The physics of time and dimension in the economics of financial control

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Abstract

The provision of the goods and services of a modern economy is controlled by a multiplicity of financial instruments. The basic properties of these instruments are considered here.

Key words: Financial instruments, Contracts, Transition matrix, Dimensional analysis, Time scale
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1. Introduction

The physical aspects of any economy are reflected in the tangibles of physical and human capital. The employment of these resources is for the most part guided by a complex of money and financial instruments represented by contracts of varying complexity. In this note our concern is a parsimonious description of the physical economy and the financial instruments which guide it. In particular, we consider the properties of a minimal collection of basic financial instruments from which other more complex instruments can be constructed.

In economic life many rich institutional forms provide considerable variety in delivering the basic functions which must be provided to any viable complex economy. In a previous publication (see [1] also [2] Chapter 2) a sketch was given of the structure of the basic financial instruments of an economy. Here we re-examine and make more precise the sketch suggested there.

The approach adopted is to construct a set of the simplest basic instruments and to consider their transformation through time. We note the more basic of the many special functions called for in economic exchange, evaluation and control, as well as the role of uncertainty.

2. The transition matrices

Two physical economic entities and six basic financial instruments appear to suffice as the building blocks for any financial economic system. These are described below and three transition matrices are specified at progressively higher levels of complexity.
The first matrix fully conforms to our requirements of minimal complexity. It is restricted to relationships involving only two periods of time and one or two agents. The next matrix picks up the portrayal of an economy with a historical time profile in its real assets and financial contracts. The third matrix portrays the dynamics of uncertainty overlaid on the profile of the assets. This third matrix offers a form which can be estimated for any economy and reflects the political, legal, institutional and economic treatment of incomplete and failed contracts.

These matrices do not show the production and delivery of the goods and services rendered to the individuals within the period. An accompanying matrix must be constructed for this purpose. In essence these matrices are the first elementary bookkeeping step providing only a simple accounting scheme, rather than a full process description from which one could calculate production. The eventual goal of this work is to extend the von Neumann physical growth model to incorporate individuals, financial instruments, production and exchange explicitly. The von Neumann structure requires elementary economic goods and services as inputs to a set of production processes that produce the set of goods as outputs.

2.1. The eight instruments

We consider an economy embedded in time\(^1\) with two types of economic assets, (1) production goods yielding services and (2) point consumption goods, which may or may not be storable for more than one period; (3) flat money and (4) ownership paper and four contracts written against each of the first four items. Thus we have (5) a service contract, (6) a futures contract, (7) a loan contract and (8) an ownership paper contract.

2.1.1. Two problems with fiat money

There are two basic conceptual problems in the understanding of fiat money. The first concerns whether it does or does not involve a contract. One can argue that there is an implicit debt contract between an individual holder of a unit of currency (say a dollar bill) and the issuer of the currency. If a private individual \(i\) holds a dollar bill and brings it to the government who has issued it, if there were a debt contractual relationship the individual would obtain a payment of the debt, but in this instance it would consist of the issuance of another dollar, thus the physical state of the system is unchanged. This may be regarded as an identity contract. It maps into itself.\(^2\)

A second problem concerns the current terminology in economic theory. Dating back to Gurley and Shaw (1960, [4]), the terms “inside” and “outside” money have been adopted to stand for a dollar issued against government debt in contrast with a dollar injected into the economy with no offsetting instrument against it. But from the viewpoint of the observation or the “physics” of the instrument there is no operational way we can distinguish a single dollar that is inside or outside money. There are just dollars in the system and the dimension of all of them is the same. The confusion appears to arise from mixing in a specification of initial conditions, which are in essence boundary conditions, with the dimensional analysis.

2.2. The simplest transition matrix

Limiting our concern to the simplest form of each instrument in Table 1 we consider the transformations that take place to all eight items as they are moved through one period of time in an economy without uncertainty.

Prior to discussing the matrix, the nature of the simplest instruments is noted:

(1) Production goods yielding services or consumption goods: A service may be regarded as a flow which cannot be inventoried. It is supplied as an output of an asset (human or nonhuman physical capital). Typically a service such as storing food in a refrigerator is continuously provided. A production good such as a pear tree about to die

\(^1\) For purposes of our description it is convenient to select a minimal discrete unit of time. This itself requires some justification and concern as in noted below in Section 3.

\(^2\) For some aspects of the dynamics of fiat see [3].
at the end of the season may produce its last crop of consumption goods, pears to be consumed.

(2) Consumption goods: An act of consumption such as eating a ripe pear or canned pears may be regarded as a discrete event terminating the life of the good.

