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Chapter Author: Hugh Rockoff

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14 Some Evidence on the Real Price of Gold, Its Costs of Production, and Commodity Prices

Hugh Rockoff

Under the classical gold standard the level of prices and economic activity depended to a considerable extent on the supply of new gold. This paper is about the stability and elasticity of that function. Periodically, the supply of gold was disturbed by a wide variety of factors: the discovery and subsequent exhaustion of gold fields, technological change in mining and extraction, government policies toward mining, and wars and revolutions. Below I survey these disturbances and answer some important questions about them. What kind of disturbance was the most important? How significant were the disturbances in terms of their effect on the world's stock of monetary gold? Perhaps of most interest is whether major disturbances were really lagged responses to changes in the real price of gold. In particular, to what extent can the great increase in the supply of gold at the turn of the century be more properly viewed as a movement along a long-run supply curve than as the product of an accidental, if fortunate, series of shifts in the supply curve?

The notion that changes in the real price of gold influenced the subsequent supply of gold, and hence the general level of prices, is hardly new. Many references could be given, including Friedman and Schwartz (1963, p. 188) who noticed the broad trends in the relationship between increases in the real price of gold and increased supplies, Cagan (1965, pp. 60–67) who offered some qualitative evidence on the relationship, and

Hugh Rockoff is professor of economics at Rutgers University, New Brunswick, New Jersey.

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Bordo (1981, p. 10) who showed that deviations from trend in the purchasing power of gold were significantly correlated with later deviations from trend in the world's supply of monetary gold. My intention here is to chart in detail the channels through which increases in the real price of gold influenced the supply. The exercise, I hope, will permit inferences to be made concerning the direction of causation with greater confidence that has hitherto been possible.[1]

The motivation for exploring the supply of gold under the classical standard is clear. The gold standard is a device that depends on a privately produced supply of gold to replace deliberate governmental control of the stock of high-powered money. For the gold standard to provide superior monetary management, the disturbances produced by the factors mentioned above should be small and well timed in the sense that supply-augmenting disturbances should occur when commodity prices are falling or economic activity is at a low ebb. Before considering a return at the present time to the gold standard, we ought to know how significant disturbances were under the classical gold standard and whether conditions have changed in a way that makes such disturbances more or less likely.

The paper is divided into six sections. Section 14.1 discusses the classical cost of production or "metallic" theory of the long-run price level under the gold standard. The section describes how the disturbances mentioned above would influence commodity prices under a gold standard and highlights the distinction between random disturbances and movements along a long-run supply curve. In the last part of the section I describe some ways in which the classical theory might be modified to incorporate the results of recent research on the economics of nonrenewable resources. Section 14.2 discusses actual fluctuations in the supply of gold under the classical gold standard and compares them with fluctuations in U.S. high-powered money in the post–World War II period. The surges in gold production during the middle and toward the end of the nineteenth century receive special attention. The latter surge, in addition, is also considered in detail in subsequent sections. According to section 14.2, it is fair to describe the fluctuations in the supply of gold under the classical standard as small and well timed.

Section 14.3, which is concerned with the role of discoveries of new gold fields, begins the survey of disturbances to the supply of gold. The question explored is whether the great discoveries toward the turn of the century were endogenous, and some evidence is examined that suggests they were. Section 14.4 discusses the influence of technological changes and whether these changes were responses to changes in the real price of gold. The major concern in the section is with the origins and impact of the cyanide process for extracting gold from ore. This process is frequently cited as a disturbance that could have had great impact on commodity prices. This section also deals with annual productivity change in gold production during the classical period to the extent possible, given limited data from which to construct quantitative estimates. Some judgments, however, can be made, and more recent evidence from South Africa is also presented. Section 14.5 then surveys disturbances emanating from governments. Both deliberate and inadvertent disturbances—the latter, by-products of wars and revolutions—are considered. It turns out that both types of disturbances were more important than has heretofore been recognized and that at least the deliberate policies, and possibly some of the seemingly inadvertent ones, were influenced by prevailing economic conditions. Section 14.6 summarizes the main conclusions.

14.1 The Cost of Production Theory of the Value of Money

The relationship between the cost of producing gold and the equilibrium price level under a gold standard was well understood by earlier generations of economists including Ricardo (1821, pp. 238–39), Mill (1871, pp. 499–506), Wicksell (1906, 2: pp. 146–53), Fisher (1922, pp. 99–104), and Marshall (1929, pp. 38–53, 282–84). The gold standard literature also contains rigorous modern treatments by Friedman (1953) and Barro (1979). What follows is a brief synthesis of this literature that highlights the significance of the issues discussed in this paper.

Figure 14.1 displays the basic relationships. The vertical axis shows the real price of gold. This is the ratio of the nominal price of gold (P_g) set by the government (the mint price) to the commodity price level (P). The horizontal axis shows the stock of monetary gold measured in physical units. At time 1 the real price of gold is determined by the intersection of the demand curve D and the short-run supply curve at time 1, $SRS1$. This equilibrium then determines the price level whether measured in ounces of gold (P/P_g) or, given the nominal price of gold, nominal units (P). The long-run supply of gold (LRS), of course, then determines the analogous long-run magnitude.

Before going further, several assumptions implicit in the traditional analysis should be mentioned. The appropriate geographical unit is the set of countries that adheres to the gold standard. The horizontal axis then measures the stock of monetary gold across all those countries, and the vertical axis measures the average real price of gold, conversions from different monetary units being made at the exchange rates fixed by convertibility into gold. To explain the movement of gold among regions of one country on the gold standard, or the movement of gold between different countries on the standard, or changes in relative prices among different countries induced by monetary flows, the classical economists had recourse to some variant of Hume's price-specie-flow mechanism.

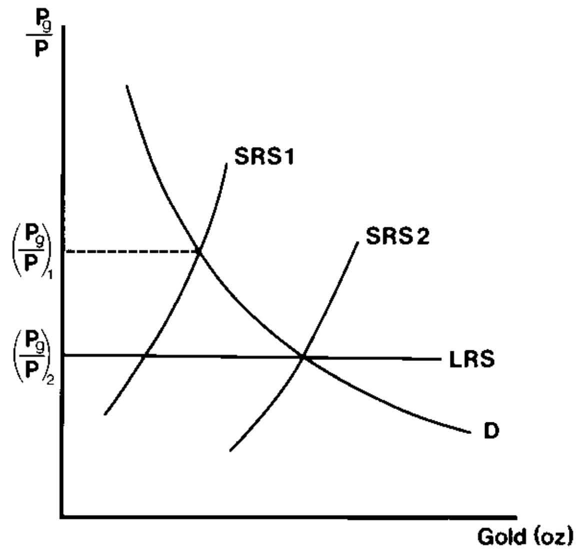

Fig. 14.1 Supply of and demand for monetary gold.

That need not concern us here. It should also be noted that the figure depicts stock equilibria. The impact of the flow equilibria is crucial, but it is not depicted explicitly. Finally, the figure is drawn to focus attention on the determinants of the price level, pushing into the background concerns about the short-run relationship between prices and real output.

The demand curve (D) in figure 14.1 is determined by three factors: the demand for money measured in nominal units, the ratio of the stock of gold measured in nominal units to the stock of money measured in nominal units, and the nominal price of gold. The demand for money in the classical theory was explained by the quantity theory of money. Thus, the D curve would shift to the right with increases in real income and to the left with increases in velocity. Again, because of the quantity theory, the demand for monetary gold slopes downward because as the price level measured in nominal units rises (and hence as the real value of gold falls given the nominal price of gold), the demand for nominal money balances rises. Given the nominal demand for money, the demand for monetary gold would tend to increase with an increase in the ratio of nominal gold stocks to nominal money stocks. Increases in the demand for monetary gold resulting from increases in the amount of money "backed" by a nominal unit of gold would raise the real value of gold and lower the nominal price level. The ratio of the nominal stock of gold to the nominal money stock was determined in turn by the behavior of the banking system with respect to reserves, the government's regulation of banks, and the public's preferences with respect to monetary assets.

Finally, changes in the nominal price of gold would be associated with inverse effects on the demand for monetary gold and direct effects on the nominal price level. Changes in the nominal price of gold, of course, were a form of monetary policy alien to the spirit of the classical gold standard and were rare during the classical period.

The short-run supply curves of gold slope upward because of the existence of nonmonetary stocks of gold—the gold used for industrial and ornamental purposes. An increase in the real value of gold would discourage the use of gold for other purposes and increase the residual available for monetary purposes. Shifts in the demand for gold for nonmonetary purposes—due to changes in fashion, technological changes in gold-using industries, or changes in government policies—would produce opposite shifts in the short-run supply of monetary gold, with corresponding effects on the nominal price level. But in the absence of such nonmonetary demand shifts, the existence of nonmonetary stocks would cushion the economy against shifts in the demand for monetary gold.

