The Economics of Information: Part 3

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"True knowledge is knowing the extent of one's ignorance."

— Confucius, *Analects* 2.17 (paraphrase)

Abstract

This paper reviews the economics of information through a simple proposition: information comes to market through costly action. Private knowledge becomes economically consequential when a person acts on it—by trading, entering production, committing resources, or producing a verifiable proof. Such actions create public signals that others can interpret without observing the knowledge, costs, or expectations from which they arose. Markets aggregate these signals into prices and patterns of participation, transforming dispersed private judgments into information that can guide further decisions. The meaning of a signal, however, remains bounded by the mechanism that produced it. A price does not reveal a complete or final truth, just as a proof does not disclose its producer's exact costs or establish claims beyond the rule it satisfies. Each instead provides evidence of commitment under particular constraints, incentives, and conditions of uncertainty. Automated proof makes this relationship especially visible by joining economic reward, physical expenditure, probabilistic selection, and public verification within a single process. Information thus moves through a recurring cycle: private judgment produces costly action; costly action produces public evidence; evidence changes economic decisions; and those decisions reshape the conditions from which new information emerges. Thermoeconomics describes this feedback between information, incentives, and the physical organization of economic activity.

What a Proof Reveals

The successful proof reveals at least four kinds of information.

First, it reveals **validity**. The submitted object satisfies a protocol's rule, which makes this information the narrowest content of the proof. This revealed information necessarily carries limited meaning beyond what the protocol technically imposes.

Second, it reveals **selection through probability**. The submitted output is not accepted because its producer declares it valid or because the source was previously trusted. It is accepted because it satisfies a known condition that only a limited share of possible outputs will satisfy. Under the protocol's rule, the successful output is therefore evidence of a larger process of probabilistic selection. This reveals information about how the output was generated, but not yet what its producer has economically sacrificed.

Third, it reveals **commitment to uncertainty**. To participate in the probabilistic search, the producer commits energy, equipment, capital, and time before knowing whether a qualifying output would be found or rewarded. The proof does not reveal information about this producer's exact costs, but it establishes that some combination of scarce resources were placed at risk in pursuit of the result. This reveals information about the willingness of a producer's economic sacrifice.

Fourth, it reveals **macroscopic information** when many proofs are aggregated. The system's total behavior becomes inferable. At this level, an economic observer obtains a barometer of the total underlying physical process which reveals information about the holistic system.

These forms of revelation should not be reduced into one claim of knowledge. Their boundaries are their strength—they make a proof precise for stating what cannot be known at each level. This type of system attains its reliability when its interpretation remains within the limits of what the protocol's rules can establish.

Any interpretation of loses potency when observers treat proof of one proposition as proof of another.

What a Market Reveals

Markets make dispersed information consequential through prices. Bids, offers, and completed transactions convert private judgments about cost, scarcity, risk, and future conditions into observable commitments. Because acting on an incorrect judgment carries a financial consequence, price is more than a statement of belief—it is a public signal produced under constraint.

Prices therefore compress heterogeneous private information into a common, actionable measure without requiring its sources to be disclosed. A participant can respond to a price without reconstructing the private knowledge, circumstances, or reasoning that produced it.

Markets also reveal the incentive to produce and act on information. Acquiring information is costly. If every relevant fact were already reflected perfectly in price, an informed participant could not recover the cost of discovering it. The prospect of profit is therefore what gives private information a path into the public price.

When a participant perceives a mispricing, the expected return provides a reason to act. That action becomes observable through an order or transaction, and its informational consequence becomes part of the price-discovery process. Information is not brought to market merely because it exists; it is brought to market when the expected return from acting on it exceeds the expected cost.

Price aggregation therefore reveals two things at once: the public consequence of dispersed private judgments and the incentive that makes their expression possible.

The Incentive of Proving

Let a producer's expected reward from attempting to generate a qualifying proof be R. Let the total private cost of the attempts be C, including energy, equipment, capital, time, labor, and opportunity cost. Let p denote the producer's probability of receiving the relevant reward over the chosen interval. A minimal participation condition is:

$$pR \geq C.$$

The inequality is simple. It doesn't claim that all producers face the same costs or estimate the value of the reward in the same way. Its purpose is to identify an economic threshold. A producer enters when its private estimate of the opportunity supports participation and exits when the expected return no longer covers the resources placed at risk.

