of pollution control devices. There is good reason to believe that the auto industry may never return to previous production levels of cars and trucks. This is exemplified by Ford's decision to permanently close three plants, including its Mahwah, New Jersey assembly location, and to permanently dismiss 15,000 workers, and by the federal government's decision April 18 to turn down the Chrysler loan guarantee. There is speculation that Chrysler's facilities, regardless of the disposition of the company itself, will be turned toward war material production and that some part of the antipollution device investment could be similarly turned around.

### Aerospace orders

According to industry statisticians, the machine tool industry is "strong across the board" and is receiving heavy orders from the oil industry and aerospace. The oil orders are buoyed by heavy purchases of pipe-threading equipment, while aerospace reflects the largest aircraft industry backlog ever recorded.

Aircraft, at year end 1979, showed an order backlog of $23 billion, in contrast to a 1975 year-end backlog of $6.0 billion. The usual explanations of the very heavy orders from air carriers are that newcomers are scrambling to enter the deregulated market. But many of these orders are "soft," and the question remains why they were placed and why the aerospace companies are accepting them as bona fide.

### The labor angle

The Schachtian shift in the U.S. economy has produced very high unemployment in heavily unionized sectors of the economy and relatively strong employment in nonunionized economic sectors and areas of the nation.

For example, while northern homebuilding is all but at a standstill, unemploying large numbers of unionized building trades workers, sunbelt, southwestern and Pacific petroleum-related nonunionized areas show strong employment. The intensifying "open shop" drive in construction and FEMA's announcement of future "labor registration" cards and restrictions on the free flow of labor, particularly in labor-short categories and locations, augur a very rapid collapse of unionized labor and their higher wage levels.

The LaRouche-Riemann computer projections indicate, however, that to sustain the Schachtian economy, as envisioned by the Carter-Volcker strategists, requires virtual zero-wage levels in some industries in order to maintain an apparent profit rate. This process would "mature" considerably more rapidly in a Schachtianized U.S. economy than in the economy of 1930s Germany.

# Economics: the

by Dr. Steven Bardwell and Dr. Uwe Parpart

In a recent series of articles in the *EIR*, Contributing Editor Lyndon LaRouche coined the term "thermohydrodynamics" to describe the subtle combination of energy-technical processes with economic (financial and investment) activity by which the time evolution of a national economy can be described. The sometimes conflicting interaction of these two levels of an economy determines the dynamics of the current crisis in the U.S. economy and an understanding of this interaction is essential if this crisis is to be resolved or longer-term policy questions successfully decided.

Concrete examples of the qualitative character of this economic-technical determination are abundant: a recent *EIR* economic analysis of the underlying energy balance and flow in the U.S. economy (by Goldman and Parpart) used Fig. 1 to discuss the changes in energy consumption in the United States since the 1973 oil price rise. As these authors noted, the U.S. economy has, on the technological side, become more energy efficient, as evidenced by the reversal in 1974 of the curve plotting output per manhour against energy use per manhour. That is, output per manhour is rising after 1974, while energy use per manhour is falling. This measure of efficiency has been used by several economists to document their claim that the U.S. economy has successfully adapted to higher energy prices and can respond to continually rising oil prices with an otherwise beneficial program of conservation and increased efficiency.

This conclusion is fundamentally misleading because it ignores the underlying duality of any economy—the interaction between this technical side and the economic financial superstructure. Fig. 2 shows the data from Fig. 1 now plotted in three dimensions, as a function of changes in capital investment. That is, Fig. 1 is a two-dimensional projection of the curve in Fig. 2. In this

# thermohydrodynamic view

more complex diagram, the two phases of the economy are shown together and the real impact of the supposed "efficiency" is explained. The increase in energy efficiency is a result of the substitution of energy by labor and capital by labor. Indeed, a careful comparison of these series with productivity for the same period (another *economic* measure) shows a *slowing* rate of growth of productivity as labor replaces capital. As we shall see, these developments presage dire consequences for the economy as a whole.

Similarly, as LaRouche's analyses in a recent *EIR* article shows, tax policy, capital investment, and technological innovation, are intimately related. Their mutual interplay shows quite strikingly in historical analyses done of the aerospace industry in the U.S. and Germany [for example, the one done for the American Aerospace Institute in 1976]. Technological innovation is stymied without aggressive programs of capital investment, but capital investment depends sensitively on accounting and tax procedures regarding depreciation. The net result is that in U.S. industry there is an *inverse* relationship between capital intensivity and obsolescence. This is due in large part to tax and accounting laws specifying depreciation at historical values (and hence understating it during periods of inflation and so decreasing reinvestible profits). In contrast, West Germany, with a tax law based on *replacement cost* depreciation, has maintained much larger rates of capital formation.

