

A Preliminary Perspective: From Group Theory to Economics in a Field-Theoretic Framework, and Emergent Justice

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Abstract

We propose a unified formal framework that connects welfare economics, algebraic group theory, differential topology, and gauge field theory. Beginning from the observation that indifference curves in consumer theory are level sets of a utility functional, we show that these level sets carry a natural group-orbit structure whose symmetry group acts as an invariance group of the utility function, in analogy with Noether's theorem. Budget constraints are reinterpreted as mechanisms of spontaneous symmetry breaking, and price signals are identified as the resulting Goldstone modes. The Pareto frontier is characterised as the boundary of the reachable allocation manifold under the induced product partial order. We examine the dynamical question of whether social systems necessarily converge to such boundary states, and argue that the standard equilibrium paradigm rests on mathematical convenience rather than empirical necessity. Departing from both terminal and procedural conceptions of justice, we introduce the notion of *generative justice*: justice as an attribute of the normative generation process itself, formalised as a functional over trajectory space. Connections to Eduardo Kohn's biosemiotics and the theory of universal grammar across symbol systems are briefly discussed.

Keywords: Pareto efficiency, group action, symmetry breaking, Goldstone theorem, fibre bundle, gauge field, dynamical systems, generative justice, biosemiotics.

1 Introduction

The standard welfare-economic concept of Pareto efficiency [Pareto, 1906] rests on a purely ordinal and qualitative foundation: a state is optimal if no reallocation can make one agent better off without harming another. While this criterion is elegant, it is both empirically inert (utility functions are unobservable) and normatively impoverished (it legitimises any initial endowment distribution, however unjust).

Independently, mathematical physics has demonstrated that many of the deepest structural features of physical theories derive from symmetry considerations and their spontaneous breaking [Goldstone, 1961, Anderson, 1984]. The present work draws

an explicit correspondence between these two traditions, arguing that the geometry of indifference curves, the emergence of price signals, and the boundaries of efficient allocation are all naturally expressed in the language of group orbits, fibre bundles, and gauge fields.

A further motivation is the inadequacy of existing theories of justice for dynamic, non-equilibrium social systems. Terminal justice [Rawls, 1971] locates the normative ideal in a target state; procedural justice [Nozick, 1974] locates it in rule-conformance. We argue that both are structurally insufficient and propose a third conception, *generative justice*, which locates justice in the act of normative generation itself.

The paper is organised as follows. Section 2 develops the partial-order reformulation of Pareto optimality. Section 3 discusses the equity critique and its classical responses. Section 4 introduces stochastic perturbation as a symmetry-breaking mechanism. Section 5 analyses boundary states, fixed points, and the failure of the equilibrium paradigm. Section 6 develops the group-theoretic structure of indifference curves. Section 7 identifies price signals as Goldstone modes. Section 8 constructs the fibre bundle and gauge interpretation. Section 9 introduces generative justice. Section 10 connects the framework to biosemiotics. Section 12 closes with open questions.

2 Pareto Optimality as a Partial Order

Definition 2.1 (Attribute space). Let Ω denote the space of feasible social allocations. Let $\{X_i\}_{i=1}^n$ be a family of observable real-valued attribute functions $X_i : \Omega \rightarrow \mathbb{R}$, each equipped with a partial order $\leq_i$ on its range.

The family $\{X_i\}$ replaces the unobservable utility function with concrete, measurable indicators such as health outcomes, income, access to services, or waiting times [Sen, 1985]. The product partial order on $\prod_{i=1}^n X_i(\Omega)$ is then defined componentwise.

Definition 2.2 (Pareto dominance). An allocation ω_m *Pareto-dominates* ω_k , written $\omega_k \prec_P \omega_m$, if and only if

$$(\forall i, X_i(\omega_k) \leq_i X_i(\omega_m)) \wedge (\exists j, X_j(\omega_k) <_j X_j(\omega_m)). \quad (1)$$

Definition 2.3 (Pareto frontier). The *Pareto frontier* is the antichain of maximal elements under $\prec_P$:

$$\mathcal{P} = \{\omega^* \in \Omega \mid \nexists \omega \in \Omega \text{ s.t. } \omega^* \prec_P \omega\}. \quad (2)$$

Remark 2.1. Because $\prec_P$ is a strict partial order rather than a total order, two allocations may be mutually incomparable. The existence of incomparable maximal elements is precisely what gives the Pareto frontier its extended, multidimensional structure [Ehrgott, 2005].

