Metrological Aspects of an Energy-Based Currency System

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Abstract

An energy-based currency or currency system is the only one to implement clearly defined metrological principles as they apply in physical sciences. In metrological terms, money is needed as measurement instrument for economic activity, which is a complex supply and demand driven "income game". A measurement instrument is however distinct from the measurement unit upon which it is calibrated or standardized and which may designate basic quantities measured in economics such as wealth and value. Energy is the basis for defining a measurement unit for these quantities. This author has proposed an energy-based definition for value called *walras* in 2007. This definition is materially compatible with the System of International units (SI) administered by the *Bureau International des Poids et Mesures* in Paris. The exchange rate between the *walras* and any currency can be called energetic or physiological purchasing power (PhPP) of the currency. Its inverse is the hedonic energy price (HEP) or hedonic walras price (HWP). Both, PhPP and HWP are estimated by hedonic statistical methods. This author has estimated the PhPP and HWP of the Swiss franc in 2003 and plans in his current research to estimate the PhPP and HWP of some further currencies and years. The paper shows that even with an energy-based definition of a wealth or value unit, wealth and value remain clearly distinct from energy.

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1. Introduction

The measurement paradigm of economics and the theory of value is the Achilles heel of modern economics and econometrics. The problem stems from a missing part in the theory of value. This article aims at showing how the link between energy and money can bridge this gap and at the same time contribute to introducing the idea of an energy based currency into economic thought. It starts with describing the challenge of measurement of the "income game", then introduces basic metrological principles that can be applied to economics, further presents the definition of the *walras* as the value or wealth unit based upon energy and finally discusses several options of introducing energy standards in practice.

2. Challenge of measurement in economics and finance

Economics is usually considered as a quantitative social science studying production, distribution and consumption. The term "econometrics" literally designates measurement of economic activity. Economic activity can be compared to a competitive game whereby agents strive for income[2]. It may be convenient to call this process an "income game[3]".

The term "measurement", applied to economics, can mean either measuring an accounting aggregate, such as income, or setting a price. Note that in spite of prices being attributes of products (i.e. goods or services), they are in reality not properties of goods or services. Rather, prices, multiplied by the quantities of goods or services sold by an agent, can be seen as marginal or incremental contributions to this agent's income. In this sense, income is a more fundamental concept than price. Scientifically interesting economic observations are also the price-based transactions ("quantities") of products.

If economic activity can be called a kind of a competitive "income game", it can be compared to a competitive sports game in which winning consists in running over a certain distance in the shortest possible time. Examples are a popular marathon, a cycling, a skiing, yachting or a motor racing competition. The competitors of the "income game" are the producers and sellers of goods and services. Whereas cyclists or yacht race participants have to run over a given distance in the shortest possible time, market agents have to produce goods and services at least cost. In sports and in the "income game", playing may be more essential than winning. Competition need not

[2] In non-cooperative games, the equilibrium is called Nash equilibrium, cf. J. Nash, (1951), "Non-Cooperative Games" *The Annals of Mathematics* 54(2):286-295. The prisoner's dilemma is an example of a non-cooperative game, see for instance http://en.wikipedia.org/wiki/Prisoner%27s_dilemma, retrieved June 2012

[3] „Game" is understood here in a broader sense than in game theory. Wittgenstein showed that there is no exact definition of the word „game" and that it does not need any definition because it is understood anyway, Wittgenstein, Ludwig (1953/2001). *Philosophical Investigations*. Blackwell Publishing, §3.

necessarily take place only between individuals. Just as in a sports game like yachting, where competition takes place between teams within which individual athletes do not compete, economic competition may take place between enterprises within which individuals cooperate.

All games have in common to need rules. It is a breach of rules to run a cycling race on a motorbike, just as it is inadmissible to employ unpaid child or slave labour for producing or selling commercial goods or services. Note that these rules, also called framework conditions, are entirely man-made. It is therefore not true that economics is a purely descriptive science. Just as any sports competition has its rule-setting component, the "income game" has a normative, prescriptive component, namely how to design optimal man-made rules or framework conditions. Note that one set of rules may "work better" than another one, whereby "work better" means either that it produces an overall better performance of athletes when all other things are being kept unchanged ("ceteris paribus"), or that other specific social objectives are better attained. Fundamental framework conditions of the "income game" can be divided into two categories:

- the generic rules of the game such as property rules and the exchange principle, without which the game would not take place because it would be easier for agents to grab and steal, i.e. to play another game;
- the accompanying rules such as labour or environmental conditions, without which slaves or unpaid children could be employed or the natural environment could be depleted for free, i.e. the game would take place, but allow for more or less severe cheating.

Cheating occurs when agents pursue their own goals. In economic theory, pursuit of one's own goals will lead to a social or Pareto optimum except in cases of market failure. Economic theory distinguishes between more or less three types of market failures which have to be corrected by state intervention:

- If an agent is so dominant on a market that he might set a price independently from any other agent, he has a dominant position. This market will fail, i.e. lead to cheating, unless controlled by special legislation[4]. In the ideal case, markets work under conditions of perfect competition, meaning that no seller or producer has an influence on price.
- If a producer causes negative effects on others for which he does not pay, this is called external effect, or externality. The biggest ever market failure of this type is climate change[5], which is caused by incomplete internalisation of external costs due to green house gases such as CO2. External effects should be corrected by taxes or by any other

[4] Competition or antitrust legislation, e.g. in the US: Sherman Act, 1890, whose section 2 prohibits monopolies, (Public Law 94-435, Title 3, Sec. 305(a), 90 Stat. 1383 at p. 1397)
[5] Stern, N. (2006). "Stern Review on The Economics of Climate Change (pre-publication edition). Executive Summary". HM Treasury, London., http://www.webcitation.org/5nCeyEYJr, retrieved June 2012

appropriate instrument. Climate policy also shows the political and economic limits of science: if a decision maker is paid for not knowing climate change, scientific evidence will not be in a position to change this situation[6]. A special kind of a positive externality is the public good[7] or public service, where the state that produces it can not exclude any consumer from using it (no rivalry of consumption). Public goods have to be financed by taxes.

- A third type of market failure is caused by asymmetry of information[8], where a producer or seller has much more information about a product than a buyer. A special kind of information asymmetry is in the principal-agent problem[9], when an agent may not want to share all information with his commanding authority or person, creating an information asymmetry on the labour or agency market. Information asymmetry and principal-agent problems play a certain role in the failure of systemically-important banks. As it is difficult to force all agents to cooperate and to fully share all information at all times, this market failure also needs to be addressed by ethical standards of culture.

A particularity of the "income game" is that it has no beginning, no end, and no geographic limitation and that it is to a certain extent compulsory in that it is hardly possible in civilization to survive without playing this game.

All the framework rules mentioned above are seller or producer oriented and condition the "income game" itself and the results obtained by players. The market failures describe three different ways of breaking the rules, i.e. of cheating. In metrological terms, cheating will lead to false measurement of performance, particularly of those who cheat, only marginally of all the others. This is different in the rules that will be explained hereafter, which are buyer or consumer oriented and are genuinely of metrological relevance. The absence of clear metrological rules in the economic game is not a market failure in the above sense, but rather more a failure of economic theory entailing a systemic failure, meaning that all measurement results are false. The metrologically relevant rules are buyer or consumer oriented and will be explained hereafter.