The foregoing analysis governed the attitude of economists toward the relative variability of the supply of and demand for money. Modern economists tend to regard the demand for money as stable and the supply as more variable. But the classical economists, given the tie of money to the stock of gold, given the existence of buffer stocks of nonmonetary gold, and given the adjustment response of the gold-mining industry (to be discussed shortly), tended to regard the supply of money as stable and the demand for money as more variable.

The equilibrium in figure 14.1 determined by the intersection of *SRS*1 and the *D* curve, however, would be temporary because the long-run supply curve of gold, *LRS*, is lower. With a real price of gold of $(P_g/P)_1$, gold mining would be highly profitable. New gold mines would be opened, lower-grade ores would be brought into production, and prospecting would be increased, with a possible outcome of new gold fields; other changes leading to more gold, discussed below, would occur. As a result, the short-run supply would shift to the right. Eventually, the short-run supply would shift as far as *SRS*2 and the long-run equilibrium value of gold and the price level would be reached at $(P_g/P)_2$. The period between the short-run equilibria would be one of commodity-price inflation. The gold-mining industry would perceive it as one of high but falling profits, as costs that were responsive to the general level of prices rose but the price of gold, fixed at P_g, did not. Similarly, a short-run equilibrium in which the real price of gold was below $(P_g/P)_2$ would give way to a period of decreased gold production and falling commodity prices.

The long-run supply curve in figure 14.1 is drawn as perfectly elastic. In this special case the long-run price level is solely a function of the nominal price of gold, set by the government (but not regularly adjusted so long as the government adheres to the spirit of the gold standard), and by the costs of producing gold. Changes in the demand for gold—due to changes in velocity, in real income, or even in the ratio of gold to money produced by the banking system—could not affect the nominal price level in the long run. The determination of the price level in this case appears to be completely divorced from governmental decision-making processes. If there were some slope to the long-run supply curve, perhaps due to the exhaustion of high-grade ores, then variables influencing demand could influence the long-run equilibrium price level. To a considerable extent, however, the determination of the price level would have been taken out of the hands of government.

The long-run classical equilibrium described in figure 14.1 could be disturbed by a variety of factors that are usefully divided into three categories.

1. *Discoveries of new gold supplies.* The discovery of an unusually rich source of ore, for example, might be regarded as a downward shift of the long-run supply curve. But to the extent that new discoveries are regarded as an economic response to a particular value of gold, the discoveries could be treated, alternatively, as movements along a "long-run supply."[2]

2. *Technological progress in the production of gold.* The adoption of a new process, for example, the cyanide process for extracting gold from ore, would lower the long-run supply curve. In a growing economy one would want to look at the rate of technological progress in gold mining relative to the overall rate of technological progress. Again, if technological progress were endogenous, one could regard the resulting output changes as movements along *LRS*.

3. *Governmental policies influencing the supply of gold.* Gold mining, like other industries, may be influenced in a host of ways by governmental policies designed to influence costs and output. Such policies, of course, have monetary consequences. Through this channel governments can reclaim some of the influence over economic activity that the gold standard appears on the surface to deny.

The classical theorists, as suggested by the perfectly elastic *LRS* curve, did not dwell on the fact that gold was a nonrenewable resource. The reason is probably that the nineteenth century, taken as a whole, was one of increasing supplies, with important new finds in many parts of the world. In other words, over that century gold in fact had been a renewable resource. For the twentieth century, however, models that treat gold as a nonrenewable and durable resource may be appropriate. A full exploration of the ways in which such models might be used to refine the classical theory of the long-run price level under a gold standard is beyond the scope of this paper. But a brief look at two of the key propositions from that literature suggests some possible lines of inquiry.

First, Hotelling's rule—that the rent on the unexploited reserves of a nonrenewable resource owned by a competitive industry will rise over time at the real rate of interest—has been shown to apply to a durable resource such as gold as well as resources that are consumed as they are used (Stewart 1980; Levhari and Pindyck 1981). There seems to be no reason why the proposition should not apply to the monetary commodity as well as to durable resources produced for other purposes. The clear implication is that under a gold standard the behavior of the commodity price level will be described by Hotelling's rule.

Hotelling's rule does not mean, however, that the real price of gold will always be rising and that under a gold standard with a fixed nominal price of gold, the nominal price level will always be falling. Decreases in extraction costs at the margin would permit Hotelling's rule to be satisfied even with a falling real price of gold. In fact, as Levhari and Pindyck stressed, the price profiles of many resources seem to have been U shaped, with a period in which the real price fell followed by a period in which it rose. Levhari and Pindyck present an ingenious explanation of a U-shaped profile, one that does not depend on new supplies of low-cost ores. Nevertheless, in the case of gold, it appears that the U-shaped patterns were due to the discovery of fresh supplies.

Consider for example, the broadly U-shaped pattern that prevailed from the 1850s until the late 1890s. During the period following the discoveries in California and Australia, the real price of gold fell as it followed the decline in extraction costs. Later, as the rich alluvial deposits were exhausted and as the ore in the mines exhibited the common tendency of gold ore to decline in quality with depth, marginal extraction costs rose, and with them the real price of gold. The process then began again with the discoveries in South Africa and elsewhere.

A second implication of the renewable-resource approach is that the classical gold standard could have generated an optimum quantity of money. This follows from the demonstration in the literature that if the industry that produces the durable resource is competitive—as gold mining undoubtedly was during the classical period—then the resource will be extracted at the optimal rate in the sense that the discounted sum of producer's and consumer's surplus will be maximized. This procedure would have been second best because a perfectly managed fiat standard could have produced a higher level of welfare in the community. Resources would be saved in the production of money. But the point is that under the gold standard, market forces—one of them being the profit-maximizing behavior of the gold miners—could generate the optimum. Under a fiat standard, as we well know, there are no corresponding assurances that the optimal monetary policy would be followed.

An analogy may be drawn between these propositions concerning the gold standard and Friedman's (1969) discussion of the optimum quantity of money under a fiat standard. Drawing out this analogy will serve to clarify and perhaps reinforce the main points. In that discussion Friedman argued that the optimal monetary policy would reduce the marginal nonpecuniary service flow from money to zero since the marginal social cost of producing fiat money was zero. Since each wealthholder would equate the real return on money (the marginal service flow less the rate of inflation) with the real rate of interest, the optimal policy for a fiat standard implied a price level falling with the real rate of interest. Under a gold standard, by way of contrast, the marginal social cost of producing money would be positive. With constant extraction costs at the optimal intensity of extraction, and neglecting the other costs of production, the marginal social cost would simply be the product of this extraction cost and the rate of interest (to convert to a flow). This social cost in conjunction with the wealthholder's equilibrium implies a nominal price level falling at the real rate of interest weighted by one minus the real cost of extraction.

This result, arrived at by extending Friedman's logic, is precisely what Hotelling's rule tells us will result from market forces if gold is produced competitively. Or to look at the matter slightly differently, we can view Friedman's rule as a special case of the general rule for a metallic standard, the case in which the costs of extracting, refining, and minting the monetary commodity are zero.

These results are merely a part of a full analysis. For example, if marginal extraction costs are not constant, the concept of the social cost of adding to the money stock would have to be modified. A full analysis would also examine the case in which gold was produced by a monopolist. The analogous case in the theory of fiat money in which the government is typically assumed to maximize the discounted revenues from creating money has been explored by Friedman (1971) and Calvo (1978) among others. While the case of a monopolistic producer of gold is not realistic for the nineteenth century, it may be relevant, at least as a polar case, for some future period in which we return to gold. Perhaps the examination of both the competitive and monopolistic cases will lead to a theory of the optimal monetary constitution that examines the costs and benefits of alternative monetary arrangements under alternative assumptions about how those arrangements are managed—a theory that contrasts a revenue-maximizing producer of fiat money, for example, with a gold standard in which gold is produced competitively. These speculations, however, must be left for future research.[3]

14.2 The Growth of the World's Stock of Monetary Gold

Before proceeding to the sources of disturbances to the supply of gold, it is worth examining their cumulative impact. Were the disturbances of such magnitude and timing that the growth of the world's monetary gold stock was slower, more stable, and more elastic in the sense of better calculated to maintain price stability than what has been observed of comparable variables under favorable modern circumstances? Table 14.1 provides a tentative answer. It compares annual rates of growth of the world's monetary gold stock, 1807–1929, with rates of growth of the U.S. monetary base, 1949–79. This is a fair comparison for our purposes. The latter period, although punctuated by two wars, was free from the much greater disturbances produced by the world wars and the Great Depression. The U.S. monetary authorities, moreover, appear to have been as concerned with long-run price stability as managers of a fiat standard are likely to be in modern circumstances.