The Knaster–Tarski fixed-point theorem guarantees the existence of $\mathcal{P}$ when Ω is a complete lattice and the dominance relation is monotone, conditions that are typically assumed in the axiomatic treatment of social choice [Tarski, 1955, Arrow, 1951].

The crucial observation is that the choice of $\{X_i\}$ is not a neutral technical decision. It embeds an ethical commitment: selecting which dimensions of welfare are counted and in which direction is an act of valuation [Sen, 1999].

3 The Equity Critique

A fundamental limitation of Pareto efficiency is that it provides no basis for comparing allocations on the frontier $\mathcal{P}$ with one another, and no criterion for rejecting initial endowments that are themselves unjust. A degenerate allocation in which a single agent holds all resources can be Pareto-optimal, since any redistribution would reduce that agent’s attribute values.

Three canonical responses appear in the literature. Rawls [1971] replaces utilitarian aggregation with the *difference principle*: inequalities are permissible only insofar as they maximise the welfare of the least advantaged member of society, formalised as

$$\max_{\omega \in \Omega} \min_{i=1, \dots, n} X_i(\omega). \quad (3)$$

Sen [1985, 1999] replaces utility-space analysis with *capability sets*: the morally relevant object is what agents are able to do and be, not what they consume. Nozick [1974] grounds justice in the legitimacy of the acquisition process rather than the distribution of outcomes, which in principle permits any Pareto-optimal distribution arising from voluntary exchange.

All three positions converge on the observation that

$$\text{Pareto efficiency} \not\Rightarrow \text{distributive justice}. \quad (4)$$

The formal machinery of efficiency analysis operates within a given structure of rights and endowments, and is silent about whether that structure is itself legitimate.

4 Stochastic Perturbation and Symmetry Breaking

To escape allocations that are locally Pareto-optimal but globally unjust, we introduce a stochastic perturbation:

$$\omega_{t+1} = f(\omega_t) + \varepsilon_t, \quad \varepsilon_t \sim \mathcal{D}_t(\omega_t). \quad (5)$$

This is formally isomorphic to the Metropolis–Hastings algorithm and to simulated annealing [Kirkpatrick et al., 1983], where an inverse temperature parameter β controls the probability of accepting welfare-deteriorating transitions:

$$P(\text{accept } \omega_{t+1} \mid \omega_t) = \exp(-\beta \Delta E(\omega_t, \omega_{t+1})). \quad (6)$$

When $\beta \rightarrow \infty$ the system converges to the global optimum; when $\beta \rightarrow 0$ all transitions are accepted with equal probability.

The perturbation converts a *certain* harm (any deterministic improvement requires harming a specific individual) into a *probabilistic* harm (each agent faces a positive but bounded risk of loss). Whether this transformation is itself just depends on the moral framework applied. Rawls [1971] would require that the distribution $\mathcal{D}_t$ be chosen behind a veil of ignorance. Dworkin [2000] would insist that only brute-luck outcomes can be legitimately redistributed, not option-luck outcomes arising from voluntary gambles.

A critical observation is that the design of $\mathcal{D}_t$ is itself an exercise of power. The distribution over perturbations cannot be chosen from a neutral position; it embeds prior valuations about which directions of departure from $\mathcal{P}$ are acceptable. The justice question is therefore not dissolved by randomisation but displaced onto the choice of $\mathcal{D}_t$.

5 Boundary States, Fixed Points, and the Equilibrium Paradigm

Definition 5.1 (Boundary state). In a topological space (Ω, τ) , the boundary of a subset $A \subseteq \Omega$ is

$$\partial A = \bar{A} \cap \overline{\Omega \setminus A}, \quad (7)$$

where $\bar{A}$ denotes the closure of A . A point $\omega \in \partial A$ is a *boundary state*: every neighbourhood of ω intersects both A and its complement.

The Pareto frontier $\mathcal{P}$ is the boundary of the set of Pareto-improvable allocations. Boundary states are distinguished by their epistemic inaccessibility: an agent at $\omega \in \partial A$ cannot determine from local information alone whether the system lies inside A or outside it [Luhmann, 1995].