Of metrological relevance is the fact that in sports competitions like cycling or skiing, the performance of athletes is measured by a clock, i.e. a precisely indicating measurement instrument. In the "income game", the performance of a seller is measured in terms of a currency

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[6] Al Gore, in Davis Guggenheim's documentary film "An inconvenient truth", 2006

[7] Cf. Paul A. Samuelson, (1954). "The Pure Theory of Public Expenditure". *Review of Economics and Statistics* (The MIT Press) **36** (4): 387–389. DOI:10.2307/1925895. JSTOR 1925895. Also knowledge is an example of a global public good, cf. Joseph E. Stiglitz, Knowledge as a Global Public Good in *Global Public Goods*, ISBN 9780195130522

[8] Akerlof, George A. (1970). "The Market for 'Lemons': Quality Uncertainty and the Market Mechanism". *Quarterly Journal of Economics* (The MIT Press) **84** (3): 488–500; and: Spence, Michael (1973). "Job Market Signaling". *Quarterly Journal of Economics* (The MIT Press) **87** (3): 355–374; and also: Stiglitz, Joseph E. "The Theory of Screening, Education and the Distribution of Income." *American Economic Review*, June 1975, 65(3), pp. 283-300

[9] Stiglitz, Joseph E. (1987). "Principal and agent, *The New Palgrave: A Dictionary of Economics*, v. 3, pp. 966-71

of the buyer. More precisely, money in this context means buyers' purchasing power. Purchasing power of the buyer sets the scale for the income of the seller. Without purchasing power, there is no "income game". If e.g. purchasing power of all buyers is numerically divided by a factor 1000 due to a money reform consisting in taking off three zeros from all bank notes, the corresponding seller income will divide by the same numerical factor.

In this situation economic theory states that it is not nominal or current, but real or constant prices that matter. The former is transformed into the latter by taking account of inflation or, more generally, the change of purchasing power of the currency, which is calculated on the basis of the underlying consumer basket. In this context it should be mentioned that there are in principle two types of currencies: a commodity currency linked to a commodity having intrinsic value, and a fiat currency (or pure legal tender[10]) not directly linked to any commodity. Today all main currencies are fiat currencies. Inflation indices establish a link between fiat currencies and consumer baskets.

A clock and a fiat currency have both in common to be measurement instruments. The question is what differentiates them from each other. The answer is that the clock is calibrated for a conventionally standardised measurement unit for time, namely the second, whereas a fiat currency is not calibrated. A fiat currency unit is merely a unit of a scoring system (also called numeraire) rewarding producers or sellers of goods and services. The metrological difference with respect to a measurement unit is that the latter is fix, whereas the unit of the economic scoring system is variable. As a matter of fact, there are many fiat currencies in the world, and many of them have flexible exchange rates against each other[11], and all of them experience either some form of inflation or, at certain times, deflation.

3. Basic metrological principles

The science of measurement and its application is called metrology. The internationally standardized definitions of basic and general metrological concepts and principles can be found in the International vocabulary of metrology, 3rd Edition (VIM3), available on the website of the Bureau international des poids et mesures BIPM[12]. The metrological definitions used in this article are taken from the VIM3.

[10] A pure legal tender is means of payment that has no other function except for settling debts; cf. "Legal Tender Guidelines", British Royal Mint. http://www.royalmint.com/Corporate/policies/legal_tender_guidelines.aspx. Retrieved June 2012

[11] 68 of 188 countries classified by IMF have chosen to let their currencies float, cf. Uri Dadush/Vera Eidelmann (Ed.): Currency wars, Carnegie Endowment for International Peace, Washington, 2011

[12] International vocabulary of metrology, 3rd edition, 2008 version with minor corrections, Joint Committee for Guides in Metrology JCGM, 2012, available for free on the BIPM website, http://www.bipm.org/en/publications/guides/vim.html, retrieved June 2012

A quantity is a property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference (1.1.)[13].

If economic activity may be characterized as "income game", its fundamental quantity is income. Income mostly applies to physical persons or households. For enterprises, it is often called gross revenue or turnover, and for non-profit organizations it is called gross receipts. In finance, too, income is the main aim, whereas wealth is an important means to achieve it. Wealth is the stock, whose corresponding gross flow is income. In order to better understand the income flow, it is necessary to look at its stock equivalent, namely wealth. A succinct description of the quantity "social wealth" has been given by Léon Walras in the following terms:

"By social wealth I mean all things, material or immaterial … that are scarce, that is to say on the one hand useful to us and, on the other hand, only available in a limited quantity" [14].

Note that useful[15] alone does not mean wealth. The oxygen in the air is certainly very useful, but it becomes wealth only if its availability is sufficiently limited so that it gets a price. The same can be said for limited availability. A dangerous virus may not be available in large quantity, but it is not wealth as long as it is not useful. Utility of any product may be extremely variable and its sign (positive or negative) may depend on the kind of interaction of the economic agent with a product. Utility of a gun is different (has opposite sign) for the owner than what it is for the victim.

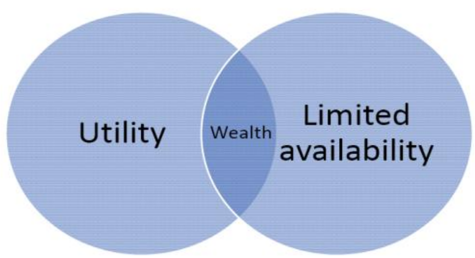

Fig. 1, Walrasian definition of wealth

Income in general, or gross receipts, is not to be confused with profit or net receipts, the net income flow after deduction of cost, i.e. losses. Price has been described above as incremental income of a seller having sold a good or service. The fundamental quantities of interest of

[13] Numbers in brackets refer to numbers of the respective definition in the (VIM3), http://www.bipm.org/en/publications/guides/vim.html, retrieved June 2012.

[14] L. Walras, Elements of Pure Economics or the Theory of Social Wealth, translated by William Jaffé, Orion Editions, Philadelphia, PA, 1984, p. 65

[15] Synonymous for: having utility

economics and finance are therefore: income (flow), wealth (stock), profit (net), cost (losses), and price (value). Note that income, wealth and profit refer to entities (e.g. "the income of Mr. Smith", "the profit of the ABC Corporation" or "the wealth of nations"). Entities in this sense are individuals, households, firms, governments or nations. Cost, price and value refer to products (e.g. "the price of bread", "the cost of a house" or "the value of an hour of my labour"). Products are goods or services. For a list of products see e.g. the Central Product Classification[16]. All these quantities are expressed in terms of money and therefore satisfy the basic requirement, stated in VIM3, that they may be expressed as a number.

The above definition from VIM3 (1.1), however, also requires the existence of a reference:

A reference can be a measurement unit, a measurement procedure, a reference material, or a combination of such (1.1., note 2).

It is worth to look at these terms in more detail:

A measurement unit is a real scalar quantity defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number (1.9.).

The biggest deficit of economics is that there is no conventionally agreed measurement unit for expressing the fundamental quantities of income, wealth, profit, cost and price. This is not totally surprising, as economic theory is not unequivocally clear whether the basic quantities of economic science are cardinal or ordinal quantities. Utility is the most commonly used ordinal quantity of economic science[17].

