A QUEST FOR DEVELOPMENT METROLOGY

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Abstract. *This paper explores development metrology in the framework of social field theory (SFT). Two intensive properties of the SFT, "economic temperature" and "economic entropy," are candidate variables to measure magnitude and direction of development. We show, by comparing the United Nations Development Programme (UNDP)'s Human Development Index (HDI) with the economic temperature, that the HDI needs to be augmented with additional variables to account for harmony between a society and an individual. The paper also suggests a number of relevant variables that might help advance the analytical study of social science disciplines.*

Keywords:*development metrology, Human Development Index, economic temperature, economic entropy*

INTRODUCTION

Many scholars and institutions have attempted to answer the following overarching questions: How do we measure development? What does it mean for a country or a society to be considered developed?

Conventional approaches used to classify societies based on their Gross National Income (GNI) per capita or Gini coefficient fail to answer these questions, although these measures provide some insights into the comparative development of different societies. Societies that are comparable with respect to those measures may significantly differ from each other in regard to other indices of overall development, such as the Human Development Index (HDI) or the Energy Development Index (EDI). In a report to the United States Congress in 1934, Simon Kuznets, the creator of the concept of GDP, admitted that the welfare of a nation can scarcely be informed from a measure of national income. A consensus has yet to be built on global quantitative measurements of development. Furthermore, what is missing is the "development metrology": a scientific foundation and framework for measuring overall development.

The "social field theory" (SFT)bolsters the "capability approach" developed by the Nobel laureate Amartya Sen [1] and Martha Nussbaum [2] that inspired the United Nations Development Programme's composite HDI. The theory quantifies capabilities as the potential energy of an individual [3]in the "Social Field" – one of the means of production. The HDI is missing the underlying science foundation[4], which this development metrology is expected to complement.

Science and technology advancements have long made contributions to human development. Recently, multilateral organizations have focused on behavioral science in their models for understanding development. Gradually, science has been sought out and is making an impact on policy formulation, including mainstream development policies. According to the World Development Report 2015 [5] development economics and policy are due for a redesign following new insights in behavioral economics. This is a favorable shift in economic ideas that is in line with development metrology. The conventional piecemeal approach of addressing social issues with an economic lens has resulted in many divisions among economics scholars. The economics of development can only be revamped through a foundation based on science that economists have been attempting to implement since the time of William Jevons (1835–1882), who introduced mathematical methods in economics.

The SFT serves as the missing foundation in our understanding of development, as evidenced by the many social dynamics it has helped explain[3, 6]. The SFT preserves an understanding of the uniqueness of an individual at the same time that it captures the general patterns of a society. The theory is in line with the ideas of Kurt Lewin[7]: "to understand or to predict behavior, the person and his environment have to be considered as one constellation of interdependent factors."

Not all aspects of a society may be measured precisely. Albeit, this does not imply we should not aspire to it. Our society reveres the use of numbers as they relate to qualitative perception. Physicians in western society have even championed numbers to quantify pain (the one-to-ten scale of pain). Most importantly, assigning a number value to a parameter of interest provides us an opportunity to

measure and control it. After all, it's well understood that we achieve what we measure. Furthermore, the efficacy of interventions in development – local or international – may be measured by the metrics provided by the SFT. Assigning a number to the development of a society can elicit a better strategy and standardization for interventions by governments and multilateral organizations mobilizing Official Development Assistance (ODA) or other forms of foreign aid.

Identifying the most useful variables of a research question is paramount to discovering the underlying relationship and causality. Exact sciences aspire to define the most important variables and to measure them. It helps if underlying relationships, if any,are uncovered among the variables, which later can be upgraded to laws through independent scrutiny by the scientific community. The evolution of natural science can be credited to years and years of systematic observation and persistent assembling of data.

The SFT developed at the University of Massachusetts promises to serve as a framework for the quantitative measurement that is missing in the current scholarship. The economic temperature defines magnitude, whereas the economic entropy defines a direction of development. These two intensive properties of SFT are the function of social strength (S), individual strength (I) and the trust vector (Γ). These terms – not well identified in social science, and currently expressed in their natural units – need to be updated using their proper, more complex system of units. This theory looks at human psychology in a pragmatic way – with all these components intermingling – and tries to quantify the results of the interactions, as well as is scientifically possible.