As both of these examples show, there is a deep and reciprocal interaction between the technical half of an economy—as measured by its energy consumption, technological level, and research programs—and that economy's "superstructural" half—as measured by capital investment, depreciation, and profit rates. In a causal sense, the mediation between these two halves is provided by the productivity of the labor force. The ultimate impact of capital investment is determined almost solely by its influence on productivity. Conversely, the economic significance of energy-capital tradeoffs and the intro-

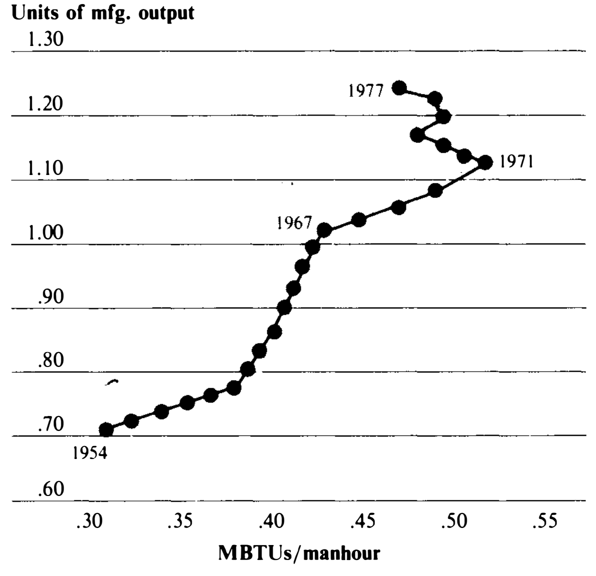



**FIGURE 1**
**Apparent energy efficiency in U.S. economy.**
This graph shows the trajectory of a scalar measure of the energy balance in the U.S. economy over the past decade, plotting output per manhour against energy use (in million BTU) per manhour. The inflection in the curve at the point of the 1973-74 oil price rise has been taken by many to indicate the economy's entry into a new stage of development in which energy use and economic growth are decoupled.

duction of new technologies is *not* directly on profits, but rather on productivities.

This insight is not, of course, new. An early American economist, E.P. Smith—Henry Carey's self-described "mentor," and a seminal influence on the Meiji capitalist circles in 19th century Japan—noted the same inseparability of energy and economics. So did the other "American System" economists, like Friedrich List, Henry Carey himself, and, from a different standpoint, Karl Marx.

It has, however, in the past five years, become fashionable in economic circles to downplay or totally ignore what LaRouche calls the thermohydrodynamics of the economy. It has been replaced by ideas like "decoupling"—the supposed independence of energy growth from economic growth—and the "economics of scarcity"—the theory that capital investment and productivity meet insurmountable barriers because of technical considerations (like energy). As we shall show, these ideas are not only wrong, but policy based on them is catastrophic. The current decrepit state of U.S. industry is due to their application; the problem of structural inflation is worsening because of the "cures" proposed by this new economics. In fact, a severe economic collapse is imminent unless these policies are reversed.

## Elaboration of the LaRouche-Riemann analysis

The LaRouche-Riemann economic model has proven to be a powerful tool for the analysis of the sort of phenomena in the economy falling under the name of

