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# Planet Earth's General Equilibrium

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**Planet Earth's General Equilibrium**

## Abstract

If the reproductive mechanism and the criminal behaviour of the earth's inhabitants are exogenously put under control (by laws, regulations, institutions and policies such as educational reforms), then our planet is to be repeatedly found in an optimal (in the sense of maximising the whole population's utilitarian welfare) and temporarily-steady balance, likewise, in an *ex ante* to *ex post* stable general equilibrium, among two opposite sides or forces, in between the existence or the survival of humanity is placed. The one is the endogenous-optimal *food* and *water* supplies of people, which are consumed (thus, get gradually extinct) with some (endogenous) general equilibrium rates, in fixed proportions. The other is the endogenous-optimal *environment* (i.e., the *nature*) and the endogenous-optimal *energy* (that is sourced and emitted from the *non-renewable natural resources*) of the earth, which, both, determine our food and water balances, by being destroyed (or exacerbated) and extracted-or-used (or depleted), respectively, with their own (endogenous) general equilibrium rates, under a reasonable pre-agreed rule. During the realisation of this optimal balancing process, the earth's random *climate* (deterioration) renders the attainment of this general equilibrium risky, but the correct or rational (namely, the without estimation or expectation errors) prediction of the climate change does not dampen the general equilibrium outcome, when moving from the *ex ante* to the *ex post* instant of time.

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*Key Words*: Planet Earth, Ecosystem, Reserves, Humanity, Food, Water, Environment, Resources, Energy, Climate, Extinction, Destruction, Utilitarian Welfare, Leontief, Walras, Arrow-Debreu, General Equilibrium with both Goods and Bads.

*Classification*: D5, D6, D7, D8, Q0, Q3, Q4, Q5.

This paper poses the question of whether and how our planet manages to reach across time a (i) sustained (i.e., unstoppable), (ii) sustainable (i.e., with maintenance of its material structure or composition), (iii) minimally-regulated (i.e., almost decentralised), and (iv) periodically steady (i.e., stable) general equilibrium. In the follow up, a nuanced theoretical answer is formally provided to this question by picking (and concentrating up-onto) some (repeatedly replicated) time-period of the world, which period consists of the *ex ante* and the *ex post* points of time.

On the one hand, to make a start on this project, we are all accommodated in planet earth by being embodied into its ecosystem, and we all mutually enjoy two fundamental *goods*: *food* ($F \geq 0$), i.e., animals and plants, and *water* ($W \geq 0$). $F$ and $W$ are the deterministic, for now, alternative quantities, of some quality, of food and water, respectively. These quantities are consumed (equivalently, they get gradually extinct) by people. It is assumed that, more or less, all the animals and all the plants in the planet are edible, and all the planet's water is potable, after their appropriate process. On the other hand, we all collectively suffer from five distinguishable *bads*, which are herein listed. 1: Overpopulation. 2: Criminality or, more generally, ethical decline. 3: *Energy* deficiency, which is nearly equivalent to saying 'depletion of the reserves of the planet's *natural* (*non-renewable*) *resources*'. 4. Pollution, industrial and domestic waste, wild nature lessening and so forth, which is, pretty much, equivalent to saying 'destruction of the *environment* or of the *nature*'. 5. *Climate* deterioration.

To build first some intuition, 1,2,3 and 4 supra are principally man-made bads, thus, should be initially seen and treated with the use of deterministic (exogenous or endogenous) variables for the ecosystem, as if they were fully determined by our actions or choices. But the bad 5, although admittedly is a partially self-inflicted bad, should be viewed and handled with the employment of a random (or exogenous) variable for the ecosystem, as if it is fully determined by brute luck; and then imposed upon all the rest of our decisions with respect to our goods and bads, thus, eventually, randomising them.

To gain next somewhat more formal theoretical insight as far as the bads 3,4 and 5 (of the numbered list of the prequel) are concerned at this moment, denote: (i) with $R \geq 0$ and $E \geq 0$ some quantity, of some quality, of the resources and of the environment, respectively, that are deterministically (for the time being) chosen to being put under usage, and (ii) with $C \geq 0$ the climate or the weather, where $C$ is randomly admitting the finite only in number values $\{c_1, c_2, ....., c_n\}$, such that the positive real number $c_i$ $i = 1, 2, ..., n$ represents an alternative climate state (or weather status) of the ecosystem. More precisely, $R$ captures all the alternative (qualitative) quantities of resources that could be chosen and set for extraction or consumption, for our benefit, whilst $E$ captures all the alternative (qualitative) quantities of the environment that could be chosen and set for destruction or ruin, for our interest again. And $C$,