Before discussing the two periods, however, a word on the sources of the data is in order. The world's stock of monetary gold is from Kitchin (1930). He constructed his estimates by assuming a base stock and then adding to it each year the difference between an estimate of world production and an estimate of the gold used for industrial and certain other nonmonetary purposes. The derivation may have contributed to stability of the final numbers. Kitchin's estimates were criticized by several scholars whose work is summarized by Hardy (1936, pp. 205–7).

Table 14.1 **A Comparison of Changes in the World's Stock of Monetary Gold, 1807–1929, with Changes in the U.S. Monetary Base, 1949–79**

	Average Annual Percentage Rate of Change (1)	Standard Deviation of Annual Percentage Changes (2)	Coefficient of Variation (2) ÷ (1) (3)
World's Stock of Monetary Gold			
1807–1839	0.63	n.a.	n.a.
1839–1849	1.16	1.27	109.48
1849–1859	6.39	1.95	30.52
1859–1869	2.64	0.64	24.24
1869–1879	1.63	0.48	29.45
1879–1889	1.07	0.42	39.25
1889–1899	2.98	0.93	31.21
1899–1909	3.79	0.68	17.94
1909–1919	3.17	1.12	35.33
1919–1929	1.95	0.68	34.87
U.S. Monetary Base			
1949–1959	1.57	2.22	141.40
1959–1969	4.39	1.98	45.10
1969–1979	7.29	1.28	17.56

Sources: World stock of monetary gold from Kitchin 1930, table B, col. 1, pp. 82–84. U.S. monetary base from Tatom 1980, table 3, June dates, p. 23.

The criticisms rely on an alternative method apparently first used by Edie (1929) who constructed estimates of the world's stock of monetary gold for 1912 and 1928 from estimates of monetary holdings of central banks and gold in circulation. Edie's figures differed from Kitchin's, showing that Kitchin had underestimated world gold stocks by about 13 percent in 1913 and had overestimated them by about 3 percent in 1928, a difference that materially affected the growth rate between those years. But, as Kitchin (1931, pp. 69–71) argues, Edie's estimates were not themselves free of the sort of fill-in-the-blanks that make Kitchin's estimates uncertain. In any case, Kitchin's estimates seem to be the best long-run series now available. Clearly, revised figures would be useful.

The U.S. monetary base—the St. Louis Federal Reserve's estimate—takes into account concurrent changes in reserve requirements that offset or reinforce the effects of actual changes in the monetary base on the money supply. Tatom (1980) describes the rationale and procedures for estimating the series. It appears to be the correct measure for comparison, if one has in mind a return to the gold standard in which the monetary base behaves as it did under the classical gold standard, and governments take no actions to alter the ratio of money stock to the monetary base.

On the whole, the growth rate of the world's stock of monetary gold appears to have been slower and more stable in the classical period than in the modern period. The growth rate of the U.S. monetary base during the past decade was more rapid than in any of the decades listed for the gold standard. During the 1960s the growth rate of the monetary base was more rapid than in any decade except the 1850s when the great flows from California and Australia were entering the world economy. The comparison includes, it should be noted, the growth of the world's gold stock in the decade following the turn of the century when the flows of gold from South Africa, Western Australia, and other regions were making themselves felt. The year-to-year standard deviations of growth rates also appear to have been greater in modern times than under the gold standard, again with the exception of the 1850s. If the coefficient of variation is used as a measure of year-to-year stability, the overall comparison also favors the gold standard, although in this case there is an important exception—the 1970s were a period of high but stable growth by this measure.

The growth of the gold stock was also elastic in the sense that low rates of growth were followed by surges that brought the average up to a long-run level consistent with a stable real value of gold. There were two major surges. The world's gold stock grew slowly in the period 1800 to 1850 and the real price of gold (based on U.K. Prices) rose at an annual rate of 1.3 percent per year (Jastram 1977, pp. 34–37). Growth of the gold stock then accelerated in the 1850s and 1860s, producing a fall in the real price of gold at an annual rate of −1.1 percent per year from 1850 to 1870. Growth of the gold stock decelerated in the 1870s and 1880s, producing an increase in the real price of gold at an annual rate of 1.4 percent from 1870 to 1890. The second surge in world gold production followed, bringing with it a fall in the real price of gold at an annual rate of −0.4 percent from 1890 to 1910. Over the long run, from 1800 to 1910, the real price of gold was extraordinarily stable rising at 0.6 percent per year. The question is whether these surges should be regarded as fortunate random events that helped preserve price stability (and possibly the gold standard itself) or as movements along an elastic long-run supply curve.

14.3 Discoveries of New Gold

The proximate causes of the major surges in the supply of gold during the classical period were a small number of great discoveries. These were the discoveries in Siberia (1814, 1829), California (1848), eastern Australia (1851), western Australia (1889), and South Africa (1886). Table 14.2 arranges the production data in a way that illustrates the point. It shows the "concentration ratio," the share of the four top countries, in total output, by decade from 1801–10 to 1921–30. It also shows the share of the four countries containing the new gold fields referred to above. The dominance of these countries once their major fields were opened is clear. The data underlying table 14.2 (Ridgway 1929) appear to be the most comprehensive accounting available, but subject to a wide margin of uncertainty, particularly for the period before 1850 and for less developed countries. Here, too, a good deal of fill-in-the-blanks was required in order to arrive at comprehensive estimates. Ridgway, for example, shows exactly the same output for Africa in the three decades from 1801 to 1830 to six significant figures. The largest source of error, perhaps, was the undercounting of gold that was removed and sold secretly to avoid government taxes or other restrictions (deLaunay 1908, pp. 157–66).

Table 14.2 shows that the long-run supply of gold can be described in terms of three phases. During the first phase, 1801–48, the supply of gold was dominated by South America (not shown) and the Soviet Union. Over the period 1801–40 it averaged about 0.5 million ounces per year. Then, with the discoveries in California and Australia, a shift took place to a new plateau. During the second phase, 1851–90, production averaged about 5.9 million ounces per year. Finally in the 1880s and 1890s, further discoveries, particularly in Australia and South Africa, produced a second shift in the supply of gold. From 1901 to 1930 world production averaged about 19.0 million ounces per year.

Another way of viewing the dominant role of the great discoveries is by

Table 14.2 **Concentration of Gold Production under the Classical Gold Standard**

	Annual World Production (thousands of fine ounces) (1)	Top Four (2)	Percentage of Annual World Production: United States (3)	South Africa[a] (4)	Australia (5)	Soviet Union (6)	(3) + (4) + (5) + (6) (7)
1801–1810	585	74.9	2.3	—	—	0.9	3.2
1811–1820	382	66.0	3.5	—	—	2.7	6.2
1821–1830	469	68.5	3.2	—	—	23.2	26.4
1831–1840	657	73.3	4.8	—	—	34.5	39.3
1841–1850	1,712	83.4	30.2	—	—	42.3	72.5
1851–1860	6,456	93.7	41.3	—	37.9	12.8	92.0
1861–1870	6,110	90.8	37.5	—	30.8	14.2	82.5
1871–1880	5,658	87.6	33.8	0.1	25.8	21.5	81.2
1881–1890	5,239	77.5	30.2	2.2	22.6	20.7	75.7
1891–1900	10,161	76.5	24.5	19.1	21.3	11.6	76.5
1901–1910	18,381	74.0	23.0	26.0	18.2	6.8	74.0
1911–1920	20,639	74.7	19.3	42.2	8.5	4.7	74.7
1921–1930	18,012[b]	75.6	12.8	50.4	3.6	3.5	70.3

Source: Ridgway 1929, table 58, an unnumbered appendix.

[a]Includes British South Africa and the Transvaal before 1901. Includes Bechuanaland and Swaziland after 1901.

[b]Ridgway's data only go through 1927, so his figures for the first seven years were multiplied by 10/7 to make this figure a decadal total comparable to the others.

asking how long a country was able to remain among the top four once it entered the list. Leadership, it turns out, typically was held for a long time. In the early decades of the century, Latin American countries, notably Colombia, Chile, and Brazil, were the leading producers. Colombia led the list in the first and second decades of the nineteenth century and finally dropped from the top four in the 1850s. What is now the Soviet Union led in the 1830s and 1840s and did not drop from the list (temporarily) until the 1920s. The United States entered the list at the top in the 1850s as a result of the discoveries in California. The United States then held first place until overtaken by South Africa in the first decade of the twentieth century.

Table 14.2 also suggests that the supply of gold was potentially vulnerable to political shocks. In every decade the four leading producers mined two-thirds or more of total gold, and in slightly more than half the decades, over three-quarters of total gold. In the period from the California discoveries until the 1890s, the United States typically produced over 30 percent of the world's new gold. Thus, it was possible for policies or struggles for power that influenced supply in one country, to influence the world's supply.

In short, while minor discoveries, changes in costs, and technological advances all impinged on the growth rate of the stock of monetary gold—these influences will be discussed in subsequent sections—the dominant role belongs to the great discoveries.