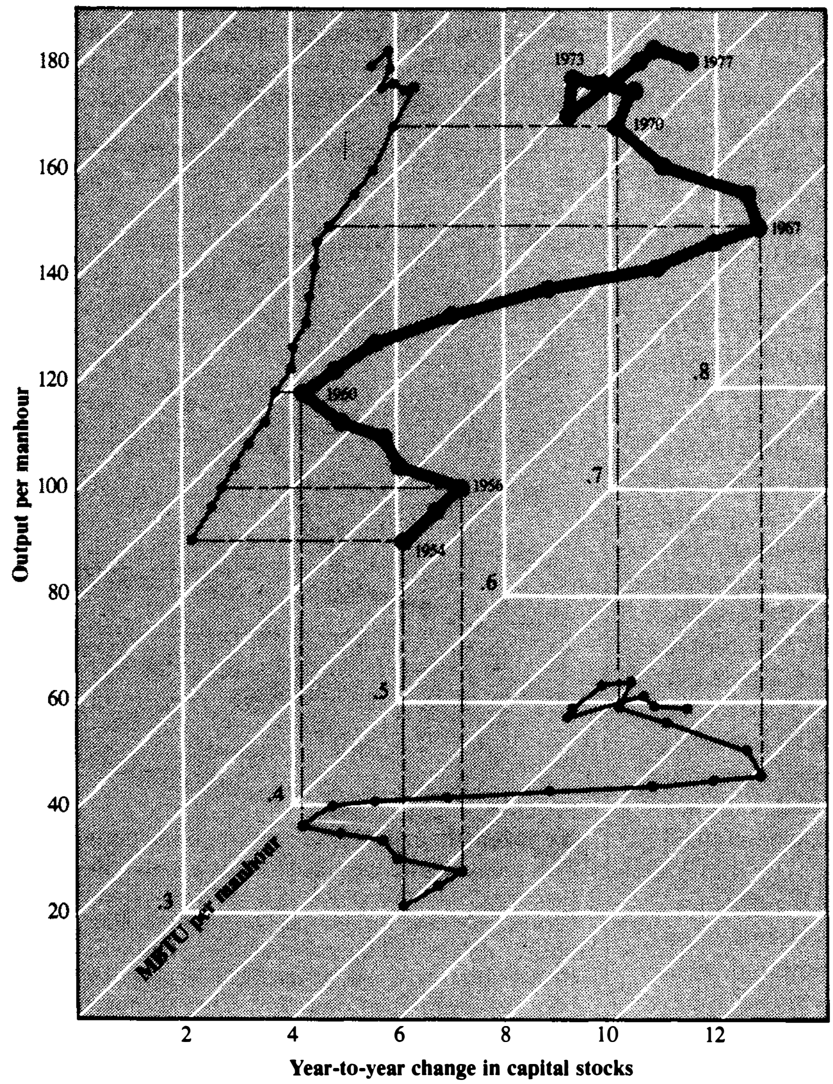



**FIGURE 2**
**Actual energy efficiency in U.S. economy**
This graph shows the trajectory of the U.S. economy in a space which elucidates the real significance of the apparent energy efficiency of Fig. 1. This three-dimensional graph includes as a new axis, year-to-year changes in capital stocks for the energy data plotted in Fig. 1 (that is, Fig. 1 is a projection into two dimensions of this figure). It is clear from this graph that the reason for the seeming energy efficiency of the economy since 1973 is due to a substitution of capital by labor, a fact correlated with the dramatic slowing of productivity growth in the same period. Energy efficiency is a scalar measure for an economy, whose qualitative significance is derivable from a consideration of the "economic" superstructural features in which it is imbedded—in this case, productivity and capital investment.

thermohydrodynamics. It embodies three critical features of an economy, namely:

1) The capital investment-productivity causal link;

2) A distinction between productive and nonproductive economic activity, and

3) The capability to treat noncontinuous (singular) behavior.

The Riemannian model has forecast with repeated accuracy the economic consequences of policy decisions as disparate as trucking deregulation and the credit policies of Federal Reserve Chairman Volcker.

In the past two months, an elaborated set of equations have been developed for the model which now allows a systematic treatment of depreciation and net capital formation. These new equations are a simple generalization of the previous equations (see glossary, p. 35). Any economy can be studied from a thermodynamic point of view, and these equations have a deep thermodynamic significance permitting a detailed analogy with classical thermodynamics. The fundamental problem which motivates both economic and thermodynamic systems analysis is that of "useful" or "free" energy. In both systems, the amount of accessible energy is less than the total energy. Thermodynamics and economics are (or should be) directed toward minimizing the difference, the wasted energy. Specifically, we are interested in *maximizing* the ratio of free to total energy—a quantity we call the free energy ratio.

(Classical thermodynamics only rarely looks at this *ratio*—studying rather the difference between free and total energy. As we shall see, this approach is incorrect but follows from Clausius' formulation of thermodynamics: "The energy of the world is constant; the entropy tends toward a maximum.")

The distinction between total and free energy can be seen from an example cast in thermodynamic terms. If we have four gallons of water at 0 degrees Centigrade and 1 gallon at 100 degrees Centigrade, in a room at 20 degrees (ambient), useful work can be extracted from the temperature differences between the two bodies (we could, with an ideal engine, change all the internal energy into electricity, for example).

The total internal energy of the system is the sum of the energy of the two parts. Now, if we mix the five gallons of water together, we will have five gallons at 20 degrees C, a mixture with the same total energy as we started with—but with no "free" energy. Since the temperature difference between the water and air is zero, no work can be done with the total (internal) energy in the water. The free energy ratio has changed from 1 to 0!

It is clear that the free energy ratio will be intimately related to both the economic and technical aspects of the economy; in some sense, it must measure the appropriateness of the economic superstructure to the underlying mode of industrial production. A fall in the free energy ratio indicates the transition of the economy into a state of "inappropriate" economic reproduction—a property of the change shown in Fig. 1 and 2 during 1973-1974, for example. A rising value of the ratio, on the other hand, indicates an "appropriate" economic superstructure, whose investment pattern is enhancing the productivity of the labor force, and, in turn, fostering capital formation. Zero or negative values of this ratio are also possible, indicating a net *destructive* effect of the economic activity on the physical economy. A value of zero for this ratio is a "crucial point" in thermodynamic terms, measuring the onset of a phase transition or other singular phenomena (in economic terms, a depression).

The first step in a thermodynamic analysis of an economy is to find the parallels to the two laws of thermodynamics; the first, an energy balance law, and the second, a cause for dissipation or impossibility of attaining a free energy ratio of 1. (Sometimes the first

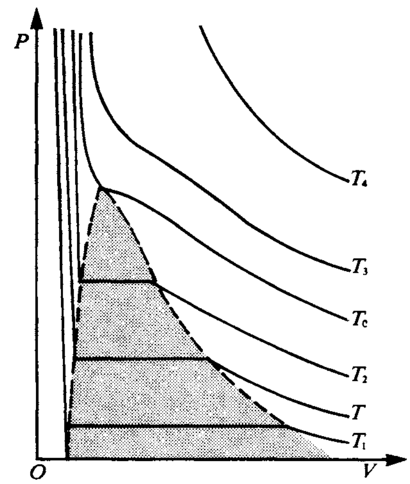



**FIGURE 3**
**Equation of state for a real gas**
A useful analogy to the equation of state of an economy is provided by that for a real gas, shown above. The pressure of the gas is on the vertical axis, and the volume of a given amount of the gas at that pressure on the horizontal axis. At high temperatures, the pressure and volume are inversely related, generating the family of hyperbolae shown (labeled $T_4$, $T_3$). As the temperature decreases, however, these hyperbolae become distorted, until at a temperature Tc, the curve becomes horizontal for one value of pressure and volume. This is the highest condensation temperature of the gas—the singularity in the slope of the P—V curves indicates the onset of a phase change, liquefaction (in the shaded region).