more accurately, accounts for the sizeable risk of the planet earth's ecosystem. Subsequently, since $C$ is finite, it is manageable, while a sensible hypothesis is that $C$ is fully and publicly known (and fully taken advantage of) by all people in the planet, who have formed a social (subjective) prior or belief with regard to its events. So $C$ cannot shock humanity with unknown, indistinguishable and probabilistically non-quantifiable states that could have been hidden inside its elemental synthesis, and, thereby, knock the ecosystem down. Concurrently, although the bads 1 and 2 (of the enumerated list above) are sturdy in modern societies, we can safely champion that policy has successfully managed to control and suppress the adverse effects of them[1]. Thence, in the end, the (qualitative) quantities pertaining the bads 1 and 2 previously are exogenous fixed policy choices. In fact they are already chosen quantities (of some quality), so they can be, either way, omitted without loss of generality from the analysis, by always having in mind that the endogenous social choices of $W$, $F$, $E$ and $R$ are made given the workings of the bads 1 and 2, to wit, they are made trivially conditionally upon the (qualitative) quantities that represent them. At the same time, nonetheless, the decisions of people for $W$, $F$, $E$ and $R$ are continently taken upon the exogenous $C \ni c$, with $Card(C) = n \in \mathbb{N}$, $n \geq 2$, the operation of which is influential to the earth's ecosystem and its general equilibrium outcomes.

We are now ready to discard all the expositional filters, define the random variables $F, W, E, R : C \to \mathbb{R}_+$ upon the probability space $(C, 2^C, p)$, where $p : \mathcal{P}(C) \to [0, 1]$ is an additive probability measure that has been already equipped upon the measure space $(C, 2^C)$ and, to resume with rigour, let the following planet earth's ecosystem:

$$Ecosystem = \{\mathbb{R}_+; (C, 2^C, p); H; U_H, \mathcal{E}, \mathcal{D}, \overline{F}, \overline{W}, \overline{E}, \overline{R}\},$$

where $C$ and $p$ are already defined, $R_+$ is the underlying action and re-action (or outcome) set of the infused with humans (equivalently, with rational decision makers) ecosystem, $H$ stands for the humanity of the ecosystem, $U_H$ is a social utility function of the ecosystem, which is to be soon defined along with the functions $\mathcal{E}$ and $\mathcal{D}$, and $\overline{F}, \overline{W}, \overline{E}, \overline{R} > 0$ are the ecosystem's initial endowments of the extant levels of food, water, environment and resources, respectively, which are available for up to (randomly-potentially) complete exploitation or entire usage (see also in the sequel).

Observe at this point that the sum $\overline{W} + \overline{E} + \overline{R} = \overline{M} > 0$ constitutes the exogenously given, extra-humanitarian economic morphology of earth, scilicet, the planet's economic geography and economic geology. To figure this out, we need to go ahead realising that: (i) $\overline{W}$ is the water that (partially) covers most of the earth's surface, (ii) $\overline{R}$ is the land, which covers the remaining part of the planet's surface, plus what is embedded underneath the earth's surface and which, specifically, conveys economic

[1] In practice, they increase in a steady (dangerless) pace.

significance, and (iii) $\overline{E}$ is what stands upon the planet's surface and is, in particular, economically important. All water and all land are by default economically meaningful. Crucially, $\overline{M}$ has to be sustainable (i.e., maintained) within the planet's general equilibrium.

Introduce next the ecosystem's *destruction function* $\mathcal{D}|C := \mathcal{D} : \mathbb{R}^2_+ \to \mathbb{R}_+$, such that $\mathcal{D}(E(c), R(c)) \geq 0$, for every $c \in C$. $\mathcal{D}$ is (at least two times) continuously differentiable, concave and increasing on each one of its arguments, thus, on its domain. To make sure that, given (any realised unfavourable state of) $C$, $E$ and $R$ are lost or exhausted with control along time[2] for our sake exclusively, something that would secure that their reserves could last forever[3], let $\mathcal{D}$ be defined as

$$\mathcal{D}(E(c), R(c)) = eE(c) + rR(c),\ c \in C,$$

where $e \in [0, 1]$ is the (endogenous) rate at which the endogenously (randomly) chosen environment for usage is exploited, and where $r \in [0, 1]$ is the (endogenous) rate at which the endogenously (randomly) chosen resources for usage are extracted. This simply means that $E$ and $R$, given $C$, are perfect substitutes, to wit, there is infinite elasticity of substitution (or substitutability) among them. More concretely speaking, to get some desirable fixed level of aggregate (i.e., of both resources and environmental) destruction, one gets substituted for the other under a constant (negative) slope or derivative, or marginal rate of substitution, i.e., under a constant ratio between the marginal destruction of environment and the marginal destruction of resources. Actually, one only of either the environment or the resources is enough to get destroyed, with zero destruction of the other, so as to maintain the desirable level of total destruction[4]. Note that $E \geq 0$ and $R \geq 0$ account for *necessary or essential bads*, since with the partial erosion of the whatever nature becomes randomly available, and with the partial depreciation of the whatever (non-renewable) energy becomes randomly available, we gain our existence or survival on this planet.

