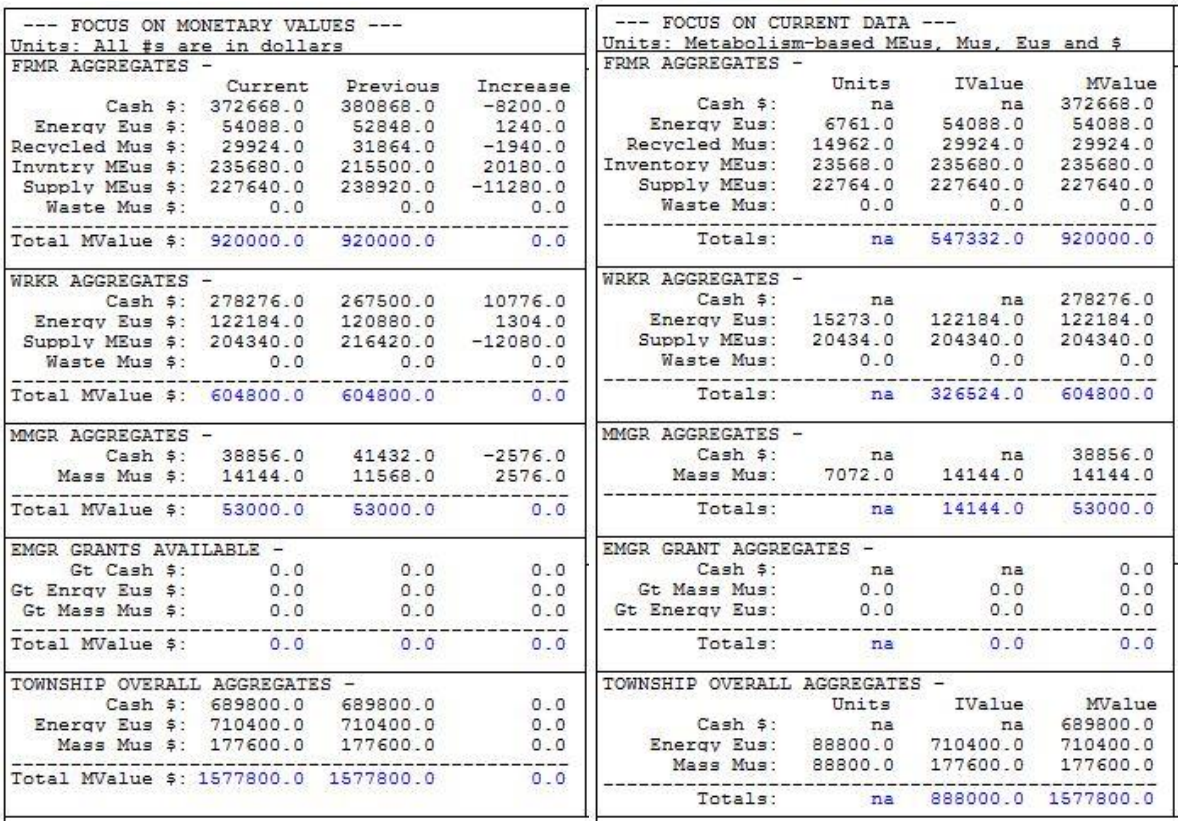
```
 --- FOCUS ON INTRINSIC VALUES ---
Units: All $s are in dollars
FRMR AGGREGATES -
                    Current     Previous     Increase
  Energy Eus $:     54088.0      52848.0       1240.0
Recycled Mus $:     29924.0      31864.0      -1940.0
Invntry MEus $:    235680.0     215500.0      20180.0
 Supply MEus $:    227640.0     238920.0     -11280.0
   Waste Mus $:         0.0          0.0          0.0
-------------------------------------------------------
Total IValue $:    547332.0     539132.0       8200.0

WRKR AGGREGATES -
                    Current     Previous     Increase
  Energy Eus $:    122184.0     120880.0       1304.0
 Supply MEus $:    204340.0     216420.0     -12080.0
   Waste Mus $:         0.0          0.0          0.0
-------------------------------------------------------
Total IValue $:    326524.0     337300.0     -10776.0

MMGR AGGREGATES -
                    Current     Previous     Increase
    Mass Mus $:     14144.0      11568.0       2576.0

EMGR GRANT AGGREGATES -
                    Current     Previous     Increase
Gt Enrgy Eus $:         0.0          0.0          0.0
 Gt Mass Mus $:         0.0          0.0          0.0
-------------------------------------------------------
Total IValue $:         0.0          0.0          0.0

TOWNSHIP OVERALL AGGREGATES -
                    Current     Previous     Increase
  Energy Eus $:    710400.0     710400.0          0.0
    Mass Mus $:    177600.0     177600.0          0.0
-------------------------------------------------------
Total IValue $:    888000.0     888000.0          0.0
```

The first three of these four versions of the panel have the same layout and structure, and vary only in the content displayed. For the first three versions, there are four columns:

- Column of item stubs
- Current data, aggregated during the current tick, or, if the "1 Fn" toolbar button was clicked, during the execution of the most recent function.
- Previous data, aggregated during the immediately preceding tick (or Fn).
- Increase, being the difference between the current data and the previous data.

For the final version, all four columns refer to the most recent tick (or Fn):

- Column of item stubs showing quantity type and unit type
- The number of units.
- The intrinsic value (IValue) of the units.
- The monetary value (MValue) of the units.



--- FOCUS ON MONETARY VALUES ---
Units: All $s are in dollars

FRMR AGGREGATES -

	Current	Previous	Increase
Cash $:	372668.0	380868.0	-8200.0
Energy Eus $:	54088.0	52848.0	1240.0
Recycled Mus $:	29924.0	31864.0	-1940.0
Invntry MEus $:	235680.0	215500.0	20180.0
Supply MEus $:	227640.0	238920.0	-11280.0
Waste Mus $:	0.0	0.0	0.0
Total MValue $:	920000.0	920000.0	0.0

WRKR AGGREGATES -

Cash $:	278276.0	267500.0	10776.0
Energy Eus $:	122184.0	120880.0	1304.0
Supply MEus $:	204340.0	216420.0	-12080.0
Waste Mus $:	0.0	0.0	0.0
Total MValue $:	604800.0	604800.0	0.0

MMGR AGGREGATES -

Cash $:	38856.0	41432.0	-2576.0
Mass Mus $:	14144.0	11568.0	2576.0
Total MValue $:	53000.0	53000.0	0.0

EMGR GRANTS AVAILABLE -

Gt Cash $:	0.0	0.0	0.0
Gt Enrgy Eus $:	0.0	0.0	0.0
Gt Mass Mus $:	0.0	0.0	0.0
Total MValue $:	0.0	0.0	0.0

TOWNSHIP OVERALL AGGREGATES -

Cash $:	689800.0	689800.0	0.0
Energy Eus $:	710400.0	710400.0	0.0
Mass Mus $:	177600.0	177600.0	0.0
Total MValue $:	1577800.0	1577800.0	0.0