This paper aims to underpin the UNDP's HDI. In Section 2, we review the SFT and present a concordance table to facilitate connection and exchange of knowledge between natural and social sciences. Section 3 presents economic activities as an analogue mechanism of energy conversion process. Section 4 presents a capital-capabilities-based model of development process. We elaborate on development metrology in Sections 5 through 7. Finally, we conclude in Section 8, with recommendations that might bolster the UNDP's composite HDI.

THE SOCIAL FIELD THEORY (SFT): A REVIEW

SFT is an eclectic analytical construct on the foundation of classical field theories. SFT originated from positivism, a philosophy of science that suggests that society, like the physical world, operates according to some general law. According to the SFT, the Social Binding force (in natural units) at social distance r is:

$$F = \frac{\mathrm{S\,I}}{r^2} \tag{1}$$

where S and I are social strength and individual strength, respectively. According to Wright [8], social distance is the relation of social entities to others measuring the degree of their contact or isolation. In equation (1),*r* represents social distance between a society and an individual. A reciprocal of social distance may be defined as trust vector (Γ), which can be a measure of degree of social cohesion or well-being. It can be measured utilizing Self-Anchoring Striving Scale [9], known as Cantril's Ladder popular in public opinion research.

This theory draws upon how similar interaction takes place in many other fields (such as gravitation, electrostatic, and magnetic fields). In the "Social Field," potential corresponding to r is equal to

$$V = -\frac{\mathrm{S}}{r} \tag{2}$$

and, the potential energy

$$PE = -\frac{\mathrm{S\,I}}{\mathrm{r}}. \tag{3}$$

In the extant literature, the potential V is called the "economic temperature." This is a phrase conceived by Emanuele Sella in 1915 with an aim to supersede challenge associated with *value* measurement[10]in economics.

The potential energy, PE, of an individual is equivalent to the capabilities following the nomenclature of the "capability approach". Capabilities à la Amartya Sen $\rightarrow 0$ as $r \rightarrow \infty$.

A concordance table of terminology between thermodynamics and economics was developed based on a seminal work by Irving Fisher [11] in his Yale University PhD dissertation. Table 1 incorporates knowledge from the most profound discoveries of the twentieth century – namely quantum mechanics, relativity theory and the capability approach.

Table 1. CONCORDANCE TABLE

Thermodynamics			Economics	
CV	control volume		Ω	a political region (society)
Q	heat		Q	aggregate value, in absolute sense
T	temperature		S/r	economic temperature
ds	entropy change		dSI/S	economic entropy change
W	work		W	input for an economic process
KE	kinetic energy		C_1	capital, SI/2r
PE	potential energy		C_2	capabilities (knowledge, skill, etc.), – SI /r
E	energy (ke + pe)		A	asset (capital + capabilities), A = C_1 + C_2
m	mass		ℑ	social inertia
v	velocity[a]		G	growth/development, dA/dt
a	acceleration		dG/dt	rate of change of growth, d^2A/dt^2

[a]In the term analogous with classical mechanics, the velocity corresponds to the rate of change of the social distance, dr/dt. In the Social Field$F = \frac{S\,I}{r^2}$, and the asset A $= -\frac{1}{2}\frac{S\,I}{r}$. Combining, we can write: $F = -\frac{2Ar}{r^2} = -\frac{2A}{r} = -2A\Gamma$.For a given time, if F is assumed constant, the product of the asset and the trust vector is constant. This implies that dA/Adt =– dr/rdt. Hence, the growth rate, dA/dt, can function as a proxy of velocity in classical mechanics.

Two postulates of the Social Field are as follows:

HP01: Social Field is a quasi-conservative field, defined as a field for which total energy is a monotonic function of time.

HP02: Poverty levels are quantized in similar notion as in established models of an atom, Bohr's theory [12] of the hydrogen atom and Schrödinger's equation.

