CHAPTER 10

Long Waves 1790–1990: Intermittency, Chaos, and Control

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There are two contending views of economic dynamics. Insights into their validity may be provided via concepts of catastrophe and chaos. The dominant paradigm is that optimizing behavior produces an economy that is inherently equilibrating, tending toward steady-state growth in the absence of random shocks. Such shocks, in the Slutsky-Frisch-Tinbergen view, are transformed into cyclical oscillations through the filtering properties of the economy's growth-propagation mechanisms (Boldrin 1990, 126–27). A contending paradigm associated with Hicks, Kaldor, and Goodwin is that endogenously driven growth is inherently unstable, with deviations that move between upper and lower limits to investment and consumption (Boldrin 1990, 126–27). What we will show in this paper is that long-wave rhythms of prices and growth (Berry 1991) accompanied by shorter-term oscillations display unpredictable dynamic system order, or deterministic chaos. Phase portraits reveal both intermittent crises at long-wave peaks and quasiperiodic limit cycles that encompass attractor basins between the peaks (for a discussion of limit cycles see Bergé, Pomeau, and Vidal 1984). It is the presence of these properties that supports the Hicksian view before 1919. We also show that institutional changes since the Great Depression have reduced the limits within which prices and growth oscillate, significantly altering long-wave and short-run dynamics by forcing attractor basins toward stabler equilibria.

Specifically, we document the following:

1. Slow-moving long-wave rhythms of prices are the outcome of the half-century-long logistics by which new techno-economic paradigms move from innovation to market saturation (Berry, Kim, and Kim 1993). The usual definition of chaos results in instabilities at the top of such logistics (Modis and Debecker 1992), and indeed they leave in their wake the inflationary spirals that define long-wave peaks.
2. Faster-moving annual fluctuations oscillate around the long-run

rhythms of prices, urged toward acceleration on the upwave and deceleration on the downwave.

3. The tension between low-frequency rhythms and high-frequency oscillations produces chaotic limit cycles in the periods between long-wave crises.
4. Instability at the long-wave price peaks gives rise to bifurcations. Upwave limit cycles may be different from those observed during a downwave.
5. Similar bifurcations and limit cycles characterize quarter-century-long swings and annual oscillations in the rate of economic growth.
6. Since World War II, both institutional changes and policies designed to fight inflation have dampened the higher-frequency oscillations of prices, leaving the long-wave rhythms as the dominant fluctuations: the first return map of prices has been reduced to the long-wave attractor.
7. But contrariwise, stabilization programs aimed at fluctuations in economic growth have had the opposite effect. It is the long swings of growth that have been dampened, leaving behind the higher-frequency oscillations of the business cycle: the first return map of rates of economic growth has been simplified to the characteristic cobweb of a business cycle.

The usual notes of caution are in order. We have at most two hundred data points: It is not possible to prove statistically "from a data set of the lengths available in economics . . . whether the data are generated by high-dimensional chaos" (Brock, Hsieh, and LeBaron 1991, 3). "If long cycles . . . exist, we will need another 200 years of data to determine whether they do exist or are just a statistical figment of an overactive imagination" (Becker 1988, 7). At best, therefore, what we have to offer are suggestive graphics.

Long Waves of Prices

The idea that there have been half-century-long waves of prices in the past two centuries begins with the observation of rhythms in the moving averages of the annual growth rates of prices upward and downward on the sides of inflationary spirals (fig. 10.1). These movements have occurred with a broad cross-national consistency (fig. 10.2). Russian economist Nikolai Kondratiev argued that such roughly 55-year trough-to-trough waves (hence, Kondratiev waves) were a fundamental characteristic of capitalist economies, each wave representing a radical regrouping of, and change in, society's productive forces (Berry 1991; also Rosser 1991, 138 ff., for a discussion of Schumpeterian discontinuities and historical reswitching). Later investigations confirm that these regroupings represent the crystallization of new

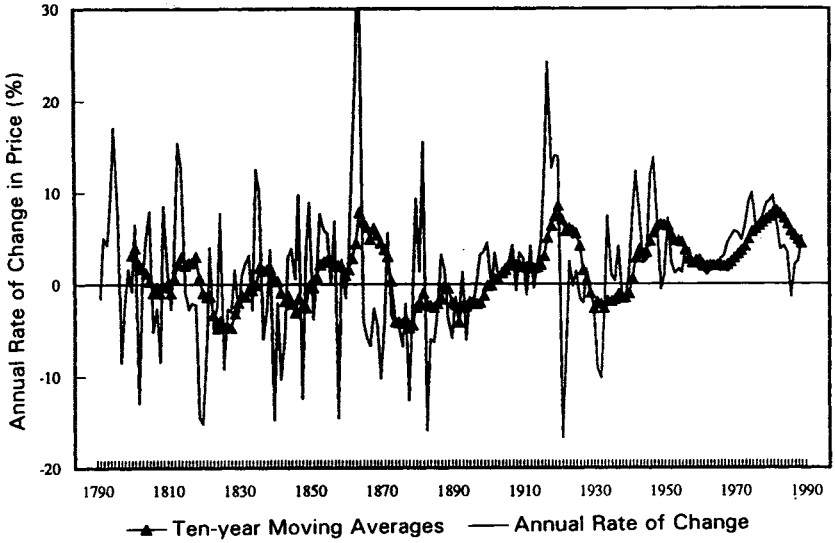

Fig. 10.1. Annual and ten-year moving averages of the growth rates of U.S. wholesale prices 1790–1990. The moving averages have been used as evidence of half-century-long wave rhythms, around which the annual oscillations fluctuate.

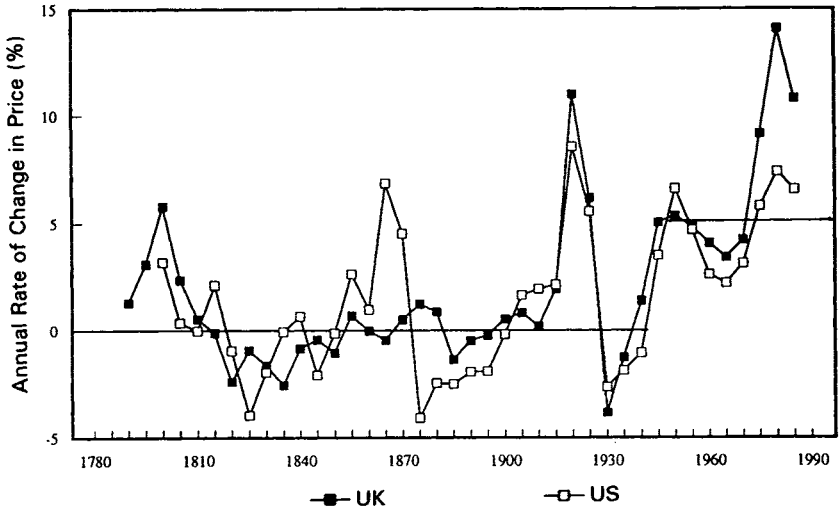

Fig. 10.2. Ten-year moving averages of U.S. and British wholesale prices, 1790–1990. Note the broad consistency of the long-wave rhythms, as well as the upward translation of the level around which prices oscillate after World War II. A combination of departure from the discipline of gold and the adoption of Keynesian macroeconomic philosophies produced a rise of 5 percentage points in the annual inflation rates in both countries.

techno-economic paradigms in the aftermath of inflationary spirals/stagflation crises that define the Kondratiev peaks. Such spirals/crises come in the decade following market saturation by a previous techno-economic paradigm (" . . . the inflationary pressure generated during the final stages of an upswing continues for about 10 years . . . ," Rasmussen and Mosekilde 1989, 279). Thus, the surge of U.S. growth after the Civil War centered on the steel industry as the leading sector and on the expansion and completion of the railroads, after the canal-building and wind-powered transportation era had peaked in the late 1850s (fig. 10.3, from Berry, Kim, and Kim 1993).

