



The *Real*, Real Price of Nonrenewable Resources: Copper 1870–2000

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Summary. — Over the past 40 years, economists have devoted considerable effort to estimating long-run trends in commodity prices. The results indicate that the real prices for many commodities have fallen, suggesting to the surprise of many that resource scarcity is declining over time. Almost all of this work, however, uses the US producer price index or other standard price deflators, which recent research shows overestimate inflation for several reasons. This article examines copper prices with adjusted deflators designed to eliminate this bias. It finds that the trend over time, which is significantly downward when no adjustment is made to the deflator, displays no tendency in either direction or is significantly upward depending on the magnitude of the deflator adjustment employed. These findings suggest that real resource prices provide less support than widely assumed for the hypothesis that resources are becoming more available or less scarce over time.

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1. INTRODUCTION

Copper, oil, and many other natural resources are nonrenewable at least on any time horizon of relevance to the human race. As the easiest-to-find and richest deposits are exploited, many anticipate that the real price of mineral commodities will rise reflecting their increasing scarcity. However, dozens of empirical investigations using modern econometric techniques have failed to detect statistically significant upward trends in the long-run real price of mineral commodities, as Krautkraemer (1998) notes in his review of this literature. The standard explanation is that new technologies, the discovery of new deposits, recycling, and other forces have more than offset the cost-increasing effects of depletion over time.

In earlier work on commodity prices, nominal prices are almost always reported in US currency, and converted to real prices using the US producer price index (PPI) and other

standard deflators. The choice of deflator is rarely explained in any detail, and in a few cases not even identified. Krautkraemer (1998), for example, in his review of the literature only mentions his own choice of deflator (the US consumer price index (CPI)) in a footnote. A more serious problem, which provides the motivation for this study, is that a growing number of studies have found that the traditional price deflators overstate inflation. This paper reassesses the long-run real price trends for one nonrenewable resource, copper, using deflators designed to correct for this bias.

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Copper is a good choice for a pilot study for several reasons. First, it is an important metal. Recently the world has produced some 15 million tons of refined copper annually (World Bureau of Metal Statistics, annual), worth 25–50 billion dollars depending on the market price. Only the iron and steel, aluminum, and gold industries have higher sales. Second, there are reliable and consistent data on annual copper prices back to 1870 (and even before). Third, copper is a homogeneous good. Unlike petroleum, for example, with its many grades, refined copper is 99+% pure copper.¹ Fourth, the cost of transporting copper is a small percentage of its final price. Fifth, copper is sold on global markets rather than in various regional markets. As a result, the prices in the two main markets, the United States and the London Metal Exchange (LME), move together within the bounds set by the cost of transporting copper across the Atlantic. Over the entire 1870–2000 period, the simple correlation coefficient between the LME and US producer price, both expressed in US dollars and deflated by the conventional CPI, is 0.90. Sixth, the copper market is reasonably competitive. During certain periods, collusive activities by producers or price controls by governments have affected prices. But, thanks to a number of scholars—Herfindahl (1959) and Howie (2002), for example—who have studied the copper industry, these periods are well documented, allowing one to control for their influence.²

The analysis begins in Section 2 with a brief review of the theory and previous empirical evidence on long-run trends in real resources prices. Section 3 presents the reasons why the standard deflators overestimate inflation during recent decades, and hence the adjustments required to eliminate the bias. Section 4 considers the inflation bias before 1950. Section 5 estimates the *real*, real price of copper and carries out a series of robustness tests. Section 6 highlights the main findings, examines some of the implications, raises a few caveats, and makes suggestions for further research.

2. RESOURCE PRICE CHANGES: THEORY AND EVIDENCE

One of the main reasons for assessing long-term price trends for nonrenewable commodities is the concern that depletion over time is increasing their scarcity. As society exhausts existing mineral deposits, it is forced to exploit

lower grade, more remote, and more difficult to process mineral resources. This tends to push the costs and prices of mineral commodities up over time. Simultaneously, however, new discoveries and new technologies in exploration, mining, and mineral processing tend to reduce the costs and prices of mineral commodities. If the cost-increasing effects of depletion are greater than the cost-reducing effects of new discoveries and technology, the real prices of mineral commodities tend to rise over time, reflecting growing scarcity and declining availability. Just the opposite is the case when the cost-reducing effects of discoveries and technology are greater than the cost-reducing effects of depletion. As a result, long-run trends in real prices are widely accepted as a useful measure of changes in resource availability.³

The formal theory in this area dates back to Hotelling (1931). His seminal article considers the optimal output over time for a mine with a fixed quantity of mineral reserves. Hotelling shows that the mine will behave differently than firms whose production is not ultimately limited by an exhaustible resource. In particular, it will expand its output during any period only up to the point where the cost of producing an additional unit plus user costs equals the market price, where user costs reflect the present value of the future profits forgone by producing an additional unit of output now.

Hotelling also demonstrates that user costs must rise by $r\%$ per year, where $r\%$ is the market rate of return on investments that are of similar risk and in other ways comparable to an investment in mineral reserves. If, for example, the return on comparable investments were higher, then mine owners would have an incentive to exploit all of their reserves during the current period (Hotelling imposes no constraints on output other than the total quantity of reserves) and invest the profits in other investments. This behavior would raise the price of the mineral commodity in the future and so increase user costs. Not until the growth in user costs was comparable to the return on other similar assets, would mines have an incentive to stop diverting output from the future to the present. Should the pendulum swing too far, so that the user costs increased at more than $r\%$ a year, mines would want to hold onto their reserves. The diversion of output from the present to the future would slow the pace at which user costs rise until the latter was growing at $r\%$ a year.