An ordinal quantity is a quantity, defined by a conventional measurement procedure, for which a total ordering relation can be established, according to magnitude, with other quantities of the same kind, but for which no algebraic operations among those quantities exist (1.26). Ordinal quantities can enter into empirical relations only and have neither measurement units nor quantity dimensions. Differences and ratios of ordinal quantities have no physical meaning (1.26, note 1)

Most contemporary authors refuse the concept of cardinal utility and argue that utility is only ordinal. Indeed, Debreu has proved that order or preference relations of economic agents suffice to create general equilibrium[18]. Figure 1 shows that wealth is at the intersection between utility and limited availability. This means that if utility was always ordinal, wealth would necessarily

[16] http://unstats.un.org/unsd/cr/registry/cpc-2.asp, retrieved June 2012
[17] Utility is synonymous with want, desire, cf. Alfred Marshall. 1920. Principles of Economics. An introductory Volume. 8th edition. London: Macmillan.
[18] G. Debreu, Theory of Value, an Axiomatic Analysis of Economic Equilibrium, Cowles Foundation Monograph 17, Yale University Press, 1959.

be ordinal, too, as it would inherit this property from utility. Wealth, which is not necessarily produced but can exist in form of natural capital[19], is however usually seen as cardinal. If utility is ordinal, wealth necessarily inherits cardinality from limited availability, its other conceptual component. In other words, utility is ordinal except where it is wealth, i.e. where it has also limited availability and is therefore cardinal. Note that in economic theory, it is common to differentiate utility for getting marginal utility, and to take utility ratios. These operations implicitly suppose that utility is a cardinal quantity, i.e. wealth. For ordinal quantities not having any measurement unit, the reference – according to the above definition of the reference (1.1. note 2) – may be a measurement procedure or a reference material, or a combination of such. It is now worth looking at the definition of measurement procedure:

A measurement procedure (2.6.) is a detailed description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result.

This requires explanation of the terms used in this definition:

A measurement principle (2.4.) is a phenomenon serving as a basis of a measurement.

In a market economy, the main phenomenon serving as a basis for measuring prices is the market, i.e. the set of all exchange possibilities of a good or service of a given agent at a given place and moment in time. Not all markets are equal; some allow quite fair competition, while others are seller-dominated (oligopolies)[20] and again others are buyer-dominated (oligopsonies)[21]. The type of market may influence the price level of goods and services traded on that market.

The measurement method (2.5.) is a generic description of a logical organization of operations used in a measurement.

In economic activity, the predominant measurement or the price formation method is price taking – used for most consumer goods – whereby the consumer takes or leaves a good or service that is proposed at a given price. Besides that, other price formation methods are auctions that are used

[19] Cf. Capital approach to sustainable development, OECD (2005) glossary of statistical terms, http://stats.oecd.org/glossary/detail.asp?ID=6360, retrieved June 2012

[20] Oligopolies even exist in areas where the entry barrier into the market is not an issue, such as for auditing, where four big companies dominate the global market, http://en.wikipedia.org/wiki/Big_Four_auditors, retrieved June 2012, or for credit rating agencies, dominated by three big US companies, http://en.wikipedia.org/wiki/Big_Three_(credit_rating_agencies), retrieved June 2012

[21] Examples of oligopsonies can be found in international trade of agricultural commodities such as bananas or cocoa where a small number of buyers meet a large number of producers. This situation was at the heart of fair trade initiatives. These are now grouped in the World Fair Trade Organization WFTO, a worldwide NGO whose global office is in the Netherlands, http://www.wfto.com/, retrieved June 2012

on specific markets, and price negotiations that are common for investments or large equipment contracts. Most consumer surveys use prices stemming from the price taking method.

A measurement model (2.48) is a mathematical relation among all quantities known to be involved in a measurement.

Simple examples of measurement models used in economics are utility maximization under budget constraint[22], or cost minimization under production constraint[23].

To sum this up, the measurement procedure in economics consists of a detailed description of price formation on one or more kinds of market (e.g. competitive or oligopolistic) where agents use a given price formation mechanism such as price taking, based upon a model such as utility maximization under budget constraint, including calculations to obtain a price.

Definition (1.1. note 2) also mentions reference material:

A reference material (5.13) is material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties.

In this definition the following two terms occur:

A measurement (2.1.) is the process of empirically obtaining one or more quantity values that can reasonably be attributed to a quantity.

A nominal property (1.30) is a property of a phenomenon, body or substance, where the property has no magnitude (e.g. sex of a human being, colour of a paint sample, ISO two-letter country code).

In economic activity and economic science an example of a reference material is any commodity having intrinsic value so that it can be used as a basis for a commodity currency.

Any numeraire, no matter whether it exists in form of a commodity currency or whether it exists as fiat currency, is a measuring instrument, defined as follows:

A measuring instrument (3.1.) is a device used for making measurements, alone or in conjunction with one or more supplementary devices.

[22] E.g. in Alpha C. Chiang, Fundamental Methods of Mathematical Economics, Third Edition, Mc Graw Hill, 1984, pp. 400 ss

[23] See Alpha C. Chiang, Fundamental Methods of Mathematical Economics, Third Edition, Mc Graw Hill, 1984, p. 418 ss

In the Walrasian general equilibrium approach, there is exactly one (scalar) numeraire, which in theory may be freely built upon any product. This numeraire is the scoring unit of the "income game" as well as the accounting unit of the system. In contemporary reality, the choice of the numeraire is mostly a fiat currency. The monetary system therefore describes nominal wealth; all the other theoretical choices of numeraire describe some form of real wealth. If all relative prices were always the same, the economy would be in perpetual equilibrium, in which case the choice of the numeraire would not matter. In reality, relative prices vary however as a function of relative scarcity and relative utility of their underlying products, therefore the choice of the numeraire matters.

An indication (4.1.) is a quantity value provided by a measuring instrument or a measuring system.

In economics, nominal (or current) prices are indications provided by a fiat currency. It should be stressed again that the numeraire of a fiat currency is a measuring instrument, not a measurement unit because the value, or more precisely the purchasing power of one currency unit, e.g. one USD, depends on basic economic phenomena such as the equilibrium between total supply of goods and services and total money supply, contrary to, e.g. the mass of a kilogram that is fix. Measuring instruments must be calibrated.

Calibration (2.39) is an operation that … uses … information to establish a relation for obtaining a measurement result from an indication.

In economics, calibration is attempted when transforming nominal (or current) prices into real (or constant) prices. Calibration is the operation that eliminates money illusion[24]. In economics, calibration is made by dividing the nominal prices by the price of the numeraire whose commodity or commodities are chosen as numeraire. In the special case of neoclassical economic theory, the price of the numeraire (in terms of the numeraire) is set equal to 1 by definition.

The more general case with inflation[25] may be illustrated in the following example. Let the nominal (or current) wealth of Mr. Smith be equal to 400 USD. This is the non-calibrated indication of the measurement instrument, in this case the USD. Calibration in the mainstream sense means calculating the real (or constant) price by eliminating inflation. For this, one chooses a base year (e.g. 2000), determines the current inflation index (2012) on basis 2000 (i.e.

[24] Fisher, Irving (1928), *The Money Illusion*, New York: Adelphi Company

[25] Note that inflation is not simply an increase in the price level, as there are many other factors of price level increases than inflation, which is a loss in money's purchasing power (as a result of which, the price level increases). See Sergio Rossi (2001), Money and inflation, a new macroeconomic analysis, Edward Elgar.

1.33)[26] and divides the nominal price by the inflation index, giving 400 USD/1.33 = 300 USD. This is a short form for:

$$\frac{400 USD_{2012}}{1.33 USD_{2012}/USD_{2000}} = 300 USD_{2000} \qquad \text{(Eq. 1)}$$

This more elaborate form states that a wealth of 400 USD of the year 2012 translates to 300 USD of the year 2000 by dividing by the ratio of the USD of the year 2012 and the USD of the year 2000 (i.e. 1.33 USD of 2012 correspond to 1 USD of 2000). This shows that calibration must account for the specific circumstances in which a measurement is made (e.g. translate the 2012 context into the 2000 context). This also exists in physical sciences. Take e.g. a balance, i.e. a measuring instrument for mass. Due to a change in gravity, a balance on the moon gives a different indication for the same mass than a balance on the earth. This “balance illusion” originates from the fact that a balance usually measures weight and not mass, and that mass and weight are only identical under normalized terrestrial gravity conditions. Appropriate calibration may eliminate the “balance illusion”.