Viewed in this way, inflationary spirals/stagflation crises delineate transition points beyond which the older techno-economic paradigm declines and a new paradigm takes off, with growth centering on new leading sectors and new supportive infrastructure networks. Initially, new product prices are high, but they decline with achievement of scale economies and with routinization. Simultaneously, as consumers switch from older to newer products, product prices associated with the now-declining paradigm also collapse, and along with them the values of their raw materials and fixed assets. Only after the new paradigm achieves market dominance in the next Kondratiev trough and then diffuses toward market saturation do demand pressures once again force prices upward, ultimately to be driven by speculation into the next spiraling Kondratiev peak.

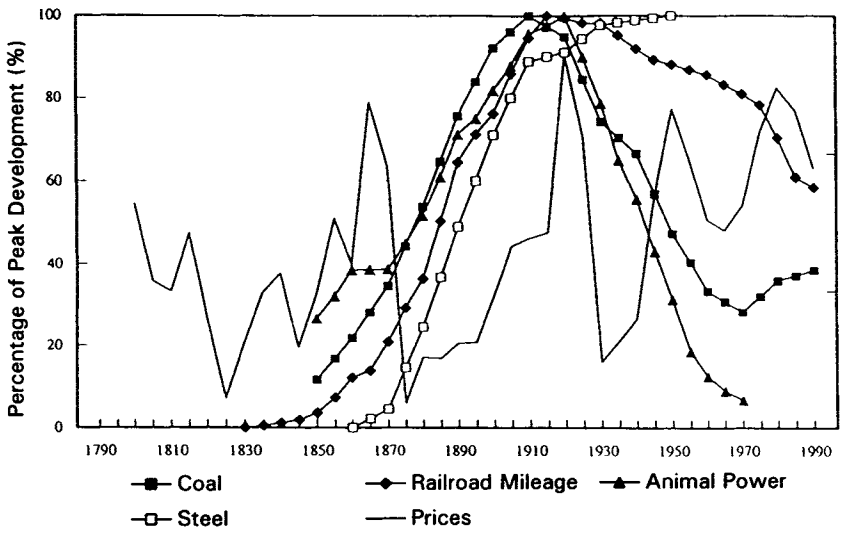

Fig. 10.3. Relationship between expansion of a techno-economic paradigm to market saturation and the long wave of prices. (From Berry, Kim, and Kim 1993.)

The regular succession of inflationary spirals/Kondratiev peaks at 50–60 year intervals (fig. 10.2) suggests a pattern of *transition via intermittency* that may generally be confirmed by the existence of a channel in the first return map, $\dot{P}_{t+1} = f(\dot{P}_t)$, as discussed in Bergé, Pomeau, and Vidal (1984, 245). Evidence for such channels has been presented elsewhere (Berry 1991, 22ff.); suffice it to say that *Kondratiev peaks represent critical bifurcation points* beyond which clusters of innovations can move the economy on to alternative evolutionary logistics (De Greene 1988, 291–92). The alternatives are not ordained: there are usually several competitors, of which only one becomes paradigmatic.

The new growth logistic produced by the successful paradigm may be characterized by the same kind of equilibrium-seeking behavior as the previous techno-economic paradigm, or it may result in a different pattern. In either case, just as the success of a new paradigm may be taken to be stochastic, the equilibria are chaotic, in that the dynamic processes that are unleashed are captured by attractors of one kind or another.

We seek to document the equilibrium-seeking/shifting behavior of prices for the successive Kondratiev waves, 1790–1845, 1845–95, 1895–1930, and 1955–present, plus the transition period 1930–55, when, in the aftermath of the Great Depression and the New Deal/WWII/Bretton Woods/Korean War period, the adoption of macroeconomic policies moved the U.S. economy into an environment of permanent inflation (Berry 1991, 13, 31–34). Prior to the transition, long waves moved with inflationary/deflationary rhythms; afterward, the successions became inflationary/disinflationary.

Shifts on either side of Kondratiev peaks are of interest, but of course so are the peaks themselves. As Friedman and Schwartz note (1963b, 62–64):

> The process we have described will tend to overshoot the mark; it will not simply produce a smooth movement to the new path consistent with the new rate of growth of the money stock assumed to prevail . . . . (I)n the process of going from the initial to the new equilibrium, prices must rise at a faster rate than their ultimate rate. Hence the rate of price rise must overshoot . . . . The tendency to overshoot means that the dynamic process of transition from one equilibrium path to another involves a cyclical adjustment process. The final picture that might ultimately develop could be of a partly self-generating cyclical mechanism. Disturbances in the rate of change in the money stock set in train a cyclical adjustment mechanism including a feedback in the rate of change in money itself. Additional disturbances from time to time would prevent the fluctuations from dying out.

For each of the time periods we plot the fluctuations in the annual growth rates of prices ($\dot{P}$) in three spaces:

$\dot{P}_t = f(t)$, the conventional time series graph;
$\dot{P}_t = f(P_t)$, the growth rates of prices with respect to price levels; and
$\dot{P}_{t+1} = f(\dot{P}_t)$, the Poincaré first-return map, of which two versions are given, the scatter diagram and the temporally connected sequence.

We ask how the price rhythms have been reset after each inflationary surge, whether there is evidence of a *catastrophic* switch in behavior in the catastrophe theory sense of the term, and what the underlying conditions producing such a shift might have been.

We begin with figure 10.4, covering the period 1790–1845. In the P/P space (top right-hand graph), oscillations are evident around two price levels. The first and higher level is that of the *upwave* leading toward the 1815 Kondratiev peak. After this stagflation crisis, the short-run fluctuations switch to oscillate around a lower *downwave* level. There is thus evidence of a bifurcation astride the Kondratiev peak, with oscillation around a higher price level before the main inflation surge, and around a lower level after the surge.

The Poincaré first-return maps (two bottom graphs in fig. 10.4) reveal something else, however: despite the switching of annual oscillations after the Kondratiev peak, there is a single underlying chaotic regime in which the oscillations are contained by well-defined limits (see Bergé, Pomeau, and Vidal 1984, 66–71, 103–4, 181). The motions are those of an endogenous chaotic cycle, as evidenced by successive returns to the outer limits in the graph (Rosser 1991, 114), with moderate *boom and bustiness* revealed by the elongation of the ellipse of points along the 45° diagonal (Gleick 1987, 176–77; Glass and Mackey 1988, 26–34; Casti 1989, 249–53). Even without the filtering presented by Berry (1991) in the attempt to isolate the attractor describing the longer-run pattern of boom and bust, the movements point to a strange-like attractor structure that is consistent both with the notion of a limit cycle (see also Goldberger and Rigney 1990, 32–33) and with that of an *attractor basin*. Normally, in a limit cycle, the expectation is that sequential movements will be around the edge, with a hollow interior. In the case of an attractor basin, the interior of the ellipse is noisy and there is skateboard movement across the short axis that gradually climbs the long axis (the principal attractor) before descending rapidly from inflationary peak to deflationary depression.