Table 1. *Selected studies examining long-run trends in copper prices*

Study (year)	Price ^a	Period	Deflator ^b	Findings
Herfindahl (1959)	USPP ^c	1870–1957	PPI and CPI ^c	Finds no persistent upward or downward trend in real copper prices after eliminating abnormal periods (when cartels, wars, or other events artificially raise or lowered prices) and after controlling for a one-time downward step in price around World War I
Potter and Christy (1962)	USPP	1870–1957	PPI	Shows real copper prices fall over the period covered, with most of the decline occurring in the 1915–20 period
Barnett and Morse (1963)	USPP	1870–1957	Prices of non-extractive products	Builds on the study by Potter and Christy, and examines a composite of mineral commodities, not copper. Concludes that mineral prices over the period examined did not rise
Nordhaus (1974)	USPP ^d	1900–70	Wage rate	Finds copper prices fall dramatically over the period examined with all of the decline occurring during 1900–50
Manthy (1978)	USPP	1870–1973	PPI	Updates the Potter and Christy study. Finds that copper prices fell during 1870 and early 1930s and then rose, with little overall change between the beginning and end of the period examined
Slade (1982)	USPP	1870–1978	PPI	Compares linear and quadratic trends, and finds that the latter provides the best fit for copper prices. Concludes that the long-run trend in copper prices, after declining for many years, has been rising since the early 1930s up to 1978
Krautkraemer (1998)	USPP ^e	1967–94	CPI	Shows the price of copper dropping significantly, though the period examined is relatively short
Howie (2002)	USPP	1870–1997	PPI	Updates Slade and compares linear, quadratic, and inverse trends. Finds that the latter provides the best fit for copper prices, suggesting that real long-run copper prices are declining but at a falling rate
Crowson (2003)	LME and other	1771–2001	PPI ^f	Finds that copper prices declined over the entire period considered but with both upward and downward trends over extended sub-periods

Sources: See reference list.

^a USPP is the US producer price of copper. LME is the London Metal Exchange price of copper.

^b PPI is the US wholesale price index prior to 1978 and the US producer price index thereafter. CPI is the US consumer price index.

^c Herfindahl uses the “price of copper at New York,” which presumably is similar to, or the same as, the US producer price. He also uses both the PPI (wholesale price index) and an index of prices of final products. The latter is similar to, or the same as, the CPI.

^d Nordhaus examines the prices for a number of mineral commodities using several sources. The copper price is for the United States, and is similar to, or the same as, the US producer price.

^e Krautkraemer uses copper price data from a US Geological Survey internet site that probably reported US producer prices.

^f Crowson uses a mixture of wholesale prices and implicit US GNP price deflators.

Some followers of Hotelling argue that his analysis implies that the market prices of mineral commodities will rise at $r\%$ a year. However, Hotelling's results depend on a number of strong assumptions. In his model, for example, there is no exploration or additions to reserves, no technological change, and no uncertainty. Modified Hotelling models that relax these assumptions no longer make clear predictions regarding user costs and prices.

This means that empirical studies are needed to determine if the influence of technological change, new discoveries, and other developments pushing real mineral commodity prices down have more than offset the effects of mineral depletion and other factors tending to increase mineral scarcity over time. Many such studies have been carried out and generally they find that prices since the 1870s, despite quite large fluctuations in the short run, have followed either constant or falling long-run trends. Table 1 identifies a selected number of these studies, particularly those focusing on copper, and briefly describes their principal findings.

3. INFLATION BIAS IN RECENT DECADES

Claims that the official price series in the United States and elsewhere overstate inflation arose over 40 years ago (Stigler, 1961), but had little impact on the collection and reporting of the official US price indexes over the next 35 years. In the mid-1990s, the interest in price indexes re-emerged and the Boskin Commission was set up with a mandate to evaluate and suggest improvements in the CPI. It found that the CPI overestimates inflation by some 1.1% points per year (Boskin, Dulberger, Gordon, Grilliches, & Jorgenson, 1996). Subsequently, a string of studies of the inflation bias has come forth, applying different estimation technologies (Table 2).

The renewed interest in price indexes has been spurred by a growing realization of the adverse consequences of incorrectly measuring inflation. As noted by Boskin, Dulberger, Gordon, Grilliches, and Jorgenson (1998, p. 3): "Accurately measuring prices and their change, inflation, is central to almost every economic issue. There is virtually no other issue that is so endemic to every field of economics. Some examples include aggregate economic growth and productivity; industry prices and produc-

tivity; government taxes and spending programs that are indexed to inflation; budget deficits and debt; monetary policy; real financial returns; real wages; real median incomes and poverty rates; and the competitive performance of economies." ⁴

To the above list one should add the ramifications for deriving real price trends for primary commodities, which is the focus of this study. Inaccurately measured prices also have important ramifications for the related issue of trends in the barter terms of trade for countries exporting and importing mineral commodities, a topic the concluding section argues is in need of further research.

(a) Sources of bias

There are three main reasons why the US and other price indexes overstate inflation.

(i) Substitution bias

In constructing the price series, the Bureau of Labor Statistics (BLS) used a modified Laspeyres index up to year 2002 (see below). In this type of index, the weights of the different items are derived from consumption expenditure surveys from a particular base year. This base-year "basket" has been re-estimated infrequently: in the case of consumer goods, only about every 10th year (Abraham, 2003). When there are shifts in relative prices over time, buyers substitute toward items with falling relative prices, signifying the need for a change in the weights, which the fixed-weight Laspeyres index ignores. Boskin *et al.* (1998, p. 7) finds the use of such an index "extreme, unrealistic, and unnecessary," and estimates that it has caused the CPI to overestimate inflation by 0.4% point per annum in the 1974-95 period.