The question naturally arises whether in the long run discoveries, particularly those that occurred when the real price of gold was high, should be regarded as endogenous. Some evidence is provided by the record of the local circumstances leading up to the discoveries. In one important case, California, the discovery seems to have been the accidental by-product of the expansion of agriculture into the interior of the state. The Spaniards, who had long resided in California, had taken gold from their Latin American possessions and even from California itself, but had not prospected in the interior. Instead, gold seems to have been discovered purely by accident near Sacramento, according to the standard account, in a stream where a dam was being built (Paul 1947, pp. 36–37). Even here, however, the discovery was not without antecedents. Gold had been discovered in the Los Angeles area in 1842 and worked for some years (Morrell 1940, p. 77). Had the real price of gold been lower in the 1840s and this find not worked successfully, the gold consciousness of the men who made the great discovery in 1848 might have been lower. It is also possible that had miners not arrived on the scene who knew how to work alluvial deposits, the initial gold rush would have petered out (Dane 1935, p. xiv). But most accounts suggest that in the absence of these factors, the California discoveries would have been delayed but not foreclosed.

In other cases, prospecting, partly in response to changes in the real value of gold, played an important role in the great discoveries. The California demonstration that unworked rich alluvial deposits could be found in newly settled territories led directly to an increase in exploration and to the quick discovery of gold in Australia and New Zealand. Blainey (1970) showed that later discoveries in Australia, including the rich western fields, were made in response to economic conditions. He emphasizes the level of unemployment rather than the real price of gold; in his view the discoveries were typically made by men who had moved from other employments into prospecting in periods of unemployment. Under a gold standard, of course, the real value of gold tended to rise during depressions when prices were low and unemployment high, so these discoveries could still be an element of the equilibrating mechanism.

The California discoveries also led to prospecting in South Africa where some gold was found in the 1850s, but there were no major discoveries until 1874. That find led to an intense period of exploration culminating in the discovery of the main reef of the Rand in 1886 (Gray 1937, p. 30). Increased production in South Africa contributed about 35.3 percent of the increase in world production between 1890 and 1905. It may be conjectured that if the real value of gold had been declining during the long period of exploration, prospecting would have been curtailed, and the main reefs might have been missed, at least for some years.

The U.S. finds that contributed about 21 percent of the increase in world gold production between 1890 and 1905 were the outcome of intense prospecting. About 39 percent of that contribution was due to increased production in Colorado, much of it from the great Cripple Creek lode. The lode, found by a persistent prospector in a region that had been actively worked for thirty years, had an ore deposit that was somewhat different from what miners were familiar with and, possibly for this reason, had been overlooked (Morrell 1940, pp. 164–65). To be sure, silver prices were low, and that gave special urgency to the search for gold in Colorado, but the search might have concentrated on other minerals had the real price of gold been lower. The second largest contribution to increased U.S. output during this period—26 percent—came from Alaska. Here, also, the discovery at Cape Nome, which led to the last of the great gold rushes, was made by a group of prospectors exploring that remote region (Morrell 1940, p. 402). Again, it may be conjectured that without the incentive provided by a high real price of gold, these major discoveries might have been missed.

These cases appear to be typical. Crane (1908) examined the origins of a large number of American gold and silver mines, distinguishing between those that were found by prospecting and those found accidentally.

Inclusion on his prospecting list depended on whether the mining journals reported the relevant information; that list appears to contain virtually every important field. Table 14.3 is constructed from Crane's data. Several conclusions emerge. First, the vast majority of finds were located by prospecting. Second, while the level of finds did not fluctuate synchronously with the real price of gold, there is a distinct fillip in the 1890s when the real price of gold was high.

The evidence is not conclusive, but it suggests that many discoveries, particularly those that influenced world gold production between 1890 and 1905, should be regarded as movements along a long-run supply curve rather than as shifts in the curve. The suggestion, however, raises an important question. Were conditions in the nineteenth century unique so that a flow of new finds was possible, or are similar results to be anticipated in any period in which gold is the monetary standard? In some ways the nineteenth century appears to have been unique. European exploitation of natural resources was expanding into regions in which individual prospectors were encouraged to search for rich alluvial supplies. In Siberia as well as in the United States, Australia, and South Africa a core of dedicated prospectors made most of the finds. The conditions that produced that core of prospectors and the virgin territories in which they worked cannot be recreated. Some set of institutional arrangements would need to be substituted for the possibility of rich, easily worked, alluvial deposits.

14.4 Technological Change in Gold Mining

Various technological innovations affecting industry generally during the classical period were quickly adapted to gold mining, at least in the United States. Several large California mines are said to have been the

Table 14.3 Gold Mines in the United States by Mode of Discovery, 1821–1905

	Accidental	Prospecting	Total
1821–1830	1	3	4
1831–1840	1	6	7
1841–1850	2	13	15
1851–1860	2	19	21
1861–1870	0	20	20
1871–1880	1	21	22
1881–1890	0	4	4
1891–1900	0	15	15
1901–1905	0	4	4
Total	7	105	112

Source: Crane 1908, appendix table 1, pp. 652–59.

first to install a long-distance telephone line (Kelley 1959, p. 50). Shortly after its invention, dynamite was first used on California's Mother Lode in 1868; electric power was first used there in 1896 (Logan 1934, p. 10). These adaptations did not disturb the commodity-price equilibrium under a gold standard; they served to maintain a rate of productivity growth in gold mining comparable to productivity growth in the economy as a whole.

Some innovations were specific to gold mining, including hydraulic mining, dredging, and the chlorination and cyanide processes for extracting gold from ore. The first two appear to have evolved gradually from known technologies in response to the exhaustion of rich alluvial deposits. Large-scale hydraulic mining began in California in the early 1850s. Once the richest deposits were exhausted, miners sought methods to permit them to wash a much larger volume of gravel per hour. It was soon discovered that by directing a flow of water against a bank containing gold-bearing material and then draining the runoff through long sluices charged with mercury, relatively low-grade ores could be worked profitably. The scale of the largest operations increased steadily. By the late 1870s, the North Bloomfield mine, one of the largest, had over a hundred miles of ditches and flumes to carry its water supply and six tunnels totaling four miles in length to drain the runoff. Streams of water hundreds of feet long fired from cannons called "little giants" were used to tear away the mountains, and sluices thousands of feet long were used to collect the gold (Kelley 1959, pp. 47–53). Despite the scale of the hydraulic mines, however, no new principle seems to have been involved. The use of mercury to form an amalgam with gold had been known since ancient times, and the process of washing the gravel from the hydraulic mines was an adaptation of the principle the forty-niners used when they panned for gold. Indeed, a similar evolution from panning to hydraulic mining occurred in Brazil during the eighteenth century, although not pursued to the same extent as was later achieved. The main effect of the development of hydraulic mining was a partial offset to the exhaustion of the richest placer deposits. A similar account applies to gold dredging, but in this case the adaptation of technologies from other industries may have been important as well (Weatherbe 1907).

The one innovation that appears to have been sudden and dramatic in character, and was therefore a potentially serious macroeconomic disturbance, was the cyanide process for extracting gold from ore. The process, sometimes known as the MacArthur-Forrest process after the leading innovators, was perfected in the late 1880s, with the initial breakthrough coming in 1886. The essence of the process was the use of dilute solutions of potassium cyanide to dissolve gold mixed with certain impurities and the use of fine zinc shavings to precipitate the gold. The process was first used commercially in New Zealand in 1889 and in South

Africa in 1890. The cyanide process revolutionized the metallurgy of gold. World consumption of cyanide was probably less than 50-tons per year in 1889 and rose to 10,000-tons per year by 1905, with about one-third of the latter total consumed by South Africa (Clennel 1910, p. 31).

The part to be assigned the introduction of this process in explaining the concurrent rise in world gold production from 5.8 million ounces in 1890 to 18.5 million ounces in 1905 is not clear. Kitchin (1931, pp. 57–58), perhaps the leading authority of his time, attributed tremendous importance to cyanide, claiming that it had increased yield per ton of existing producers by 50 percent and had permitted the treatment of much ore that would not otherwise have been profitable to mine. His view, however, may give too much weight to the early experience in South Africa where cyanide was crucial. Gold in the Rand is found in a finely divided state throughout the ore, so the ore was especially well suited to cyaniding. MacArthur's (1905, p. 314) memory of his first visit to Rand is probably accurate. A boom there had petered out as the ores that could be worked profitably with existing techniques were exhausted. One authority on South African gold (Letcher 1974, book 1, p. 99) refers to the role of the innovation as "salvation by cyanide."