ECONOMIC PROCESS AS AN ENERGY CONVERSION PROCESS

An economic process in a society may be analyzed by using the energy conservation analysis of thermodynamics, which is best known as the First Law of Thermodynamics. Following concordance Table 1, the equation of the First Law of Thermodynamics

$$dE = dQ - dW \tag{4}$$

translates to economics as

$$\Delta\text{Asset} = \Delta\text{Value} - \Delta\text{Work}; \tag{5}$$

where symbol Δ represents a change of the variable.

Let Q_1 be the value of input and Q_2 be the output of an economic process that demands work input dW. This process may be compared to the refrigeration/heat pump cycle in thermodynamics; a caveat is that those cycles do not retain internal energy, while an economic cycle must retain someinternal energy in order to perpetuate its motion. Figure 1 graphically interprets the terms of equation (5).

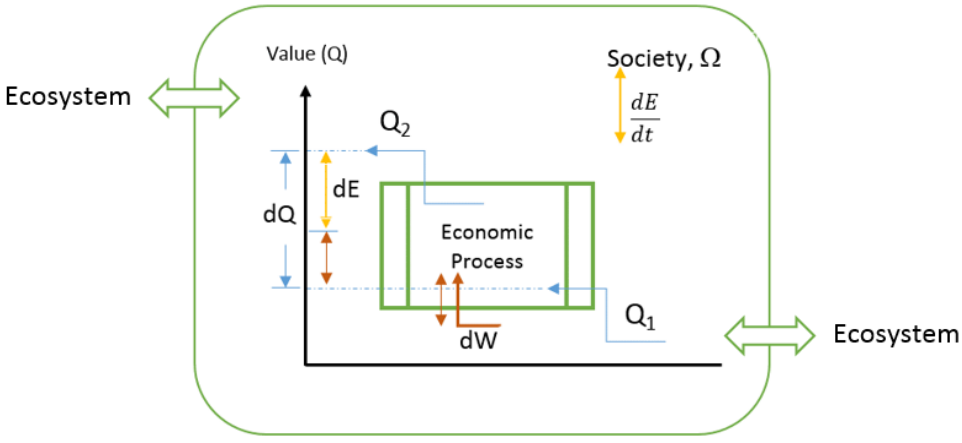

Figure 1. Economic process and the first law of thermodynamics

In terms of value addition as a result of an economic process, we can define coefficient of production (COP) as a ratio of values of output and input. Therefore,

$$COP=\frac{Q_2}{Q_1+dW}=\frac{Value of Output}{Value of Input+Work Expended}=\frac{Output}{Sum\ of\ Inputs} \quad (6)$$

It is critical for an economic process to have an operating margin to pay its fixed costs, hence COP > 1 in general. The numerator of equation (6) compares selling prices to the denominator of the cost prices of a product. The gross value addition dQ = $Q_2 - Q_1$. The net value addition is dE = dQ – dW = $Q_2 - (Q_1 + dW)$, sometimes also known as "gross margin."This value or surplus belongs to the drivers of production – capital and capabilities – that are assets of the society Ω in which the economic process (production or consumption) takes place. A rational distribution of this surplus is one of the greatest challenges of political economy today.

WHAT IS DEVELOPMENT?

Development is a general term utilized in various senses in many disciplines. For a society, "development" may be defined as a process by which the society and its members gain strengths and mutual trust that they value for upward social mobility. In other words, development is a symbiotic evolution process of capital and capabilities of members of a society.

Figure 2 presents a model of development [6] where two social assets – the capital (C_1) and the capabilities (C_2) – interact to support the upward mobility of a society. The x-axis represents the time and the ordinate represents the social asset, the driver of production that a given social class exercises. Line AB represents social hierarchy and its inclination (θ) with the x-axis representing the inequality prevalent in the society. Po_1 is the poverty level in the society at time t_1. An interplay between the capital and the capabilities can produce a upward force F_{NET}that can induce upward social mobility of the society, represented by line AB.