(ii) New goods bias

There are at least three flaws in the official CPI and PPI when it comes to handling new products on the market. The first arises because new products are introduced in the indexes with a long lag. A frequently cited example is the cellular phone, which appeared in 1983, but was not included in the CPI until 1998. Other examples include room air conditioners, VCRs, and personal computers, which were all included "years after they were first sold in the market place" (Gordon & Griliches, 1997, p. 85). As a result, the accumulated price decreases for these products during the intervening years, estimated at around 80%, were not captured

Table 2. *Estimated bias in the US consumer price index, various studies and methods (percentage point bias per annum)*

Study (year)	Coverage and special features	Period(s) covered	CPI bias (%)	Range of CPI bias (%)	
				Low	High
<i>(a) Studies based on Hedonic and related estimation methods</i>					
Gordon (1990)	About half of all consumer durables.	1947–60	2.2	2.2	4.4
	Low estimate assuming no quality change	1960–72	1.2	1.2	2.5
	in noncovered items;	1972–83	1.1	1.1	2.1
	high estimate same for all items	1947–83	1.5	1.5	3.1
Boskin <i>et al.</i> (1996)	Quality bias for selected items from 27 main categories in CPI. Extrapolation to other products	1975–95	1.1	0.8	1.6
Nordhaus (1997)	“Thought-experiment” (Gedankenexperiment)	1800–1992	1.0	0.5	1.4
Lebow and Rudd (2003)	Re-estimation of Boskin <i>et al.</i> results for a later period	1987–2001	0.9	0.3	1.4
<i>(b) Studies based on the Engel-curve method</i>					
Hamilton (2001)	1,800 households and no account of pure-quality change. Food as the instrument good	1974–81	2.5	2.5	2.9
		1981–91	1.0	1.0	1.7
		1974–91	1.6	1.6	2.2
Costa (2001)	Income and food expenditure data for 14,000–26,000 households. No account of pure-quality change. Food and recreation as instrument goods.	1888–1919	–0.1	–0.1	–0.3
		1919–35	0.7	0.4	1.1
		1935–60	–	–	–
		1960–72	0.4	–0.2	1.1
		1972–82	2.7	1.9	3.9
		1982–94	0.6	0.1	1.6
		The 1888–90 survey is not representative (heavy industry workers only). CPI (mainly food) for 1888–1919 unreliable and unofficial estimate	1972–94	1.6	1.4
		1960–94	1.1	1.1	1.3
Bils and Klenow (2001)	Quality-adjusted Engel curves for 66 consumer durable goods (80% of all and 12% of CPI)	1980–96	2.2	0.8	2.4
<i>(c) Simulations of selected biases conducted by BLS officials^a</i>					
Bosworth (1997)	Quality bias for selected goods in one year only	1995	1.0 ^b	0.3	1.8
Stewart and Reed (1999)	Estimates of what would have been the CPI if 1999 estimation practices had been applied 1978–98	1978–98	0.45	–	–
Abraham (2003)	Updating weights more frequently than actually done and geometric formula	1988–99	0.37	–	–

Sources: See reference list.

^a These studies estimate only part of the total bias in the CPI.

^b Only the range is reported in this study; the average is derived from this range.

in the official price indexes (Boskin, Dulberger, Gordon, Grilliches, & Jorgenson, 1997).

A second flaw occurs because improved versions of many products are introduced as completely new goods, which means that the quality improvements they reflect are ignored. A third flaw arises because new products are included in the indexes without allowing for the consumer surplus gain (compensating variation) they generate (Hausman, 1997, 2003). The Boskin report makes no attempt to correct for this third source of bias.⁵ The size of the new-product bias arising from the first two sources is estimated to be in the range of 0.30–0.40% points per year (Boskin *et al.*, 1997, Table 2).

(iii) *Pure-quality bias*

In the official price indexes, aside from a few recent exceptions noted below, goods are measured in standard units, such as a diesel engine or an electronic calculator, without any adjustment for improvements in quality. Thanks to such improvements, the consumer gets more for the price paid, both in a quantitative and qualitative sense.⁶ A calculator today has more capacity and many more capabilities, is less energy demanding, has lower repair costs, and lasts longer, than the calculators available some years ago. The Boskin report argues that prices of final goods and services should be divided into two separate components—one for quality improvements and one for pure price changes (inflation). It estimates that the new-product and pure-quality biases together cause the CPI to overestimate inflation by some 0.60% points per year. The pure-quality bias by itself is responsible for about 0.30–0.40% points (see above).

The quality issue has indeed become highly visible to all who follow the market for computers and related electronic products. Here quality improvements, as measured, for example, by capacity, have far outpaced prices, in fact by 15–30% per year according to several estimates for the 1980–99 period (Jorgenson & Stiroh, 2000). Such developments have helped raise the awareness of quality improvements in other product categories as well.

(b) *The Engel-curve method*

The method used by Boskin *et al.* (1996) for estimating inflation bias has been dubbed “down the trench,” as it is based on very detailed and laborious examinations of individual products. A much simpler approach, the

Engel-curve method, was introduced a few years ago.

Authors using this method (see Table 2) take the negative relationship between household income and the share of income spent on food (the Engel curve) as the starting point. With rising per capita income, the average share of food in total household expenditures has declined steadily in the United States (from about 44% in 1900 to 27% in the early 1950s and to 13% in the mid-1990s). However, there is little reason to expect that the food share of household expenditure *at a given real income level* should change over time, after controlling for changes in the relative price of food, income distribution, the demographic composition of the population, and other relevant variables.

The estimation method can be illustrated with the help of a simple graph depicting Engel curves (F/Y) for two consecutive years (Figure 1). The available studies show a drift of the Engel curve to the left over time, from say $(F/Y)_t$ to $(F/Y)_{t+1}$. That is, for a given level of real household income (as deflated by the official CPI), the food share has declined over time. The authors conclude that the observed drift is due to overestimation of inflation, and use it to estimate the bias in the CPI. In Figure 1, the bias is given by $\Delta Y/Y_t$.