A similar method is used to determine the purchasing power parity (PPP)[27] of currencies. The state of the art of calculation is the International Comparison Program ICP[28]. It is an index-based method expressing the purchasing power parity PPP of any local currency unit (LCU) per international dollar in a reference year (e.g. 2005). The international dollar is a US dollar that takes account of the price level difference between a country and the base country chosen to be the US. In the US the international dollar is identical to the national dollar. There is an analogy between PPP and inflation measurement: in both, the numeraire is a consumer basket. A consumer price index CPI expresses the current purchasing power of a currency in terms of the purchasing power of that currency unit in a chosen base year (e.g. 2000). The first to propose an index was the German economist Etienne Laspeyres (1871) [29]. His index is notorious for overestimating inflation. The index developed by the German economist Hermann Paasche in 1875[30] systematically underestimates inflation. Irving Fisher combined the two to what became known as Fisher ideal index[31]. Comparisons made by using his index are however not transitive.

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[26] US consumer price index 2012 basis 2000, IMF World Economic Outlook data base, retrieved June 2012

[27] PPP was first proposed by the Swedish economist Gustav Cassel in 1920, *Memorandum on the World's Monetary Problems,* published by the League of Nations, Geneva. The idea was also supported by J.-M. Keynes, 1923, *Tract on Monetary Reform*, London: Macmillan

[28] http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html retrieved June 2012. Due to the involvement of all major countries and extensive price information of their consumer baskets, the ICP is probably the largest statistical program of the world.

[29] Etienne Laspeyres: Die Berechnung einer mittleren Warenpreissteigerung” in *Jahrbücher für Nationalökonomie und Statistik*.

[30] Hermann Paasche in *Die Geldentwertung zu Halle a. S. in den letzten Decennien dieses Jahrhunderts*. Plötz, Halle a.S. 1875

[31] Irving Fisher (1921): *The Best Form of Index Number, American Statistical Association Quarterly*. 17(133), p. 533 - 537

Transitivity means that a comparison between A and B and one between B and C allows also inferring a comparison between A and C. For multilateral comparisons (involving more than two measures), transitivity is an obvious, but not the only requirement. Diewert has shown[32] that none of ten classes of multilateral index methods satisfies all twelve desired criteria. It is impossible to achieve numerical consistency between cross-cutting international PPP comparisons (usually based upon a star index around a base country) and inter-temporal inflation (usually computed as chain index linking each year only to its neighbour, i.e. with variable base year). In that case numerical consistency only exists for the base country, i.e. the USA. All these problems originate from the variability of consumer baskets.

Consumer basket variability occurs in at least three different ways: in size (number of items), in quantity (of each item) and in quality (of each item). Variation as a result of different consumer tastes, as described in consumer theory, is but a part of overall variability. Variability is a result of the economic process and of development in general. Hundred years ago, consumers had less choice than today, and similarly, baskets of developing countries are today still smaller than those of developed countries. Variation of consumer baskets between communities often results in adaptation of the community to specific conditions. A fridge does not have the same importance for an Eskimo as it has for a Kuwaiti, and umbrellas are more needed in Thailand than in the Sahara. Hence there are considerable differences in methodology between CPI calculations of different countries[33]. Harmonization is greater within the EU, where the relative development levels of member countries is similar so that a Harmonized Index of Consumer Prices HICP[34] has been elaborated. Note that even harmonized consumer baskets are vectors whose variable coefficients (weights) do not satisfy the metrological property of scalar measurement units.

In metrological terms, PPP merely converts indications from one non-calibrated measurement instrument into theoretical indications of another such instrument. The conclusion to be drawn from this is that the PPP method gives rise to a circular definition of wealth or value, whereby each agent takes the implicit definition of the value scale from his client, as in the tale of the cheated cheater:

A baker once went to the judge to complain that the farmer's chunks of butter were smaller and smaller every year, which according to him meant that the farmer was cheating and should be fined. Questioned by the judge, the farmer replied that he has not noticed any change and that he was obliged to use the bakers bread loafs as counterweights for setting the weight of his chunks of butter as he had no other counterweights, and that if anyone was cheating, it was the baker.

[32] Diewert, National Bureau of Economic Research, Working Paper Nb. 5559,1996
[33] For current practices, see http://en.wikipedia.org/wiki/Consumer_price_index_by_country, retrieved June 2012
[34] Erwin Diewert (2002): Harmonized Indexes of Consumer Prices – Their conceptual foundation. Working Paper 130, European Central Bank Working Paper series

This measurement paradigm is not a sufficient replacement for a measurement unit. The "income game" cannot be played in fairness if the measurement system only produces indications of non-calibrated measurement instruments. It needs measurement results that are comparable among each other.

3. Definition of the walras as measurement unit for real wealth or real value

Wealth and value are today largely understood as anthropogenic phenomena based upon utility of a consumer basket. In this respect the history of discovery of the phenomenon "value" can be compared with the history of discovery of the phenomenon "light", which in ancient times was also understood as anthropogenic phenomenon. For Socrates and Plato, light consisted of rays having their origin in the eye and being projected onto objects. Today, light is understood as a physical phenomenon emitted by a non-human source, reflected by visible objects and absorbed by the human eye, where it transforms to sight. A similar paradigmatic change needs to take place for correctly understanding wealth and value. Wealth and value originate both in the physical world and are being reflected in man-made products and may then be affected to economic agents and entities. Looking at the walrasian definition of wealth, this means simultaneously taking utility and limited availability in the definition of wealth. This is crucial for an appropriate choice of the numeraire phenomenon, body, or substance which can be used as a basis for defining a measurement unit.

Inferring from the fact that several currencies were and still are named after some kind of weight unit[35], it seems that value was defined as intrinsic to weight of rare metals used to make coins. Only a minority of agents use rare metals as inputs in production processes, hence this definition has an elitist connotation. The early writers of the 19th century, especially Ricardo and Marx, wanted to have some more common ground for defining value and therefore thought of it in terms of labour value[36]. For them, value was intrinsic in a labour hour. This idea continues to live on in time banking[37] used in local service barter systems and in the popular saying "time is money". This approach neglects the fact that labour hours are extremely unequal in quality and hence should not have the same value. This author has proposed in 2007[38] to define a real value

[35] Pound, peso, lira, mark, rouble

[36] David Ricardo (1823), Absolute Value and Exchange Value, in "The Works and Correspondence of David Ricardo", Volume 4, Cambridge University Press, 1951; Karl Marx, *Value, Price and Profit* (1865) and: Das Kapital – Kritik der politischen Ökonomie, 1867, Otto Meissner, Hamburg

[37] Seyfang, Gill. "Time banks: rewarding community self-help in the inner city?" *Community Development Journal* 39.1 (January 2004): 63

[38] S. Defilla, A Natural Value Unit – Econophysics as Arbiter between Economics and Finance, Physica A 382 (2007) 42-51; 5th International Conference on Applications of Physics in Financial Analysis, online: http://areeweb.polito.it/eventi/apfa5/Proceedings/Physica%20A%20382%202007/Defilla.pdf , retrieved June 2012

or wealth unit on the basis of energy, more precisely available energy of the highest quality[39]. The choice of energy has two motivations:

Firstly, energy is the measurement scale of physiological metabolism of living organisms including human beings. This emphasizes the role of the individual in the economic process. Physiology is the specialization of biology analyzing functions of living systems. Life of human beings is defined here in its biological or more precisely, physiological sense, by asking the question: what is the difference between a living and a dead human body? The living human body has a so-called metabolic[40] activity which the dead body does not have and which is usually expressed in terms of joules per second (= Watt) or kilocalories (kcal) per day or megajoules (MJ) per year. This gives rise to the physiological purchasing power PhPP of a currency, which is its theoretically estimated exchange rate, at a given moment in time and at a given place, with respect to a certain quantity of human physiological life. PhPP answers the question: "What quantity of human physiological life does one unit of a given currency (e.g. USD) buy in average at a given moment in time (e.g. in January 2010) and at a given place (e.g. Denver, Colorado)?"