The long wave is better defined in the period 1845–95, with a very sharp inflationary surge that peaked in 1865 (top left-hand graph in fig. 10.5). In the $\dot{P}/P$ space (top right-hand graph), upwave/downwave levels are discernible, but they are not as sharply differentiated as in the prior long wave. Likewise, while there is a set of limits in the Poincaré first-return maps, they too are less clearly defined, although the oscillations do occur within the same limits as in figure 10.4, once the 1865 boom and bust are accounted for. Certainly, the

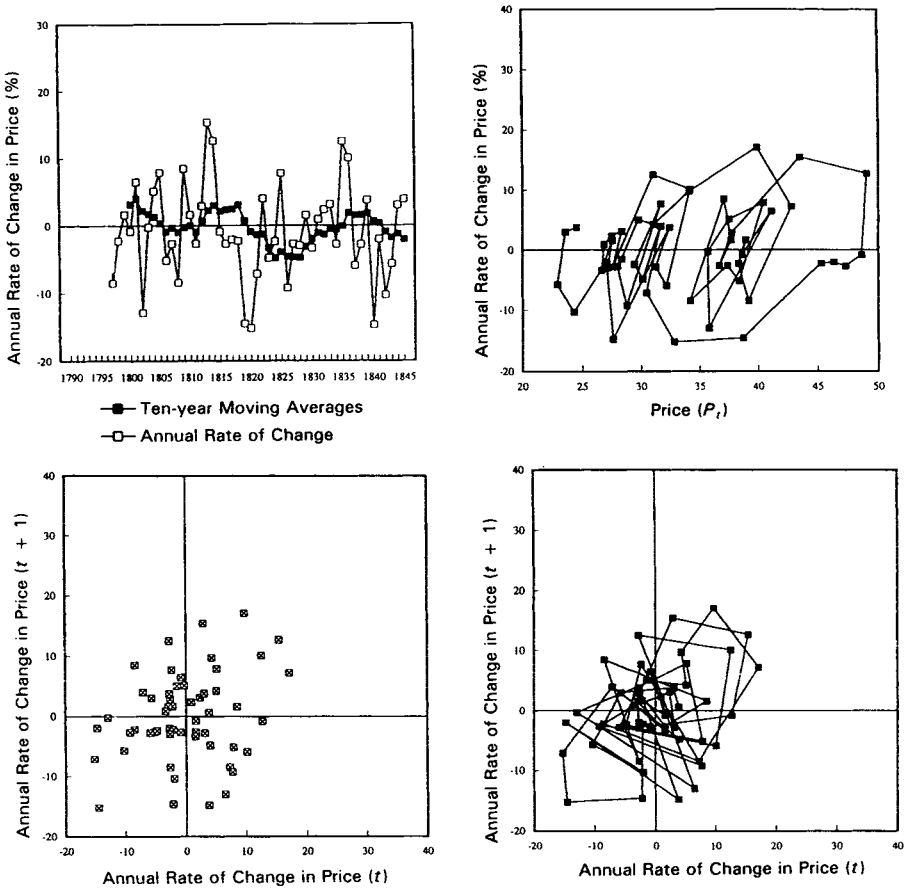

Fig. 10.4. Portraits of price movements 1790–1845. The top left-hand graph is the conventional time-series plot and shows both annual rates of change and the ten-year moving averages. The top right-hand graph plots annual changes against price levels. The two bottom phase portraits plot the annual price changes, $\dot{P}_{t+1}$, against their previous year value, $\dot{P}_t$. The left-hand graph simply shows the distribution of points, but the right-hand graph links successive points in time to reveal the year-to-year oscillations.

sharpness of the 1865 peak emphasizes the magnitude of the boom and bust, whereas the first-return maps point to endogenous chaos.

The 1867–96 downwave phase of this long wave is characterized thusly in Friedman and Schwartz's *Monetary History of the United States, 1867–1960* (1963a):

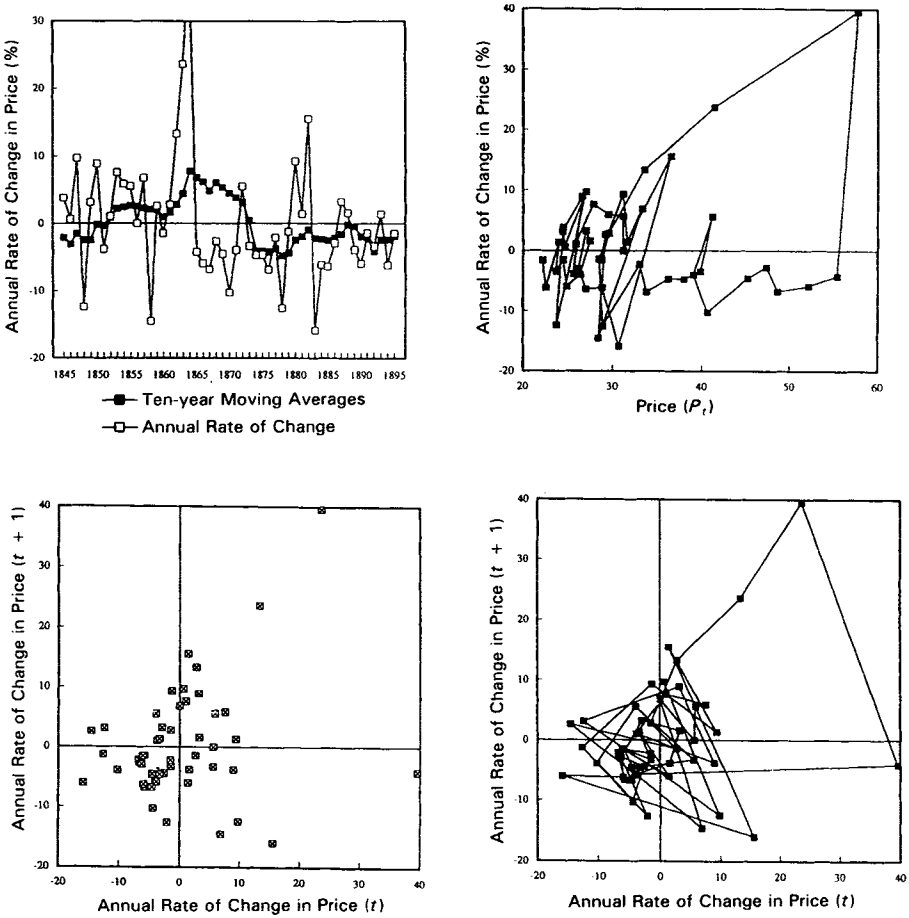

Fig. 10.5. Portraits of price movements, 1845–95. The graphs appear in the same order as in figure 10.4.

The years from 1867 to 1879 were dominated by the financial aftermath of the Civil War. In 1862, convertibility of Union currency into specie was suspended as a result of money creation in the North to help finance the Civil War. From then until the resumption of specie payments in 1879, the U.S. was on a fiduciary (the "greenback") standard, and the dollar was linked to other currencies via exchange rates that fluctuated freely. Throughout this period, Great Britain maintained a gold standard.

> In 1879 specie payments were resumed at prewar parity, preceded by a radical decline in the stock of money 1875–78. After 1879, widespread adoption of a gold standard, despite new discoveries of gold and new financial techniques for building a superstructure of money on it, contributed to a steady downward trend in product prices and mounting political discontent, expressed as "Greenbackism" and "free silver," sharpened by recurrent banking crises (1873, 1884, 1890, 1893). The period ended with the defeat of William Jennings Bryan in 1896.

The resumption of specie payments in 1879, plus the banking crises of 1873, 1884, 1890, and 1893 are readily discernible in the greater and lesser inflation spikes in figure 10.5. Yet equally apparent is that each of these politically significant events falls within the limits of the chaotic regime. No clear difference is discernible between price behavior in the greenback and gold standard periods, or on the two sides of the 1865 spiral.

Between 1895 and 1930, there is, in contrast, an exceedingly well defined two-phase relationship between price movements and levels, as behavioral switching occurs after the 1920 spiral (fig. 10.6, top right-hand diagram). Preceding the surge to the 1920 peak there is a progressive upwave acceleration of the rate of price increase within a narrowly oscillating range, a classic example of intermittency in action (Bergé, Pomeau, and Vidal, 1984, 245). After the Kondratiev peak there is retreat to oscillation around a stable attractor. Yet these are two states of the same narrowed set of chaotic limits. As is seen in the $\dot{P}_{t+1}/\dot{P}_t$ space, both prior to and after the peak, the oscillations occur within the same restricted range.