(c) *Official responses*

Results that upset conventional wisdom and established practice tend to receive mixed reviews. This was the case with the Boskin report. The first reactions by officials and researchers at the BLS were largely sceptical. Now, most of the recommendations advanced by the Boskin Commission are officially endorsed. The Commission recommended the use of a superlative Törnquist index, which is similar to the Fischer ideal price index (Boskin *et al.*, 1998). The Törnquist index is based on averaging (geometrically) the weights from the base and the most current year, which reduces the substitution bias inherent in the Laspeyres index.⁷ The BLS introduced the use of a superlative index in 2002, although only for some “strata” (sub-indexes) in the CPI index (Abraham, 2003). The Bureau of Economic Analysis (BEA) has also recently switched to a superlative index (Moulton, 2000).

BLS officials now also agree that previous methods for handling new products lead to upward bias in the CPI (Abraham, 2003; Moulton, 2000), as argued by the Boskin

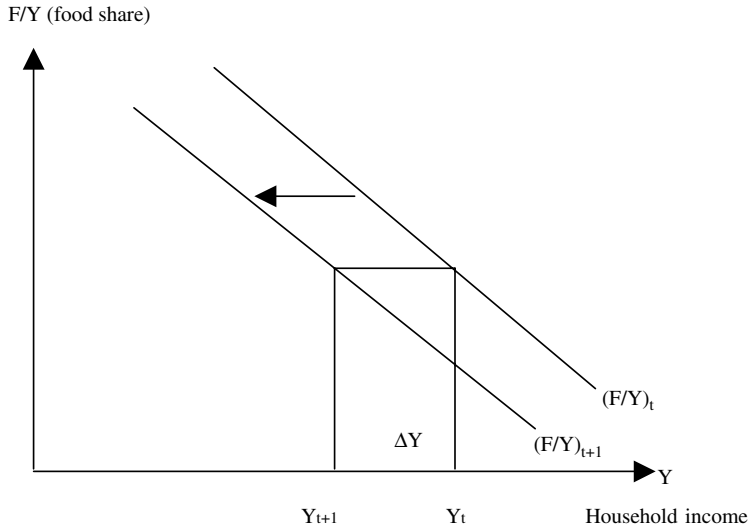


Figure 1. *The food Engel curve.*

Commission. New practices have been established or are underway. One important change since 2002 is that the weights used to aggregate the CPI indexes are now updated every two years instead of every 10th year (Abraham, 2003).

When it comes to the third bias, pure-quality changes, controversy still lingers, both regarding estimation methods and the numbers advanced by the Boskin Commission. The Commission relied mainly on the hedonic method for separating quality-induced price changes from pure inflation. With this method, price changes for a good are regressed against quality changes, as reflected by technical specifications (such as horsepower, fuel consumption, and expected life in the case of automobiles). The share of the price increases accounted for by changes in such technical characteristics is attributed to quality improvements, and the remaining share is attributed to inflation.

Objections to the Boskin report on this issue have focused on three related points. First, the method it uses for some product categories, it is claimed, is subjective and judgmental. Second, quality can deteriorate as well as improve, and for many goods and services no reliable methods for estimating quality changes exist (Schultze & Mackie, 2002). Third, the official indexes have increasingly taken quality changes into account in recent years. Examples include computer software, automobiles, and telecom-

munication equipment (Stewart & Reed, 1999).⁸

Boskin (2000) maintains that the Commission's original assessments of quality improvement hold, and that the recent inclusion into the official statistics of quality changes for a few products is insufficient. Jorgenson and Stiroh (2000) also identify further adjustment for quality changes as one of the two top priorities for the agencies producing and using price series. Outsiders are split between those who are sceptical of the estimates from the Boskin Commission (Deaton, 1998; Schultze & Mackie, 2002) and those who find them too conservative (Diewert, 1998; Hausman, 2003; Nordhaus, 1997).⁹

Lately, researchers at the BLS have themselves made some simulations of bias in the CPI during the past two decades. In one of these studies, Stewart and Reed (1999) carry out a backward re-estimation of "what would have been the measured rate of inflation from 1978 forward had the methods currently [1999] used in calculating CPI-U(rban) been in use since 1978." These new practices (14 in all) concern mainly quality change adjustment for electronic products (including computers and television sets) and a geometric formula that "assumes a modest degree of consumer substitution within most CPI item categories." They find that annual inflation would have been 0.45% points lower had these practises been applied throughout the entire 1978–99

period. Abraham (2003), who served as a commissioner at the BLS up to 2001, made another simulation: how would the 2002 new practice of introducing new goods more expediently have affected the CPI in earlier years? She finds that the CPI would have been 0.17% points lower per annum since 1987.

Adding up the overestimation of CPI due to neglect of quality improvements and consumer substitution, and late introduction of new goods, as estimated by Stewart and Reed and by Abraham, suggests that inflation in recent decades has been overestimated by at least 0.62% points (0.45 + 0.17). This number is not that different from the low-point estimate derived by Boskin *et al.* (0.8% points). Moreover, it should be noted that the BLS revisions are understated since they take into account only quality changes for a few selected products. The Boskin Commission claims that quality improvements in a long range of other products should also be accounted for.¹⁰

Revisions in the official CPI indexes, starting in 1983, probably explain why many studies listed in Table 2 (e.g., Gordon, Hamilton, and Costa) report a decline in bias over time. This may also be the reason why Lebow and Rudd (2003) found the overall, and the quality, bias for the recent period 1987–2001 to be somewhat smaller than reported by Boskin *et al.* (1996) for 1974–95 (see Table 2).