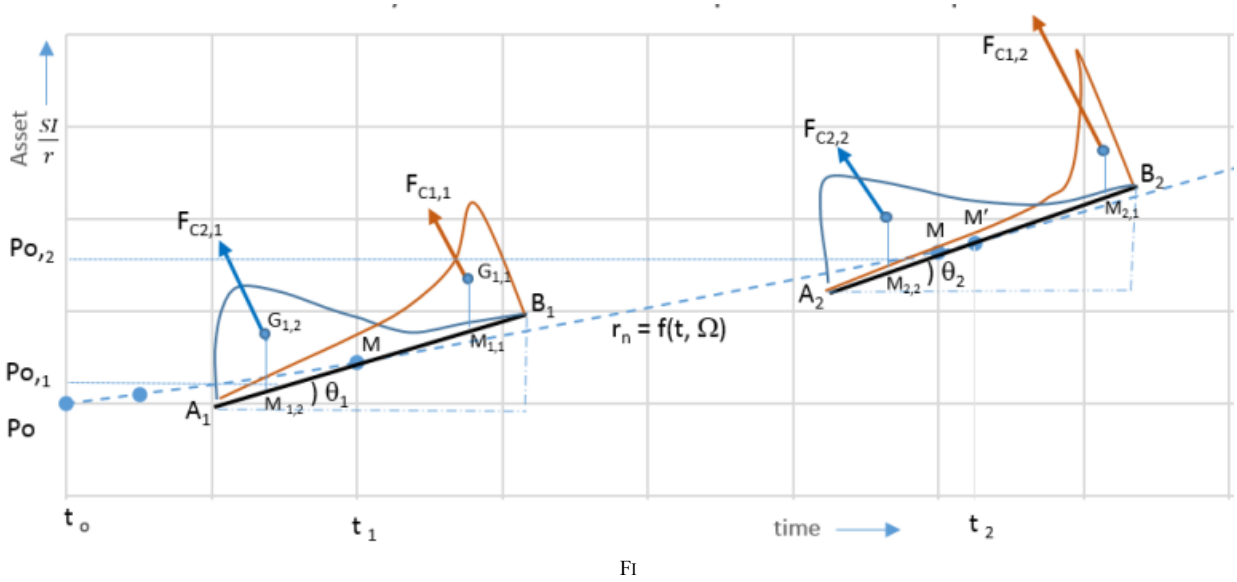

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Figure 2. Dynamics of growth – capital and capabilities

Suppose F(y) represents capital distribution function in a society, such that dF(y) is the proportion of population (or economic units) that own capital y. In terms of probability density function f(y), we can write: dF(y) = $\int_{Po}^{\infty} f(y)\,dy$. Consider c_m = max (SI/r), and Po the absolute poverty in Ω at given time.

Forces of Capitalism F_{C1} = Area under the curve F(y) and the social hierarchy line AB

$$=\int_{Po}^{c_m} F(y)\,dy.$$

This force F_{C1} acts at centroid G_1 of capital the distribution curve. In a similar way, we can compute F_{C2} and centroid G_2 given a capabilities distribution curve. At time t_1, M is the social fulcrum at which the social inertia,ℑ, of the society may be assumed to be concentrated.

The capital-capabilities-based model of development in the SFT framework above highlights two sources of assets in the society: kinetic and potential. Capital is a kinetic asset, whereas the capabilities are a latent asset, in some cases not yet realized as contributing to the development of the society. These social assets are the means of production in today'sknowledge-based economy. In order for a society to be termed "developed," realization of both of the means of production is very important.

The first Human Development Report (HDR) was launched by the UNDP in 1990 under the leadership of MahbubulHaq. The HDR aimed to shift the focus of development economics from national income accounting to people-centered policies [13], sometimes also known as the Human Development Paradigm [14]. A HDR includes HDI of countries for a given year. The HDI is a summary measure of average achievement in key dimensions of human development. The methodology underlying synthesis of the HDI is probably one of the most debated

topics in economic science. Selim Jahan [15] and Elizabeth Stanton [16] have documented a brief account of the evolution of the HDI. Martin Ravallion [4] suggested that future progress in devising useful new composite indices of development will require that theory catches up with measurement practice. The HDI, as it is now, does not carry information about the future level of development[17]or direction of development. Many scholars – including Ravallion [18] – have highlighted its weakness, but only a few studies[19, 20] have suggested ways to improve it. In response, the metrology is evolving but at a snail's pace. The organization unit of the UNDP responsible for the HDR, the Human Development Report Office (HDRO), has been very responsive to the critique and has gradually updated underlying methodology. The 2014 HDR incorporated geometric methods of aggregation of its three underlying indices related to income, health and education.