What could have caused these switches? The Friedman-Schwartz (1963a) characterization of this period is that

> 1897 to 1914 combined a long peacetime rise in prices with a relatively high degree of economic stability.
>
> But discontent with the banking structure came to a head in 1907, followed by the temporary Aldrich-Vreeland Act of 1908 and the permanent step of the Federal Reserve Act of 1913. During and after World War I, weakening of the international gold standard gave the Federal Reserve System greater freedom of action than might otherwise have occurred. During WWI, the system served as the engine for inflationary financing of government expenditures, which continued for eighteen months after the war and then was reversed by abrupt Federal Reserve action. After this reversal, the Federal Reserve assumed a strong directive role, expanding the stock of money at a steady rate until the Great Depression hit.

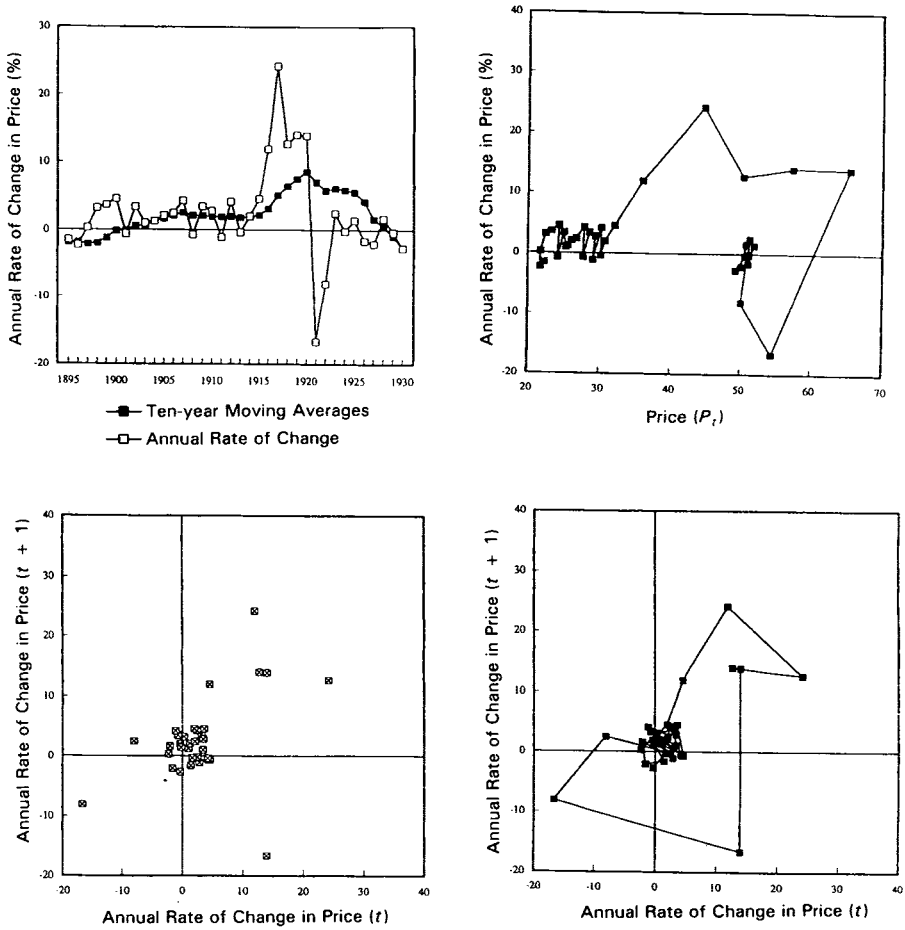

Fig. 10.6. Portraits of price movements, 1895–1930. Note the two-phase structure athwart the 1920 stagflation crisis (top right-hand graph) but the common phase portraits (lower graphs).

What was at work were institutional changes resulting from dissatisfaction with the boom and bustiness of the banking system. The Fed's actions with respect to the stock of money had the effect of changing inflationary creep into a decade of relative price stability (although Weiher (1992) says that this was the inadvertent consequence of policy designed to help Britain return to the gold standard, rather than purposeful countercyclical policy). But Friedman and Schwartz (1963a) continue:

> The downturn of 1929 marked a major transition. There were major bank failures, whose effects were multiplied by tight money policies and by the Fed's reactions to Britain's departure from the gold standard. There began the *Great Contraction*, during which one-third of the nation's banks went out of existence, and there was a catastrophic drop in aggregate demand, a result of the Fed's failure to stop an enormous decline in the money supply.

On the heels of the Great Depression, the relative price stability of 1921–29 vanishes. Rather, in several surges defined by a limit cycle, prices were ratcheted upward (top right-hand graph in fig. 10.7) as the Fed followed a reflation strategy. Note that the Poincaré phase portraits again assume the form of chaotic limit cycles. The first points are in the deflationary lower left quadrant during the depression, but the limit cycling is confined thereafter to the upper right quadrant as a permanently inflationary environment is created (bottom graphs in fig. 10.7).

Friedman and Schwartz (1963a) say that with the coming of the New Deal:

> Like many countries abroad, the United States entered a phase of *cheap money* policy, with a network of controls that only partially and ineffectively combatted inflationary pressures. The proponents of the New Deal were strongly in favor of easy money: "Easy money was the near-uniform prescription. Inflation was the near-uniform result" (Friedman and Schwarz 1963a, 700).
>
> In 1934 came federal deposit insurance as one of the reactions to the contraction, the dollar was devalued, and subsequently the United States departed from gold. Most importantly, faith in the potency of the Federal Reserve System collapsed as the United States adopted a fiduciary standard, and the system assumed a passive and reactive role. Federal Reserve policy was subordinated to Treasury policy during WWII. The stock of money became a function of governmental taxing and spending and rose 2.5 times between 1939 and 1945, and then once again during the Korean conflict.

This inflationary environment, combined with a reactive Federal Reserve, provides the context for the final set of graphs (fig. 10.8). Prices march steadily upward, but annual oscillations are restricted to a limited range along the diagonal in the $\dot{P}_{t+1}/\dot{P}_t$ space. With the compression of the chaotic limit cycle, what is left are the longer-term booms and the busts, displaced upward to prevent deflation. Only a little more than one-half of a long wave is