In summary, there is now wide agreement that the CPI has overestimated inflation in the United States for the four decades prior to the late 1990s, when more important revisions were initiated. Disagreement and uncertainty remain over the size of the bias (as is evident from the large confidence intervals reported by most authors in Table 2). On the methodological front, the debate is now largely focused on how to best account for quality change (Schultze, 2003). It is important, finally, to recall that the historical CPI index has not been revised (Stewart & Reed, 1999). So all the biases reported for recent decades exist in the price indexes for earlier years. This is particularly important for our purposes, since almost all of the period we are examining is before the 1990s.

It is also notable that the consumer or retail price indexes in other large countries, though not examined in the same detail, contain similar biases as in the United States.¹¹ However, as copper and other metal prices are largely quoted in US dollars on international markets, our main concern is with the US deflators.

4. INFLATION BIAS BEFORE 1950

There are three main hurdles when it comes to estimating the inflation bias over the 1870–1950 period. First, there is only one systematic attempt to estimate inflation bias for years prior to 1950 (Costa, 2001), and it does not take quality changes into account. Therefore, we have to rely on evidence of quality change from numerous case studies. Second, an official CPI index in the United States was first compiled in 1917 and extended backwards to 1913. Third, the unofficial CPI series for 1870–1914 are based on very few goods (mainly food) and are hence relatively unreliable, a problem that we will attempt to control in the estimations to follow.

(a) *Substitution bias and new goods bias*

As the BLS has used the Laspeyres index since 1917, the substitution bias that it produces clearly dates back to the earliest official CPI figures. Similarly, the late introduction of new goods is not a new problem. It seems to have been as pronounced, if not more so, before the 1950s as after. Stigler (1961, p. 38) cites as examples that “new automobiles were not introduced until 1940, used automobiles... until 1952,” some 40–50 years after they were on the market, and that “refrigerators were introduced only in 1934,” with an equally long lag. He concludes that: “Our observations suggest that in many cases the need to introduce a new variety of a commodity is felt (by the BLS) only when it becomes impossible to price the old variety because it has disappeared from the outlets.” (Rather the same observation is made by Abraham (2003, p. 52), reflecting on the 1990s.)

The only comprehensive study that has estimated inflation bias before 1950 is Costa (2001). The Engel-curve method she uses takes all technical index-related flaws into account, but not the pure-quality bias. As Table 2 shows, her partial estimate indicates practically no inflation bias in the 1888–1919 period, and a bias in the range of 0.4–1.1% points for the 1919–35 period. Her mid-point estimate of the substitution and new goods biases for this period (at 0.7% points) is of the same order as reported by the Boskin Commission for the 1974–95 period (about 0.6% points).

(b) *Pure-quality bias*

The type of systematic and broad-based estimations of quality change in products and ser-

vices that the studies cited in Table 2 have undertaken for recent decades does not exist for the period before 1950. This, however, does not mean that information is totally lacking. For instance, Griliches (1961) estimates that quality improvements accounted for more than half of the price increase that the US wholesale price index (WPI) reported for automobiles over the 1937–60 period. There is also the celebrated history of lighting by Nordhaus (1997). Gordon (1990), Bresnahan and Gordon (1997), and Stigler (1961) cite several additional studies. The quantitative estimates of the quality change in the particular goods examined in all these case studies are similar to, or greater than, those reported by the studies listed in Table 2 for later periods.

It is also the case that during the 1920s and 1930s, a long range of what were then technically sophisticated consumer goods, including telephones, radios, and electrical appliances of various types, became widely available for the first time. Clearly there were many quality improvements in such products in the years up to 1950, although they have not been estimated.

There is also an *a priori* reason to expect that numerous major technological innovations in the past—including electricity, railroad equipment, the internal combustion engine, a wide range of petrochemicals, and communication equipment—led to major quality improvements in many goods with such inputs during the first half of the 20th century. Gordon (1990, pp. 11–12) conjectures that one would “suspect that existing capital goods deflators significantly overstate quality-corrected inflation in capital goods prices... all the way back to the dawn of the industrial age.” Nordhaus (1997) arrives at a similar conclusion and provides an exhaustive list of “great inventions” dating back to the 19th century, whose influence on prices is not reflected in the official indexes.

While there is little reason to believe that quality improvements in technically advanced products were any less pronounced before 1950 than after, the overall bias induced by quality changes may nevertheless have been smaller. Far less quality change tends to occur in what Nordhaus (1997) labels as “run-of-the-mill sectors.” According to his estimates, the importance of these sectors has declined from 75% to 28% of the US economy during 1800–1991. Along with this shift, from standard bulk goods to more technologically sophisticated products, the overall quality bias

may have grown. Although no quantitative data are provided, Gordon (1999, p. 126) in extensions of his previous work on durables, found “much smaller rates of [quality] bias before 1947.” This conjecture is shared by Boskin *et al.* (1996, p. 42) for the CPI.

5. COPPER PRICE TRENDS

This section estimates the trend in real copper prices over the 1870–2000 period using as deflator an adjusted CPI that reduces the reported inflation. In the benchmark case, we take the inflation bias to be 1.0% point a year throughout the period. This number is smaller than the estimates for recent decades reported by most of the studies listed in Table 2, and slightly above the estimate by Costa for the 1919–35 period (which disregards quality change). It is also the number that Nordhaus (1997) comes up with in his “thought-experiment” (*gedankenexperiment*). In addition to this benchmark or base case, we subsequently provide alternative estimates of the real price trend for copper assuming that the CPI bias is 0.5% and 1.5% points. Our objective is not to advocate one particular figure, but to consider a range within which the true bias is likely to fall. We can then explore how the long-run trend in the real price of copper changes as the magnitude of the bias varies over the range of likely possibilities.

Figure 2 shows the average annual US producer price of copper for the years 1870–2000 deflated by the CPI and the CPI minus (a) 0.5% points a year, (b) 1.0% points a year, and (c) 1.5% points a year. When no adjustment is made to the CPI, a downward trend is quite apparent. As the annual adjustment to the CPI increases from 0.0% to 1.5% points, this figure shows that a reversal in trend occurs, calling into question the presumed decline in real copper prices. The following sections examine the statistical significance, stationarity, and robustness of these trends. It begins with the base case and then examines how the trends change when the assumptions are altered.