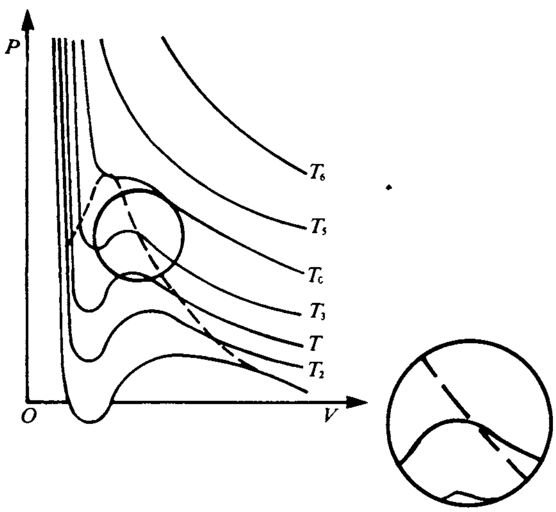



**FIGURE 4**
**Phase diagram for an economy**
By the same arguments which underlie classical thermodynamics, it can be shown that a capital-intensive economy has a phase diagram similar to that for a real gas, where pressure is replaced by $\alpha \cdot \delta$ (see text) and volume by V (variable capital). The depreciation rate corresponds to temperature. Thus, the hyperbolae shown above for $T_6$ expresses the fact that for a given depreciation rate (i.e., capital investment and composition of investment) the size of labor force and productivity required to maintain that depreciation schedule are inversely related. And, as in the case of a gas, lowering the depreciation rate corresponds to cooling of the economy, a process which can be carried on for only a finite amount of time before a phase change occurs, in the case of the economy corresponding to a depression.

The inset shows in greater detail the dynamics of this phase change. It is known that some gases have the property that they can be supercooled below their nominal condensation point predicted by the phase diagram shown in Fig. 3. In this case, the isotherm (the path at constant temperature) changes the sign of the slope. In the case of the economy, this property characterizes the present situation in which a phase change has yet to occur, but during which the dynamics of the economy are opposite from their normal behavior. The usual methods for dealing with inflation, for example, not only do not work, they make the problem worse, precisely because of the inflection in the phase diagram.

The trajectory of the U.S. economy over the last 10 years does not follow an isotherm, but has followed a trajectory taking it from near the curve labeled $T_6$ to that near $T_3$ as the productivity-composition product (the vertical axis) has decreased, and the labor force increased (see Fig. 5).

law is erroneously called the conservation of energy—it is clear from its economic version that it actually describes the law of energy transfer.)

The economic first law (which is derivable from the differential equations in the Riemannian model), is:

$\Delta E$ = change in total economic value
= $\delta W + \delta Q$
= increment of capital consumed and reproduced continually + increment of capital not consumed and replaced annually.

That is, there are two distinct forms of economic value added by the production process. The first is that portion of production which is consumed (and reproduced) continually in the economic process. In this category belongs, for example, productive workers' wages (V), raw materials, etc. The dynamics of this portion is basically different from the second category which includes all economic production "lost"—for whatever reason—from continued production. This portion includes all waste, nonproductive expenditures (military, most bureaucratic expenses, etc.), and that portion of plant and equipment not consumed during a given production period (i.e., the nondepreciated part of gross capital stock).

As in thermodynamics, where the first law is usually written $\Delta E = \delta Q - \delta W$ ($\delta Q$ being heat exchanged, $\delta W$ being the work done by the system), neither $\delta Q$ nor $\delta W$ are so-called "state variables." This means that their value depends on the trajectory of the system as it changes and not only on the initial and final states. Thus, $\delta W$ and $\delta Q$ may differ depending on the path taken during the change as long as their sum remains the same. Therefore, we must express $\delta W$ and $\delta Q$ in terms of state variables like in the economic case, V, $C_1$, $C_2$, and S'. The work-like term in our economic first law is straightforward and some algebraic manipulation shows that:

$$\delta W = \alpha\delta dV + (1 - \alpha)\eta dC.$$

(For simplicity, we take $\eta = 0$ in this discussion. This is not a restriction in principle and all our conclusions hold, though in more complex form, for nonzero $\eta$.)

Thus, the path-independent difference has been replaced by a total differential.