In other regions, however, cyanide appears to have contributed much less to the second surge in gold production. Increased production in the United States was second to the rise of the Rand in explaining the increased production at the turn of the century. California, long the major source of gold in the United States, increased production about 43 percent between 1890 and 1905, acounting for about 12 percent of the increase in U.S. output and about 2.5 percent of the increase in world output. But cyanide does not appear to have been a significant factor in California. About one-half of the increase in California's output was due to the expansion of dredging. The ores of the Mother Lode, moreover, were not well suited to cyaniding (Logan 1934, p. 10). Colorado, the largest contributor to the increase in the U.S. gold production, contributed about 8.6 percent of the world increase between 1890 and 1905. Much of the gold came as noted above from the rich Cripple Creek lode where chlorination, the older process, and cyaniding were highly competitive (Crane 1908, pp. 491–92).[4] Colorado attained peak output in 1900. In certain other areas of the world that had long been producers, notably Europe and South America, there were no increases in production during the period in which cyanide was introduced.

Further research may show that some of the other new fields that contributed to the increase in world gold production between 1890 and 1905 were made profitable by cyanide—fields in Australia, which contributed 18.9 percent of the increase; Mexico, which contributed 5.9 percent; and Canada, which contributed 4.9 percent. These three fields were next in importance to the South African and U.S. fields. Tentatively, however, it seems that the cyanide process must be rated an innovation that had a major impact on world stocks of monetary gold primarily because of the joint discovery of the main reefs of the Rand.

Strong circumstantial evidence indicates that the discovery of the cyanide process, like the discovery of some of the major gold fields discussed above, was the product of the high real price of gold prevailing in the mid-1880s. In other words, the increases in production attributable to cyanide must also be deemed movements along a long-run supply curve.

Consider first that MacArthur and the Forrests, the innovators, were engaged in a commercial venture with the object of finding cheaper means of extracting gold from ore. According to MacArthur's own account (1905, p. 312), their syndicate was originally formed with the intention of perfecting the chlorination process. They simultaneously carried out research on a list of other solvents, one of which was potassium cyanide. Their research was clearly profit oriented; their discovery was not the accidental by-product of other research, for example, basic research on the characteristics of cyanide. Basic research did account for the presence of cyanide on their research agenda and influenced their experiments, but the basic research had been done much earlier.

Consider next that a number of other metallurgists were simultaneously studying potassium cyanide as a gold solvent with an eye to improving the extraction process. The degree of originality claimed for the MacArthur-Forrest process was challenged in the courts by metallurgists asserting their own claims; the process thus gave rise to considerable litigation. One writer summed up the litigation this way: "An examination of the patents granted for the cyanide processes and improvements shows that it is an easy matter to obtain a patent, but a difficult matter to retain it if someone else wants to make use of anything claimed in the patent" (Wilson 1902, p. 15). The most negative assessment of the originality of MacArthur and the Forrests that I have found is by Gaze (1898, p. 5), who maintains that several metallurgists were close to perfecting the process (himself included) and that the process was well known in the jewelry trade. But even Clennell (1910, p. 23), who believes that MacArthur and the Forrests were well in front of the competition, acknowledges that there was one patent, issued to the American Jerome Simpson in 1865, for a process that might have been modified into a commercial success had it been tried. Evidently, the extensive experimentation with cyanide in the late 1880s would sooner or later have yielded a commercially feasible process. It is hard to escape the conclusion that this activity was the product of a high real price of gold.

A similar conclusion applies to the chlorination process that was used in many regions before cyanide. Chlorination was discovered independently by metallurgists in the United Kingdom in 1848 and Germany in 1849 (Rose 1915, pp. 300–301) when the price of gold was nearing its midcentury peak. The German discoverer had in mind the commercial exploitation of certain gold-containing residues from the production of arsenic. Thus, the chlorination innovation appears to have been motivated by the high real price of gold.

To go beyond qualitative evidence on particular aspects of the production of gold to year-by-year measures of total-factor productivity would require data directly measuring stocks of capital and labor or indirectly measuring costs. Unfortunately, the data for most areas, for the United States in particular, do not appear to be adequate. It is possible, to be sure, to collect observations on what the industry referred to as working costs. Janin (1912, 1915), for example, reports data on mining costs, usually expressed as dollars per ton of ore mined. But these figures generally omit capital and exploration costs and sometimes other overhead costs as well. They also show enormous variation from place to place, as is to be expected. High-grade ores are worth exploiting even if mining costs per ton are high. The variance and the absence of continuous observations on a particular site make it impossible, in most cases, to construct a usable time series. For an amusing view of the difficulties involved in measuring mining costs, it is instructive to peruse the replies to a U.S. Senate Committee which asked various experts to give their opinions on the cost of mining silver in the early 1890s. The data offered were sparse, and opinions ran the gamut from the vew that silver mining was highly profitable to the view that, if exploration costs were included, silver was mined at a loss (U.S. Congress, Senate, Committee on Mines and Mining 1892).

For South Africa, however, there may be sufficient data on resources employed or costs to compute annual measures of productivity change. Some crude measures, tons of ore milled per worker and tons of ore hoisted per worker in large mines, are shown in table 14.4. The measures suffer the problem common to all measures of labor productivity; they confound changes in the ratio of capital to labor with technological change and do not deal with the additional problem of aggregating white and nonwhite labor. The first and third columns in table 14.4 aggregate white and nonwhite labor on a one-for-one basis; the second and fourth columns weight white labor by the prevailing ratio of white to nonwhite wages. The latter procedure undoubtedly overstates productivity differences between the two classes of labor because the racial situation distorts the wage data. Thus the two estimates probably bound the true measure. Despite the weaknesses in the approach, the data suggest some plausible conclusions.

The shorter-run movements shown in the upper part of the table appear to be influenced a good deal by discoveries, particularly the

Table 14.4 Productivity Change in South Africa's Gold Mines, 1910–60

	Tonnage Milled per Worker	Tonnage Milled per Equivalent Nonwhite Worker at Prevailing Wages	Tons Hoisted in Large Mines per Worker	Tons Hoisted in Large Mines per Equivalent Nonwhite Worker at Prevailing Wages
	(annual percentage rates of change)			
	(1)	(2)	(3)	(4)
1910–20	0.96	−0.73	−0.12	−1.21
1920–30	1.37	3.92	2.17	4.77
1930–40	1.54	0.42	1.42	0.84
1940–50	0.51	−1.16	0.40	−1.39
1950–60	−0.10	−0.74	0.51	−0.05
1910–60	0.86	0.36	0.88	0.59
1910–50	1.10	0.64	0.97	0.75
1920–60	0.83	0.61	1.13	1.04

Source: Katzen 1964: tonnage milled, number of workers, and wages, pp. 18, 19; tons hoisted per workers in large mines, p. 26.

opening of the "New Rand" region which became significant in World War I. Over the long run some growth in labor productivity apparently occurred, although at a slower rate than for economy-wide measures. Kuznets's (1971) survey of growth rates showed output per worker growing at 1.81 percent per year in the United States, 1920–60, which is higher than any of the comparable rates in table 14.4. He also showed that output per capita in a number of industrial countries was growing more rapidly than labor productivity in the gold mines. If one recomputes the first two columns of table 14.4 using gold mined, rather than tons milled, the long-run growth rates are still lower due to the exhaustion of more accessible ores. Similar calculations for the nineteenth century, based on a wide geographic area in which new mines were included, if feasible, would probably show higher rates of productivity change that were closer to economy-wide measures. Such a result would have been conducive to price stability under a gold standard. In effect, the supply of gold was shifting out as rapidly as the demand, abstracting from other influences, thus maintaining commodity-price stability.

14.5 Politics and the Supply of Gold

In this section I examine ways in which governments influenced gold mining, including both deliberate acts of monetary policy and other acts that inadvertently altered the supply of gold. It will become obvious as I proceed that the real price of gold also influenced the supply indirectly through its effects on government policies toward mining. Neither set of influences was a major source of variability in the supply of gold during the classical period, but both are important because they occurred when the role of government in gold standard countries was more limited than it is today. The history of political influences on the supply of gold thus provides an important set of analogies for understanding the significance of a return to the gold standard in modern circumstances.

14.5.1 Deliberate Intervention

In the period prior to the discoveries of gold in California and Australia, production was dominated by supplies from South America and Russia. In both regions heavy taxes were imposed on gold mines, but tax collection varied with the profitability of the mines. Thus in periods of low commodity prices, when gold-mining profits were high and profits in other industries low, the equilibrating mechanism was hampered as governments in those regions attempted to collect shares of the profits of the mines. The regimes there found mercantilist policies congenial, so a gold standard based on supplies from these regions was unattractive.