(a) *The base case*

The base case focuses on the real copper prices over the period 1870–2000. It considers the average annual US producer price. While the LME price of copper would also be quite appropriate, we use the US producer price in the base case to facilitate comparisons with

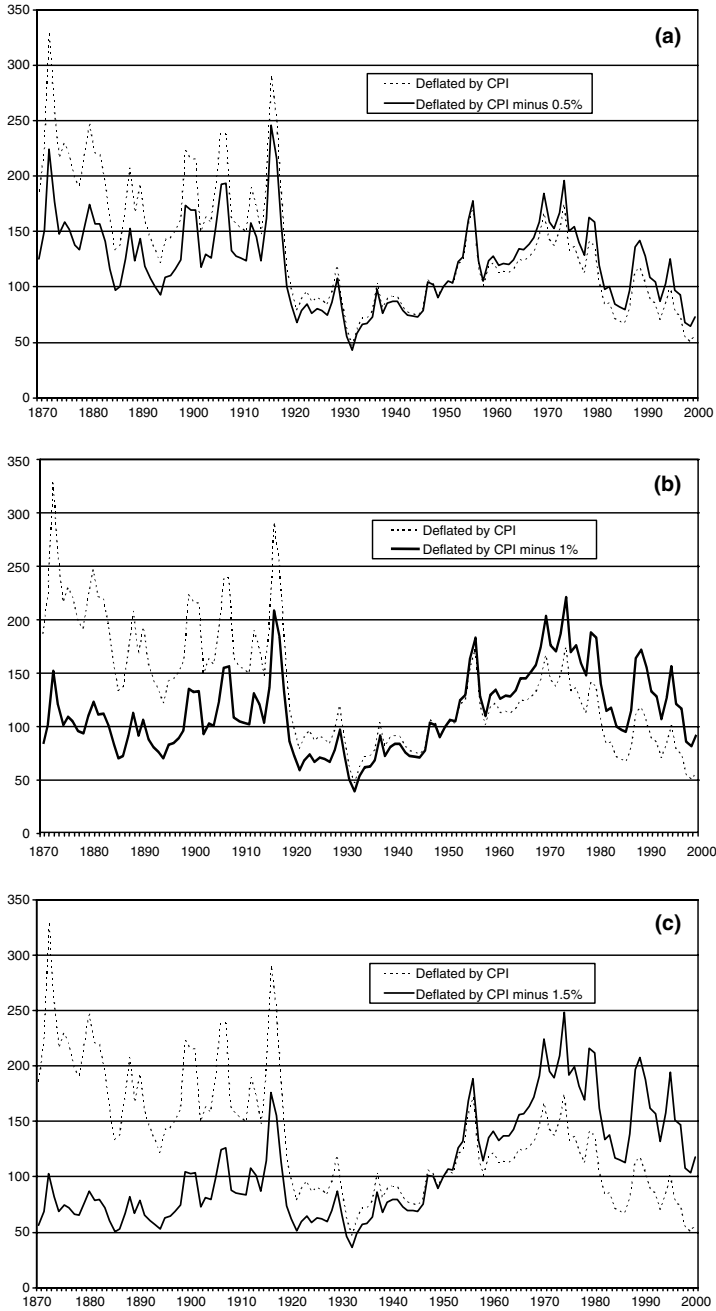


Figure 2. Index of the US producer price of copper from 1870 to 2000 with 1950 = 100. Copper price deflated by the CPI and the (a) CPI minus 0.5%, (b) CPI minus 1.0%, and (c) CPI minus 1.5%.

the many earlier studies that use this price (see Table 1).

The base case also uses the US CPI to deflate nominal prices rather than the more commonly

Table 3. Results for the US producer price of copper deflated by CPI and adjusted CPI^a

	CPI adjustment			
	Conventional (0.0%)	Low (0.5%)	Base case (1.0%)	High (1.5%)
Constant				
Coefficient	195	136	89	50
<i>t</i> -Statistic	8.50	8.27	5.32	3.23
Probability	0.00	0.00	0.00	0.00
Time				
Coefficient	-0.93	-0.25	0.34	0.87
<i>t</i> -Statistic	-3.76	-1.18	1.58	3.62
Probability	0.00	0.24	0.12	0.00
ADF test statistic ^b	-4.03	-4.40	-4.11	-3.85
Adjusted <i>R</i> ²	0.79	0.67	0.72	0.84
Durbin-Watson statistic	1.89	1.90	1.91	1.93
<i>F</i> -statistic	159	88	108	223
Schwarz criterion	9.43	9.11	8.93	8.89

^a All equations are estimated using GLS with a two-lag autoregressive residual. Some *t*-statistics are derived from White heteroscedasticity-consistent covariance matrix.

^b The critical ADF test statistic values are -4.03, -3.45, and -3.15 for significance at the 1%, 5%, and 10% levels, respectively.

used US PPI. This is in part because the inflation bias in the CPI has been studied more thoroughly than in the PPI or other price indexes. The major consideration favoring the use of the CPI, however, is the fact that it reflects the real price of copper in terms of a representative basket of consumer goods and services. As a result, it more accurately assesses the impact of commodity price trends on the welfare of society—that is, consumers or people in general—than other deflators.¹²

The base case further assumes that the long-run trend in real copper prices is linear and it reduces, as mentioned, the official inflation rate by 1% point a year to correct for the overestimation of the CPI. Specifically, the base case estimates the following equation:

$$P_t = \beta_0 + \beta_1 t_t + \varepsilon_t. \quad (1)$$

P_t is the average US producer price of copper for year t , deflated by the CPI adjusted by subtracting 1% point each year from the annual increase in the CPI. The variable t_t is the time trend. It takes the value of 1 for 1870 (or for 1871 or 1872 when lagged values of the dependent variable are included on the right hand side of the equation to eliminate autocorrelation) and increases by 1 for each succeeding year. The β 's are the parameters to be estimated and ε_t is the disturbance term. The results for this model are compared with the results when no adjustment is made to the CPI.