A "unit human physiological life" can then be defined by taking the basal metabolic rate (BMR)[41] or resting energy expenditure (REE) of a reference person with a reference activity, gender, age, weight and height, during a given period of time in a neutrally temperate environment. For reasons that are explained further down, the "unit human physiological life" is chosen to correspond to the basal metabolism of a sleeping person of female gender, aged 20 years, weighing 53 kg, of height 162 cm, during one year. For that reference person and her reference activity, which could be more familiarly called "sleeping beauty", the resting energy expenditure calculated with the Mifflin equation[42] (1990) often used in calorie calculators[43] lies between 60 and 65 joules per seconds (= 60 to 65 W) or between 1250 and 1300 kcal a day or between 1900 and 2000 MJ a year. The Mifflin equation has been estimated for males and females separately and has the following formulae:

REE (kcal/day, males) = 10 x weight (kg) + 6.25 x height (cm) - 5 x age (y) + 5 (Eq. 2)

REE (kcal/day, females) = 10 x weight (kg) + 6.25 x height (cm) - 5 x age (y) – 161 (Eq. 3)

With non-metric units (pounds, feet, inches) the coefficients have to be adjusted accordingly. These equations can be simplified to a single equation by adding a discrete variable "gender".

[39] High quality energy is sometimes also called exergy. For a comprehensive bibliography on exergy, see also: http://exergy.se/, retrieved June 2012

[40] Metabolism is the set of chemical reactions that happen in the cells of living organisms to sustain life

[41] Basal Metabolic Rate (BMR), and the closely related resting metabolic rate (RMR), or Resting Energy Expenditure, is the amount of daily energy expended by humans and other animals at rest.

[42] M D Mifflin, S T St Jeor, L A Hill, B J Scott, S A Daugherty, and Y O Koh: A new predictive equation for resting energy expenditure in healthy individuals, The American Journal of Clinical Nutrition, vol. 51 no**. 2** 241-247, February 1990

[43] E.g. http://www.scientificpsychic.com/health/cron2.html, retrieved June 2012

For persons not at sleep the effective caloric daily need depends on effective activity. REE has to be multiplied by a factor ranging from 1.2 for sedentary activity to 1.9 for extra high activity. As the year is the predominant time period used in accounting, it is convenient to define also annual REE, meaning that the daily REE shown above has to be adjusted accordingly.

Whereas the PPP approach is relative to cost of living, the PhPP approach is relative to cost of life: PhPP considers that income should be measured in terms of cost of units of human physiological life.

Secondly, energy, more particularly solar energy in form of extraterrestrial radiation, is the only commonly used resource which is of extraterrestrial origin. This motivation emphasizes the role of the global system in the economic process. The intensity of solar radiation is a particularly good indicator for global limited availability in the long term. Theoretically it is the only factor that could determine a maximum achievable real annual income per person.

The intensity of solar energy is determined by the so-called solar constant[44]. At the distance of the earth from the sun, this amounts to 174 PW (Petawatt or 10^{15} W) equalling 1367 W per square meter cross section. Given that the surface of any sphere is exactly four times its maximal cross section and hence the surface of the earth is four times its cross section, the solar constant amounts to 342 W of solar energy per square meter of earth surface, averaged over day and night, all seasons and all locations. These values apply at the outer atmosphere. At the earth surface, there remains about 122 PW or 239 W per square meters at sunny conditions and 89 PW or 175 W per square meter at average weather conditions. The resulting solar energy flow per square meter is of the same order of magnitude as the REE of our reference person, which is 62 W.

The solar constant is a much more fundamental limit than the limits of the four types of capital that are described in the capital approach to sustainability[45]. This approach states that overall capital should not be destroyed in the long term. Overall capital is defined as the sum of four types of capital:

Financial capital (bank deposits, bonds, equity stocks and their financial derivatives),

Produced capital (fixed capital such as infrastructure, buildings, machinery, livestock, and variable capital such as manufactured durable and consumable goods),

Human capital (demography, its skills and knowledge as well as those forms of human health that can be capitalized),

[44] http://en.wikipedia.org/wiki/Solar_constant, retrieved June 2012

[45] Pearce, D.W., Barbier, E.B. & Markandya, A. (1990): *Sustainable development: economics and environment in the third world*. Hants: Edward Elgar, as well as: Stern, D.I. (1997). "The capital theory approach to sustainability: a critical appraisal". *Journal of economic issues* **31** (1): 145–73

Natural capital (covering the four spheres: biosphere including plants, animals and their biodiversity, atmosphere including atmospheric oxygen and atmospheric pollution, hydrosphere including sweet water and its quality, and the lithosphere including land, stones and minerals).

In the format of the international system of units, units are sometimes named after eminent scholars having favoured scientific progress of their discipline. To distinguish units from the respective scholar, units are written in lower case letters.

Derived quantity	Name	Symbol	Expressed in terms of other SI units	Expressed in terms of SI base units
plane angle	radian [(b)]	rad	1 [(b)]	m/m
solid angle	steradian [(b)]	sr [(c)]	1 [(b)]	m^2/m^2
frequency	hertz [(d)]	Hz		s^{-1}
force	newton	N		$m\ kg\ s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
energy, work, amount of heat	joule	J	N m	$m^2\ kg\ s^{-2}$
power, radiant flux	watt	W	J/s	$m^2\ kg\ s^{-3}$
electric charge, amount of electricity	coulomb	C		s A
electric potential difference, electromotive force	volt	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
capacitance	farad	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
electric resistance	ohm	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
magnetic flux	weber	Wb	V s	$m^2\ kg\ s^{-2}\ A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
inductance	henry	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
Celsius temperature	degree Celsius [(e)]	°C		K
luminous flux	lumen	lm	cd sr [(c)]	cd
illuminance	lux	lx	lm/m^2	$m^{-2}\ cd$
activity referred to a radionuclide [(f)]	becquerel [(d)]	Bq		s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2\ s^{-2}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent	sievert [(g)]	Sv	J/kg	$m^2\ s^{-2}$
catalytic activity	katal	kat		$s^{-1}\ mol$

Fig. 2, Examples of some SI units bearing names of eminent scholars[46]

In honour of Léon Walras, whose definition of wealth is of striking simplicity yet clearly superior to the one given by Adam Smith[47], it is proposed to name the measurement unit for real wealth *walras* and describe it in familiar language as follows:

In terms of wealth, one walras may be interpreted as the theoretical minimum quantity of real wealth consumed in one year by the metabolism of the sleeping beauty[48].

Note that in order to eliminate money illusion the definition explicitly refers to real wealth, not to wealth, as "wealth" is more often understood as "nominal" rather than "real" wealth. It is

[46] Source: http://www.bipm.org/utils/common/pdf/si_brochure_8_en.pdf
[47] Adam Smith (1776), *An Inquiry into the Nature and Causes of the Wealth of Nations,* W. Strahan and T. Cadell, London, described wealth as "the annual produce of the land and labour of the society"
[48] See also: S. Defilla, Physica A (2007), 42 - 51, online: http://areeweb.polito.it/eventi/apfa5/Proceedings/Physica%20A%20382%202007/Defilla.pdf, retrieved June 2012

possible to give alternative equivalent familiar language descriptions of the walras as unit of real income, real cost and real value respectively:

In terms of income, the walras may be interpreted as the theoretical minimum real annual income necessary to cover the metabolic energy use of the sleeping beauty during one year.