This state of affairs was well understood by Jevons. Writing in the wake of the discoveries in California and Australia, he foresaw a period in which the supply of gold would be more abundant, more stable, and more responsive to the real value of gold. The abundance and, in part, the stability of supply were to be accounted not only by the richness of the finds, but also by the location of the finds in regions subject to the rule of laissez-faire. Accordingly, in the future the supply of gold would be more responsive to changes in its real value. To quote Jevons (1884, p. 74):

> Before the recent discoveries, no gold mines of value have been in possession of any Anglo-Saxon nation. They have been chiefly in the hold of the Spanish and Russian Governments, subject to arbitrary restrictions and taxes. In English or American hands the production of gold becomes a matter of free industry and skill. It must follow that the produce will conform more closely to commercial principles; a rise or fall in the value of gold will be followed more exactly by an extension or cessation of the production. At the same time, the greater area of production, offering scope for more various competition and equalization of local fluctuations, and the greater and more various modes of consumption, will all tend to render the demand and supply of gold more equable and its value more constant.

While Jevons was right about the direction of the change in the role of politics, the U.S. and Australian experience were not free of interactions between politics and gold mining. Perhaps the most interesting U.S. example was the restriction of hydraulic mining in California and its subsequent removal. In section 14.4, I mentioned the large-scale operation of hydraulic mines in California during the 1870s. Privately some of these mines were highly profitable, but they created a significant externality. The debris they produced moved downstream, ruining farmland and clogging navigable rivers. The protracted legal and legislative battle between the farmers and the miners was documented by Kelley (1959). The farmers prevailed. In a series of injunctions issued between 1882 and 1884 the courts closed the major hydraulic mines. The battle went on for several more years, with some operations continuing on a clandestine basis and others openly in regions where the damage to farmland was less severe.

The effect on the output of gold from California was pronounced, although an exact estimate cannot be made. One problem is that the best source of data (Hill 1929, pp. 20, 21) on the output of the California mines splices two series in 1883 in the midst of the hydraulic-mining controversy. Nevertheless, a plausible estimate of the effect of the closing of the hydraulic mines can be made by subtracting average production in 1885–87, the first three years in which the full effect was felt, from the average in 1879–81, the last three years of unrestricted hydraulic mining. The shortfall amounts to 289,000 ounces per year, about 5.7 percent of world production in 1885—a small but not trivial effect. This analysis, incidentally, adds one more irony to the long list of those in monetary history. A small part of the price decline of the 1890s of which farmers complained so bitterly might have been produced by those in California who forced the closing of the hydraulic mines.

To be sure, the closing of the hydraulic mines was not a conscious act of monetary policy. Farmers trying to protect the value of their property were responsible for closing the mines. Monetary considerations played a role, however, in the early 1890s when there was an attempt to revive hydraulic mining; the Carminetti Act, a federal law signed in 1893, established a California Debris Commission to authorize the opening of mines, provided they had made adequate preparations in the form of dams or settling basins to prevent debris from entering the water supply. In part, the act simply aimed to start up a profitable industry in a period of depression, a course that might have been equally appealing with respect to a nonmonetary industry, although the fixed nominal price for gold made hydraulic mining a better candidate for aid. But in part, the support for the bill reflected a desire to expand the money supply (Kelley 1959, pp. 271–72). The act's costly requirements for restraining debris, however, prevented a renewal of hydraulic mining on the scale of the 1870s.

A crude estimate may be calculated of the increased production owing to the Carminetti Act analogous to the estimate of the shortfall computed above. Subtract average output in 1890–93, the three years preceding the act, from average output in 1895–97, the first three years following the effective removal of the restriction. The increase amounts to 172,000 ounces per year, about 1.8 percent of world production in 1895—again, a small but not trivial effect. Thus, this increase in output, and certain increases attributable to dredging where environmental concerns were also important, can be linked to the high real value of gold or at least to the associated economic conditions. The law was amended again in the 1930s to provide for a federal dam to hold back debris and thus permit greater hydraulic mining, a response comparable to that in the 1890s in similar economic conditions.

The hydraulic-mining controversy is the most dramatic U.S. example, but it is not the only example nor probably not the most important one. Meade (1909, pp. 112–13) regarded the extension of the railroad network into gold-mining areas the single most important factor that lowered private-gold-production costs by reducing freight costs and making the introduction of heavy machinery possible. As a result, both the United States and Mexico substantially increased their production at the turn of the century. Given the long history of government involvement with railroads in this country and Mexico, an element of subsidy likely was present and, given the timing of the construction, overall economic conditions likely influenced the decision to expand the supply of gold.

In eastern Australia, the first region opened, production was initially based on placer mining. When production declined, the government imported and worked diamond drills to facilitate finding and working deep lodes (Jevons 1884, pp. 117–18). In western Australia, the government built stamp mills to which small mines brought their ore. It also introduced a water system to facilitate production at the Kalgoorlie mines (Mead 1909, pp. 115–16). In both areas, the government probably responded to output declines resulting from the exhaustion of high-grade ores rather than to larger monetary considerations. In eastern Australia, the actions were destabilizing in the sense that they tended to increase world production in a period of rising prices, although the gentle upward trend in prices might have been desirable.

In South Africa, the government influenced the production of gold in a host of ways. Trying to predict in the midthirties the long-run supply from South Africa, Hardy (1936, p. 67) argued that any tendency for the supply to fall could be offset by actions that reduced the burden of direct and indirect taxation. In his words:

> In short, the present level of costs is shot through with items which really constitute a distribution of the net income of the industry to elements in the community which are able to grasp it rather than the payment of costs that really have to be met in order to maintain a high level of output. Account must be taken of the gradual elimination of these elements . . . as the industry approaches the time when further maintenance of production would involve a cost disproportionate to the return.

The costs included direct taxation, which was higher on the gold mines than on other industries in South Africa (Busschau 1936, pp. 165–78), railway rates, and even some elements of wages. It was clear, then, that the supply of South African gold could not be projected without taking into account the political response of the South African government to changes in the value and output of gold. Hirsch (1968) documented many of these interventions for later years.

The 1930s, although they lie outside the classical period, provide further evidence of the role of politics. The real value of gold rose during the early 1930s, and world output increased. The largest increases between 1929 and 1934 were recorded by the Soviet Union (about 3.1 million ounces), Canada (1.0 million ounces), and the United States (0.7 million ounces). South Africa, by contrast, raised its output only by .07 million ounces. The increase in the United States was attributable to the working of low-grade ores including the revival of placer mining—much of it panning in California—undoubtedly a response to the rising real value of gold. The exploitation of new finds in Ontario, also partly in response to the rising real value of gold (Hardy 1936, pp. 58–60), accounted for the increase in Canadian production. In the case of the largest increase, that of the Soviet Union, the role of politics was pronounced.

By one account, and given the nature of things the account would be a difficult one to verify, the increase in Soviet output ultimately flowed from Stalin's judgment that Siberia could be developed more rapidly by emphasizing gold. Stalin, supposedly familiar with the history of gold in California, including the vivid writings of Bret Harte, thought that the California gold rush had led to rapid economic development and had provided the North with an important war chest for use in the Civil War. As a result, he gave a high priority to the revival and expansion of gold production in Siberia (Littlepage 1937, pp. 26–33). Indeed in order to increase prospecting, the Soviets introduced their own form of the gold rush in 1933. Private prospectors were rewarded with a lump-sum payment and the right to work their claims for one year. All payments were in "gold rubles," a currency that could be used in special stores and worth considerably more than the paper ruble in which other wages were paid. The campaign was apparently successful (Littlepage 1937, pp. 125–31). In the midst of the Depression, Keynes (1936) argued that communist efficiency in producing gold might save capitalism by encouraging expansionary monetary policies. He might have been surprised, however, at the extent to which the increase in production relied on capitalist techniques.

14.5.2 War, Revolutions, and Strikes

During the decade in which U.S. and Australian supplies dominated the growth of the gold stock, interruptions due to wars and revolutions did not occur. In earlier and later periods, however, such interruptions were common. The Latin American wars of independence in 1815 were associated with a sharp drop in world gold production. World output fell from 5.9 million ounces in the first decade of the nineteenth century to 3.8 million ounces in the second. All of this fall can be accounted for by the decline in South American and Mexican production; production in other areas was stable or increasing. It is true, as Von Humbolt (1900, pp. 32–33) argues, that particularly in Brazil, before political upheavals shook the region, placer-mining output was declining in South America, and some of the decline may have been in reported rather than actual output. But it seems likely that the upheavals, at least in the Spanish-speaking areas, if not in Brazil, did leave a substantial mark on the growth rate of world monetary gold stocks.

The greatest producer of gold toward the end of the classical period was South Africa. Significant interruptions in the flow of gold occurred there, the most severe during the Boer War. Tensions of long standing in southern Africa between settlers of Dutch and British descent were heightened in 1886 when the discovery of gold in the Transvaal brought an influx of British and other foreigners into a region formerly controlled by Dutch descendants. The conflict began in the fall of 1899 and was not concluded until the spring of 1902. After some initial Boer successes, the British in the summer of 1900 seemed to win control of the region by capturing Johannesburg, the center of the gold-mining industry, and other towns. But the Boers then turned to guerilla warfare and only two years later were finally subdued.