--- FOCUS ON CURRENT DATA ---
Units: Metabolism-based MEus, Mus, Eus and $

FRMR AGGREGATES -

	Units	IValue	MValue
Cash $:	na	na	372668.0
Energy Eus:	6761.0	54088.0	54088.0
Recycled Mus:	14962.0	29924.0	29924.0
Inventory MEus:	23568.0	235680.0	235680.0
Supply MEus:	22764.0	227640.0	227640.0
Waste Mus:	0.0	0.0	0.0
Totals:	na	547332.0	920000.0

WRKR AGGREGATES -

Cash $:	na	na	278276.0
Energy Eus:	15273.0	122184.0	122184.0
Supply MEus:	20434.0	204340.0	204340.0
Waste Mus:	0.0	0.0	0.0
Totals:	na	326524.0	604800.0

MMGR AGGREGATES -

Cash $:	na	na	38856.0
Mass Mus:	7072.0	14144.0	14144.0
Totals:	na	14144.0	53000.0

EMGR GRANT AGGREGATES -

Cash $:	na	na	0.0
Gt Mass Mus:	0.0	0.0	0.0
Gt Energy Eus:	0.0	0.0	0.0
Totals:	na	0.0	0.0

TOWNSHIP OVERALL AGGREGATES -

	Units	IValue	MValue
Cash $:	na	na	689800.0
Energy Eus:	88800.0	710400.0	710400.0
Mass Mus:	88800.0	177600.0	177600.0
Totals:	na	888000.0	1577800.0

Annex C – Notes Panel

The bottom (Notes) Panel is toggled through six versions using the "N" button on the toolbar.

The six versions are:

- Physical Model Size
- Economic Profiles
- Performance Ratios Per Tick
- Performance Ratios Per Increment

The Physical Model size panel gives some basic information on the size of the demonstration being run – namely, the size of a lot and the height and width of the township, in lots.

MODEL ECONOMY CELLULAR DESIGN SPECIFICATIONS:
(All units are 'Lots'.)

	Width	Height
Lot	1	1
Township	20	15

PHYSICAL MODEL SIZE SPECIFICATIONS:
(All units are 'meters'.)

	Width	Height
Lot	1.00e+002	1.00e+002

With a second click of the "N" button on the toolbar, you access the "Economic Profiles" charts. This is a set of bar graphs, one set for each agent, and one average set for each of Frmrs and Wrkrs. These were developed as a debug tool, allowing me to visually see the effects of various techniques added to try to stabilize the economy.

There are four types of profle:

- "Economic Profiles – Average Frmr" – showing the average values for all Frmrs;
- "Economic Profiles – Frmr S/N = x" – showing the specific values for the indicated Frmr;
- "Economic Profiles – Average Wrkr" – showing the average values for all Wrkrs;
- "Economic Profiles – Wrkr S/N = x" – showing the specific values for the indicated Wrkr.

The "F->" and the "W->" buttons on the toolbar will cycle you through all possible Frmr and Wrkr profiles.

Two of the profiles for specific agents are shown.

The following legend is shown to the right of the profiles in the Notes panel.

LEGEND: (Note: Ages are in ticks; other values are in $.)

ADT - Age Death Threshold	Cash - Cash On Hand
ART - Age Reproductive Threshold	Recycled - MValue of Recycled MbMus
AGE - Age of F/W in weeks	Inv - MValue of Inventory MbMEus
MAX - Max. Value for all Fs/Ws	Sup - MValue of Supply MbMEus
CRT - Cash Reproductive Threshold	Waste - MValue of Waste MbMus
CMT - Cash Move Threshold	BRF - 'Buy Recycled' factor
CDT - Cash Death Threshold	HWF - 'Hire Wrkr' factor
MVal - Net Monetary Value	BSF - 'Buy Supplies' factor
MV - Maximum Net Monetary Value	
Energy - MValue of Wrkr or Frmr MbEus	

The Frmr Economic Profile has the following structure"

- Left-most bar
  - The black bar shows the age of the Frmr
  - The red line marked ART shows the value of the "Age Reproductive Threshold" gene for this Frmr, the age at which fission becomes possible
  - The ADT shows the value of the "Age Death Threshold" gene for this Frmr, the age at which the Frmr dies of old age.
  - The height of the green box indicates the maximum value of ADT for all Frmrs.
- Second bar from left
  - The black bar shows the monetary value (MVal) of this Frmr
  - The height of the green box indicates the maximum MVal of all Frmrs
  - The red line marked CDT shows the value of the "Cash Death Threshold" gene for this Frmr, the level of MVal at which the Frmr dies of bankruptcy.
  - The red line marked CRT shows the value of the "Cash Reproductive Threshold" gene for this Frmr, the level of MVal at which the Frmr becomes able to reproduce.
- Set of six conjoined asset class bars, one for each asset class
  - The height of these six bars represents the MVal of this Frmr.
  - The black bars add up to a single column, and show the relative portion of assets held in each asset class.
  - First of six
    - The black bar indicates the total cash of this Frmr
  - Second of six
    - The black bar indicates the monetary value of the recycled Mus in this Frmr's recycled store

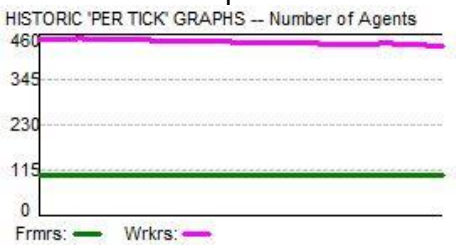
    - The red line marked BRF shows the value of the "Buy Recycled Factor" for this Frmr, the level of MVal at which the Frmr buys recycled Mus. The BRF label is to the left of the cash asset class bar, and the red line is barely visible at the bottom of the second asset class bar.
- Third of six
    - The black bar indicates the monetary value of the Frmr's Energy store. This energy is available for the Frmr to do work in the field.
- Fourth of six
    - The black bar indicates the monetary value of the inventory MEus in this Frmr's inventory store
    - The red line labelled HWF line indicates the value of the "Hire Wrkr Factor" gene, below which value the Frmr will attempt to hire a worker, resulting in the creation of inventory Meus. In the above diagram the HWF label is hidden behind the BSF label, to the left of the cash asset class bar.
- Fifth of six
    - The black bar indicates the monetary value of the supply MEus in this Frmr's supply store
    - The red line labelled BSF (to the left of the cash asset class bar) indicates the value of the "Buy Supply Factor" gene, below which value the Frmr will purchase supply MEus
- Sixth (right-most) bar
    - The black bar indicates the monetary value of the waste Mus in this Frmr's waste store

The Wrkr economic profiles are the same, except that there are no recycled Mu or inventory MEu stores, so the set of six asset classes becomes a set of four. In the MVal bar, the three new lines are CDT, cash death threshold, CMT, cash move threshold, and CRT, cash reproductive threshold.

With a third click of the "N" button on the toolbar, you access a set of charts in which you can watch a variety of measure of scale of the economy. The Performance Ratios panel displays three charts, giving scale and performance information on the economy. For each graph 60 records are maintained in a revolving data base. Once the first 60 seconds have been taken, new records are added to the right, old records are removed from the left, and the displays slide to the left.