In terms of cost, the walras may be interpreted the theoretical minimum real cost of conserving the physiological human life of the sleeping beauty during one year.

In terms of value, the walras be interpreted as the theoretical minimum real value of the energetic characteristic consumed by the sleeping beauty in goods or services during one year.

None of these interpretations in familiar language is exact. Before arriving at the exact definition of the walras, some further clarifications have to be given. In metrological terms, metabolic activity is a quantity of the same kind as energy use. The international metrology vocabulary (VIM3) gives the following definition for kind of quantity:

The kind of quantity is the aspect common to mutually comparable quantities (1.2).

Only quantities of the same kind can be added to each other. The earlier mentioned interval of 1900 to 2000 MJ per year for the resting annual energy expenditure (REE) is too large for a precise definition of a measurement unit. Precision of the measurement unit determines precision of the measurement results. Within the mentioned interval there is a quantity of 1956.1 MJ also known as Planck mass energy equivalent, i.e. the energy equivalent of Planck mass or, in short, Planck unit for energy (PUE)[49]. Planck units are the so-called natural units of the Universe that are based upon fundamental physical constants. As Planck, who discovered them in 1899, wrote, they are "constant for all times and all civilizations, even for non-human ones"[50]. Since then their quantitative determination has greatly improved. Planck units simplify theoretical physics and sometimes designate extremes such as the smallest or the biggest quantity of their kind to be found in the Universe[51]. The Planck unit for energy is an exception as it is of human scale: Besides being within the interval of the annual resting energy expenditure, 1956.1 MJ corresponds also approximately to a 60 W lamp burning during one year (more exactly it equals 61.99 Wyears) or to a car tank filling of 52 litres diesel oil, i.e. to quantities used in everyday transactions. From its magnitude, the Planck unit for energy is ideally suited to be taken to define a measurement unit for wealth. The energy quantity referenced in the definition of the walras is therefore made to coincide with the Planck unit for energy.

[49] http://physics.nist.gov/cgi-bin/cuu/Value?plkmc2gev|search_for=universal_in, retrieved June 2012; Planck mass energy equivalent is defined in terms of three fundamental physical constants: c (speed of light in vacuum), h-bar (Planck constant over 2 pi) and G (Newtonian constant of gravitation)
[50] M. Planck, Sitzungsberichte der Preussischen Akademie der Wissenschaften 5, 479 (1899).
[51] See the Annex the formulae of the Planck units

A wealth measurement unit defined according to the conventions of the SI system can only be defined in language form, not as a mathematical formula. This is so because wealth is a base quantity, just as luminous intensity and the other base quantities of the SI system. Base quantities shown in Figure 3 are not reducible to any other quantity found elsewhere.

Base quantity Grandeur de base	Symbol for dimension Symbole de la dimension
length longueur	L
mass masse	M
time temps	T
electric current courant électrique	I
thermodynamic temperature température thermodynamique	Θ
amount of substance quantité de matière	N
luminous intensity intensité lumineuse	J

Fig. 3: Base quantities of the SI system[52]

In other words, wealth is a quantity sui generis that cannot be defined by a definite mathematical formula as a function of any other physical quantity, including energy.

In the SI system, all base units are defined in language form, e.g. the kilogram, defined as the “mass of the international prototype of the kilogram”. The derived units are expressed as mathematical formulae using base units, e.g. the energy unit joule ($J = kg\ m^2\ s^{-2}$). In SI terminology, the walras would have the following exact definition:

1 walras (Wal) is the real wealth in, or the real value of, 1956.1 MJ of the energy characteristic available in an environment at physical and chemical equilibrium[53].

The proposed abbreviation for the walras is Wal. It has already been mentioned earlier that energy is not a single good, but a characteristic found in many goods. The addition "in an environment at physical and chemical equilibrium" is necessary for the precise definition of the available energy which is only defined with respect to an environment in equilibrium[54]. For the specialist, there is in fact a small difference between “energy” and “available energy”. Energy is

[52] VIM3, http://www.bipm.org/en/publications/guides/vim.html, retrieved June 2012
[53] See also: S. Defilla, Physica A (2007), 42 - 51
[54] See Diederichsen Ch.: Referenzumgebungen zur Berechnung der chemischen Exergie. Fortschritt-Ber. VDI-Reihe 19, Nb. 50. Düsseldorf, VDI, 1991

a quantity that can enter or leave a system, but that remains constant in time at the level of the Universe, whereas available or Gibbs free energy, more recently called exergy, can enter or leave a system just like energy, but that can only decrease in time at the level of the Universe. Available energy takes account of the thermodynamic quality of energy and is closely related to negentropy, a quantity that can only decrease in time at the level of the Universe. Available energy corresponds more or less to the popular understanding of "energy", with some minor differences, mainly concerning the thermodynamic quality of heat.

At this stage, two propositions merit demonstration. First, the definition of a base unit such as a wealth or value unit is a necessity without which no meaningful economic science can exist. Imagine for instance choosing the Big Mac wealth unit[55]. The total wealth of, say, Mr. Smith would then amount to 400 Big Macs. Yet he does not necessarily consume or possess one single Big Mac, but merely the equivalent of 400 Big Macs, i.e. an amount of wealth that could be exchanged for 400 Big Macs. This shows that a wealth unit cannot be identical to its underlying commodity. In this example the wealth unit should be called Big Mac Unit (BMU), so that the wealth of Mr. Smith is 400 BMU. This fact is independent from the choice of the underlying commodity. If the choice of the underlying commodity is energy, the error is particularly serious, as can be shown in the following. Admit that the wealth of Mr. Smith is 400 current USD and that this non-calibrated indication should be calibrated by using an energy price which we admit as being, say, 10 current USD/MJ. We then get a wealth of 40 MJ, as the USD cross away.

$$\frac{400USD_{2012}}{10USD_{2012}/MJ} = 40MJ \qquad \text{(Eq. 4)}$$

That would mean that the creation of wealth would violate the energy conservation principle in that it increases total energy of the Universe, which is pure nonsense. The correct way is to give to Cesar what belongs to Cesar (i.e. the walras) and to God what belongs to God (i.e. energy). The above example, if correctly stated, will attempt to calibrate wealth using a walras price of, say, 100 USD per walras:

$$\frac{400USD_{2012}}{100USD_{2012}/Wal} = 4Wal \qquad \text{(Eq. 5)}$$

The second proposition of interest states that a wealth or value unit cannot be defined in terms of a mathematical formula. Take the formula: 1 kilojoule = 1 Eco Unit[56]. Equality is a very strong relation as it means that also the dimension and unit are equal on both sides. If the wealth of Mr. Smith is 400 Eco Units, it is also equal to 400 kJ. This again means that the creation of wealth would violate the energy conservation principle.

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[55] http://www.economist.com/search/apachesolr_search/big%20mac%20index, retrieved June 2012

[56] http://ecounit.org/system/money/ , retrieved June 2012

One can conclude this section by stating that the necessary precondition for an energy based currency is that a unit for real wealth or real value is defined in language form, thereby making clear that real wealth and real value are distinct from energy.

The study of the interaction between economics and physics is also the subject matter of econophysics and thermoeconomics.

4. Pilot estimation of PhPP

An energy based currency may be useful for metrological purposes. Energy is however not a commodity, but a characteristic[57] that can be found in many commodities, namely in (final) energy products, in human food products as well as in animal feed bought on marketss. Estimation of the ratio between currency and walras, i.e. the walras price and its inverse, PhPP, remains a challenge. These can both be estimated by so-called multiple hedonic regression[58] involving the energetic characteristic alongside with other characteristics and with price. As the estimation is hedonic, the resulting walras price should be called hedonic walras price (HWP). It is a conditional mean price. Price data are taken from individual energy prices from price surveys of consumer price indices (CPI) and producer price indices (PPI).