The failure of function may also indicate the death or exit of an asset. The problem of free disposal may be important in many instances; for example, disposal of the dead refrigerator may be costly. For the simplest case we may assume free disposal.

(3) Fiat: Fiat money is an independent entity created by the state with an indefinite life and ideally no depreciation. A key service rendered by the fiat is its use in a transaction where it may serve to relax a constraint on trade.

(4) Ownership paper: The main forms of ownership paper are titles to land, housing, automobiles, other large durable assets and common stock. The problems with indivisibility, size, transportability, bookkeeping and many other specifics create the need for experts, specialists and markets. Here at the simplest level if we consider only one person and ownership paper which does not take on a financial dynamics separate from the underlying asset, we could ignore the category as the decision and time path of the paper will be identical with the asset. A somewhat more complex instrument will permit the trading of the ownership claim separate from that of the asset. The trading of a common stock provides one of the most important examples.

Against each of the four items noted above, a contract can be written. Thus we have:

(5) a service contract: The simplest service contract is a nontransferable nonrenogotiable contract between two parties at time \( t \) for the provision of one period’s services at time \( t+1 \) in return for a single payment of fiat in time \( t \).

(6) a futures contract: The simplest futures contract is a nontransferable nonrenogotiable contract between two parties at time \( t \) for the provision of a specific durable good at time \( t+1 \).

(7) a loan contract: The simplest loan contract is a nontransferable nonrenogotiable contract between two parties at time \( t \) for the provision of a unit of fiat at time \( t \) in return for a payment of a sum of fiat at time \( t+1 \).

(8) an ownership paper contract. An example of the simplest ownership paper contract is a nontransferable nonrenogotiable contract for an option between two parties at time \( t \) for the purchase of a unit of stock at time \( t+1 \) at a specified price. A purchase of a new issue directly from the corporation can also be regarded as an ownership paper contract between the firm and the new stockholder.

If there is no uncertainty there is no operational need for an instrument such as an option. When there is uncertainty, as the name “option” implies, there is a choice or option to be made at time \( t+1 \) to purchase or not purchase the stock. But if the option has an expected value at \( t+1 \) it may have a positive price at \( t \). The purchaser of the simplest option will need to make a purchase in fiat at time \( t \) and has the option to make a payment at \( t+1 \) if she wishes to exercise the option. We keep ownership papers and their contracts separate from those on goods, even in the absence of uncertainty, to reflect the important legal distinctions relating control to ownership common in the two cases.

In Table 1 a production good of duration one period, if it yields a service, is converted into nothing at the start of the next period; if it yields a

<table>
<thead>
<tr>
<th>t=t+1</th>
<th>PCG</th>
<th>DPG</th>
<th>Fiat</th>
<th>Ownership</th>
<th>Contract1</th>
<th>Contract2</th>
<th>Contract3</th>
<th>Contract4</th>
<th>Null</th>
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<td>PCG</td>
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Table 1: Transformation under certainty. PCG = Point Consumption Good (perishable or storable); DPG = Durable Producer Good (consumer or producer owned)
storable consumption good, it is converted into $\delta$ of the consumption good. A consumption good with a single period storage life is converted into nothing at the end of a period regardless of whether it is consumed.

Fiat money maps into itself. “A dollar is a dollar”. Its purchasing power may have changed but it is physically the same object. In fact, the wear and tear of a physical dollar bill is high. Its half life is under two years and the costs are several cents to withdraw and replace it, thus one must consider the “ideal dollar” as depreciation-free with some scepticism.

In an economy with ownership paper written against goods with a finite life, does the ownership paper die with the end of the life of the good? As a reasonable first order approximation we suggest that their lives are fully correlated with the assets they represent. We nevertheless note that collectors’ items such as old stock certificates in companies that have long since disappeared take on economic lives of their own.

In this simplest transition matrix without uncertainty all contracts are honored and thus in period $t+1$ each is transformed into the appropriate one of the four individual ownership instruments.

2.3. The transition matrix with a time profile for capital stock

Many goods are durable relative to the time unit selected. In Table 1 durability was limited to one period. Here the importance of capital structure is recognized in the time profile.

Most of the reproducible capital stock of any economy is under 40 years old and the expected life span of humans is no bigger than of the order of 80. Thus (setting aside uncertainty) but considering some large enough number of time periods $T$ we can consider the transition matrix in Table 2.

As durable producer goods have a time profile of up to $T$ some fraction $1 - \eta_2$ at the end of their productive life will transform into nothing and the remainder will transform into durables with a life of one period less. All may provide a stock of the consumer good.