The analysis of the heatlike term is more subtle and involves the equivalent of the second law of thermodynamics formulated for an economy. Clearly, one term of the heat-like $\delta Q$ is given by $d$, the nonproductive expenditures in the economy. But, the economy also produces fixed capital which is added to the total economic value but is removed from circulation. This amount depends on cumulative capital formation, $\delta C_f$, and on the depreciation of that capital over its lifetime. That is, the second contribution to $\delta Q$ is itself path-dependent. However, it is easy to see that we can change $\delta C_f$ into a total derivative by introducing an integrating factor, which we call R, such that:

$$\delta Q = d + dJ = \int_1^2 (\delta C_f/R) + d$$

(Note that for $d$, R is in effect 1; $d$ depreciates completely each year. In thermodynamics, temperature is introduced as the integrating factor for heat, exactly as we have defined R. Note also that $d$ or nonproductive expenditures should be distinguished from differential expressions such as, in the above case, the derivative dJ.)

Now, R must be the factor that measures the noncirculating part of fixed investment, that is, R is simply the depreciation rate. The equivalent of the second law of thermodynamics states for the economy that:

$$d + dJ \geq 0$$

for any complete cycle, or:

$$d + dJ \geq \int_1^2 (dC_f/R) + d$$

This means that it is never possible to reduce "overhead" costs to zero, and that the difference from zero is the "entropy" of the economic system.

These results can be combined into the so-called fundamental relation of thermodynamics:

$$\Delta E \leq RdJ + d + \alpha\delta dV$$

where, we can make the parallel with thermodynamic variables:

| Thermodynamics | Economics |
|---|---|
| Pressure (P) | $\alpha\delta$ |
| Volume (V) | Variable capital (V) |
| Temperature (T) | Depreciation rate (R) |
| Entropy (S) | $J = \int(\delta C_f/R)$ |

Finally, we can derive the equivalent of the *free-energy ratio* for an economy, by analogy with the Helmholtz free energy in thermodynamics:

$$\Delta\mathscr{H}/E = \Delta(E - TS)/E = S'/(C_1 + C_2 + V)$$

(Strictly speaking, $\mathscr{H}$ is the free energy at constant temperature. We believe this to be the closest analogy with free energy in economics.)

This is a striking result; it says that the free energy ratio is equal to the portion of surplus productivity reinvested as a ratio of the total economic activity.

Several important features of the thermohydrodynamics of the economy—that is, the relation between the economic superstructure and industrial base—are evident from this formulation:

1) The useful work available from the economy is

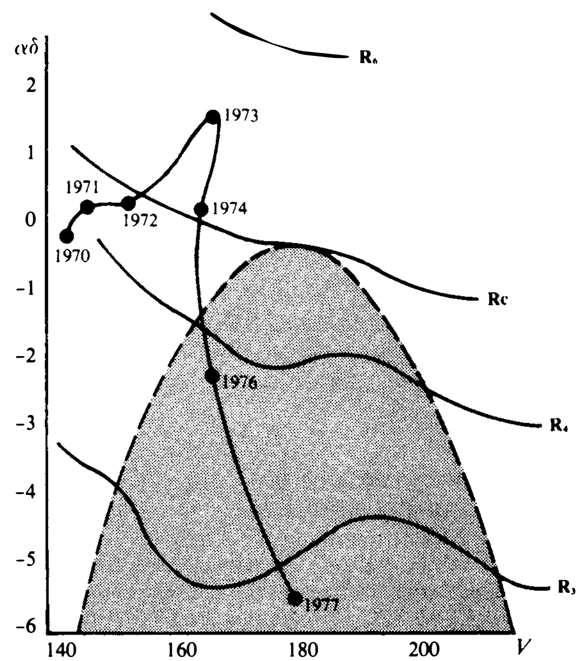



**FIGURE 5**
**Trajectory of U.S. economy over 10 years in phase diagram**
The trajectory of the U.S. economy through the phase diagram of Fig. 4 is shown above. The actual motion of the economy changed from one isotherm (that is, trajectory of roughly constant depreciation rate) to another in approximately 1974. This new isotherm put the economy on a trajectory leading to a phase change as shown. The present position of the economy is shown by the termination of the trajectory in the "supercooled" region of the phase diagram. Note that there *was*, as many economists have noted, a qualitative acceleration of the energy-labor trade-off with the 1973 oil price rise. However, the significance of this change is only shown by the above considerations.

dependent on the productivity of labor. In fact, at a fixed value of R,

$$(\partial \mathscr{H}/\partial V)\mid_R = \alpha\delta$$

This corresponds to the thermodynamic result:

$$(\partial \mathscr{H}/\partial V)\mid_T = -P$$

2) The depreciation rate plays a central role in the health of the economy, but in a somewhat surprising way. At first glance, it would seem that an individual firm would benefit from extending the life of its capital as long as possible. Obsolescence *from an accounting standpoint* is not bad since it represents a savings of capital investment. However, this is not actually the case. The higher the depreciation rate, the lower the entropy of the production process (see the definition of J) and the more efficient the economy becomes. High depreciation rates ensure this. As Samuel Insell is reported to have said: "The scrap heap is the capitalists' greatest asset."