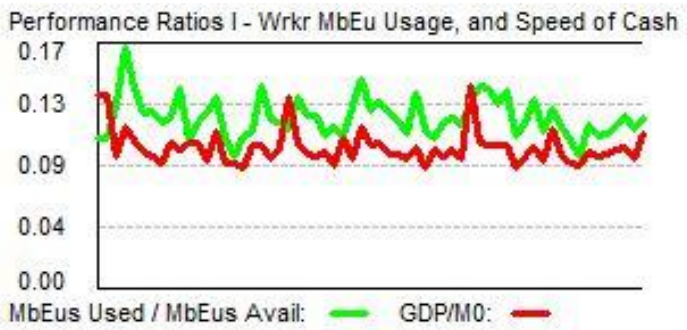
The first chart displays:

- Frmrs – the number of Frmrs in the township
- Wrkrs – the number of Wrkrs in the township



The second chart displays:

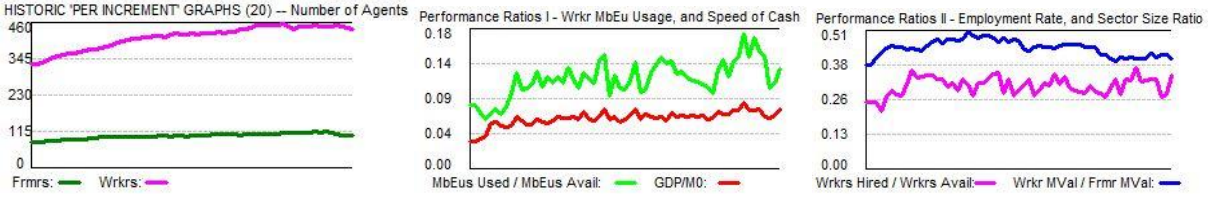
- MbEus Used/MbEus Available – the ratio of Eus used on work to Eus saved in agent stockpiles. If this measure is high, most agents did the maximum possible work.
- Velocity of Cash – the ratio of GDP, measured by cash that changed hands in a transaction, to M_0, the total amount of cash in circulation. The higher this measure, the more mobile value is in the economy.



The third chart displays:

- Employment Rate – the ratio of Wrkrs hired to Wrkrs available for hire.
- Sector Size Ratio – the ratio of total monetary value held by Wrkrs to total monetary value held by Frmrs.

With a fourth click of the "N" button on the toolbar you get another set of three graphs that are very similar to the previous three. These records are taken every 20 ticks, giving you a much longer time perspective. 20 is the 'increment' between records. This value can be altered in the "real time data" tab of the EWiz and IWiz control dialogues. (See Annex F).



A fifth click of the "N" button closes the Notes panel.

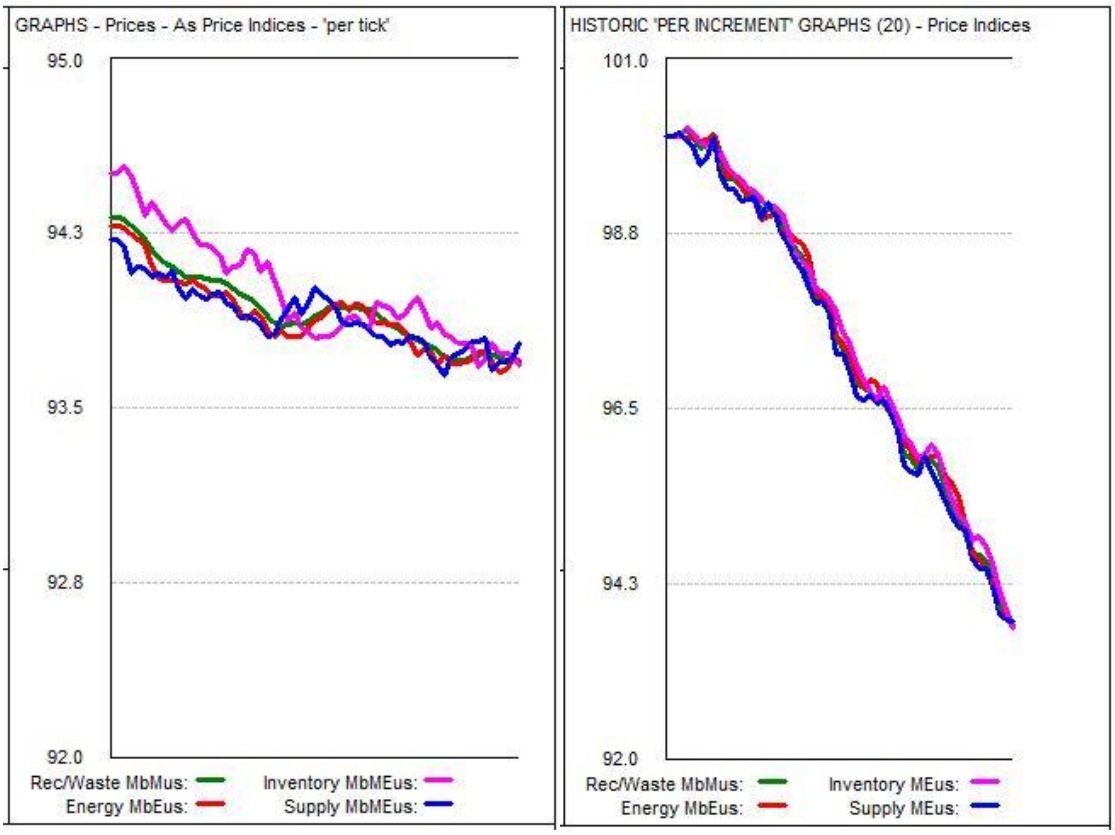
Annex D – Right Panel

The right panel is toggled through six versions using the "R" button on the toolbar.