This decision reveals information through action. Entry indicates that the producer's private cost and expectation fall inside the region compatible with participation. Exit indicates the opposite. Neither action reveals an exact cost curve, but aggregate behavior narrows the range of plausible conditions.

Competition strengthens this process. When rewards are available to multiple producers, private information about costs is expressed through the willingness to perform work. Lower-cost or better-informed producers can continue under conditions that force higher-cost or less-informed producers to withdraw. The market therefore searches over optimal production methods as well as proof generation. The system induces production by offering a reward for achieving a verifiable condition, essentially purchasing a public signal from competing private actors.

The Cost of Proving

Cost refers to several distinct quantities in a proof of work process. Again, each belongs to a different level of analysis.

The first is the **thermodynamic lower bound**. Logically irreversible operations are subject to a minimum energetic cost under specified physical conditions. This bound identifies the floor imposed by thermodynamics, not the energy consumption of any deployed machine, facility, or network.

The second is the **realized physical cost of computation**. This category combines the device-level and facility-level costs required to produce proofs. It includes the energy consumed by processors, memory, switching, and control systems, together with power conversion, cooling, networking, redundancy, maintenance, and other operational infrastructure. Real systems operate above the thermodynamic lower bound, and the distance between the bound and realized consumption is determined by engineering.

The third is the **producer's private economic cost**. This includes both explicit monetary expenditures and opportunity costs. Electricity has a price; equipment must be purchased and depreciated; capital must be financed; labor, taxes, contracts, downtime, and regulatory obligations must be borne. At the same time, every committed resource has an alternative use. The producer's economic cost is therefore the sum of what is paid and what is forgone.

The fourth is the **market cost of obtaining verifiable information**. Proof is produced through competitive search, so the information available to the system is supported not only by the successful computation but by the full distribution of successful and unsuccessful attempts required to produce it. At the aggregate level, this is the resource cost the market must induce in order to obtain a reliable public signal.

The fifth is the **cost of interpretation**. A proof may be inexpensive to validate while still remaining difficulty to understand. This interpretive process is where physical evidence becomes economically

legible to those who are well-incentivized.

What matters is understanding the various levels of cost to reveal the regions where an observer acquires economically meaningful information.

Thermoeconomic Loop

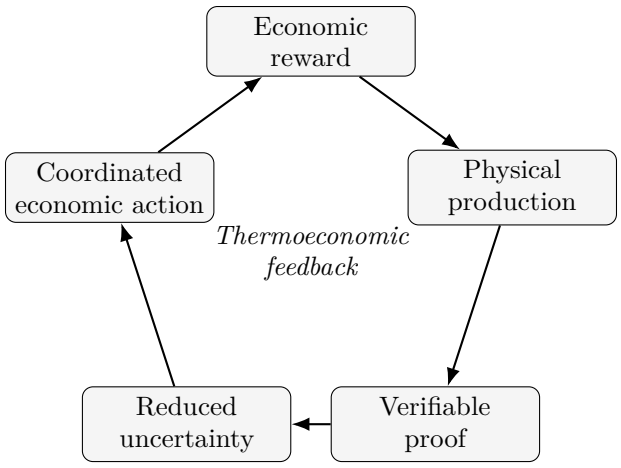
An automated proving system can be described through three accounts.

The **physical account** records matter, energy, computation, and dissipation. It asks what transformations had to occur for the system to produce its outputs.

The **informational account** records uncertainty, probability, error, noise, verification, and inference. It asks what an observer can rationally conclude after seeing a valid proof and the aggregate behavior of the system.

The **economic account** records prices, incentives, private costs, opportunity costs, and allocation. It asks why producers perform the work, how resources are directed toward proof production, and what coordinated actions the resulting information enables. Thermoeconomics begins where these accounts meet.

Each transition can be analyzed separately.



The physical account constrains the informational account because proofs must be implemented in physical processes. The informational account constrains the economic account because rewards depend on what the system can verify. The economic account constrains the physical account because prices and incentives determine how much equipment and energy producers can rationally commit. Separating the transitions prevents causal shortcuts. A reward does not directly create trust. It induces production. Production does not directly create truth. It generates an output under a rule. Verification does not eliminate all uncertainty. It reduces uncertainty about the proposition actually tested. Coordination improves only when that proposition is relevant to the decisions participants need to make.