3) The danger to the economy comes from a discrepancy between the economic (tax or legal) rate of depreciation and the actual (technical) rate. If the legal rate of depreciation is lower than the technical rate for any extended period of time, the observed rate of profit will fall secularly—or, to prevent this fall, the larger (nominal) amount of capital chasing a fixed or declining amount of profit will generate inflation. In either case, the conflict between the economic superstructure and the industrial underpinnings will push the real free energy ratio towards or below zero, causing a depression.

## An 'equation of state' for the economy

The above analysis will apply to any economy, but to study the U.S. economy specifically, we must discover the equation of state for an advanced, capitalist economy. That is, we must supplement the above equations with a relation:

$$F(P, V, T) = 0 \longrightarrow F(\alpha\delta, V, R)$$

The functional form of F will be determined by the causal relationship among the three state variables. Simple arguments show that:

$$(\alpha\delta + A)(V + B) = \text{const}\bullet R,$$

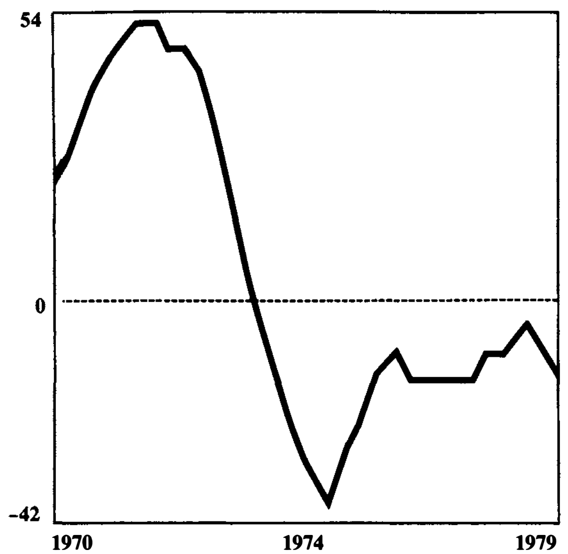



**FIGURE 6**
**Reinvested profit since 1970**
The reinvested profit (S') in the U.S. economy suffered a collapse in 1973 from which it has not recovered, even in the past five years of supposed upturn. This lack of capital investment is the fundamental causal feature of the present state of the economy.

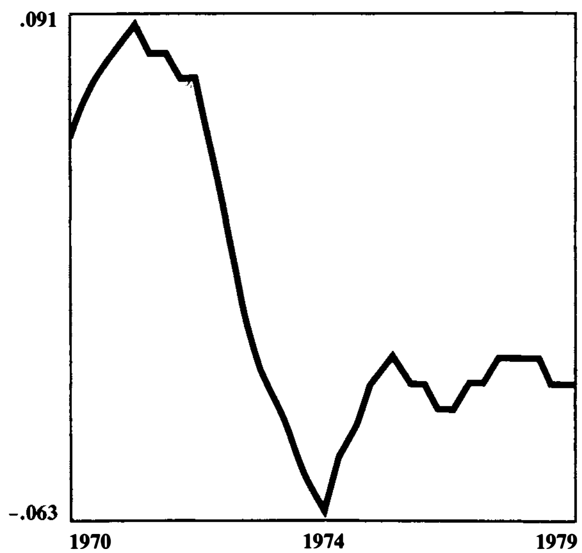



**FIGURE 7**
**Free-energy ratio of the U.S. economy since 1970**
The underlying thermodynamic state of the economy is shown by the ratio of the reinvested profit (usable or free thermodynamic energy) to the replacement costs of the economy S'/(C+V). As this graph shows, there was a drop in this ratio of catastrophic proportions in 1973-1974.

(Since productivity and the size of the labor force—at a given depreciation rate—can be traded off, we assume a simple inverse relation between the two: $(\alpha\delta + A)(V + B) = \text{const}$. Since at a fixed labor force, a higher productivity is required to sustain a higher depreciation rate, we assume: $(\alpha\delta + A)(V + B) + \text{const}\bullet R$. It appears that A decreases with increasing V, giving rise to a Vander Waal's equation of state.)