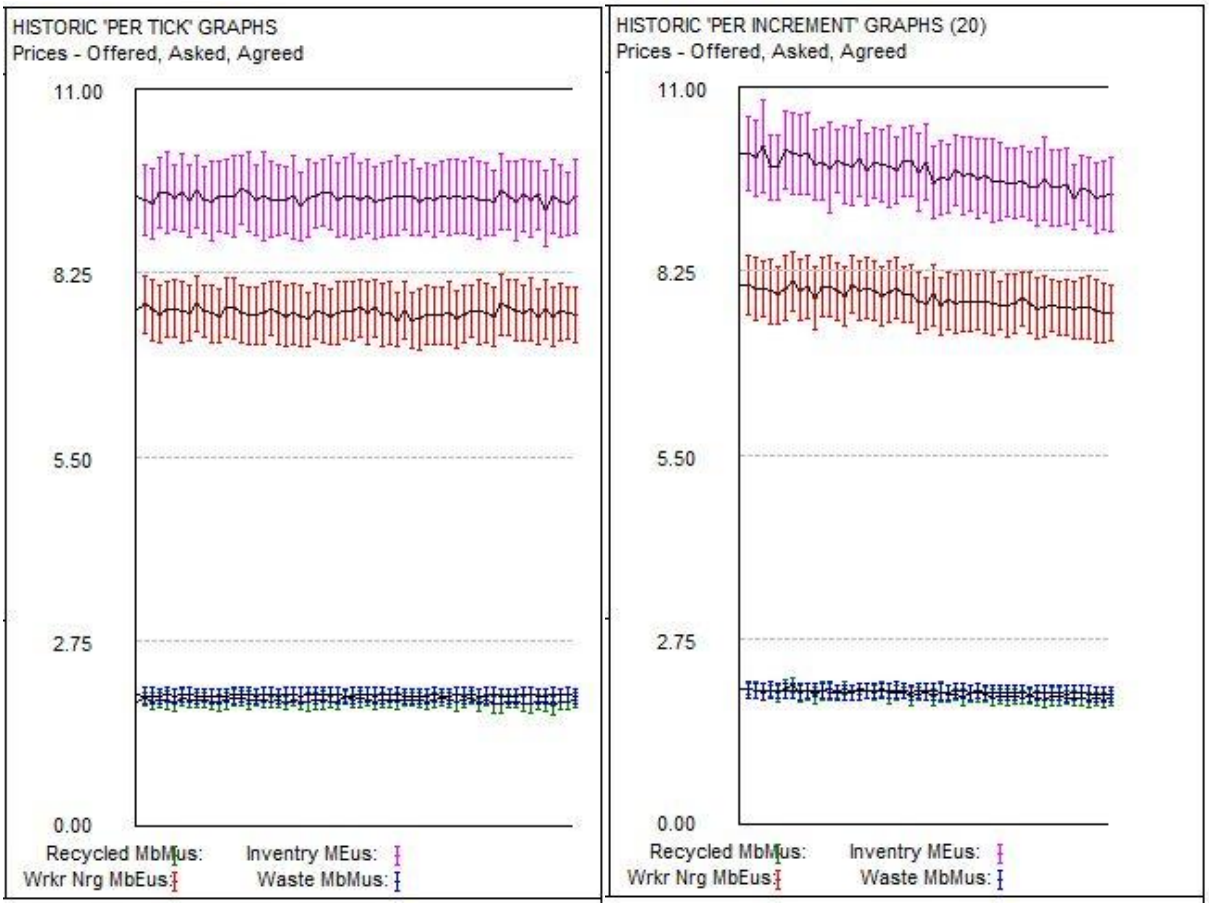
The six versions are:

- Price Indices Per Tick
- Price Indices Per Increment
- Prices Offered, Asked, Agreed Per Tick
- Prices Offered, Asked, Agreed Per Increment
- Price Gene Profile
- Distribution of Wealth

With the first two clicks of the "R" button we get these two graphs. Here we see an example of an economy in steep decline. The increment is 20 ticks by default, but is controlled in the IWiz and EWiz control panels.

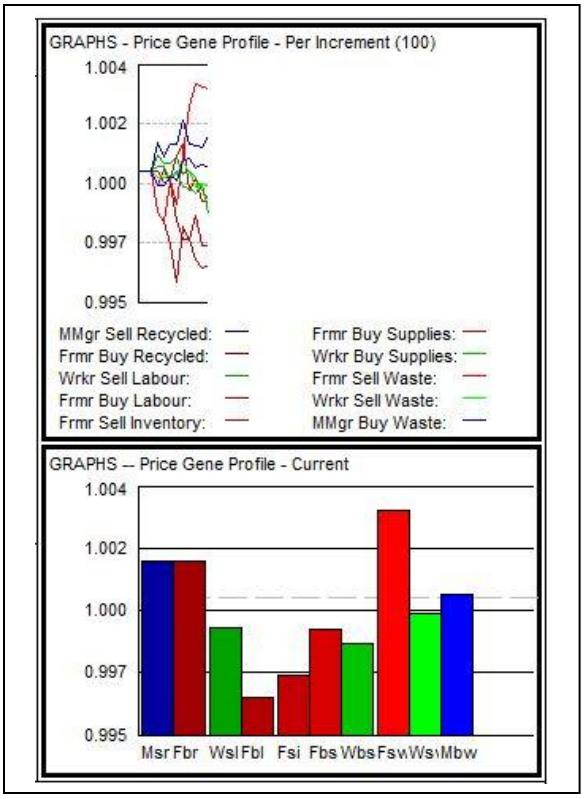


With two more clicks of the "R" button you have access to the "Offered, Asked, Agreed" charts, in two versions, as shown below.

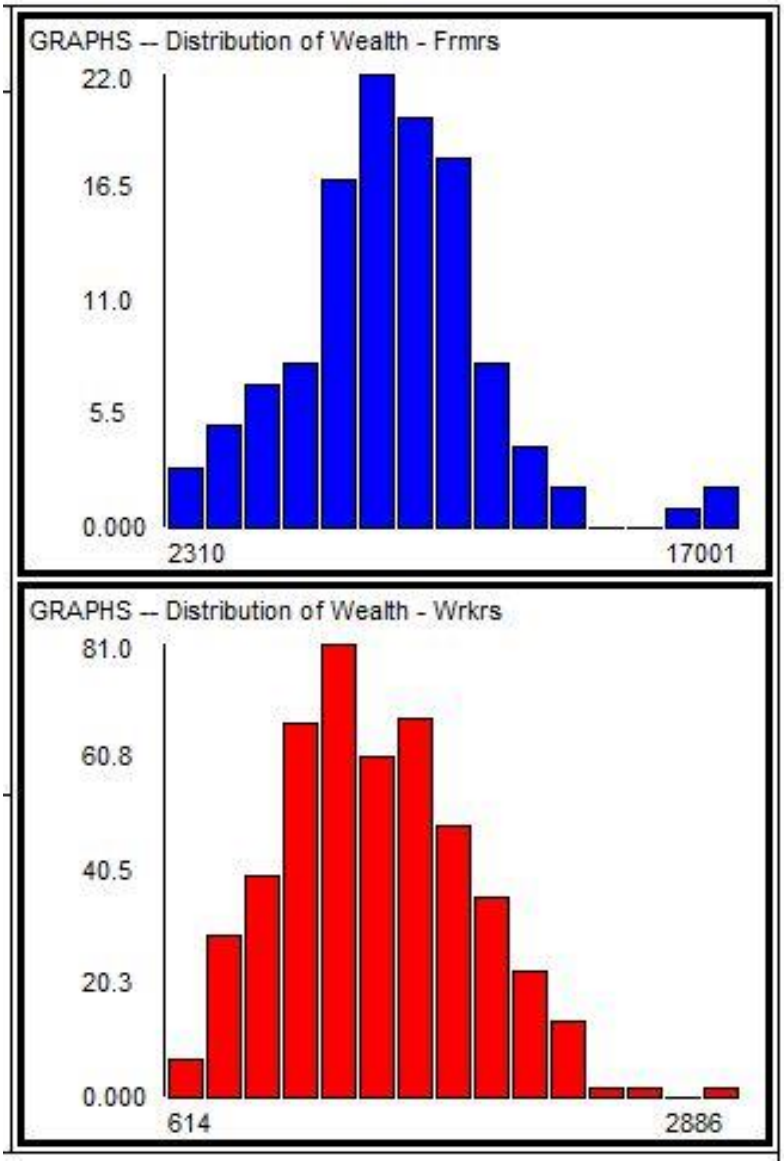


With the fifth click of the "R" button you have the Price Gene panel. The Price Gene Panel shows two charts displaying

- The average of each agent gene type charted across time
- The average of each agent gene type current value



With the sixth click of the "R" button you have access to the "Distribution of Wealth" panel showing two charts displaying, for each agent type, the number of agents in each wealth bracket. Each bracket is the same width.