The consumer goods available will age and be consumed, wasted or saved.

Fiat and ownership paper map into themselves if they are considered to have an infinite life; otherwise they must be dated as a period closer to expiration.

There are many different ways to write a multi-period contract even without uncertainty. For example there could be a periodic payout of a dividend from a long term bond. The payout profile provides many degrees of freedom in constructing the instrument.

For all of the contracts, the time profile of the contract combined with the period by period payout rules will determine in each instance the size of the payout in services, goods, fiat or ownership paper and the residual emergence of aged contracts.

2.4. The transition matrix with a time profile and uncertainty

In the dynamics of any economy there are many factors involving uncertainty. Although there are reasons to have financial instruments even without uncertainty, one of the overarching functions of financial instruments is to facilitate efficient allocations of resources in an economy with uncertainty.

Even a crude empirical evaluation of this transition matrix would provide some insights into the economic-financial dynamics of an economy.

When uncertainty is introduced we must consider that the treatment of virtually all contracts and ownership paper must take into account the possibility of the incomplete specification

<table>
<thead>
<tr>
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<th>$t \rightarrow t+1$</th>
<th>PCG</th>
<th>DPG</th>
<th>Fiat</th>
<th>Owner</th>
<th>Ctrct1</th>
<th>Ctrct2</th>
<th>Ctrct3</th>
<th>Ctrct4</th>
<th>Null</th>
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Table 2: Transformation with time profile under uncertainty.
Table 3
Transformation with time profile under uncertainty.

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<tr>
<th>t→t+1</th>
<th>PCG</th>
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<th>Owner</th>
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<th>Contract2</th>
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representations of durability and uncertainty. They have in common a discrete periodization of time, which formally fails to distinguish events consumption of goods from processes like consumption of services, either of which occupies a single period. Both are subsumed in the category of Point Consumable Goods (PCGs). The distinction missed by discrete minimal models is essentially one of topology: the economy is part of a larger physical world in which time passes continuously, and in which processes and events induce different transformations on agents, goods, and contracts. In some cases economic dynamics reflects the differences among these underlying physical processes.

The distinction between processes and events is not only topological, but also presumes a scaling relation for processes that does not characterize events: however the accomplishment of a process is measured, the measure is proportional to the time interval over sufficiently short times. Scaling relations, like fungibility, are captured in the notion of dimensions [5,6], and processes have in common that their dimensions are rates, a quantity of something accomplished per unit time.

As we extend the minimal-model hierarchy from discrete periods to distinguish processes from events, it becomes natural also to distinguish outputs of individual production from inputs to individual consumption, a property carried by many processes but not intrinsically by PCGs. Of particular interest is the distinction between Labors (outputs) and Services (inputs), which refines the notion of a general Durable Producer Good (DPG) to the particular concept of a Capital Good. A richer model of ownership recognizes that the maintenance of goods (or of the ownership of goods) requires a continuous provision of labor, or possibly input of services. A Capital Good is one that produces either a stream of PCGs or some Service, essentially converting the Labor supplied to an output of different value.

A new category of continuous transformations characterizes Goods, Labors, and Services, which we sketch here for the simplest case of certainty. An application of this case is the demonstration that the cost of the financial float of an economy is itself a rate, on dimensional grounds.

3. The topology of time and richer models of ownership

The three transition matrices considered so far differ in their complexity and the richness of their
A number of new concepts emerge from the treatment of Labors and Services under conditions of uncertainty, and of Fiat and contracts generally. For instance, Labor and Service contracts are defined as either constraints or the release of constraints on the choice set of agents. Their economic identity and valuation are defined by differences in the values of differently-constrained choice sets, which must then be related to valuations of goods whose persistence or ownership is contingent on the Labors, or produces the Services. The tables of discrete-time transformations at this point become more complex structures, which space does not permit us to develop here. We therefore limit ourselves to the simplest continuous transformations, refining only the first two rows of Table 1. For more detail the reader is referred to a lengthier version of this paper given in [7].

3.1. Dimensions, types, and type constructors

To capture the dimensionality that distinguishes processes from events, it is useful to borrow the notion of types from formal language theory. An economic type corresponds to a rule for assigning dimensions and time-transformation properties to the name of a particular object or activity. For example, PCGs and DPGs are types. Each instance of a PCG may be fungible with a different class of other instances, and thus have its own dimensions, but all PCGs have in common the transformation properties of Table 1. In the same way Labors and Services define types, for which the instances may have distinct dimensions, but which transform under the passage of time in a uniform way.