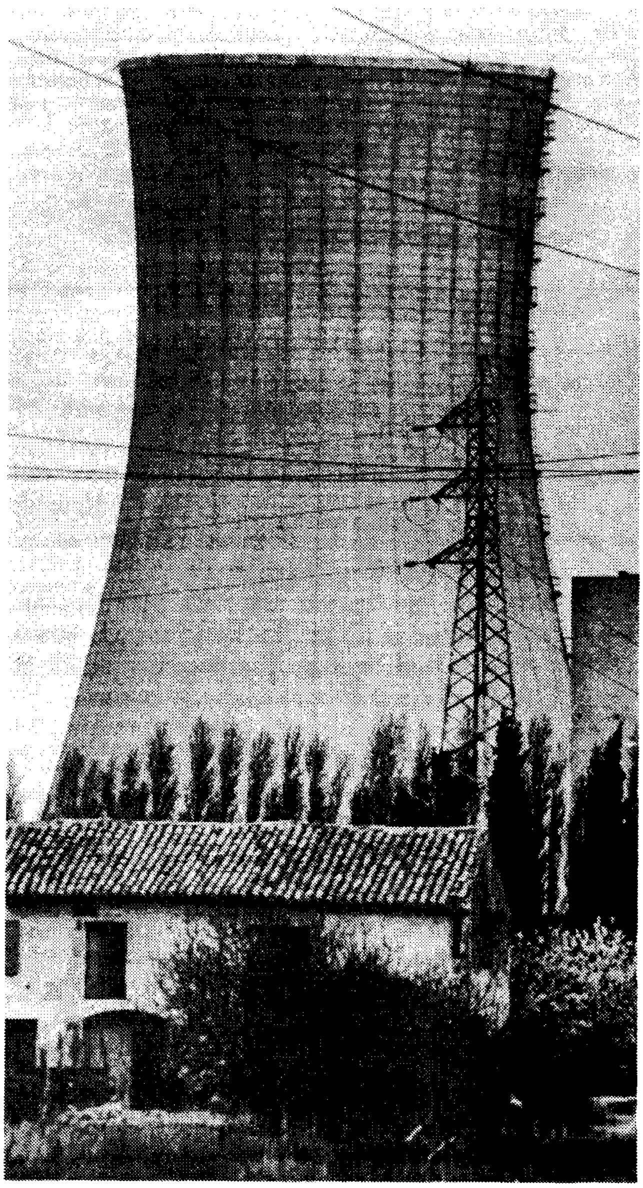
This form of equation of state is well known in thermodynamics and describes most real gasses. Figure 3 shows the "phase diagram" for such a gas. The pressure and volume, for high temperatures, are inversely related, generating a family of hyperbolae (the isotherms marked $T_6$ and $T_5$ in the figure). As the temperature is lowered, these hyperbolae become distorted, until at a temperature below the critical temperature (marked $T_c$ in the figure), there is a discontinuity in the slope of the isotherm. The shaded region, enclosed by these discontinuities, is that region of the phase plane in which the gas has liquified.

We have drawn a similar plot for an advanced capitalist economy in Fig. 4. The vertical axis is now $\alpha\delta$, the horizontal axis, V, and the isotherms correspond to lines of constant depreciation rate. The higher the depreciation rate, the hotter the economy, and the farther away from a phase change. As the depreciation rate is lowered, and a discrepancy arises between the real and nominal value of capital, the "isotherms" become distorted. The value $T_c$ corresponds to the point at which S′ becomes zero, *either* because no surplus is reinvested *or* because net investment in plant and euqipment is negative although V is increasing (this makes $\alpha$ negative). The dotted line delineates this region. In a real gas, as in the economy, the phase change process is more complex than Fig. 3 indicates. There are metastable states, so-called supercooled vapor states, in which a *gas* in the liquid region of the phase plane has not yet condensed, having yet to receive a shock or perturbation sufficient to precipitate the condensation. A supercooled vapor will follow the isotherm along the doubly curved path shown in the liquid region of Fig. 4. A supercooled economy, like a supercooled gas, is highly unstable, amplifying fluctuations until the phase change occurs.

Figure 5 shows the trajectory of the U.S. economy in this phase plane over the past eight years. The economy, while not healthy in an overall sense, was recovering slowly in the early 1970s. But, the oil price rise in 1973-1974, as we have seen, qualitatively changed the economy's evolution, as the abrupt change in the trajectory shows. Very quickly the economy entered a metastable state, crossing "isotherms" whose slope is positive. In this metastable region of the phase plane, traditional economics is turned on its head! Conventional "cures" for inflation, for example, (like tightening credit to de-

**TABLE 1**
**Energy output/8 hours**

| | |
|---|---|
| Man (manual labor) | 100 kwh |
| Horse | 1,500 kwh |
| Windmill | 12,000 kwh |
| Pearl St. station (Edison's first electrical plant—1882) | 270,000 kwh |
| Hoover Dam generator | 345,000,000 kwh |
| Typical nuclear plant | 5,400,000,000 kwh |



*Top, the chart shows that nuclear technology is the most energy-efficient source yet developed. Below, the nuclear power installation at Pierrelatte-Tricastin, France.*

**TABLE 2**
**Energy use per hectare in rice production in various countries***

| Country | Installed horse-power per hectare farm machines and draft animals only | Energy for farm operations (million Btu's per hectare)† | Energy for irrigation and nitrogen fertilizers manufacture (million Btu's per hectare) | Total energy input per hectare (million Btu's) | Rice yield kilograms per hectare | Energy intensity (million Btu's per ton of rice) |
|---|---|---|---|---|---|---|
| India | 0.7 | 20 | 6.5 | 26.5 | 1,400 | 19 |
| China | 0.7 | 20 | 12 | 32 | 3,000 | 10.7 |
| Taiwan | 0.5 | 10 | 22 | 32 | 4,000 | 8 |
| Japan | 1.6 | 10 | 25 | 35 | 5,600 | 6.2 |
| USA | 1.5 | 7 | 25 | 32 | 5,100 | 6.3 |

* Total grain production depends not only on seed variety, soil quality, etc., but also on the mix of grains grown. Therefore, comparing a single grain gives a better comparison of the energy intensity of various farming methods.
† Energy used to perform various tillage, planting, and harvesting activities.
*Source:* Arjun Makhijani, *Energy and Agriculture in the Third World,* Cambridge, Mass: Ballinger Publisher Company, 1975, p. 17.