Annex E – View Agents Dialog Box

When you click on the "View Agent" toolbar button, you see a dialogue which presents you with information about Frmrs, about Wrkrs, or about the Township Managers.

The Frmr data looks like this:

```
TECHNICAL INFORMATION:
PrevPtr(SlotNo): 04805930(253); FrmrPtr(SlotNo): 047282B0(35); NextPtr(SlotNo): 04748AB0(67)
Generation: 1; S/N: 180; Ma's S/N: -1
Lot Address(SlotNo): 033E4040(208); Frmrs own colour: 1329958

PHYSICAL INFORMATION:
Type: Farm; Age: 1031; Col index (x): 8; Row index (y): 10
Economic Status: Post-industrial; Reproductive Status: Mature and Healthy; Has Starved Flag: No

ECONOMIC INFORMATION:
     No Of Hires Max: 4; No Of Hires: 1
         Total Value:                    IValue(  5998.970692); MValue( 17347.049852)
                Cash:                    IValue(     0.000000); MValue( 11814.805250)
              Energy: Mus(    16.000000); IValue(   128.000000); MValue(   117.683431)
           Recycled: Mus(   324.212231); IValue(   648.424463); MValue(   607.969274)
          Inventory: Mus(    47.531855); IValue(   475.318549); MValue(   437.134619)
             Supply: Mus(   461.922768); IValue(  4619.227681); MValue(  4251.149382)
              Waste: Mus(    64.000000); IValue(   128.000000); MValue(   118.307896)
  Date Last Supplied: (978)


RECENT EMPLOYMENT HISTORY:
WrkrSerNo:  581; Date: 974; Frmr offered: 9.493060; Wrkr asked: 8.110580; Agreed: 8.801820.
WrkrSerNo: 1159; Date: 975; Frmr offered: 7.341973; Wrkr asked: 7.016648; Agreed: 7.179311.
WrkrSerNo:  590; Date: 976; Frmr offered: 7.726503; Wrkr asked: 7.394841; Agreed: 7.560672.
WrkrSerNo: 1052; Date: 976; Frmr offered: 8.099547; Wrkr asked: 7.521140; Agreed: 7.810344.
WrkrSerNo:  646; Date: 977; Frmr offered: 7.528849; Wrkr asked: 6.659090; Agreed: 7.093969.
WrkrSerNo: 1322; Date: 978; Frmr offered: 8.087211; Wrkr asked: 7.351604; Agreed: 7.719407.
WrkrSerNo:  649; Date: 978; Frmr offered: 7.954239; Wrkr asked: 7.622822; Agreed: 7.788530.
WrkrSerNo: 1095; Date: 979; Frmr offered: 8.559235; Wrkr asked: 8.062683; Agreed: 8.310959.
WrkrSerNo:  833; Date: 979; Frmr offered: 7.862957; Wrkr asked: 7.789525; Agreed: 7.826241.
WrkrSerNo: 1159; Date: 980; Frmr offered: 8.861894; Wrkr asked: 6.891128; Agreed: 7.876511.
```

The Wrkr data looks like this:

```
TECHNICAL INFORMATION:
PrevPtr(SlotNo): 03D62F28(1087); WrkrPtr(SlotNo): 03BBE988(454); NextPtr(SlotNo): 03BBF428(455)
Generation: 2; S/N: 569
Ma's S/N: 144
Lot Address(SlotNo): 0337D840(126)
Drawing colour: 8621187

PHYSICAL INFORMATION:
Age: 811; Col index (x): 6; Row index (y): 6; Residence Unit Number: 1
Reproductive Status: Mature, but unhealthy; Has Starved Flag: No

ECONOMIC INFORMATION:
         Total Value:                     IValue(   641.779735); MValue(   886.283502)
                Cash:                     IValue(     0.000000); MValue(   252.674193)
              Energy: MbEus(    13.083165); IValue(   104.665321); MValue(   103.179468)
              Supply: Mus(    52.111441); IValue(   521.114414); MValue(   514.644041)
               Waste: Mus(     8.000000); IValue(    16.000000); MValue(    15.785799)
  Date Last Supplied: (979)


RECENT EMPLOYMENT HISTORY:
FrmrSerNo: 1285; Date: 957; Wrkr asked: 6.700100; Frmr offered: 8.478269; Agreed: 7.589184.
FrmrSerNo:  817; Date: 961; Wrkr asked: 8.860631; Frmr offered: 8.919950; Agreed: 8.890291.
FrmrSerNo: 1285; Date: 967; Wrkr asked: 6.452972; Frmr offered: 9.196239; Agreed: 7.824605.
FrmrSerNo:  781; Date: 968; Wrkr asked: 6.799311; Frmr offered: 7.732420; Agreed: 7.265865.
FrmrSerNo: 1001; Date: 969; Wrkr asked: 6.162329; Frmr offered: 6.541830; Agreed: 6.352080.
FrmrSerNo:  781; Date: 970; Wrkr asked: 8.588642; Frmr offered: 8.827463; Agreed: 8.708053.
FrmrSerNo:  781; Date: 971; Wrkr asked: 7.225204; Frmr offered: 9.110994; Agreed: 8.168099.
FrmrSerNo: 1060; Date: 977; Wrkr asked: 7.645209; Frmr offered: 7.648509; Agreed: 7.646859.
FrmrSerNo: 1285; Date: 978; Wrkr asked: 7.530056; Frmr offered: 7.948199; Agreed: 7.739127.
FrmrSerNo: 1060; Date: 979; Wrkr asked: 7.310746; Frmr offered: 8.363842; Agreed: 7.837294.
```

The MMgr Data looks like this:

```
TECHNICAL INFORMATION:
TownshipPtr: 03A90BD0
Age: 981; Width (x): 20; Height (y): 15

ECONOMIC INFORMATION:
    MMgr Total Value: IValue(  3913.255272); MValue(-92699.354566)
           MMgr Cash: IValue(     0.000000); MValue(-96367.283831)
      MMgr MbMu Pool: MbMus(  1956.627636); IValue(  3913.255272); MValue(  3667.929266)
```

The EMgr Data looks like this:

```
TECHNICAL INFORMATION:
TownshipPtr: 03A90BD0
Age: 981; Width (x): 20; Height (y): 15

ECONOMIC INFORMATION:
    EMgr Total Value: IValue(     0.000000); MValue(    -0.000000)
     Cash Grant Pool: IValue(na); MValue(    -0.000000)
     MbEu Grant Pool: MbEus(     0.000000); IValue(     0.000000); MValue(     0.000000)
     MbMu Grant Pool: MbMus(     0.000000); IValue(     0.000000); MValue(     0.000000)
```

Annex F – View Agent's Genes

When you click on the "View Agent" toolbar button, you see a dialogue which presents you with information about Frmrs, about Wrkrs, or about the Township Managers.