The SFT provides a scientific foundation for the HDI and some ways to improve it. The metrology based on the theory integrates, at the least, fundamental dimensions such as economic growth, inequality and poverty dynamics. A development must encompass both the capital and the capabilities. Economic growth has largely been toward capital development. Hence economic growth cannot be a measure of development itself although it is a very important part of the development process. Based on the model of development presented above (Figure 2), the rate of development

$$\frac{d\mathcal{H}}{dt} = \frac{A(M\,@\,t_2) - A(M\,@\,t_1)}{t_2 - t_1} \qquad (7)$$

where$A(M\,@\,t)$represents the social asset, a sum of capital and capabilities measured at the social fulcrum M at time t.

DEVELOPMENT METROLOGY

Following the definition of development in Section 4, the Hamiltonian $\mathcal{H}$ can be written in the Social Field as

$$\mathcal{H} = \mathcal{H}\,(\mathrm{S, I, r, t}). \qquad (8)$$

The Hamiltonian $\mathcal{H}$ corresponds to the total energy of the Social Field under analysis. Equation (8) can written in total derivative form as

$$\frac{d\mathcal{H}}{dt} = \frac{\partial\mathcal{H}}{\partial t} + \frac{\partial\mathcal{H}}{\partial S}\frac{dS}{dt} + \frac{\partial\mathcal{H}}{\partial I}\frac{dI}{dt} + \frac{\partial\mathcal{H}}{\partial r}\frac{dr}{dt}. \qquad (9)$$

The net force in an open society could be the sum of the endogenous (F_{en}) and exogenous (F_{ex}) forces that compares the body forces and surface forces in mechanics. Hence, following Newton's second law one can write,

$$F_{NET} = SocialInertia \times rateofchangeofdevelopment$$

or $$F_{en} + F_{ex} = \Im \times \frac{d^2\mathcal{H}}{dt^2}.$$

Alternatively, recalling $\mathcal{H} = \mathcal{H}\,(C_1, C_2, t)$ and $F_{en} = \frac{SI}{r^2}$, we get

$$\frac{d}{dt}\left(\frac{\partial\mathcal{H}}{\partial t} + \frac{\partial\mathcal{H}}{\partial C_1}\frac{dC_1}{dt} + \frac{\partial\mathcal{H}}{\partial C_2}\frac{dC_2}{dt}\right) = \frac{1}{\Im}(F_{en} + F_{ex}). \qquad (10)$$

Relaxing assumption (say F is not constant, Table 1), and with source/sink $\dot{\mathbb{Q}}$:

$$\frac{\partial\mathcal{H}}{\partial t} + \frac{\partial\mathcal{H}}{\partial C_1}\frac{dC_1}{dt} + \frac{\partial\mathcal{H}}{\partial C_2}\frac{dC_2}{dt} = (F_{en} + F_{ex})\frac{dr}{dt} \pm \dot{\mathbb{Q}}. \qquad (11)$$

Equation (11) describes time evolution of asset in a social field. Given a society Ωwe can assume that rate of change of asset depends on how an asset is distributed and utilized. Following an analogy similar to Fick's second law of diffusion, we may write:

$$\frac{\partial A}{\partial t} = -D_{12}\frac{\partial^2 A}{\partial \Omega^2} = -D_{12}\frac{\partial^2 (C_1 + C_2)}{\partial \Omega^2} \qquad (12)$$

whereD_{12} is the capital to capabilities diffusion coefficient, a function of political economy of a region. Hence, this coefficient can vary in space and time. The equation (12) presents a circular relationship that exists between these two means of production. In fact, one complements the other. Stiglitz and Squire [21], citing progress made by South Korea, claim that income and non-income measures of development are complementary and mutually reinforcing. This coefficient determines how responsive the economic growth is to the development of the society. Furthermore, it may explain some of the discrepancies among economists [6], at times, about the effect of the economic growth on poverty dynamics.