The impact of the Boer War on the output of gold was substantial. South African output fell from 3.6 million ounces in 1899 to a mere 0.3 million ounces in 1901. It was not until 1905 that output exceeded the level in 1898, the last full year before the conflict. The shortfall in South African output, however, did not have the severe consequences for world financial markets that one might have predicted, although Friedman and Schwartz (1963, p. 148) note that there was some stringency in money markets in the fall of 1899 that could be associated with the onset of the Boer War. There was a stock market panic, and some banks and financial institutions failed, but the period of stringency was brief. The reason the war had so little effect is that the South African shortfall occurred after several years of substantial increases in the output of gold. The decline in South Africa was cushioned by increases in other areas—Alaska, the Klondike, Colorado, and western Australia—as Clapham (1907, p. 378) noted. Total world output in 1900, although 18.2 percent lower than in 1899, was still the third highest output recorded up to that date, about equal to the average of the preceding five years.

The supply of South African gold was also interrupted in 1922 by the strike of white miners on the Rand. The fall in the purchasing power of gold relative to prewar levels and the consequent cost squeeze on marginal mines were the basic factors underlying the strike. In that environment, efforts by the mines to alter work rules soon led to fears that the color bar was being abandoned. A violent strike broke out that the government quelled, but South African production fell by about 1.1 million ounces between 1921 and 1922. This decline also was offset, to some extent, by increased production in other areas; world production fell only by about 0.5 million ounces, corresponding to a 3.4 percent fall in the rate of production.

These are the most important examples of interruptions in gold output, but there are many more. Mexico and Russia, for example, experienced significant output declines during revolutionary periods, and labor strikes in New Zealand hampered production after World War I. The main point, however, is that such interruptions in supply were rare during the heyday of the gold standard because of the political stability of the regions from which much of the gold came. It one were contemplating a return to the gold standard, one would want to know whether such conditions would again be the norm.

14.5.3 Governments and the Real Price of Gold

These examples suggest that a complete model of the gold standard would need to take into account the motives that prompt government intervention in industry generally and gold mining in particular. If government actions with regard to gold mining were undertaken with a view toward the monetary implications, then they might well be stabilizing. The measures designed to revive hydraulic mining in California, undertaken during a period of depressed prices and business activity, appear to fit the case. Such actions, moreover, could well be undertaken simultaneously throughout the gold bloc since most countries on the standard would likely be sharing similar experiences with respect to prices and real output. Intervention would also be stabilizing if the gold-mining industry were viewed simply as a particularly promising candidate for aid in a period of depressed trade and governments were shopping for likely candidates for aid. Since the demand for gold with respect to its nominal price is perfectly elastic under a gold standard, measures designed to aid the industry might appear more effective than similar efforts expended on behalf of other industries. On the other hand, if government actions were tied to circumstances in a particular gold field, there would be less chance for simultaneous responses. The efforts in Australia, for example, to stimulate deep-lode mining in the eastern fields after placer-mining output declined fit this case.

But it is not at all certain that government aid to gold mining would be countercyclical or neutral. Under a gold standard, it should be remembered, gold-mining profits tend to behave countercyclically. If the industry were able to win aid, as many industries do, when its output was depressed by rising costs, and if the rising costs were responding to a general rise in prices, then such aid would inhibit the equilibrating process. Such aid, moreover, might well occur simultaneously in the gold standard world. Consider, for example, an inflation. The cost-of-production theory of the value of gold and commodity prices envisions an inflation brought to a halt by a decrease in the output of gold caused by a rise in mining costs. But the process might be inhibited if gold-mining industries simultaneously won governmental relief that maintained production. Some recent events in South Africa and elsewhere might be interpreted in this light, but I have not found clear examples in the classical period.

Interruptions of supply that were the by-product of political conflicts, as I noted above, were important in certain periods. It might be possible in some cases to link these interruptions to the monetary role of gold and to changes in the real price of gold. So a complete theory of gold supply might consider this link as well as more conventional ones. For example, the strategic role of gold might encourage military actions to control the supply, often cited as the ultimate cause of the Boer War. In most cases, however, such interruptions appear to have been random shocks.

14.6 Conclusions

The stability and elasticity of the long-run supply of gold played a crucial role in the classical analysis of the gold standard. In the simplest case—a stable and perfectly elastic supply curve—the cost of producing gold is the ultimate determinant of the price level. Temporary increases (or decreases) in the price level lead to decreases (or increases) in supply that ultimately return prices to their long-run equilibrium. The main weakness in the classical theory from a modern perspective is that it does not treat systematically the case of gold as a nonrenewable resource. Hence, conditions appear to be favorable for a marriage between the classical theory of the gold standard and the emerging theory of the economics of a nonrenewable and durable resource. Some examples of the progeny that might be expected from such a marriage are given in section 14.1.

From a very long-run perspective, the supply curve appears to have been stable and elastic in the classical period. Rapid increases in supply occurred at points in time, at midcentury and in the late 1890s, when they served to raise the nominal price level after a period of deflation. This point is developed in section 14.2 in relation to modern changes in high-powered money. A closer look reveals, however, that the surges were due primarily to the development of new gold fields and to a lesser extent to technological changes. The question is whether these events should be viewed as fortunate accidents or as changes induced by previous changes in the real price of gold. Circumstantial evidence, particularly for the second surge in production, suggests that the discoveries were induced. Tentatively then, it seems appropriate to regard changes in supply produced by new discoveries at the end of the century as movements along a long-run curve rather than as a series of curves with arbitrary shifts between them. A similar conclusion seems in order for technological change. The most famous innovation, the introduction of the cyanide process, probably had a somewhat smaller impact on the supply of gold than has been suggested in the literature, but it appears to have been induced by the prevailing high real price of gold. Unfortunately, data are lacking to determine the exact course of technological change and its dependence on the real price of gold during the classical period. Some more recent data for South Africa are examined in section 14.4.

Governmental policies represent a third channel through which changes in the real price of gold influenced supply. Environmental regulations, for example, were weakened in California to encourage production in a period of low commodity prices. Purely random shocks from political sources were rare during the heyday of the gold standard, in part due to the dominance of supply by politically stable countries committed, to some extent at least, to laissez-faire. During the early part of the nineteenth century and after the 1890s, however, political shocks became more important.

It would be unwise, however, to infer from the stability and elasticity of the supply of gold in the nineteenth century that a gold standard would work similarly today. Certain conditions that existed then exist no longer. The regular discovery of new supplies depended on a core of dedicated prospectors working in largely unexplored areas. Neither that core of prospectors nor unexplored regions of the same type now exist. It is uncertain whether a similar core could be created by other means. The absence of political interference, moreover, hardly seems as likely in today's world as it was then. Finally, the long and uncertain lags that marked the supply response hardly seem acceptable in an impatient age.

Notes

1. I am indebted to Richard Sylla for drawing my attention to the significance of the causation issue.
2. The long-run supply curve referred to here is more general than the one ordinarily considered. It incorporates, for example, the effects of endogenous technological change.
3. After presenting this paper I learned that John McDermott had independently arrived at similar conclusions. He is currently working on a more sophisticated model of the behavior of a gold standard when gold is a nonrenewable resource.

4. In an earlier draft of the paper I tried to reinforce this point by referring to evidence showing that quoted production costs for the two processes were similar. Geoffrey Wood, however, called to my attention that average (as distinct from marginal) production costs, as these figures undoubtedly were, are of no special significance. What matters is that both processes could compete successfully for customers.

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Comment Robert J. Barro

Rockoff's paper analyzes the reaction of gold production to movements in the relative price of gold. With gold's nominal price held fixed—as it was for most of the periods and countries studied—we are considering here the response of gold output to variations in the general price level. Rockoff discusses gold discoveries, advances in mining techniques (with special attention to the cyanide process), the willingness of producers to adopt existing capital-intensive methods of production, and the tendencies of governments either to invoke environmental-protection regulations that hampered mining or to relax these restrictions. The results suggest various mechanisms by which gold output would respond to market incentives. But it is difficult to use Rockoff's findings in a quantitative manner to assess responses either at the level of an individual mining operation or at the aggregate level.

Mark Rush (1978) calculated the following regression on annual data for the 1897–1913 period (which he has been reluctant to report himself):

$$\log(g_t) = \ldots + \underset{(.12)}{.31} \cdot \log(1/P_t) + \underset{(.09)}{.82} \cdot \log(g_{t-1}),\ \hat{\sigma} = .062,$$

where g_t is the world's total gold production for the year (as reported by Warren and Pearson 1933, p. 197), and P_t is an estimate of the GNP deflator for the United States. Note that the dollar value of gold was fixed over this period, so that the variable $1/P_t$ measures the price of gold relative to other goods in the U.S. (Standard-errors-of-coefficient estimates are in parentheses—$\hat{\sigma}$ is the standard error of estimate.) The results show a short-run price elasticity for gold production of .3 and—if one takes seriously the coefficient of the lagged dependent variable—a long-run price elasticity of 1.7. There are some simultaneity problems that are not handled in Rush's regression—notably, an autonomous shift in g_t would tend to raise P_t. However, this effect is from g_t to the inflation rate rather than to the price level. The direction of bias would also seem to be downward for the estimated coefficient of $\log(1/P_t)$.