The formal representation of the map from a name to the dimensional and transformation properties of a type is called a type constructor. The equivalent relations to Tables 1, 2 and 3 will be rules that act on type constructors, in which the names of the particular instances appear as arguments.

Thus if we denote by $x$ the name of some kind of labor, we can assign it a formal type $X \equiv L(x)$ by acting on the name with the Labor type constructor $L$. $L$ ensures that $X$ has the dimension of a rate, and that its output over a time $\Delta t$ accumulates to a quantity $X \Delta t$. A relevant example to the valuation of the float is the labor of “inventorying” or “protecting” (the name $x$) some durable good used as means of exchange or standard of value. $X \Delta t$ might appear as the argument of a utility, the accumulated cost to an agent of inventory labor, which may be weighed against the value of the good kept over the same period.

Similarly, a service with name $y$ is converted to a formal type $Y \equiv S(y)$ by the Service type constructor $S$. The accumulated value of the service over an interval $\Delta t$ is then $Y \Delta t$. An example of such a service is the vanity value of gold converted from coin to jewelry during times when it is not needed for commerce, a practice once common in India. A more recent example would be the service delivered by gold in semiconductor interconnects, which has been freed from storage in Fort Knox by the use of Fiat money as a surrogate for trust in trade.

We can refine the notion of a PCG by giving it arguments $X$, some Labor which may be necessary for its persistence $^4$, $Y$, a value from the event of its consumption, and $\tau$, a lifetime at which the good spontaneously expires if it has not been consumed. (With the change from periods to continuous time, $\tau$ becomes necessary, as no nontrivial minimal expiration date is automatic.) A particular consumable good named $g$ is converted to a formal type $G \equiv \Xi(g; X, Y, \tau)$ by the PCG constructor $\Xi$.

A Capital Good is a particular refinement of the DPG, whose arguments are a Labor $X$ as for consumable goods, and a Service $Y$ rendered continuously. The good may also have a natural lifetime $\tau$, after which it disappears or is converted to a PCG whose consumption value is the cost of disposal. An instance named $g$ is given a type $G \equiv \chi(g; X, Y, \tau)$ by the Capital Good constructor $\chi$.

3.2. Continuous-time transformations

We now refine the discrete entries of Table 1 with rules relating goods, labors, and services un-
der continuous time transformation through an interval $\Delta t$. Let $X$ and $Y$ be specific Labor and Consumption values as in the type definition. A minimal state space for the cost of labor and the holding of the good now has a tensor product structure. Using the accumulation rule for the cost of Labors, PCGs age in conjunction with other costs, as

$$
(X \Delta t) \otimes \Xi (\ast; X, Y, \tau) \rightarrow \Xi (\ast; X, Y, \tau - \Delta t), \quad (1)
$$

The transformation (1) acts uniformly on the constructor $\Xi$ as on the type categories in the table, leaving the good-name argument $\ast$ a wildcard.

The consumption value $Y$ is invariant for consumable goods, so that $X \Delta t$ is the cost of preserving them purely for the sake of exchange rather than consuming them immediately. Examples in which this has defined the cost of the "noat are the use of salt or tea as moneys in central Asia, or Lucky Strikes during the US depression. In all these cases, the lifetime $\tau$ of the consumable was finite.

The equivalent rule for a Capital Good is expressed in terms of its type constructor as

$$
(X \Delta t) \otimes \chi (\ast; X, Y, \tau) \rightarrow (Y \Delta t) \otimes \chi (\ast; X, Y, \tau - \Delta t). \quad (2)
$$

The capital role of the good is the continuous conversion of the labor $X$ into the service $Y$. If a Capital Good like gold used for jewelry or semiconductor interconnects is converted into coin, the resulting cost of the float over $\Delta t$ is the value $Y \Delta t$ of services lost. Thus both consumable goods used as moneys, and capital goods converted to moneys, create a rate-valued cost of the "noat (respectively $X$ or $Y$), through different mechanisms.

4. Concluding comments on the properties of instruments

4.1. Time, Agents, Ownership, Dimensions, Measures, Other Physical Properties

The purpose of many financial instruments is to pick up microeconomic details that are required in the day to day problems of evaluating, information searching, exchanging, trading, allocating, transporting and inventorying the goods of the economy as well as arranging for the change in time and risk profiles of saving, investment and insurance. The macroeconomic functions of control involve taxation, inflation, employment and public goods. In our discussion below we only touch on some of the multitude of special functions which need to be served.