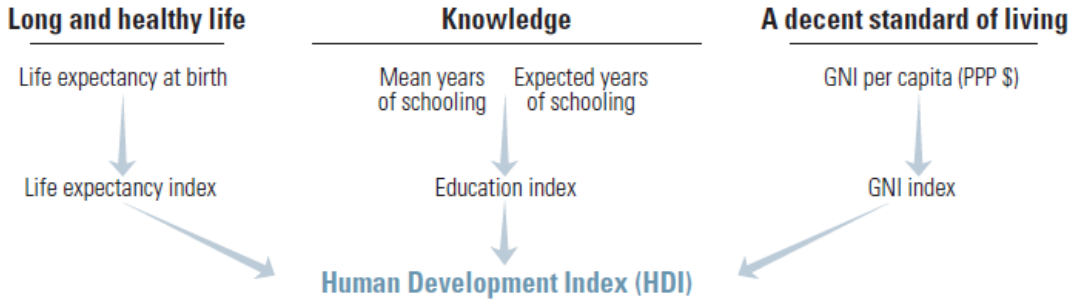
Evolution favors those species whose energy-capturing devices are most efficient. With reference to the evolution of the organic world, Boltzmann pointed out that the fundamental object of contention in the lifestruggle is available energy [22]. Capital and capabilities are energy in the social field. In the absence of an intervention, equation (12) suggests that the advantage must go to the developed society whose energy capturing skill, in general, outweighs that of developing society. Nonetheless, the latter society may also benefit sometimes during the process, partly due to the difference between social and financial cost-benefit, among many other things.

Equation (12) also provides an estimate of exogenous force (F_{ex}) due to the difference in economic temperatures between societies (say Ω_i and Ω_j). In this particular case D_{ij} may help quantify the catchup in the process of development[23, 24]. If A and B are two societies of economic temperatures T_E^A and T_E^B respectively, and $T_E^A > T_E^B$. Then, the catch-up rate of development $= f(T_E^A - T_E^B)$.

These analytical models are useful in order to bring forward additional insights to many social dynamics, but nonetheless must be assessed carefully together with underlying assumptions and limitations.

ECONOMIC TEMPERATURE VERSUS HUMAN DEVELOPMENT INDEX (HDI)

The economic temperature is the product of the social strength and the trust vector. At present, the HDI compares the social strength S that incorporates three qualities a society values: income, health, and education. Figure 3 taken from the Technical Notes of the Human Development Report (HDR) [25] presents the three HDI dimension indices that are aggregated into a composite index using geometric aggregation.



Source: Technical notes/HDR 2014

Figure 3.Human Development Index Calculation, 2014.

In terms of the social asset, income belongs to the capital set (kinetic asset), while the other two qualities (health and education) belong more to the capabilities set (potential asset). These qualities are a few of many dimensions that members of the society may value. However, in many cases, especially in a developing country, these qualities may not be enough to sustain the hopes and aspirations of its members, especially among the younger generation. These qualities are the means not the ends. If these qualities cannot help lead to a meaningful life in the society, they are not worth as much to human development. Hence, how these qualities help build trust among the society and its members are important variables of human development metrics. As it is now computed (Figure 3), the HDI does not take into account variables to gauge harmony between society and an average individual, and the impact of development on natural environments.

In a race toward material success, many of our actions are motivated by short-term private gains. The corporate world and our education systems are teaching us to value short-term, individual gains over long-term social benefit. Accordingly, social norms increasingly value material success over any other qualities. Even in many advanced societies, the capital one controls is linked to success and fortune, and accordinglyto having social privilege. This is a commonplace many of us try to emulate. These myopic activities create an undue pressure on the younger generation especially, and the trust vector between this generation and society is deteriorating, mainly in the developing countries. This has led to increased migration, asylum trends in developed countries, and further exacerbated social and regional instability in many parts of our beautiful blue planet.