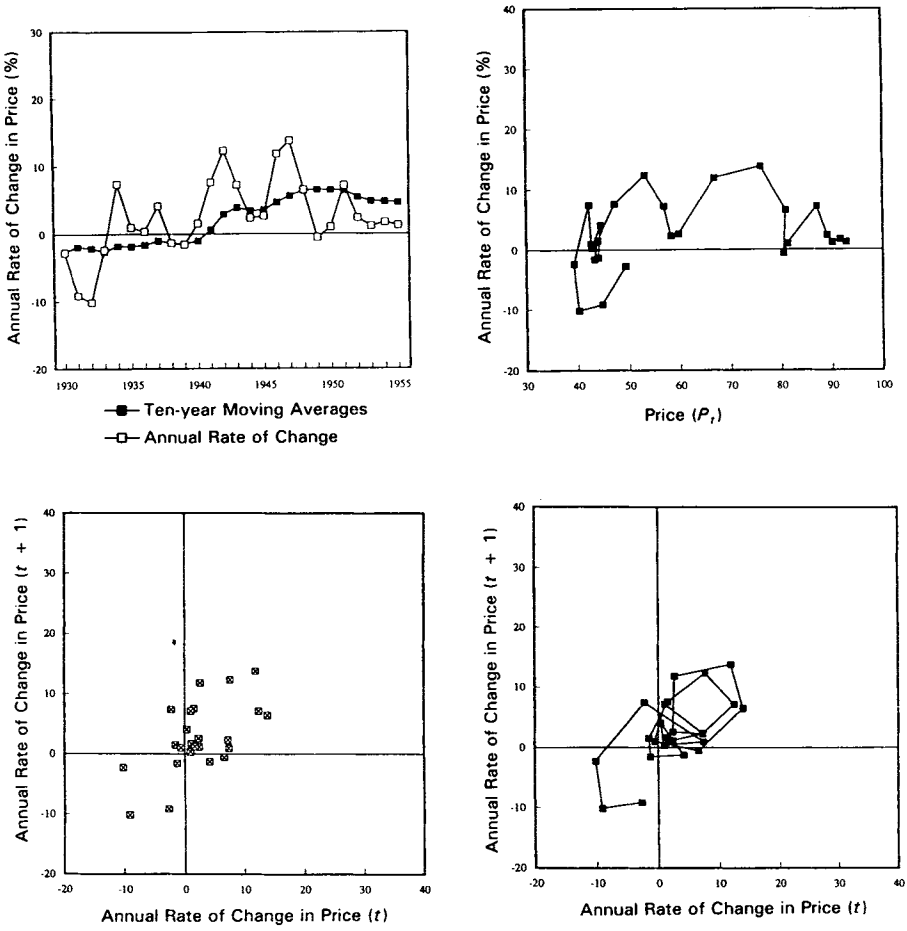

Fig. 10.7. Portraits of price movements, 1930–55

depicted; there is thus no real opportunity to observe whether any upwave/downwave switching has followed the 1980–81 crisis.

There has been much debate on whether fiscal policy has been a potent stabilization tool since the 1950s, given the Fed's inconsistent policies of money supply growth, slow in the 1950s, higher in the 1960s to keep down interest rates and fuel growth, a captive of political forces in the later 1960s and the 1970s (giving rise to runaway inflation), with a sharp reduction in M2 introduced by Paul Volcker that took hold in 1981 (Weiher 1992). If the lower panels of figure 10.8 are compared with the top four graphs in figure 10.9,

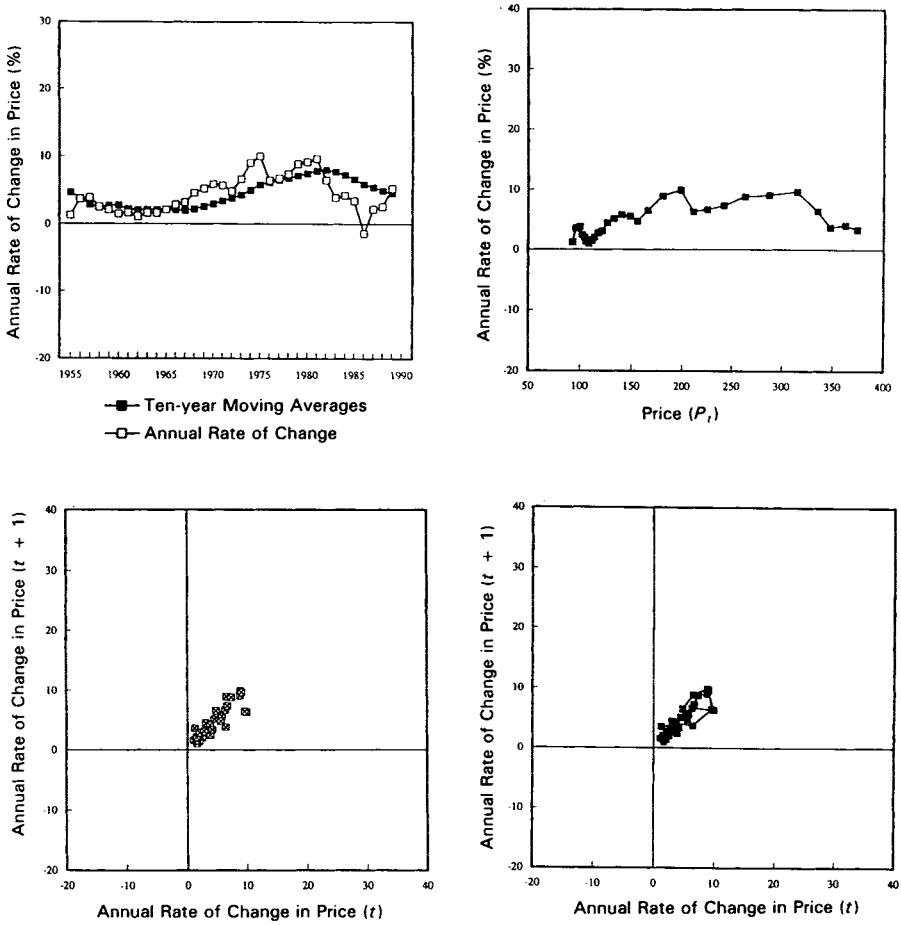

Fig. 10.8. Portraits of price movements, 1955–90

some additional insights into the consequences of stabilization emerge. Figure 10.9 plots the first-return maps for the long-wave movements of prices in each of the five time periods. Each traces out a longer-run boom-bust channel along the 45° principal diagonal of the graphs—a strange attractor that defines the underlying long-wave rhythms. The first-return map in figure 10.8 (bottom right-hand graph) looks very much like the earlier long-wave movements, showing clearly enough that since World War II, it is the annual oscillations of prices that have been suppressed: since 1955 price movements have been constrained to move along the long-run attractor. Thus, whereas short-run

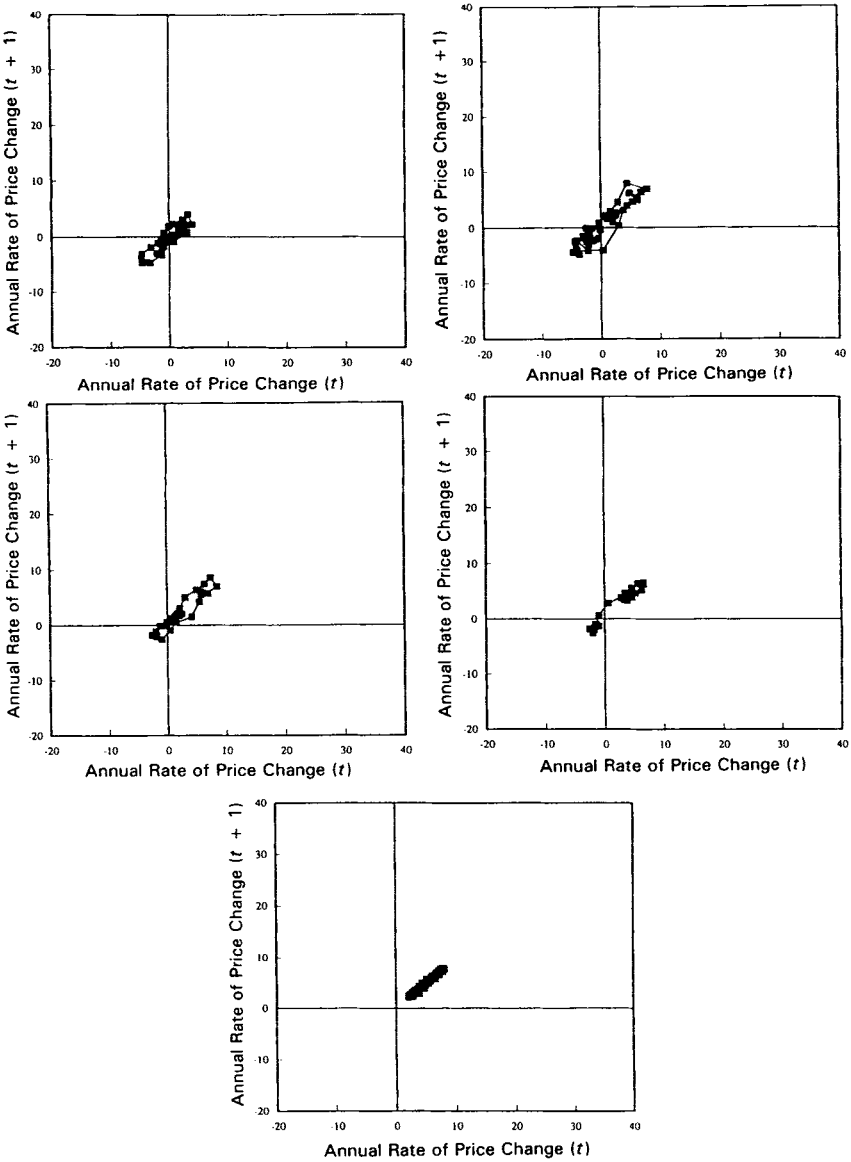

Fig. 10.9. First-return maps of prices ($\dot{P}_{t+1}/\dot{P}_t$) plotted for the ten-year moving averages, 1790–1845 (top left), 1845–95 (top right), 1895–1930 (middle left), 1930–55 (middle right), and 1955–90 (bottom).