On the basis of over 24'000 individual 2003 CPI and PPI energy price data for Switzerland and the corresponding meta data received from the Swiss Federal Office of Statistics, an identical number of transactions has been reconstructed, each involving several physical characteristics as well as money paid in exchange. The pilot estimation did not include food prices. Several hundreds of different regression specifications have been tested. The best one was found to be a log-log specification involving besides the energy characteristic (or numeraire N) and price P also the characteristic of physical mass M and one dummy variable D for each physically identical good:

$$\ln N = \gamma_0 + \gamma_P \ln P + \gamma_M \ln M + \gamma_1 D_1 + \ldots + \gamma_6 D_6 + \eta \quad \text{(Eq. 7)}$$

[57] Lancaster Kelvin J.: A new approach to consumer theory, Journal of Political Economy, 74, pp. 132 – 157, 1966
[58] The term "hedonic" has first appeared in Court, Andrew T: Hedonic Price Indexes with Automotive Examples, in The Dynamics of Automobile Demand, pp. 99-117, New York: General Motors Corporation, 1939. The hedonic or, using a less value-loaded word, characteristics approach to the construction of price indexes is based on the empirical hypothesis which asserts that the multitude of models and varieties of a particular commodity can be comprehended in terms of a much smaller number of characteristics, cf. Zvi Griliches, Hedonic Price Indexes Revisited, in: Price indexes and quality change, Studies in new methods of measurement, Ed. By Zwi Griliches, Harward University Press, Cambridge, Massachusetts, 1971. Yet, the number of characteristics does by no means always have to be less than the number of goods, cf. Kelvin J. Lancaster, A new approach to consumer theory, Journal of Political Economy, 74, pp. 132 – 157, 1966. For a complete description of the Lancaster approach, cf. K. Lancaster, Consumer Demand: A New Approach, New York, Columbia University Press, 1971

After estimation it has been found that physically similar goods can easily be grouped in coarser categories without loss of estimation efficiency. Best estimates give adjusted R squared of 99.5% and very significant t-ratios for all coefficients (see results in the annex).

On the basis of the best equation retained, PhPP has been calculated as first order partial derivative of N with respect to P at given other covariates. The natural choice of the standard values of the other covariates is the one corresponding to the energy of highest thermodynamic quality that can be shown to be electricity. The PhPP was found to be 0.010 Wal / CHF. HWP was calculated as inverse of PhPP (1/PhPP) and found to be 102.36 CHF / Wal, indicating the theoretical minimal cost of "pure sleeping" during one year. Conversion of the Swiss per capita GDP of 2003 to Wal gives 577 Wal per person per year, meaning that the total per capita output of Switzerland in 2003 is 577 times the minimum biological cost of physiological life.

The log-log specification allows in principle to detect non-linearity of money in wealth. The pilot study has shown that non-linearity is not statistically significant, as the respective coefficient is not significantly different from 1. Still, the mentioned 102.36 CHF / Wal are only exact for a real transaction size of 1 Wal. For smaller and larger transactions the HWP is slightly different. This shows that the choice of the wealth unit especially matters in a context of non-linearity.

From the point of view of data necessary to estimate PhPP, they stem from price surveys of non-core inflation items. Non-core inflation is defined as inflation without energy and food items. This shows that PhPP requires much less data than conventional PPP and is also more efficient than PPP from the metrological point of view. The fact that PhPP estimation requires regression methods is not an extraordinary one. Bear in mind that most contemporary PPP index formulae are based upon the EKS method originally based upon an idea by Gini (1924)[59], developed by Eltetö / Köves (1964)[60] and Szulc (1964)[61]. Gini has expressed the EKS in a least squares estimate which Aten and Heston in a draft paper (2009)[62] describe as GEKS.

5. Implementing Options of an Energy Standard

The interesting question following up on the definition of a real wealth or real value unit is what are the possibilities and limits of implementing an energy standard in practice. More specifically, this includes, as first question, what are the means of estimating and spreading information about

[59] Gini, Corrado (1924), "Quelques considerations au sujet de la construction des nombres indices des prix et des questions analogues," Metron, 4, 3–16
[60] Eltetö, O., and P. Köves, 1964, "On a problem of index number computation relating to international comparison," *Statisztikai Szemle* 42, 507–18
[61] Szulc, B., 1964, "Indices for multiregional comparisons," Przeglad Statystyczny, 3, 239–54
[62] B. Aten, A. Heston (2009): Are all Fishers equal? Penn World Tables research papers, online http://pwt.econ.upenn.edu/papers/AH_BA_april30.pdf, retrieved June 2012

hedonic walras prices (HWP) and PhPP of currencies, and, as second question, what would be adequate monetary systems and monetary policies for implementing an energy standard.

Answering the first question implies that hedonic estimation of HWP and PhPP should be done for each currency on at least an annual basis. It would be possible to do it more frequently, e.g. on monthly basis, with the same methodology relying upon official CPI and PPI data. Also, in the case of large currency areas such as the USD or the euro that are legal tenders in many countries, it would be possible to do country by country estimations.

As for the second question, it is more fundamental in nature. It concerns the concrete nature of the merit system of the "income game", in which metrology is but a part. In metrology, a measurement standard is defined as follows:

A measurement standard is the realization of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference (5.1).

The idea of a measurement standard is to guarantee that measurement uncertainty does not exceed a certain level. As an example, the uncertainty for the kilogram mass measurement standard is 3 micrograms (VIM3, example to 5.1), corresponding to 3 billionth of the measured mass. In economics, this degree of precision is almost unthinkable. Still, the relevant questions in this regard are how to favour the systematic diminution of measurement uncertainty of currencies, and whether and how currencies can and should be eliminated if they exceed a threshold of measurement uncertainty.

In order to answer these questions, it is necessary to look more in detail at the different functions of money and look which of them the walras could fulfil. Some authors attribute the following four functions to money[63]; however, the fourth function is sometimes subsumed in the other three functions[64]:

a) Money is a medium of exchange of (nominal) wealth. The walras cannot perform the role of unit for a medium of exchange, as it is only a measurement unit, but not a currency or measurement instrument. One could of course create a special currency called walras (or possibly with a different name so as to distinguish it from the measurement unit). Such new currency would be a better measurement instrument than usual currencies (i.e. show less measurement uncertainty) if it guarantees constant PhPP. In order to guarantee constant PhPP, the currency should be supplied strictly as a function of final energy demand and should be redeemed in a finite period. That currency would be similar to the

[63] T.H. Greco. *Money: Understanding and Creating Alternatives to Legal Tender*, White River Junction, Vt: Chelsea Green Publishing (2001). ISBN 1-890132-37-3
[64] Mankiw, N. Gregory (2007), "2". *Macroeconomics* (6th ed.). New York: Worth Publishers. pp. 22–32

ergo proposed by Sgouridis / Kennedy (2010)[65] on a model of a redeemable currency ("free currency") originally proposed by Gesell (1916)[66]. It could be a local parallel currency.

b) Money is the unit of account for (nominal) wealth. The walras could certainly become a unit of account for real wealth; this would be its primary function. The International Financial Reporting Standards (IFRS) offer as option the accounting model called Financial Capital Maintenance in Units of Constant Purchasing Power (i.e. Constant Item Purchasing Power Accounting CIPPA), which is compulsory during hyperinflation (i.e. >25% inflation during three consecutive years)[67]. The walras would eliminate the measurement and reporting uncertainty of currency accounting in non-hyperinflationary cases when historical cost accounting (HCA) is used. The walras is a better unit for storing economic and financial information than a currency unit. Ideally it would replace currency accounting, also in the public sector. That would mean that all transactions would be treated from the accounting point of view as if they were transactions in foreign currency and converted to Wal before being written into the agent's proper accounts (i.e. totally disjoining accounting from currency).