The trust vector encompasses an aggregate (and unique) perspective of individuals toward their society. One may argue about identifying trust of the individual on each quality (or dimension) a society may value, and aggregating a number based on some mathematical or statistical formula. Considering diversity among individuals, and their unique perspectives about the social qualities, it is unlikely any such mathematics will ever exist. *Trust* is more like a personal taste than a mathematical subject. Only the individuals in question can evaluate their harmony or the trust vector with their society. The trust vector gives some reflection on the basic needs, hopes and aspirations of an individual in the society.

Hence trust vector (or social well-being) is an important variable of development. It is independent of the qualities (income, health, and education) a society may value. This variable is missing from the UNDP's composite HDI.

ECONOMIC ENTROPY

An "open system" is characterized as "a system in which both energy and matter cross its boundaries, allowing the interaction and interconnection of its own elements with the external environment." Both living organisms and economic processes are open systems. Erwin Schrodinger [26] explained how living organisms maintain life by continually drawing low entropy from their environment. Living organisms feed on *negentropy* to balance natural entropy decay inherent with life. Likewise, economic process maintains its continuity drawing on value and energy from other economic units (individual, household, or firms) of society and environment, as presented in Section 3. Any real economic process that adds value, in general, also exports high entropy to the ecosystem. It is the added value and energy by virtue of which a society, as well as an individual, enhances its strengths over time.

If dSIis the change in entropy strength of a society Ω of strength S, the change in economic entropy, following the analogy from thermodynamics, can be written as

$$ds = \frac{dSI}{S} = I\frac{dSI}{SI}. \quad (13)$$

By integrating, we get

$$s = I\log(SI). \quad (14)$$

This equation is similar to the Boltzmann equation[27] rewritten in thermodynamics as

$$s = \kappa \ln W \quad (15)$$

where$\kappa = R/N_A$ is the Boltzmann constant, and W is the thermodynamic probability of a macrostate.

For a society Ω, an average individual strength can be written in terms of Hamiltonian $\mathcal{H} = \mathcal{H}$ (S, I, r, t) as $\bar{I} = \mathcal{H}/N$. Unlike κ, the average individual strength is not a constant, but rather is a monotonic function of $\mathcal{H}$. Moreover, the Social Field as in [HP01] being a quasi-conservative field, in general, $\bar{I}$must also increase monotonically with time.

In terms of social asset $A = C_1 + C_2$, the economic entropy (14) can be written as

$$\Delta s = dSI/S = 2\, dAr/S = 2/S\, [Adr + rdA] \quad (16)$$

$$\text{or,} \quad S\, \Delta s = 2\, [(C_1 + C_2)\, (r_2 - r_1) + r(dC_1 + dC_2)]. \quad (17)$$

In order to track the change of economic entropy in the society, as equations (16) and (17) suggest, either we will need to quantify the entropy strength (SI) or we will need a mechanism to keep track of time evolution of social asset A, the sum of capital and capabilities. The *Inclusive Wealth Report: Measuring Progress Toward Sustainability*[28] concedes the inability of the HDI to capture the change in natural asset as a stimulus, in part, for the environmental decline and degradation.A double-entry bookkeeping system, considering both the society and ecosystem, may help compute entropy increase as a result of development process. Hence incorporating the economic entropy into the development metrics may render the HDI a more useful indicator of overall development.

CONCLUDING REMARKS

The Social Field Theory (SFT) provides an insight on variables to be identified and systematically measured in the social science domain to advance analytical study. This preliminary paper uncovers some of those variables and presents a scientific framework for measuring development. The economic temperature (S/r) defines magnitude, whereas the economic entropy (dSI/S) defines a direction of development. We present a methodology to compute change of entropy in a social field associated with development process. In order for the UNDP's HDI to measure development more effectively, it needs to encompass an additional variable, at least, such as the trust vector of the SFT that measures harmony between the society and an individual. The HDI continues to stand for better things as MahbubulHaq intended during its inception. However, if HDI can evolve toward a vector represented by the duo – economic temperature and economic entropy – the HDI may also be able to capture the "complex reality" better.

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REFERENCES

[1] Sen, A., Development as Freedom, New York: Alfred A. Knopf, Inc., 1999.

[2] Nussbaum, M. C., Women and Human Development: The Capabilities Approach, Cambridge: Cambridge University Press, 2000.