Robert J. Barro is professor of economics at the University of Chicago and a research associate of the National Bureau of Economic Research.

Michael Bordo (1981) reports a statistically significant relation of the world's monetary gold stock to prior values of the purchasing power of gold. However, his results were not presented in a form that allows me to calculate price elasticities of output response. By looking at the monetary gold stock—which would ultimately be of concern from a monetary standpoint—Bordo's estimates would also combine responses of nonmonetary stocks of gold with changes in the output of new gold (whereas Rush looked only at the production of new gold).

Another possibility for quantitative analysis involves the detailed data that are available on equity prices for South African gold-mining companies. These figures are presented in the book by S. Herbert Frankel (1967). Frankel uses these numbers only to calculate long-period rates of return to holdings of stock in gold-mining companies. But we could utilitze these data to assess the impacts on equity values of changes in the general price level, gold discoveries, technical advances in mining, shifts in government policies, wars, and so on. That is, we could isolate quantitative effects for many of the disturbances that Rockoff discusses. A distinction between expected and unexpected events would come into play in assessing the response of equity prices to the pertinent variables.

In an earlier part of his paper, Rockoff contrasts the performance of the gold standard with that of the post–World War II U.S. monetary regime. He compares the means and standard deviations of annual growth rates for the world's monetary gold stock from 1839 to 1929 with that of the U.S. monetary base from 1949 to 1979. In terms of these monetary-base comparisons, the gold standard period looks good, even in terms of exhibiting lower standard deviations of growth rates on a year-to-year basis.

Others who have made these types of comparisons—such as Bordo (1981)—have examined broader monetary aggregates, the general price level, or real variables like output. On this basis the gold standard seems to provide for long-run nominal stability, but not for stability of nominal or real variables on a year-to-year basis. Of course, the short-run behavior of broad monetary aggregates and prices under the gold standard depends, among other things, on shocks to the banking system, on changes in the velocity of broadly defined money, and on movements in the ratio of the monetary base to the reserve stock of monetary gold. We also have to worry about the distribution of the world's total stock of monetary gold among the various countries. Basically, endogenous movements in a country's stock of monetary gold may buffer that country's price level satisfactorily against various disturbances in the long run, but not in the short run.

What should we conclude when we observe a greater year-to-year fluctuation in a country's broad monetary aggregate under the gold standard than under the post–World War II monetary regime? Perhaps the comparison reflects other changes—such as the implementation of deposit insurance for the U.S. banking system—that stabilized the ratio of broad money to the monetary base. Then if similar structural changes had been implemented under the gold standard, we might have observed the relatively low year-to-year variability in the world's monetary gold stock—which is studied by Rockoff—carrying over to relative stability in broader monetary aggregates and the price level. A comparative study of short-run variability in broader monetary aggregates and prices may reflect alterations in banking institutions or other changes, rather than the shift away from the gold standard.

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Reply Hugh Rockoff

If Barro's suggestions for estimating various regressions may be regarded as agenda for future research, then I have no quarrel with them. More information is always welcome. Nevertheless, his exclusive emphasis on quantification forces me to defend the historical approach taken in my paper.

The value of that approach is that it allows us to extract information from a knowledge of the particular circumstances that surround a particular data point, information that is lost when we quantify the data. Mark Rush's regression quoted by Barro, for example, is estimated over the years in which the discoveries in South Africa were made and the cyanide process was developed. The impact of the discoveries is clearly evident in the data that underlie Rush's regression. Should we regard them as events that shifted the level of output and possibly the supply elasticities, or should we regard them as a movement along the supply function? There are, of course, econometric techniques for attacking these issues that rely solely on the price and quantity data. But we can gain additional insight, I believe, by exploring the actual historical circumstances in which the discoveries were made. In the case of cyanide, we can ask whether the discovery was the accidental by-product of research directed toward other purposes, or whether it was the result of applied research aimed at finding better extraction methods. In the paper I argue that the latter model applies, so the case for treating the additional output associated with this development as induced is considerably stronger. In short, while I agree with Barro that a quantitative model of the supply function would be useful, I want to emphasize that the historical approach also has a role to play.

Barro cites Frankel's (1967) study of rates of return to investments in South Africa's gold mines as an additional source of quantitative evidence. I agree that these data might provide additional insights, but two qualifications should be kept in mind. First, Frankel's data, of course, begin with the founding of the industry in South Africa, so they apply only to part of the period I examined, excluding many of the important nineteenth-century developments. Second, they are based on stock-market valuations of mining stocks. For this reason proper use of the data requires exact knowledge of when it was first perceived that a technological change, or similar event, would increase the income of the mines. Beyond that date, the impact of the innovation will be capitalized in share prices and only normal returns will be observed. Share prices, moreover, are influenced by a host of factors such as the possibility of a return to the gold standard—an effect stressed by Frankel—that are difficult to evaluate. In other words the data, valuable as they may be, do not provide a short cut that avoids the need for detailed historical research to determine quantitative estimates of the effects of various disturbances.

In the last part of his remarks Barro draws attention to the relative year-to-year stability of broad monetary aggregates, prices, and real output in the post–World War II period when compared with the gold standard period. If we leave aside the problem that the stability in the world's stock of monetary gold that I found may not imply stability in the monetary base for any one country, a genuine paradox emerges. Barro's suggestion is that changes in the monetary system, particularly deposit insurance, may have stabilized the ratio of broad money to the monetary base, and that in turn this produced the greater stability exhibited by prices and real output after World War II. The implication is that if similar changes had been introduced during the gold standard period, the year-to-year stability of the stock of monetary gold might have carried through to prices and real output. Other sorts of changes after World War II, however, might have occurred that reduced year-to-year variability in the rates of growth of prices and real output relative to their trends.

Cagan (1979), for example, found that the responsiveness of prices to variations in the business cycle declined after World War II, perhaps as a result of the higher average rate of inflation. If that effect or some other nonmonetary change accounts for the relative stability of prices and real output in recent times, then the gold standard could not have produced such stability even with a modified financial superstructure.

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General Discussion

ROCKOFF was generally sympathetic with Barro's comments. He suggested that there exists a great deal of quantitative evidence on South African gold production, which would be a fruitful area for further quantitative work on the determinants of gold supplies.

He agreed that whatever the long-run responsiveness of the supply of gold, the short-run supply curve was rather inelastic. Hence, gold supplies provided little year-to-year stabilization of the price level.

MCCAULEY asked how recent evidence suggesting that despite the rapid rise of the real price of gold in the last ten years, gold production has declined, squares with the evidence presented by Rockoff.

KOCHIN replied that there is a specific phenomenon connected with the economics of deep mining. If, e.g., there is a permanent increase in the real price of gold but rich veins of gold are surrounded by lower-quality ore, an attempt to mine the high-quality ore first, bypassing the lower quality ore, will impose greater costs later on. Consequently, if it is believed that the real price of gold has risen permanently, then firms will start mining the less rich ore that sits around the rich vein. The result is that in the short run, though the number of tons of ore mined increases slightly, the average gold content of the ore in ounces per ton falls and the number of ounces of gold produced decreases. In the long run, however, the supply of gold will respond positively as expected.

BORDO expanded on Kochin's point. He described some empirical work he did for the staff appendix to the *Gold Commission Report* on the relationship between market-economy gold output and the real price of gold. Using annual data for the post–World War II period, he found a negative short-run supply elasticity. However, when he examined a longer series of data going back to the nineteenth century, he found a positive short-run response. This response is probably explained by the increased exploitation of intensive bodies of ore in South Africa in the last fifty years as well as a policy of the South African government to subsidize the mining of lower quality ore.

FLEISIG suggested a theoretical framework into which the parts of Rickoff's paper fit quite naturally—the standard model of finite-resource extraction.

ROCKOFF responded by pointing out that his paper does discuss this class of models at the end of the section on the traditional commodity theory. Some very interesting propositions also emerge from the theory of durable commodities concerning the optimal intertemporal price path in particular.

CAGAN argued that alternative gold standard rules may render the policy implications of Rockoffs paper irrelevant. He mentioned in particular Irving Fisher's idea of a compensated dollar, according to which the gold content of the dollar is changed gradually over a long period of time in order to stabilize the price level independently of the supply of gold.

While acknowledging some problems with this approach, Cagan suggested that it was certainly worthy of discussion. Under certain conditions Fisher's rule provides a way to remove any long-run drift in the price level. In effect, the regime amounts to stabilizing the price level rather than the price of gold. Of course, this raises the question of whether there is any point to being on the gold standard.