A *fixed point* of the dynamical system f is a state ω^* satisfying $f(\omega^*) = \omega^*$. The question of whether social system trajectories $(\omega_t)_{t \geq 0}$ necessarily converge to fixed points, and whether those fixed points lie on $\mathcal{P}$, is the central dynamical question of equilibrium economics.

Proposition 5.1. Under the standard assumptions of compactness, convexity, and upper hemicontinuity, the Kakutani fixed-point theorem guarantees $\text{Fix}(f) \neq \emptyset$ [Kakutani, 1941]. However, none of these assumptions is empirically justified for social systems.

Three canonical failures of the equilibrium paradigm arise. First, the state space Ω need not be compact: technical change,

population dynamics, and institutional innovation continuously expand the feasible set. Second, the dynamics f need not be continuous: revolutions, legislative discontinuities, and norm collapses introduce jump discontinuities. Third, and most fundamentally, social systems are open systems driven by continuous environmental inputs $\xi(t)$, so that

$$\dot{\omega} = f(\omega) + g(\omega, \xi(t)), \quad (8)$$

which generically precludes the existence of a global attractor [Prigogine and Stengers, 1977].

The ergodicity assumption fares no better. If a system is ergodic, the time average of any observable equals its ensemble average:

$$\frac{1}{T} \int_0^T X_i(\omega_t) dt \xrightarrow{T \rightarrow \infty} \int_{\Omega} X_i d\mu, \quad \mu\text{-a.e.} \quad (9)$$

But convergence to a fixed point concentrates the trajectory measure on a null set, violating ergodicity. The two properties are mutually exclusive: ergodicity and fixed-point convergence cannot simultaneously hold. Path dependence, institutional lock-in, and non-stationarity of the governing rule f_t further preclude ergodicity in realistic social models [Arthur, 1994].

The equilibrium paradigm in economics was borrowed from 19th-century classical mechanics via the adoption of Hamiltonian and Lagrangian variational methods [Mirowski, 1989]. Its persistence is an epistemological choice motivated by mathematical tractability, not an empirical finding about the behaviour of social systems.

6 Group-Theoretic Structure of Indifference Curves

Let the utility functional $U : \Omega \rightarrow \mathbb{R}$ be given, and define the indifference level set at value c by

$$\mathcal{I}_c = \{\omega \in \Omega \mid U(\omega) = c\}. \quad (10)$$

The quotient space $\Omega/\sim$, where $\omega \sim \omega'$ iff $U(\omega) = U(\omega')$, is homeomorphic to $\mathbb{R}$ when U is continuous, and constitutes a totally ordered family of fibres.

Definition 6.1 (Symmetry group of a utility functional). A group G is a *symmetry group* of U if G acts continuously on Ω via $\phi : G \times \Omega \rightarrow \Omega$ and

$$U(\phi(g, \omega)) = U(\omega) \quad \forall g \in G, \omega \in \Omega. \quad (11)$$

Under this action, each indifference curve is a G -orbit: $\mathcal{I}_c = G \cdot \omega_c$ for any $\omega_c \in \mathcal{I}_c$. The orbit-stabiliser theorem then gives

$$|\mathcal{I}_c| = [G : G_{\omega_c}], \quad G_{\omega_c} = \{g \in G \mid \phi(g, \omega_c) = \omega_c\}. \quad (12)$$

The utility functional is thus the group-theoretic invariant of the G -action on Ω . By Noether's theorem [Noether, 1918], this

invariance corresponds to a conserved quantity: utility conservation along the orbit is the analogue of energy conservation under time-translation symmetry in classical mechanics.

This reinterpretation has an immediate consequence for revealed preference theory [Samuelson, 1938]: the observable data of choice behaviour are the orbit structure of G on Ω , not the utility values themselves. The ordinality of utility is, in this language, the statement that only the orbit partition matters, not the labelling of orbits.

7 Symmetry Breaking and Price as Goldstone Mode

A budget constraint $B \subset \Omega$ is a proper submanifold of Ω that intersects the level sets $\{\mathcal{I}_c\}$ in a lower-dimensional set. The consumer optimum is the point $\omega^* \in B \cap \mathcal{P}$ that maximises U on B .

Proposition 7.1 (Symmetry breaking by budget constraints). If the symmetry group G of U acts transitively on each fibre $\mathcal{I}_c$, then B generically selects a unique point from $\mathcal{I}_{c^*}$, reducing the residual symmetry group from G to the stabiliser $H = G_{\omega^*} \subsetneq G$.