[3] Poudel, R., Zheng, K.,Wood D. and McGowan, J. G., "Atomic Analogy of Poverty," *Energy for Capabilities Development,* p. 1 – 7, 2014.

[4] Ravallion, M.,"Mashup Indices of Development," Oxford University Press, 2011.

[5] World Bank Group, "World Development Report 2015 : Mind, Society, and Behavior.," World Bank, Washington, DC, 2015.

[6] Poudel,R. and McGowan, J. G., "Economic Growth, Development, and Poverty Dynamics: An Insight from The Social Field Theory," *Energy for Capability Development,* p. 1 – 28, 2015.

[7] Lewin, K.,Resolving social conflicts & Field theory in social science, Washington, D.C.: American Psychological Association, 1946, p. 338.

[8] Wright, Q., A Study of War, Vols 1-2, Chicago, IL: University of Chicago Press, 1942.

[9] Cantril, H., The pattern of human concerns., New Brunswick, NJ: Rutgers University Press, 1966.

[10] Rotondi, C. "Competition and economic temperature: The entropy law in Emanuele Sella's work," in *Economics and Interdisciplinary Exchange*, London, Routledge, 2001, p. 150 – 170.

[11] Fisher, I., Mathematical investigations in the Theory of Value and Prices, New Haven: Yale University Press, 1892.

[12] Bohr, N.,"On the Constitution of Atoms and Molecules, Part I," *Philosophical Magazine,* vol. 26, no. 151, p. 1–24, 1913.

[13] Haq, M. u.,Reflections on Human Development, Oxford University Press, 1995.

[14] Fukuda-Parr, S., "The Human Development Paradigm: Operationalizing Sen's Ideas on Capabilities," *Feminist Economics,* vol. 9, no. 2-3, pp. 301-317, 2003.

[15] Jahan, S.,"Evolution of the Human Development Index," in *Handbook of Human Development: Concepts, Measures, and Policies*, Oxford University Press, 2009.

[16] Stanton, E. A.,"The Human Development Index: A History," Political Economy Research Institute (PERI), University of Massachusetts, Amherst, 2007.

[17] Ivanova, I.,Arcelus F. and Srinivasan, G.,"An assessment of the measurement properties of the human development index," *Social Indicators Research,* vol. 46, p. 157–179, 1999.

[18] Ravallion, M., "Troubling tradeoffs in the Human Development Index," *Journal of Development Economics,* vol. 99, no. 2, p. 201–209, 2012.

[19] Stiglitz,J.,Sen, A. and Fitoussi, J., "Report by the Commission on the measurement of economic performance and social progress," 2009.

[20] The Blue Planet Prize laureates, "Environment and Development Challenges:The Imperative to Act," The Asahi Glass Foundation, 2012.

[21] Stiglitz,J. E. and Squire, L.,"International Development: Is It Possible?," *Foreign Policy,* pp. 138-151, 1998.

[22] Lotka, A. J.,"Contribution to the energetics of evolution," *Proceedings of the National Academy of Sciences of the United States of America,* vol. 8, no. 6, pp. 147 - 151, 1922.

[23] Nelson, R. R.,"Economic Development from the Perspective of Evolutionary Economic Theory," *Oxford Development Studies,* vol. 36, no. 1, pp. 9-21, 2008.

[24] Chanda,A. and Putterman, L.,"Early Starts, Reversals and Catch-up in the Process of Economic Development," *The Scandinavian Journal of Economics,* vol. 109, no. 2, p. 387–413, 2007.

[25] UNDP, "Human Development Report," United Nations Development Programme (UNDP), New York, 2014.

[26] Schrodinger, E.,What Is Life?, Cambridge: Cambridge University Press, 1944.

[27] Lee, J. F., Sears, F. W. and Turcotte, D. L., Statistical Thermodynamics, Addison-Wesley Publishing Company, Inc., 1963.

[28] United Nations University International Human Dimensions Programme (UNU-IHDP) and United Nations Environment Programme (UNEP), Inclusive Wealth Report 2012: Measuring Progress Toward Sustainability, Cambridge: Cambridge University Press, 2012.