Now to proceed further, given $C$, there are two sides of the same survival story. On the one side, $\mathcal{D}$, or $E$ and $R$, positively (strictly increasingly) determine our existence on earth. Equivalently, on the other side, our survival is definitely (to begin with) positively (strictly increasingly) determined by how much food and water we consume or, to put it differently, by the food and water extinction in this

[2]Without opportunistic or lucrative deviations.

[3]Effectively, for the longest possible time henceforth.

[4]So, for example, we may not be destroying at all our non-renewable resources henceforward, go on deploying renewable forms of energy and/or agricultural or urbanisation methods that do not depend on land consumption, whilst, instead, keep destroying (polluting, wasting and so on) on a reasonable tempo the environment solely, so as to attain the required level of destruction that will be keeping (the constantly more and more of) us alive.

planet. This first of all means that $F$ and $W$ are *goods with bad implications or side-effects*. In the aftermath, for (endogenous) $f, w \in [0,1]$ and for any $c \in C$, let the ecosystem's *extinction function* (or, in more popular economic parlance, *consumption function*) $\mathcal{E}|C := \mathcal{E} : \mathbb{R}^2_+ \to \mathbb{R}_+$, which is defined in the Leontief (1941) motif as infra:

$$\mathcal{E}(F(c), W(c)) =$$

$$min\{fF(c), wW(c)\} = \begin{cases} fF(c), fF(c) \leq wW(c) \iff \frac{f}{w} \leq \frac{W(c)}{F(c)} \\ wW(c), wW(c) \leq fF(c) \iff \frac{w}{f} \leq \frac{F(c)}{W(c)} \end{cases}$$

In the outset, the initialising (core) idea is that out of all the available water in the earth, there is a certain amount of water that we are practically allowed to randomly-endogenously consume, a portion of which (i.e., the $wW(c) \geq 0$, $c \in C$) does eventually get (up to fully) consumed with some endogenous rate, $w \in [0,1]$. Similarly, out of all the available food in the earth, there is a certain amount of food that we are virtually permitted to randomly-endogenously consume, a fraction of which (i.e., the $fF(c) \geq 0$, $c \in C$) does eventually get (up to completely) consumed with some endogenous percentage, $f \in [0,1]$.

The supplementary (and auxiliary to the central) idea is that the goods water and food are perfect complements in their extinction or, interchangeably, in $H$'s consumption. For the existence of humanity, both are vital, so there is zero elasticity of substitution among them or, equivalently, there is infinite elasticity of complementarity between the two of them. Extra food without a corresponding excess of water (or *vice versa*) does not provide additional satisfaction, which here is measured in terms of survival. Food and water are consumed together in fixed proportions. For our survival, some food is always combined with some water in a fixed proportion (quotient or ratio), $\frac{w}{f} \leq 1$ or $\frac{f}{w} \geq 1$, under the plausible assumption that $f \geq w$.

Subsequently, a reasonable assumption is that, for our survival, the mass (or the quantity of some quality) of food that we need is greater than the mass (or the quantity of some quality) of water that is required, so the straightforward implication is that $fF(c) \geq wW(c)$. This constitutes water, and its extinction (or consumption) for the existence of $H$, the most valuable good on the planet earth. Indeed, $H$ can survive much longer without food (but with water) than without water (but with food). At the same time, the marginal extinction of (and survival from) water is $w$, while the marginal extinction of (and existence from) food is zero. Thereafter, the marginal rate of substitution or complementarity (i.e., the slope or the derivative) between food and water is either zero or infinity.