This is the structure of spontaneous symmetry breaking [Goldstone, 1961, Weinberg, 1995]. The Goldstone theorem states that each broken generator of G/H gives rise to a massless mode. In the economic context, these Goldstone modes are *price signals*: the gradient $\nabla_{\omega} U$ at the optimal point, projected onto the budget hyperplane, encodes how much of one attribute must be sacrificed per unit gain in another.

$$\text{Goldstone modes of } G/H \longleftrightarrow \text{price vector } p = \nabla_{\omega} U|_{\omega^*}. \quad (13)$$

The economic content of this identification is as follows. In the absence of constraints, the system is symmetric: all allocations on an indifference curve are equivalent. The introduction of a budget constraint breaks this symmetry and selects a distinguished point. The price vector measures the infinitesimal cost of moving away from that point along the constraint surface. Market failure corresponds to a pathology in this symmetry-breaking pattern: either the constraint is absent (no budget), the breaking is degenerate (corner solution), or the Goldstone modes acquire mass through institutional rigidity, suppressing the price signal [Stiglitz, 1987].

8 Fibre Bundle and Gauge Field Structure

The level-set decomposition of Ω defines a fibre bundle

$$\pi : \Omega \longrightarrow \Omega/\sim, \quad (14)$$

with base space $\Omega/\sim \cong \mathbb{R}$ (the utility range), typical fibre $\mathcal{I}_c$, and structure group G .

A connection on this bundle is a smooth distribution of horizontal subspaces $H_\omega \subset T_\omega\Omega$ that is G -equivariant and complementary to the vertical subspace $V_\omega = \ker(d\pi_\omega)$. The curvature of this connection is a $\mathfrak{g}$ -valued two-form Ω_∇ on the base.

Proposition 8.1 (MRS as connection curvature). The marginal rate of substitution between attributes X_i and X_j ,

$$\text{MRS}_{ij} = -\frac{dX_j}{dX_i}\bigg|_{U=c} = \frac{\partial U/\partial X_i}{\partial U/\partial X_j}, \quad (15)$$

is the component of the connection curvature measuring the failure of parallel transport to close around infinitesimal loops in the base.

Non-zero curvature indicates that the fibre bundle is non-trivial, which corresponds economically to non-linear (diminishing or increasing) marginal rates of substitution. A flat connection (zero curvature, constant MRS) corresponds to perfect substitutability.

The path-integral formulation of social allocation across trajectories [Feynman and Hibbs, 1965] is:

$$P(\omega_f \mid \omega_i) = \int_{\gamma: \omega_i \rightarrow \omega_f} \mathcal{D}[\gamma] \exp\left(\frac{i}{\hbar_s} S[\gamma]\right), \quad (16)$$

where $S[\gamma] = \int_0^1 \mathcal{L}(\omega_t, \dot{\omega}_t) dt$ is the action functional and $\hbar_s$ is a parameter measuring institutional rigidity. In the classical limit $\hbar_s \rightarrow 0$, the path integral is dominated by the saddle-point trajectory, recovering deterministic equilibrium analysis. In the opposite limit $\hbar_s \rightarrow \infty$, all trajectories are weighted equally, corresponding to a system with no institutional constraints.

9 Generative Justice

Two classical conceptions of justice can be rejected on the basis of the foregoing analysis.

Terminal justice [Rawls, 1971] locates the normative ideal in a target state $\omega^* \in \mathcal{P}$. But if, as argued in Section 5, social systems need not converge to fixed points, the terminal state may never be reached, and justice defined by it is permanently deferred.

Procedural justice [Nozick, 1974] locates justice in conformance to a rule. But rules are themselves social facts that must be generated within a process; grounding justice in pre-given rules merely relocates the problem to the legitimacy of those rules.

We propose a third conception.

Definition 9.1 (Generative justice). A trajectory $(\omega_t)_{t \geq 0}$ exhibits *generative justice* if justice is present as an attribute of the normative generation process at each instant, rather than as a property of any state or rule. Formally, generative justice is a functional

$$J : \Omega^{[0, \infty)} \rightarrow \mathbb{R} \quad (17)$$

over the space of trajectories such that $J(\gamma)$ depends on the entire history of symmetry-breaking choices along γ , not on $\lim_{t \rightarrow \infty} \gamma(t)$ alone.