stabilization has occurred, the long-run boom-bust pattern of the long wave remains.

Long Cycles of Economic Growth

We now repeat the foregoing for variations in growth rates of real per capita GNP for the same time periods. Note (fig. 10.10) that the long swings of growth appear to diminish after 1950, and that the short-run oscillations also are dampened between 1950 and 1990.

Growth behavior from 1790–1845 and 1845–95 is essentially similar (figs. 10.11 and 10.12). Two long cycles of growth are arrayed on either side of the 1815 and 1865 inflation peaks/stagflation crises (Berry 1991). These quarter-century-long cycles are named for Simon Kuznets, who first identified them. In both $\dot{P}/P$ spaces the first Kuznets cycle involves a surge of real growth and a cyclical drawback in the stagflation crisis. Likewise, the second Kuznets cycle also reveals growth surges terminated by drawbacks in the deflationary depressions that mark the Kondratiev troughs. The $\dot{P}_{t+1}/\dot{P}_t$ Poincaré first-return maps display chaotic limit cycles encircling attractor basins.

From 1895 to 1930 the two-cycle Kuznets pattern is not as sharply

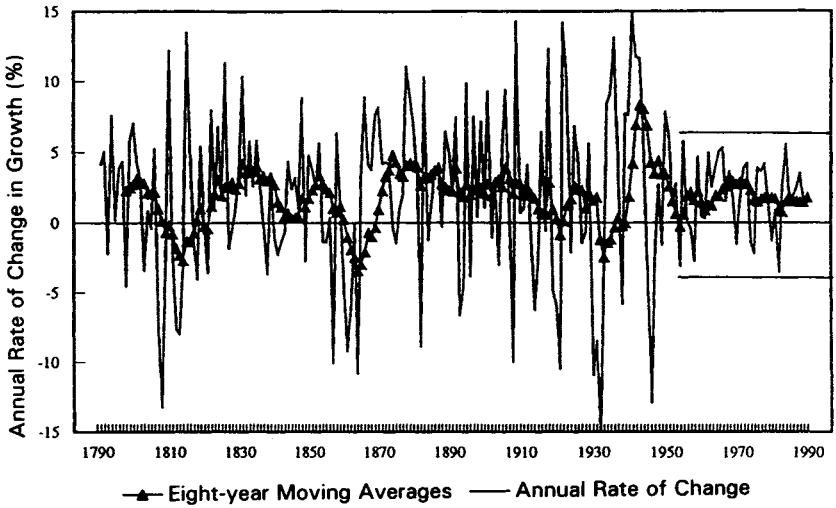

Fig. 10.10. Annual and eight-year moving averages of the growth rates of real and per capita GNP in the United States, 1790–1990. Note the compression of the annual fluctuations after World War II.

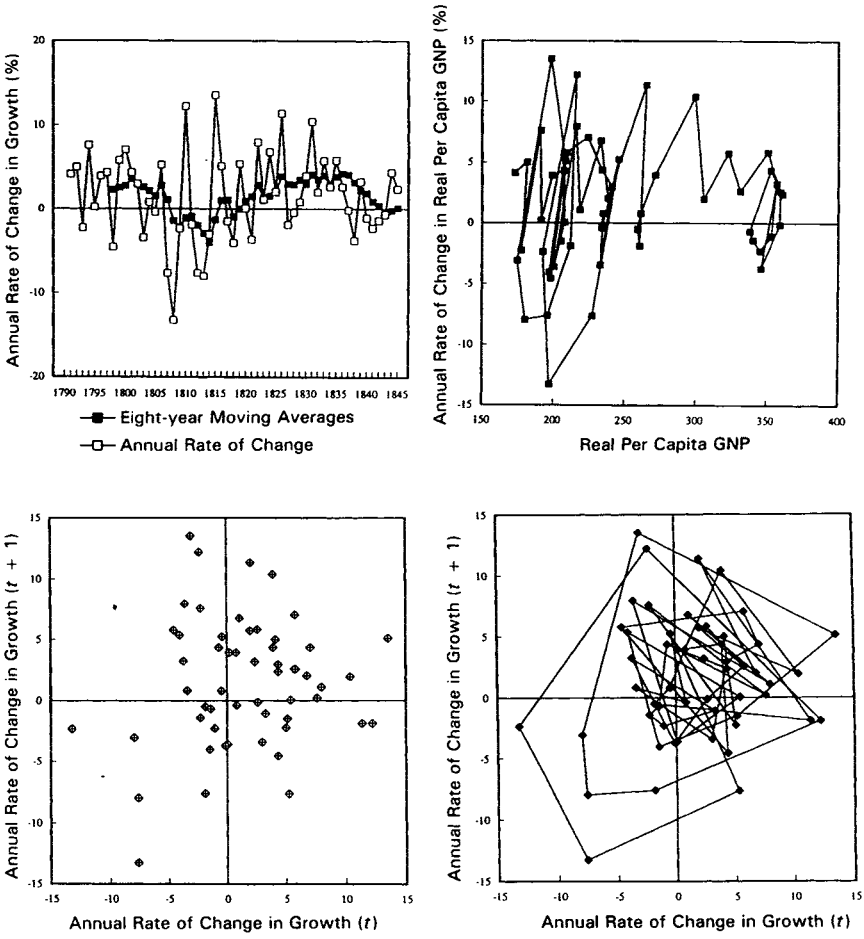

Fig. 10.11. Phase portraits of growth, 1790–1845. Diagrams organized in same manner as figs. 10.4–10.8.

defined (fig. 10.13), but nonetheless the $\dot{P}/P$ space reveals that growth proceeds until the cyclical setback in WWI and resumes again until the pullback in 1929–30. Again, the $\dot{P}_{t+1}/\dot{P}_t$ maps show a chaotic limit cycle.