The Frmr data looks like this:

```
FARMER - GENETIC MAKEUP
CHROMOSOME 1 (C1) - PRICING GENES:
                    BUYING GENES ----------- | SELLING GENES -----------|
                    Mean Gene  | StdDev Gene | Mean Gene  | StdDev Gene |
            Labour:    1.00000 |     0.10000 |        n/a |         n/a |
 Recycled/Waste Generic:    1.00000 |     0.10000 |    1.00000 |     0.10000 |
    Supply Generic:    1.00000 |     0.10000 |    1.00000 |     0.10000 |


CHROMOSOME 2 (C2) - LIFE FUNCTION GENES:
    ART:        800 (Age Reproduction Threshold)
    ADT:       1600 (Age Death Threshold)
    CRT:       1000 (Cash Reproductive Threshold)
    CDT:         20 (Cash Death Threshold)
    MPT:         16 (Materiel Per Tick)

    BRF:      0.025 (Buy Recycled Factor)
    HWF:      0.250 (Hire Wrkr Factor)
    BSF:      0.250 (Buy Supply Factor)
```

The Wrkr data looks like this:

```
WORKER - GENETIC MAKEUP
CHROMOSOME 1 (C1) - PRICING GENES:
           BUYING GENES ----------- | SELLING GENES -----------|
           Mean Gene  | StdDev Gene | Mean Gene  | StdDev Gene |
   Labour:        n/a |         n/a |    0.95238 |     0.10000 |
Sup/Waste:    1.00000 |     0.10000 |    1.00000 |     0.09901 |


CHROMOSOME 2 (C2) - LIFE FUNCTION GENES:
      ART:        800 (Age Reproduction Threshold)
      ADT:       1600 (Age Death Threshold)
      CRT:       1000 (Cash Reproductive Threshold)
      CMT:        300 (Cash Move Threshold)
```

```
      CDT:         20 (Cash Death Threshold)
      MPT:          4 (Materiel Per Tick)

      BSF:      0.250 (Buy Supply Factor)
```

The MMgr data looks like this:

```
TOWNSHIP'S MATERIEL MANAGER - GENETIC MAKEUP
CHROMOSOME 1 (C1) - PRICING GENES:
         BUYING GENES (SCRAP)---- | SELLING GENES (RAW MUS)--|
         Mean Gene  | StdDev Gene | Mean Gene  | StdDev Gene |
Generic:    0.99983 |     0.09993 |    1.00094 |     0.09988 |
```

The EMgr data looks like this:

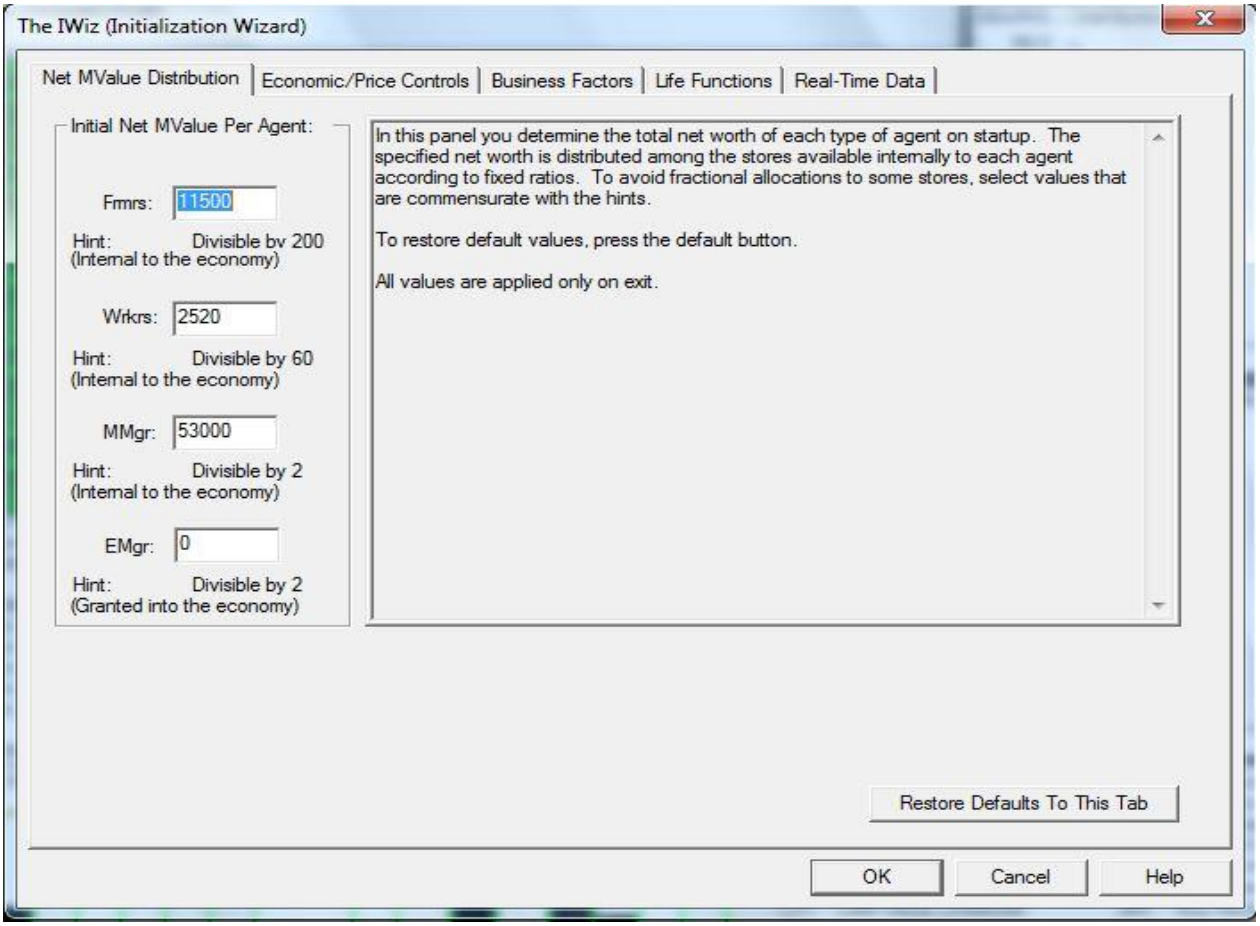
```
TOWNSHIP'S ESTATE MANAGER - GENETIC MAKEUP
CHROMOSOME 1 (C1) - PRICING GENES:
                    BUYING GENES ----------- | SELLING GENES -----------|
                    Mean Gene  | StdDev Gene | Mean Gene  | StdDev Gene |

 THE ESTATE MANAGER HANDLES MUNICIPAL GRANTS, AND NEITHER BUYS NOR SELLS.
```

Annex G – The Initialization/Economic Wizards (IWiz/EWiz)

There are two complexes of control panels that enable the user to modify the operation of the economic engine by changing parameters and enabling or disabling toggled features. The "Initialization Wizard" (IWiz) and the "Economic Wizard" (EWiz) are almost identical in design and only slightly different in purpose. The IWiz is accessible only prior to the start of a run, and it destroys the existing model and builds a new model according to the wizard. It lets you set asset levels for conserved quantities, and these cannot be changed once a run is started. The EWiz, on the other hand, is accessible only after a run is started, and does not let you change asset levels. Both, however, let the user change other parameters and toggle features.