Remark 9.1. This conception resonates with Derrida's characterisation of justice as *a venir* [Derrida, 1992]: justice is not a present state but an event that arrives in the interstice of the present. It equally resonates with Whitehead's process ontology [Whitehead, 1929], in which reality is constituted by events of becoming rather than by enduring substances.

A key implication concerns the choice of the symmetry-breaking distribution $\mathcal{D}_t$ introduced in Section 4. Because J is a trajectory functional, the evaluation of justice cannot be deferred to the endpoint; it must be exercised at each breaking event. The question "which direction shall the system evolve from this boundary state?" is a justice question that recurs at every step. The criterion for answering it is not provided by the framework itself: it must be supplied by a normative theory that operates at the level of the generation process, not at the level of states or rules. This is the irreducible political core of the problem.

10 Biosemiotics and Universal Grammar

Kohn [2013] argues, drawing on Peirce's semiotics [Peirce, 1931], that sign processes are not specific to human language but are constitutive of life itself. Forests are semiotic systems: chemical gradients, phenotypic signals, and mycelial information networks constitute a multi-species grammar in which meaning circulates across radically incommensurable symbol systems.

The parallel with the present framework is direct. The group-orbit structure of indifference curves provides a formal model for equivalence across symbol systems: two allocations lying on the same orbit are "indifferent" not because they are literally identical but because they are related by the symmetry group G . A "translation" between two agents with incommensurable preference structures corresponds to finding an element $g \in G$ that maps one agent's optimal allocation into the other's indifference class.

The *universal grammar* across symbol systems, if it exists, would be a group G_{univ} that acts on the disjoint union of all symbol spaces and whose orbits constitute the interspecies, or interpersonal, equivalence classes. The existence of such a group is not guaranteed; it is a conjecture about the structure of meaning itself. It finds partial support in the linguistic universals programme [Chomsky, 1965, Greenberg, 1963] and in the mathematical theory of institutions in categorical logic [Goguen and Burstall, 1992].

11 Unified Correspondence

The following table collects the identifications developed in the preceding sections.

Table 1: Unified correspondence across algebra, topology, field theory, and economics.

Algebra / Physics	Topology	Economics
Group G	Fibre bundle	Gauge field
Orbit $G \cdot \omega$	Indifference curve	Level set of U
Invariant of G	Quotient space	Utility function
Symmetry breaking	Constraint manifold	Budget set
Goldstone mode	Boundary crossing	Price signal
Saddle fixed point	Pareto frontier	Critical allocation
Action functional S	Path in $\Omega^{[0,\infty)}$	Welfare trajectory
Generative process	Normative generation	Generative justice

12 Open Questions

The framework raises several questions that remain open.

Endogenisation of attributes. The family $\{X_i\}$ has been treated as exogenously specified. A more complete theory would derive the relevant attributes from the system’s own dynamics, perhaps through a process of capability expansion in the sense of Sen [1999].

Non-ergodic social dynamics. If social trajectories are non-ergodic, the appropriate object of normative analysis is not a stationary distribution but a measure on path space. Developing a theory of justice for non-ergodic systems is an open problem [Peters, 2019].

POMDP interpretation. The belief state $b_t(s)$ in a partially observable Markov decision process [Kaelbling et al., 1998] is a probability distribution over hidden social states. It may be the correct formalisation of the epistemic suspension characteristic of boundary states: the moment at which a social fact is simultaneously operative and in question. The connection between the gauge-field structure of Ω and the information geometry of belief-state space [Amari, 2016] warrants investigation.

Trajectory functionals for justice. The functional $J : \Omega^{[0,\infty)} \rightarrow \mathbb{R}$ introduced in Section 9 has not been given an explicit form. Its construction requires a normative theory of symmetry-breaking choices, which is the properly political core of the problem and falls outside the scope of formal economics alone.

Universal semiotic grammar. The conjecture that a group G_{univ} underlies interspecies and interpersonal meaning exchange remains unproven. Its formalisation would require a category-theoretic treatment of sign systems that unifies Peircean semiotics with the theory of institutions in logic [Goguen and Burstall, 1992].

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These ideas emerged in conversation. The instinct to ask whether a system must converge, and whether ergodicity holds, is more valuable than any particular answer.

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