In contrast, the 1930–55 transition involves strongly cyclical behavior (fig. 10.14), but from 1955–90 what is most apparent is the steadiness of the growth path, marred by occasional business cycle downturns and by the 1980–81 stagflation setback (fig. 10.15). What emerges is an increasingly well defined limit cycle (Bergé, Pomeau, and Vidal 1984, 27, 67, 178, 181),

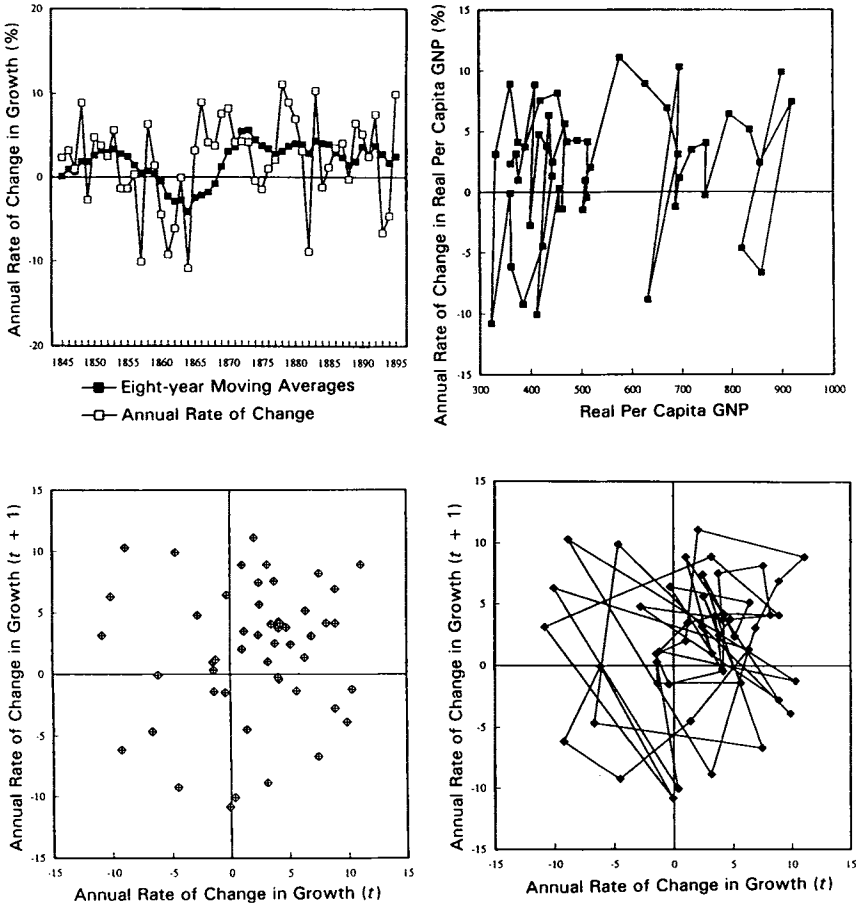

Fig. 10.12. Phase portraits of growth, 1845–95

an absence of attractor basin skateboarding, and only limited boom and bustiness, surely another outcome of the reactive federal stabilization policy that has served to suppress sharper swings. Each of the circuits around the limit cycle is one business cycle in length.

If the lower panels of figure 10.15 are compared with those of figure 10.16, the important contrast that has resulted between the stabilization of growth and prices is brought into focus. Unlike the restriction of the annual oscillations of prices after 1950 (producing an annual first-return map for 1950–90 that looks like the long-term first-return pattern before World War

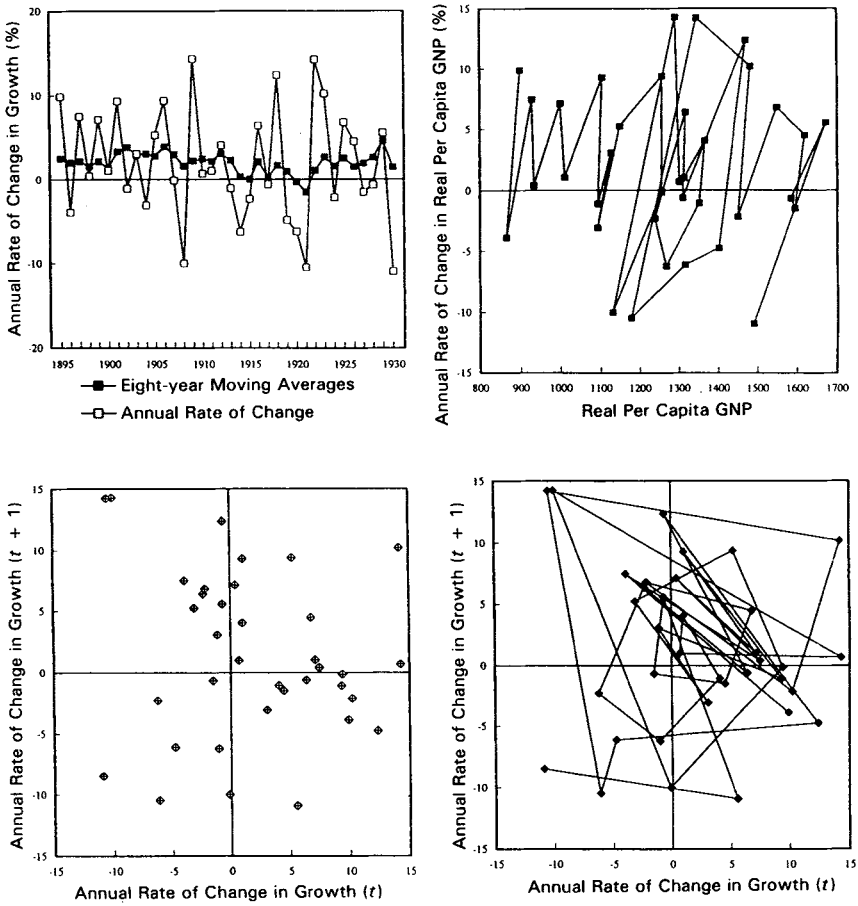

Fig. 10.13. Phase portraits of growth, 1895–1930

II), the long-term first-return maps of growth (fig. 10.16, top panels) are quite unlike the annual first-return maps after 1950 (bottom panels of fig. 10.15). The latter display a perfect limit cycle, each 360° circuit of which is a business cycle; the former shows the longer-term boom and bustiness of growth. What thus has been eliminated since 1950 is the longer-term Kuznets cyclicality: the first-return map of the moving average of growth since 1950 appears to be a stable attractor (bottom panel, fig. 10.16). What has been produced is a pattern of business cycles around a steady-state path of economic growth.

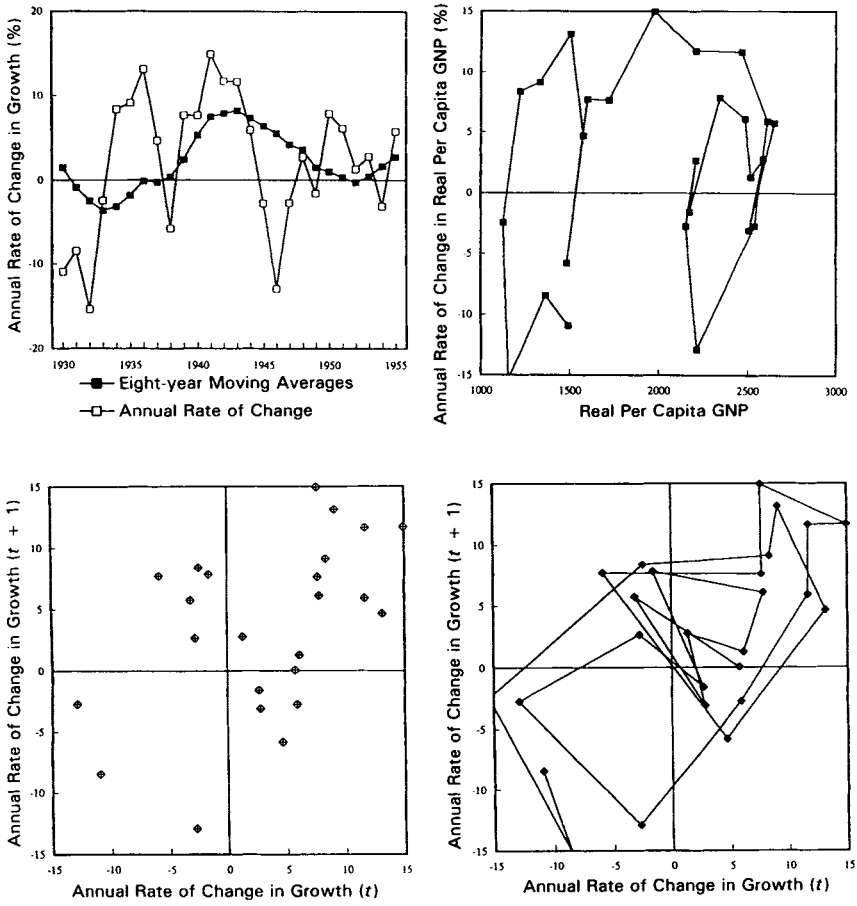

Fig. 10.14. Phase portraits of growth, 1930–55

Discussion

We see in the foregoing the advantages of using multiple phase portraits to analyze dynamic processes. Both prices and growth reveal a tension between longer-run rhythms and short-term variability. The long-run rhythms are unstable near their peaks, leading to intermittent shifts in the locus of shorter-run fluctuations. In the long run the pattern is one of Kondratiev waves of prices and Kuznets cycles of growth, and with these are associated intermittent