c) Money is a store of (nominal) wealth. The walras could only become a unit of real wealth storage to the extent that the underlying energetic goods can be stored. Energy is best stored in form of energy itself. The idea of the walras being a store of real wealth is relevant if stored energy can itself be a medium for clearing debts (i.e. if debts can be repaid by delivering energy). This way of clearing debts has storage and transaction costs which can be assimilated to metrological uncertainties that are higher than the ones of a currency. A priori this debt clearing method will be used only in case debt clearing by means of currency is not available (e.g. in emergencies). The International Energy Agency IEA has introduced stockholding obligations for its member states in 1974. This would broaden the oil asset to other energy and food products and allow the use of stocks for clearing monetary or macroeconomic imbalances and debts. The use of such energetic reserves for clearing debts in emergency times could be broadened to allow any public or private agent to participate.

d) Money is a standard for denominating deferred (nominal) debts. The walras could become a unit for denominating deferred real debts. In comparison with currency denominated debts, walras denominated debt bonds would eliminate the measurement

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[65] Sgouridis & Kennedy, Tangible and fungible energy: Hybrid energy market and currency system for total energy management. A Masdar City case study. Energy Policy 38(2010)1749 - 1758

[66] Silvio Gesell: *Die natürliche Wirtschaftsordnung durch Freiland und Freigeld.* Selbstverlag, Les Hauts Geneveys 1916, online http://www.florian-seiffert.de/doc/my_nwo.pdf, retrieved June 2012

[67] IFRS Conceptual Framework (2010), Par 4.59 (a) states: *"Financial capital maintenance can be measured in either nominal monetary units or units of constant purchasing power"*

uncertainty caused by variations of PhPP and of exchange rates. The walras is a better time storage of debts than a currency. The advantage of such real debt bonds lies in the fact that they are neutral with respect to currency risk and inflation for both, the lender and the borrower. Energy loans or debt bonds would replace and extend the SDR. For this reason, the IMF would be the predestined issuing body. There is no reason, however, to provide exclusivity of this role to any organization. In principle any debtor, public or private, can be allowed to issue walras denominated bonds, and any creditor allowed to accept them.

These four potential functions of the walras can of course be combined.

6. Conclusions

This article understands itself as a further development of the metric aspects of economics with the aim to introduce the idea of an energy-based currency into general economic theory. The absence of a measurement unit for wealth and value has been shown to be a failure of economic theory that has much more dramatic consequences than the three usual kinds of market failures. Using metrological concepts that are generally valid in quantitative sciences, it has been shown that energy is a natural choice of a numeraire phenomenon. It allows for a paradigmatic change in understanding what real wealth and value are. Based upon an earlier publication of this author it has been proven that an energy-based measurement unit for wealth and value is a necessity in order to avoid nonsense interpretations of real wealth. Wealth and value are base concepts that cannot be reduced to any other concepts. The practical implementation of energy-based currency or accounting systems is an avenue for future research.

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Annexes

1. Fundamental Planck units

Constant (Symbol)	Measured value (Codata, Nist)	In SI units	Interpretation
G	6.6742E-11	$\frac{m^3}{kg \cdot s^2}$	Newtonian gravitation
c	299’792’458	$\frac{m}{s}$	Speed of light
$\hbar$	1.05457168E-34	Js	Dirac cst. = $h/2\pi$
k	1.3806505E-23	$\frac{J}{K}$	Boltzmann entropy cst.
κ_c	8987551788	$\frac{m}{F} = \frac{kg \cdot m^3}{C^2 \cdot s^2}$	Coulomb force constant

Source: Codata http://physics.nist.gov/cuu/index.html, retrieved June 2012

If these units are set to 1, they simplify theoretical physics

2. Derived Planck units

Planck time	$\sqrt{G\hbar/c^5}$	5.39121E-44	s
Planck length	$\sqrt{G\hbar/c^3}$	1.61624E-35	m
Planck mass	$\sqrt{\hbar c/G}$	0.0217645 (= 23.9E+21m_e)	mg
Planck energy	$\sqrt{\hbar c^5/G}$	1’956.1	MJ
Planck temperature	$\sqrt{\hbar c^5/Gk^2}$	1.41679E+32	K
Planck angular frequency	$\sqrt{c^5/G\hbar}$	1.85487E+43	Hz
Planck charge	$\sqrt{\hbar c/\kappa_c}$	1.87554E-18 (= 11.7q_e)	C

Source: Codata, http://physics.nist.gov/cuu/Constants/index.html, retrieved June 2012

Planck Unit of Energy is the only Planck derived unit of anthropogenic scale

3. Statistical results of the PhPP pilot study

Computed with Data Desk 6.1

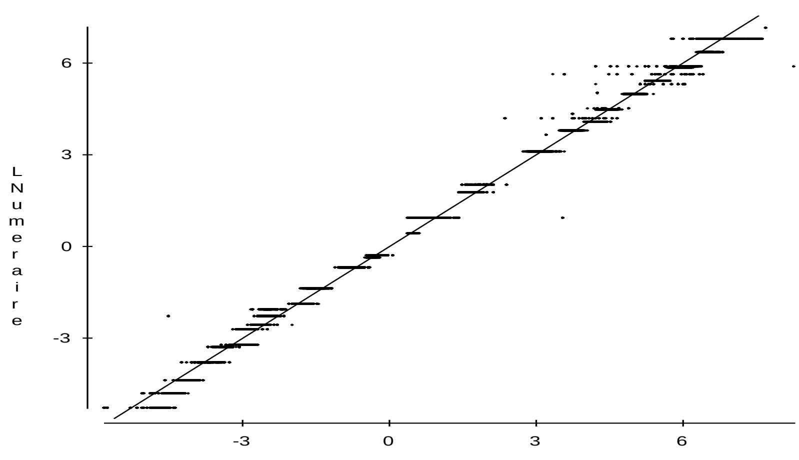
Dependent variable is: **LNumeraire**
No Selector

R squared = 99.5% R squared (adjusted) = 99.5%
s = 0.2607 with 24249 - 9 = 24240 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	321798	8	40224.8	591878
Residual	1647.38	24240	0.067961	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	2.76023	0.0993	27.8	≤ 0.0001
Lprice	0.997242	0.0016	636	≤ 0.0001
Lmass	0.143091	0.0019	76.5	≤ 0.0001
DistrHeating	-12.2567	0.1447	-84.7	≤ 0.0001
CarFuel	-10.1382	0.1345	-75.4	≤ 0.0001
ELHOil	-9.62431	0.1395	-69.0	≤ 0.0001
RawWood	-9.52903	0.1430	-66.6	≤ 0.0001
Gas	-9.25687	0.1348	-68.7	≤ 0.0001
DryWood	-8.38461	0.1435	-58.4	≤ 0.0001
Electricity	0	0	•	•

4. Graphical fit of the regression



5. **Conversion table of energy units; examples: one Planck Unit of Energy (PUE) = 1956.1 MJ; one Wattyear (Wyear) = 0.000754 tons oil equivalent (TOE)**

	kcal	MJ	kWh	Wyear	PUE	TOE
kcal	1	0.0041876	0.001163317	0.000132708	2.14079E-06	1E-07
MJ	239	1	0.2778	0.031690623	0.000511221	2.39E-05
kWh	860	3.6	1	0.114077116	0.001840249	8.6E-05
Wyear	7535	31.6	8.766	1	0.016131627	0.000754
PUE	467117	1956.1	543.4	61.99	1	0.046712
TOE	10000000	41876	11633	1327	21.4	1