3.9 Research Propositions

These propositions summarize the relationships developed in the series and provide a basis for further research.

Proposition 1. The protocol determines what a proof establishes. A hash becomes evidence through the public rule it satisfies. The target and conditions of observation allow observers to reason about the hidden search behind the result. The protocol establishes validity, while the model determines what further inference is justified.

Proposition 2. Hidden computation can be estimated without observing every operation. Proof arrivals, difficulty, and elapsed time support an estimate of aggregate computation under the stated observation model. With additional knowledge of hardware efficiency and supporting equipment, that estimate can be translated into an energetic account. Individual operations and private production records need not be reconstructed.

Proposition 3. The precision of inference can be evaluated. Under stated assumptions, the Cramér–Rao bound identifies a minimum variance for unbiased estimates. Comparing an estimator with that bound shows how efficiently it uses the available observations. This provides a basis for studying how much can be learned from a given budget of hash work.

Proposition 4. Evidence produced once can serve many observers. A proof can be verified and used by additional observers without repeating the original search. Its production cost can therefore be spread across many uses, allowing the reach of the evidence to expand without an equivalent increase in production expenditure.

Proposition 5. Participation expresses private economic judgment. Under the participation model, a producer enters when its expected return covers its economic cost relative to the available alternative. Entry, exit, and changes in production therefore provide evidence about otherwise private costs, capabilities, and expectations.

Proposition 6. Energy provides a common basis for physical comparison. Physical processes can be compared in common energy units when their boundaries and measurements are explicit. Such comparisons must preserve differences in function, timing, location, and energy quality.

Proposition 7. Price changes the physical activity being observed. Rewards, energy prices, and financing conditions influence participation and the machines producers choose to operate. These choices can change both aggregate computation and the energy required to perform it. Economic interpretation therefore feeds back into the physical process.

Proposition 8. The value of proof depends on what it enables. Proof is valuable to an observer when its evidence improves expected decisions or helps avoid losses. Net value accounts for the costs relevant to that observer, which differ between reading an existing proof and financing its production. A social assessment must also consider effects on others.

Further research must test both what observers can reliably learn and whether using that knowledge improves outcomes enough to justify its cost.

The Economics of Information

This series began with dispersed knowledge and ends with action. Information comes to market when private judgment is expressed through costly commitment. A trade, an investment, an entry decision, or a submitted proof gives economic consequence to knowledge that would otherwise remain private. Automated proof offers a particularly clear example: producers commit physical resources under uncertainty, a protocol determines whether the result qualifies, and a successful proof becomes public evidence upon which others can act.

The meaning of that evidence is not contained in the proof alone. It depends on the rule that produced it, the incentives that motivated its production, and the decisions for which it is relevant. A proof establishes that a specified condition has been satisfied, but it does not disclose the producer's exact costs, establish value, or justify claims beyond the proposition tested. Its economic significance arises through interpretation. Observers decide what the evidence permits them to infer, what uncertainty remains, and whether acting on it is worthwhile.

This makes information and thermodynamics inseparable. Information is not an abstraction laid over the physical world, and energetic expenditure is not merely an external cost attached to computation. Producing evidence requires physical transformation, while prices and incentives determine which evidence is worth producing. Proof brings these relationships together: physical constraints shape production, protocols give the result public meaning, and economic action makes that meaning consequential.

The process does not end with verification. Evidence changes expectations, and changed expectations redirect capital, energy, and production. Those changes alter the physical conditions from which later information will emerge. What results is not a one-way progression from physics to economics, but a continuing feedback among private judgment, costly action, public evidence, and economic choice.

Thermoeconomics names the study of this feedback. It treats the economics of information as a problem of how knowledge is produced, expressed, interpreted, and acted upon under physical and economic constraints. It also treats physical production as a process shaped by expectations, incentives, and prices. Thermoeconomics does not reduce value to energy or replace judgment with measurement. It explains how information acquires economic meaning through costly commitment and how economic valuation returns to reorganize the material world.

Information has always been physical, and economics has always been thermodynamic. Automated proof makes their relationship explicit.

> *"All the sciences have now to pave the way for the future task of the philosopher; that he must solve the problem of value and fix the hierarchy of values."*
>
> — Friedrich Nietzsche, *The Genealogy of Morals* (paraphrase)

Welcome to Thermoeconomics.