4.2. The role of time

The selection of the unit of time to be considered is not an innocent assumption, nor is the choice whether time is to be treated as continuous or discrete, or both (see, for example Golan, 1991 [8], Shubik, 1999 [9]). On the planet Earth the day and the year and the life cycle of the individuals are important physical and biological facts. The selection of the time units of measurement in the economies of the nation is related to these facts. Thus, for the most part, we have the tax year which tends to be a cyclical event related to the astronomical Earth year. The inheritance tax is a stochastically imposed event tax related to a specific random event.

4.2.1. Continuous or discrete

In much of finance (primarily for mathematical convenience) time is treated as continuous with continuous compounding unless otherwise specified. In much of the new macroeconomics, discrete interval Bellman equations are utilized [10]. In some simulations of the economy, actions are triggered by other events occurring. Thus instead of "clock time" governing the updating, "event time" guides the dynamics.

The selection of the type of time appears to depend upon the questions being asked. For example, continuous time appears to be excellent for many specific problems in the finance of options, but not adequate for the study of the velocity of money in a closed system.

4.2.2. Small, medium and large intervals

At a more basic level a reasonable question to ask not only of physics, but of economics as well, is do we expect the basic properties of the behavior of the system to depend on the time scale selected?

In much microeconomic theory involving the consideration of more than one period, few papers
discuss just what time period is being contemplated. Is it the hour, day, year, lifetime, century or longer. What percent of the economy operates under these different time spans? Do the laws of economics vary with size and scope?

Practical question arise such as what is the smallest interval for which an institution will be charged for borrowing money. It appears to be down to around a minute in the Federal Reserve Clearing system.

4.2.3. On labor and land

In Tables 1, 2 and 3 we presented eight instruments. From a somewhat different and more inclusive viewpoint we are tempted to raise the size to ten instruments. The extra two are classical items in early economic theorizing. They are labor/leisure and land or an essentially non-reproducible physical asset. The key operating features of note are that in a society without slavery it is not possible to buy the (human) capital producing some services although one can buy the services. Furthermore not only is the relationship between labor and leisure for an individual difficult to characterize in a satisfactory manner, an individual is not in a position to obtain more leisure time than she has time, even though others would willingly part with some of theirs.

Concerning land, as for economic purposes, raw land is deemed not to depreciate. \( \tau \to \infty \) in the above examples symbolizes the proposition that land carries an infinite stream of services. Thus the valuation of the land can be derived from the evaluation of the infinite stream of services with no need for an evaluation of the terminal asset.

4.2.4. Anonymity, Intermediaries and Aggregation

When we deal with mass markets we expect to find mass standardized financial products accompanied by independent low information anonymous trade. Thus the analogy to mass particle behavior is reasonable (see for example Bak, Paczuski and Shubik 1997a and b, [11],[12]). Mass market intermediaries provide various forms of aggregation and control over anonymity, standardization, times of trading, dimensions and complexity of the instruments and provide fixed “boilerplate” for contracts covering many contingencies.

4.2.5. Social perception, Reputation and Networks

Trust, evaluation and reputation are central to the dynamics of financial institutions. Although we do not deal directly with explicit dynamics it is worth noting that in mass financial markets the phenomenon of the polarization of perception is present. This may convert a situation in which an apparently reasonable application of a law of large numbers to the stable behavior of independent particles is destroyed by correlated behavior leading to large fluctuations.

The language and practices of finance indicate the importance of assessment, perception and reputation. Terms such as “due-diligence”, “prime names and lesser names” and triple-A bonds indicate the importance of search and evaluation in the reinforcement of reputation.

In attempting to account for the influence of “acts of God” and the presence of “fat tailed distributions” the key difficulties in finance are illustrated in going between the qualitative and quantitative in the selection of the description and dimensions of risk, even before one places a quantitative assessment on subjective probability.

4.2.6. Economics, Finance and Dynamics

Much of micro-economics and finance has been equilibrium oriented at the cost of ignoring process. Much of macro-economics has been directly applied in an ad hoc manner to problems and structures, though apparently of great socio-political importance today are transient phenomena. In spite of the vast and constantly changing institutional structure of economic life, at a somewhat more abstract level there appears to be a small set of basic invariant instruments whose minimal dynamics can be defined. This paper is aimed at that goal. We conjecture that explicit prediction of the dynamics of a complex economy may not be feasible beyond a locality over a brief interval of time; however the problems of overall prediction and control are different. Unpredictable behavior may be quenched by control over the state space, rather than by attempting to improve path prediction.
But the ability to fully understand the domain of the state space requires a full process description.

References