U.S. agricultural production is more energy-efficient overall because it uses intensive methods of mechanization and chemical inputs. As the table shows, increased irrigation and fertilizer energy per hectare and reduced manual labor lead to dramatic increases in rice production.

crease V and so, in normal times, shift a trajectory upwards in the phase plane) now have the opposite effect and increase V—and worsen inflation! The metastability is obvious in the wild gyrations of the money markets, commodity prices, etc. which amplify small jolts into large fluctuations and which can be damped only with the greatest difficulty. These phenomena occur in an almost identical way in a supercooled gas.

(Phenomena at the critical point are notorious for their ability to amplify fluctuations and for the large-scale coherent motion which spontaneously arises in them. Critical opalescence in a liquid-gas change is one example.)

The actual causal mechanism whose effects are evident in Fig. 5 is the approach of the free-energy ratio to and then below zero sometime between 1974 and 1975 (see Figs. 6 and 7). This change in the free-energy ratio created an accelerating devolution in the U.S. economy involving a net *decrease* in capital stocks, rising energy prices, decreasing growth in productivity, and decreasing capital- and energy-intensivity of production (see Tables 1 and 2).

## Dynamic formulation of thermohydrodynamics

It is possible to recast the equations of the model, as described above, in light of these thermohydrodynamic considerations. The equations in their simplest form, only describe the *economic* side and treat only implicitly the underlying technical aspect of the economy. But, by recognizing that the technical base shapes the economy in a geometric (not parametric) way, the two aspects of the economy can be treated together. The more complex economic space implied by these geometric considerations has, now, two "time-like" dimensions, calendar time (the t of our ordinary derivatives) and an energy intensity measure, called x, related to the level of technology employed in industrial production. Thus, we replace the propagator $d/dt$ with

$$(\partial/\partial t) + u(\partial/\partial x).$$

where the partial derivatives model this multidimensional economic geometry, and

x = "energy intensity flux" of production, and
u = rate of real investment in the most advanced technologies.

(In hydrodynamics, this set of partial derivatives is called the convective derivative. From this analogy, the name thermohydrohynamics was derived.)

Although the complete quantification of these variables has not been completed, there are several important consequences of this generalization of the model:

1) A quantification of the interplay between technical variables (t and x) and economic ones (u, S′, etc) is established, at least in principle.

2) These equations support shock wave solutions of exactly the sort required to describe phase changes. Since, if S′ is negative, we know that u decreases faster

# Glossary of equations

The differentials
$dS'/dt = \alpha\delta S' - \alpha\gamma S' + \dot{\delta}V - \dot{\gamma}V,$

$dV/dt = \alpha S',$

$dC_1/dt = (1 - \alpha)\eta S',$ and

$dC_2/dt = (1 - \alpha)(1 - \eta)\epsilon S',$
where

$\alpha$ = composition of reinvested capital $= \Delta V/S'$

$\delta$ = productivity = $S/V$

$\gamma$ = nonproductive expenditure $= d/V$

$\eta$ = circulating to fixed capital ratio $= \Delta C_1/(1 - \alpha)S'$

$\epsilon$ = depreciation rate

V = output required for replacement of productively employed workforce

$C_1$ = output required for replacement of productively consumed raw materials

$C_2$ = output required for replacement of productively employed plant and equipment

S = total output—$(V + C_1 + C_2)$

$S'$ = that section of S invested in new productive capacity (i.e., next year's V, $C_1$, or $C_2$)

$d = S - S'$

Notice that this system of equations is a slight generalization of the previous Riemannian models, in which equations (1) and (2) have not been changed, and (3) and (4) subsume the old equation for C.

for smaller $S'$, and, for positive $S'$, u grows faster for larger $S'$, the equation for $S'$:

$$(\partial/\partial t)S' + u(\partial/\partial x)S' = \alpha(\delta - \gamma)S' + (\dot{\delta} - \dot{\gamma})V$$

has shock wave solutions, for both $S' > 0$ and $S' < 0$. When $S'$ is positive, we have a characterization of the self-feeding process of industrialization. For $S'$ negative, the depression collapse in Fig. 5 occurs.

3)The discontinuous solutions to this set of partial differential equations introduce in a rigorous way the nested manifold structure of Riemannian mathematics and physics. (See S. Bardwell, U. Parpart, "Economics Becomes a Science," *Fusion* magazine, June, 1979.)

4) These partial differential equations contain two natural time-scales, one economic (due to u) and one technical (due to x). Historically, the interplay between the shorter economic time scale, as seen in business cycles and the like, and the longer technical time scales (determined by the lag times for technological innovation) have had important consequences for economic development. The present seems well-characterized by such a conjunction of an "economic crisis" in the realm of capital investment intersecting a deep technological shift required over the next 10-20 years into nuclear (fission and fusion) technologies. Without the increasing energy intensities and hence productivities implied by these investments, the present crisis is insoluble in purely economic terms. This conjunction defines the real significance and magnitude of the present economic crisis.