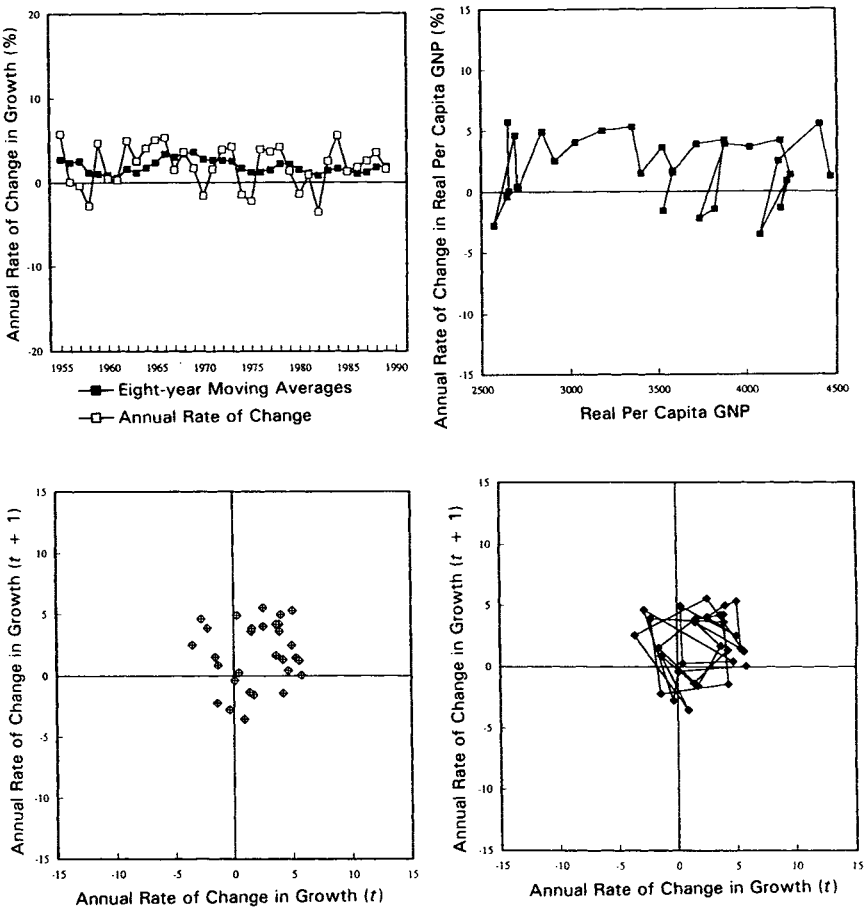

Fig. 10.15. Phase portraits of growth, 1955–90

booms and busts. In the shorter run, fluctuations were chaotic within limits until the Great Depression.

The rhythms have not been immutable, however. Institutional changes and policy interventions since the Great Depression have raised the level around which prices fluctuate by five percentage points and, simultaneously, have suppressed short-term oscillations, leaving behind more gradual upward and sharper downward movements along the long-wave attractor. But simultaneously, economic growth has been constrained to fluctuate around a long-term steady state of roughly 2 percent per annum while preserving the shorter-term rhythms of the seven- to eleven-year business cycle. Thus, since the

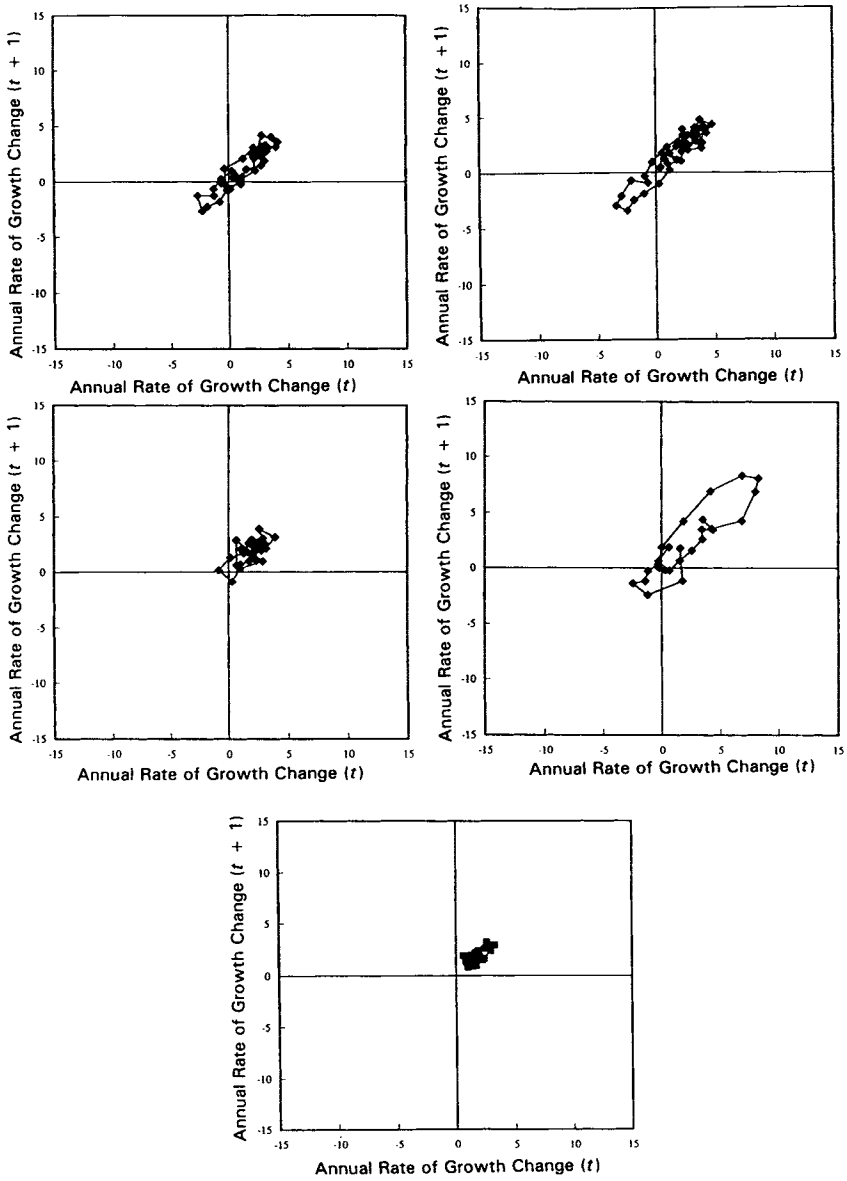

Fig. 10.16. First-return maps of long-term growth, 1790–1845, 1845–90, 1890–1930, 1930–55, and 1955–90

Great Depression, a combination of institutional changes and public policies has resulted in more optimizing (Slutsky-Frisch-Tinbergen) economic growth behavior, but the interventions have had a different consequence for prices, constraining them to move within a narrower (but still boom-and-busty) limit cycle.