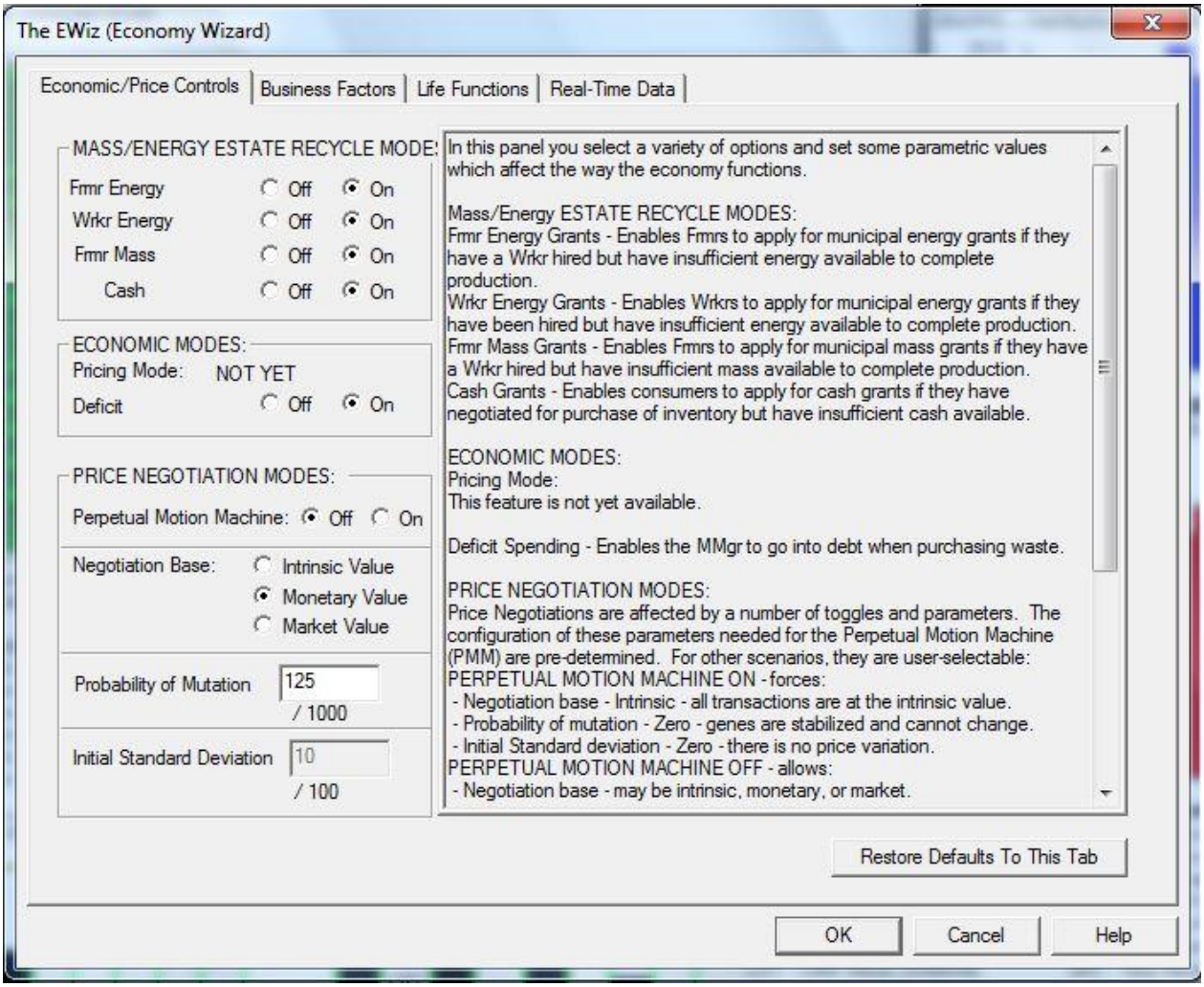
Net MValue Distribution Tab

- **Initial Net Mvalue Per Agent Pane –** Only in IWiz, this allows configuration of the starting net monetary value (MVal) of each agent type prior to initialization of the economy.