Since the independent variables (time and the constant) are predetermined, we use generalized least squares (GLS) to estimate the parameters. We also use the augmented Dickey-Fuller (ADF) procedure—or where necessary the Ouliaris, Park, and Phillips (OPP) test—to test for stationarity, as only data series that are trend stationary can be modeled in their level forms (that is, un-differenced) without generating possibly spurious results.¹³

Table 3 shows that the long-run trend in real copper prices derived with the unadjusted deflator is downward. This decline is statistically significant at the 1% level. In contrast, the results for the base case (adjustment by 1.0% point) suggest that the real price of copper has trended upward over the past 130 years. Though significant only at the 12% level, the estimated parameter for the time variable is positive.

(b) Robustness tests

(i) Alternative adjustment factors

The results when we re-estimate Eqn. (1), using annual deductions of 0.5% and 1.5% points from the annual increase in the CPI, are shown in Table 3. The lowest estimate of the bias (0.5 points) can be thought of as representing a case where no quality improvements in goods and services occurred over the entire 1870–2000 period. In this case, the only biases in the CPI stem from the use of the fixed-weight

Laspeyres index and the delayed introduction of new goods. According to Stigler (1961), these flaws plagued the official CPI index from the time it was introduced in 1917 and all the way to 1999, when it was first modified (Stewart & Reed, 1999).

The second alternative, a correction of 1.5% points per year, is similar to the upper tail of the range of bias estimates put forth by Boskin *et al.* (1996). It also squares with the mid-point estimates derived by Gordon, Hamilton, and Costa for years in the post-1950 period. It is worth noting that the latter two studies do not take quality change into consideration. The one study based on the Engel-curve method that does (Bils & Klenow, 2001), reports a higher number for consumer durables (2.2% points).

An adjustment of 0.5% points suggests that the long-run price trend is downward as when no adjustment is made to the CPI. However, it is no longer significant. With the 1.5% point deduction, the long-run trend is upward, as in the base case, and statistically significant at the 1% level.

(ii) *Alternative copper prices*

Using the LME price instead of the US producer price does not affect the results, as Table 4 shows. When no adjustment is made to the

CPI, the long-run trend in the real LME price of copper is downward and significant at the 1% level. When the CPI is reduced by 1.0% points a year, the long-run trend is upward, and the coefficient on the trend variable is significant at the 6% level. However, the ADF test in this case suggests that the LME price of copper may not be trend stationary, raising the possibility of spurious results.

(iii) *Alternative deflator*

Several earlier studies use the PPI to deflate nominal commodity prices. To determine if our results are sensitive to the choice of deflator, we re-estimated Eqn. (1) using the PPI deflator.¹⁴ Copper prices deflated by both the adjusted and unadjusted PPI are trend stationary. When the PPI is reduced by 1% point a year, the long-run trend in real copper prices is upward, as in the base case, though it is now significant at the 1% level (as compared to the 12% level with CPI). So using the PPI instead of the CPI actually strengthen our benchmark finding, meaning that we have stacked the cards against us rather than in our favor.¹⁵

(iv) *Alternative trends*

The base case assumes that the long-run trend in real copper prices is linear. There are, of course, other possibilities. Slade (1982), for

Table 4. Results for LME copper prices deflated by the CPI and for US producer prices deflated by the PPI^a

	LME price deflated by the CPI		US producer price deflated by the PPI	
	CPI adjustment		PPI adjustment	
	(0.0%)	(1.0%)	(0.0%)	(1.0%)
Constant				
Coefficient	174	79	189	78
<i>t</i> -Statistic	8.54	5.44	8.69	4.83
Probability	0.00	0.00	0.00	0.00
Time				
Coefficient	-0.71	0.44	-0.73	0.66
<i>t</i> -Statistic	-2.73	1.91	-2.98	2.83
Probability	0.01	0.06	0.00	0.01
ADF test statistics ^b	-4.32	-2.77	-3.98	-3.59
Adjusted <i>R</i> ²	0.73	0.71	0.75	0.79
Durbin-Watson statistic	1.93	1.90	1.93	1.96
<i>F</i> -statistic	116	106	127	151
Schwarz criterion	9.52	9.37	9.29	8.91

^a All equations are estimated using GLS with a two-lag autoregressive residual. Some *t*-statistics are derived from White heteroscedasticity-consistent covariance matrix.

^b The critical ADF test statistic values are -4.03, -3.45, and -3.15 for significance at the 1%, 5%, and 10% levels, respectively.

example, argues the trend is quadratic, falling for a time and then rising. Yet another alternative is the inverse function, which has the advantage over the linear trend that it need not at some point become negative when prices are declining. It is more difficult to rationalize, however, if real prices are rising. To assess how dependent our results are on the assumption of a linear price trend, we estimated these two nonlinear functions—the quadratic and the inverse—using Eqns. (2) and (3).

$$P_t = \beta_2 + \beta_3 t_t + \beta_4 t_t^2 + \varepsilon_t, \quad (2)$$

$$P_t = \beta_5 + \beta_6 t_t^{-1} + \varepsilon_t. \quad (3)$$

Since the ADF test is valid only when the underlying trend is linear, we used the OPP procedure to test for stationarity. When copper prices are deflated by the adjusted CPI (using a 1.0% point annual reduction) and the unadjusted CPI, this test indicates that the resulting real copper price series are trend stationary. This finding holds both when real copper prices are assumed to be following a quadratic trend and an inverse trend.