To conclude thus far, we have derived the following *survival or existence constraint* of humanity, within the planet earth's ecosystem:

$$\mathcal{E}(fF(c), wW(c)) = \text{survival or existence} = \mathcal{D}(E(c), R(c)),\ \forall\ c \in C,$$

$$min\{fF(c), wW(c)\} = \text{survival or existence} = eE(c) + rR(c),\ \forall\ c \in C,$$

$$wW(c) = eE(c) + rR(c) \iff wW(c) - [eE(c) + rR(c)] = 0,\ \forall\ c \in C.$$

The interpretation of this restriction as follows: to survive (or to exist) with the subsistence consumption of water (combined in some fixed proportion with food), for originally available $\overline{W}, \overline{E}, \overline{R} > 0$, for any exogenous $c \in C$, for endogenously realised $w, e, r \in [0, 1]$, and for randomly-endogenously chosen $0 \leq W(c) \leq \overline{W}$, $0 \leq E(c) \leq \overline{E}$ and $0 \leq R(c) \leq \overline{R}$, the trimming of the water (combined in some fixed proportion with food) reserves, which is the quantity $wW(c) \geq 0$, must be equal to the aggregatively combined reduction of the reserves of the environment and the natural (non-renewable) resources, which is the quantity $eE(c) + rR(c)$. This is evidently a general equilibrium signalling condition, since it basically reduces to an equitability condition, of both fairness or justice, and impartiality, neutrality, indifference or unbiasedness. Moreover, this condition is technically important, as it also holds whenever $0 < W(c) = \overline{W}$, $0 < E(c) = \overline{E}$ and $0 < R(c) = \overline{R}$, for some $c \in C$. This implies that *ex ante*, when the probable occurrence of each and every one of the states $c$ of $C$ is considered, the following condition shall be true:

$$wW(c) - eE(c) - rR(c) = w\overline{W} - e\overline{E} - r\overline{R} = 0.$$

If $\rho = (w, -e, -r)^T \in [-1, 1]^3$ is a *vector of rates* by which the *vector of* (randomly-chosen) *reserve-quantities* $q(c) = (W(c), E(c), R(c))^T \in \mathbb{R}^3_+$, $c \in C$, with specifically $\overline{q} = (\overline{W}, \overline{E}, \overline{R})^T$, is driven down, the prior condition becomes

$$\rho^T q(c) = \rho^T \overline{q} (= 0)\ [\Rightarrow \rho^T q(c) \leq \rho^T \overline{q}],\ \forall c \in C.$$

In addition, the emanated ecosystem's *feasibility of reverses constraint*

$$W(c) + E(c) + R(c) \leq \overline{M},\ \forall\ c \in C,$$

which is also the ecosystem's *sustainability of economic morphology constraint*, guarantees, specifically, that $q(c) \in [0, \overline{M}]^3$, for every $c \in C$, where $q(c)$ is a value of an alternative random choice function $q : C \to \mathbb{R}^3_+$; more precisely, $q : C \to [0, \overline{M}]^3$.

Lastly, inside the ecosystem, if the peoples' (primitive) random utility function $U_H|C := U_H : \mathbb{R}^3_+ \to \mathbb{R}$, or, more accurately, the function $U_H : [0, \overline{M}]^3 \to \mathbb{R}$, defined by $U_H(W(c), E(c), R(c)) = U_H(q(c))$, $c \in C$, is, on each one of its arguments separately and, thus, jointly: (i) (at least two times) continuously differentiable on the interior of its domain, and (ii) concave on its domain, with

$$\tfrac{\partial U_H}{\partial W(c)} \geq 0, \tfrac{\partial U_H}{\partial E(c)}, \tfrac{\partial U_H}{\partial R(c)} \leq 0 \text{ and } \tfrac{\partial^2 U_H}{\partial W^2(c)}, \tfrac{\partial^2 U_H}{\partial E^2(c)}, \tfrac{\partial^2 U_H}{\partial R^2(c)} \leq 0, \text{ as } c \in C,$$

then let the functional $\mathcal{U}_H : C^{[0,\overline{M}]^3} = [0, \overline{M}]^3 \to \mathbb{R}$, or $\mathcal{U}_H \circ q : C \to \mathbb{R}$, defined by

$$\mathcal{U}_H(q) = (\mathcal{U}_H \circ q)(c) = \sum_{c \in C} U_H(q(c))p(c) \text{ [+ expectation error]},$$

be the humanity's (secondary) expected utility function(al) within the ecosystem. The expected utility comes with zero anticipation error, because people make acute weather forecasts.

Penultimately, as time elapses from the *ex ante* to the *ex post* instant, we end up with the following definition.

**Definition**. The pair $(\rho^\star, q^\star(c))$, $c \in C$ is an *ex ante*-to-*ex post general equilibrium of the ecosystem* (of planet earth) iff for every $c \in C$, with the pair $(\rho^\star, q^\star(c))$, $\mathcal{U}_H$ is maximised subject to conditions: (i) $\rho^T q(c) = 0$ and (ii) $W(c) + E(c) + R(c) \leq \overline{M}$.