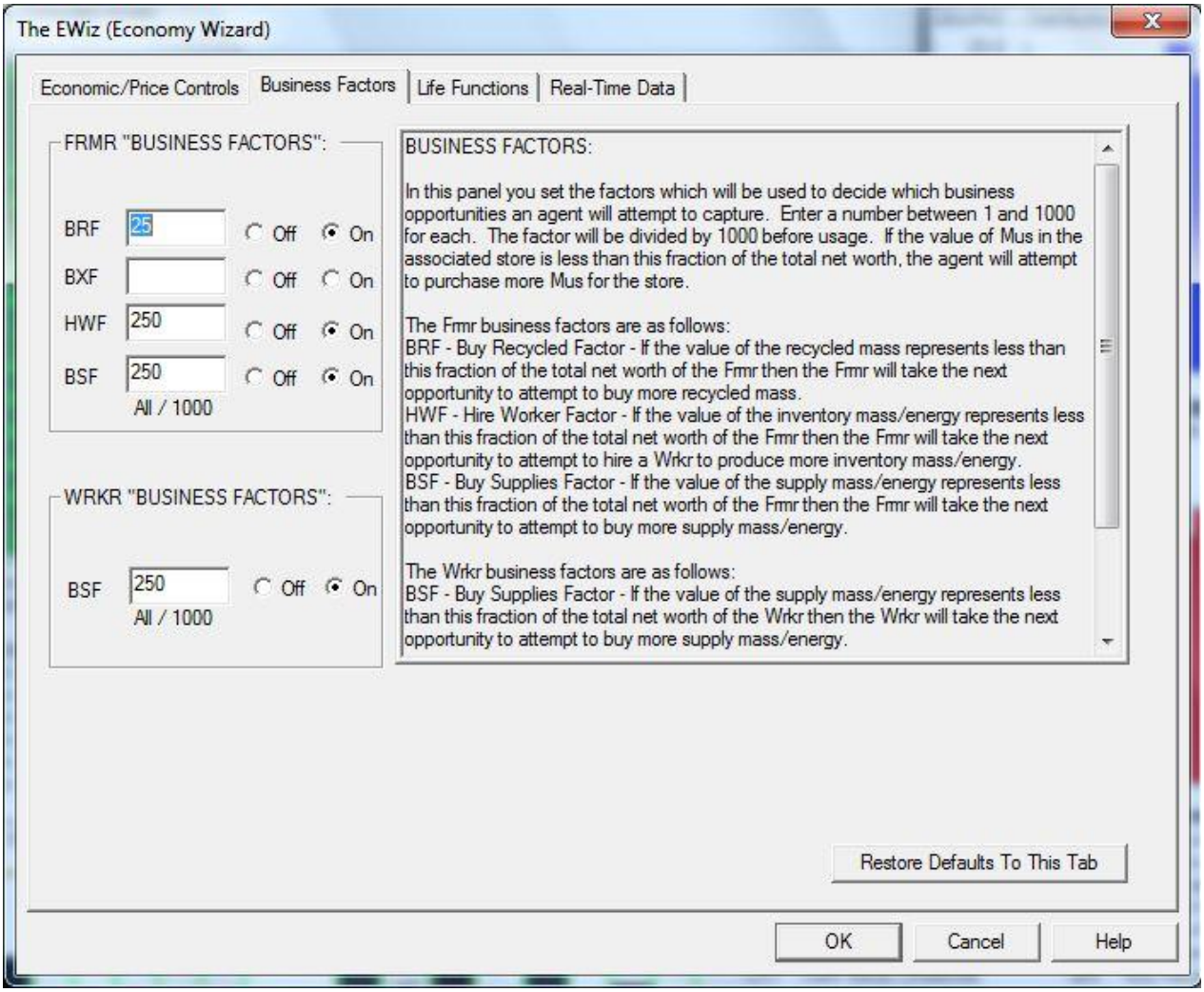
E-Modes Tab

- **Estate Recycle Modes** – Toggles the four types of grants on or off.
- **Economic Modes Pane** – Allows configuration of pricing mode (currently deactivated) and toggles quantitative easing, allowing or disallowing the MMgr to go into debt.
- **Price Negotiation Modes Pane** – Allows enabling of PMM mode, which disables price gene mutations and changes all negotiations to be made based on intrinsic instead of monetary value, or allows manual configuration of the negotiation base, probability of mutation per gene per generation, and standard deviation of initial price genes.



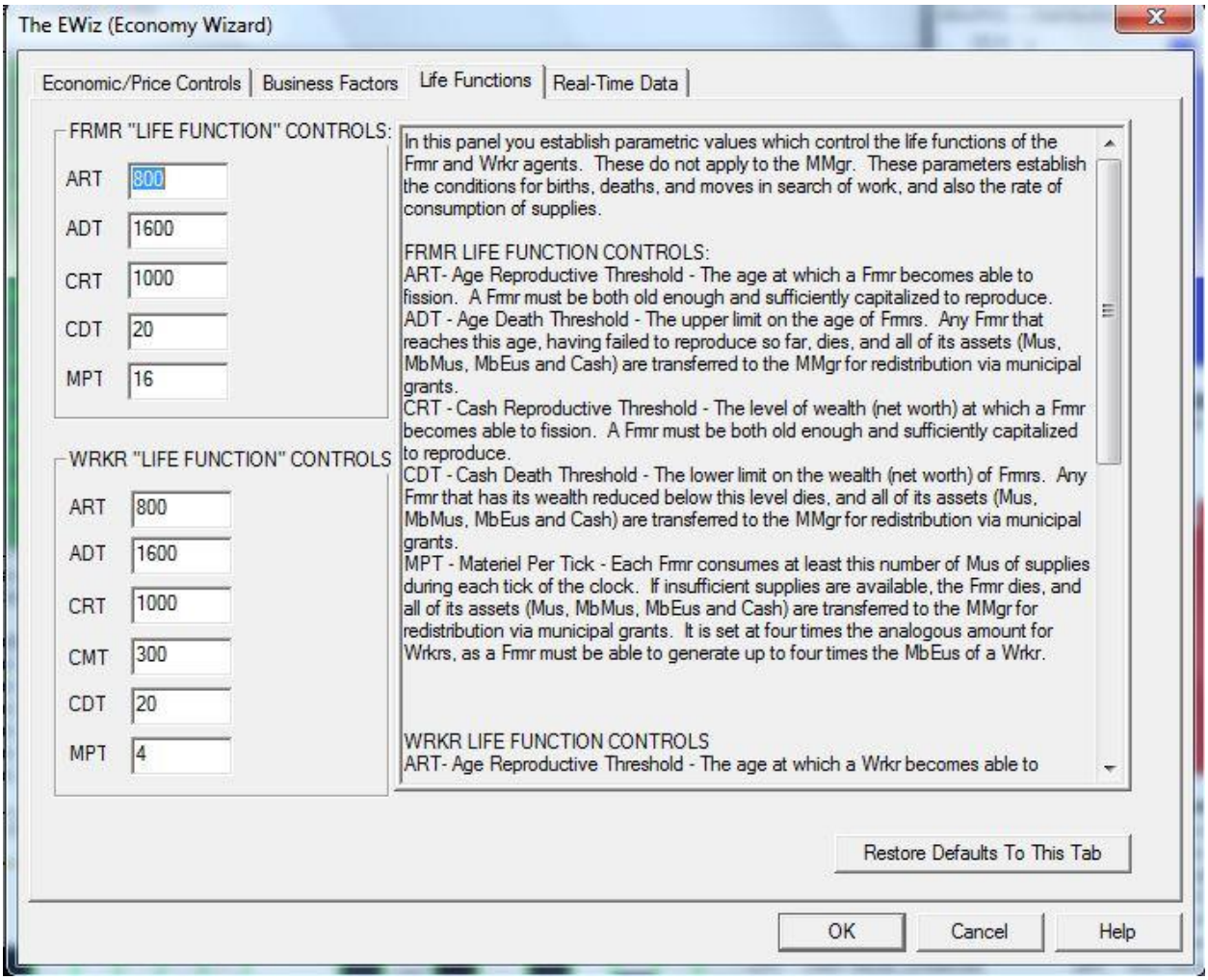
Business Factors Tab

- **Frmr Business Factors Pane** – Allows configuration of the proportions of Net Monetary Value (MVal) below which a Frmr will buy particular units
- **Wrkr Business Factors Pane** – Allows configuration of the proportion of Net Monetary Value (MVal) below which a Wrkr will buy supply MEus



Life Functions Tab

- **Frmr Life Function Controls Pane** – Allows configuration of the Life Functions of Frmrs – the age and cash thresholds above which they can reproduce and those below which they die, and the rate at which they consume materiel.
- **Wrkr Life Function Controls Pane -** Allows configuration of the Life Functions of Wrkrs – the age and cash thresholds above which they can reproduce and those below which they die, and the rate at which they consume materiel.



Real Time Data Tab

- **Genetic Data Pane –** Allows configuration of the time increment used in the 'per increment' graphs of genetic data. Higher values mean longer periods with lower resolution.
- **Macroeconomic Data Pane –** Allows configuration of the time increment used in the 'per increment' graphs of macroeconomic data. Higher values mean longer periods with lower resolution.