Transparently, if an *ex ante* (for any probable $c \in C$) general equilibrium of the ecosystem exists, which would then automatically mean that an *ex post* (for some realised or revealed $c \in C$) general equilibrium of the ecosystem exists, then this general equilibrium is stable, socially optimal and equitable, hence, it is fully normative.

Although muted heretofore, it has eventually become clear that an ecosystem's *ex ante* to *ex post* general equilibrium shares, essentially, the same template with a Walras (1874) or competitive general equilibrium with both (positively priced) goods and (negatively priced) bads. It is widely known in the general equilibrium literature that such competitive or Walrasian general equilibria exist whenever the agents' utility functions are not (globally) increasing on consumption, but they are, instead, increasing on consumption of goods and decreasing on consumption of bads. Agents like goods (which here is the volume of water combined in some fixed proportion with food) and draw positive utility and marginal utility from them, whereas they dislike

bads (which here are the magnitude of environment and resources that are randomly-chosen to be destructed to some extent) and receive dis-utility (i.e., negative utility and marginal utility) from them[5]. Besides, with little exception, monotonicity of the agents' primitive preferences is actually needed solely for the centralisation of a competitive general equilibrium, by means of the application of a first welfare theorem, something that herein is granted by default, because the social optimum is directly attained.

Ultimately, the instructive discussion above paves the way for the statement, and then the proof, of the following theorem:

**Theorem**. A (competitive) general equilibrium for the ecosystem (of planet earth) exists.

**Proof**. Consider the product topology on $\mathbb{R}^3$. Then, $[-1,1]^3$ and $[0,\overline{M}]^3$ are compact in $\mathbb{R}^3$ with respect to that topology. Also, $\mathcal{U}_H$ is continuous and concave on its domain, because $U_H$ has the same properties on its own domain. Then, it follows from Arrow and Debreu (1954) that a general equilibrium for the ecosystem exists.

To render the analysis and its results tenable, the paper closes by providing a numerical example.

**Example**. Consider an ecosystem with: $C = \{c_1, c_2\} = \{0, 1\}$, where $p(c_1) = p(c_2) = \frac{1}{2}$ (i.e., 0 and 1 are equiprobable), $\overline{M} = 4$, $H$'s continuously differentiable and concave

$$U_H(W(c_i), E(c_i), R(c_i)) = ln(1 + W(c_i)) - 0.2E(c_i) - 0.3R(c_i),\ i = 1, 2,$$

in which the $ln$ function satisfies the desirable conditions of Inada (1963), and the functions $\mathcal{D}$ and $\mathcal{E}$ defined as in the text. Then, one can check that the triplet of rates $(w, -e, -r) = (1, -0.5, -1)$ together with the triplet of random choices $(W(c_i), E(c_i), R(c_i)) = (1.5, 1, 1)$, for $i = 1, 2$, is a (competitive) general equilibrium of the ecosystem in reference (as stated in the Definition previously).

[5]If, as a matter of fact, the bads of this paper (that is, the dilution of the nature and its recourses) were to be priced in underlying markets, then these bads could not be freely disposed, so the (priced in this case) competitive general equilibrium would have to be viable without free disposal, namely, without (penalty-free) throwaway.

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ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

ΣΧΟΛΗ ΟΙΚΟΝΟΜΙΚΩΝ ΕΠΙΣΤΗΜΩΝ
SCHOOL OF ECONOMIC SCIENCES

ΤΜΗΜΑ ΟΙΚΟΝΟΜΙΚΗΣ ΕΠΙΣΤΗΜΗΣ
DEPARTMENT OF ECONOMICS

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## Athens University of Economics and Business

The Department is the oldest Department of Economics in Greece with a pioneering role in organising postgraduate studies in Economics since 1978. Its priority has always been to bring together highly qualified academics and top quality students. Faculty members specialize in a wide range of topics in economics, with teaching and research experience in world-class universities and publications in top academic journals.

The Department constantly strives to maintain its high level of research and teaching standards. It covers a wide range of economic studies in micro-and macroeconomic analysis, banking and finance, public and monetary economics, international and rural economics, labour economics, industrial organization and strategy, economics of the environment and natural resources, economic history and relevant quantitative tools of mathematics, statistics and econometrics.

Its undergraduate program attracts high quality students who, after successful completion of their studies, have excellent prospects for employment in the private and public sector, including areas such as business, banking, finance and advisory services. Also, graduates of the program have solid foundations in economics and related tools and are regularly admitted to top graduate programs internationally. Three specializations are offered:1. Economic Theory and Policy, 2. Business Economics and Finance and 3. International and European Economics. The postgraduate programs of the Department (M.Sc and Ph.D) are highly regarded and attract a large number of quality candidates every year.

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