The Schwartz criterion, which is conventionally used to compare the performance of different equation specifications, indicates that the inverse relationship provides a slightly better fit than the linear trend, and that both the inverse and linear trends do better than the quadratic. The inverse function, however, implies that the price of copper is gradually approaching some stationary or permanent level, which seems questionable when prices are rising.

Whether one uses the linear or the inverse relationship, however, does not greatly alter our earlier findings. With the inverse function, the trend in real copper prices is significantly downward if no adjustment to the CPI deflator is made. When the CPI is reduced by 1% point a year, the trend is upward, and the coefficient is statistically significant at the 10% level.

Of course, if the quadratic were the true long-run trend, this would have important implications for availability and prices in the future. The estimated quadratic trends reported in Table 5 indicate a decline in the long-run trend in copper prices until 1986 when no adjustment is made to the CPI, and a decline only until

Table 5. Results for US producer copper prices deflated by the CPI assuming quadratic and inverse trends^a

	US producer price deflated by the CPI, quadratic trend CPI adjustment		US producer price deflated by the CPI, inverse trend CPI adjustment	
	(0.0%)	(1.0%)	(0.0%)	(1.0%)
Constant				
Coefficient	230	101	93	131
<i>t</i> -Statistic	6.34	3.73	8.44	8.87
Probability	0.00	0.00	0.00	0.00
Time variable				
Coefficient	-2.37	-0.12	1,487	-992
<i>t</i> -Statistic	-2.16	-0.13	3.15	-1.71
Probability	0.03	0.90	0.00	0.09
Time variable squared				
Coefficient	0.01	0.00		
<i>t</i> -Statistic	1.45	0.52		
Probability	0.15	0.60		
OPP test statistic ^b	23.21	16.81	25.19	14.64
Adjusted <i>R</i> ²	0.79	0.71	0.80	0.72
Durbin-Watson statistic	1.88	1.91	1.96	1.78
<i>F</i> -statistic	122	81	175	109
Schwarz criterion	9.44	8.97	9.35	8.93

^a All equations are estimated using GLS with a two-lag autoregressive residual. Some *t*-statistics are derived from White heteroscedasticity-consistent covariance matrix.

^b The critical OPP test statistic values are 19.95, 15.61, and 13.49 for significance at the 1%, 5%, and 10% levels, respectively.

1890 when the CPI inflation rate is reduced by 1% point a year. Thereafter, the indicated trend rises. There is, however, little to suggest that the true long-run trend is quadratic. The coefficients for the square of the time variable, as shown in Table 5, are insignificant and the Schwartz criterion favors both the linear and inverse over the quadratic relationship.

(v) *Excluding noncompetitive market periods*

According to Herfindahl (1959) and Howie (2002), interventions by governments and collusive actions by producers distorted the market price for copper during the following periods: 1870–83, 1888–90, 1900–01, 1914–18, 1929–35, 1939–57, and 1962–64. There are (at least) two, quite different, ways to take account of such market manipulations. The choice depends on how one believes temporary market interference affects long-term prices.

One possibility is that the long-term price trend is unaffected. Successful efforts to raise copper prices artificially tend to reduce demand and stimulate supply. So once they collapse, a competitive market will for a period generate prices below the level that would otherwise have prevailed. Just the opposite occurs when

government price controls or other market interventions keep the price below competitive levels. If the higher or lower prices that follow such market interventions offset the price distortions they produce while in place, nothing has to be done in the estimation of long-term price trend to account for their effects. We then “only” have the problem that the price swings, caused by market interference, induce noise in the estimations, which lowers the *t*-values and the overall fit, but has no effect on the coefficients to be estimated (the β 's).

The alternative (extreme) assumption is that once the supply restrictions are relaxed, prices move directly back to their long-run competitive trend. That is, artificial price distortions, once over, have no subsequent influence on either supply and demand. In this case we can estimate the true long-run price trend during periods under competitive conditions by omitting the years when collusion is in effect. Table 6 shows the results from such estimations when the CPI is adjusted by 0.0% and 1.0% points a year. As before, the coefficient on the time variable when no adjustment is made to the CPI is negative and significant. When the CPI is adjusted by 1.0% point, the coefficient is positive,

Table 6. Results for the US producer price of copper deflated by CPI and adjusted CPI (a) for 1870–2000 excluding noncompetitive market periods and (b) for 1917–2000^a

	1870–2000 Excluding noncompetitive market periods		1917–2000	
	CPI adjustment		CPI adjustment	
	(0.0%)	(1.0%)	(0.0%)	(1.0%)
Constant				
Coefficient	209	108	82	9
<i>t</i> -Statistic	4.57	2.55	3.31	0.28
Probability	0.00	0.01	0.00	0.78
Time				
Coefficient	–1.00	0.17	0.18	0.12
<i>t</i> -Statistic	–2.09	0.38	0.70	3.19
Probability	0.04	0.71	0.49	0.00
ADF test statistic ^b	–2.01	–2.07	–6.04	–4.21
Adjusted <i>R</i> ²	0.76	0.76	0.71	0.80
Durbin–Watson statistic	1.67	1.84	1.86	1.90
<i>F</i> -statistic	111	109	92	113
Schwarz criterion	9.02	8.92	8.56	8.85

^a All equations are estimated using GLS with a two-lag autoregressive residual. Some *t*-statistics are derived from White heteroscedasticity-consistent covariance matrix.

^b The critical ADF test statistic values are –4.07, –3.45, and –3.16 for significance at the 1%, 5%, and 10% levels, respectively for the 1917–2000 period. The comparable values for the 1870–2000 period excluding noncompetitive market periods are –4.09, –3.47, and –3.16.

though highly insignificant. Furthermore, the ADF test fails to reject the hypothesis that the series is stationary, raising the possibility of spurious results.

(vi) *The 1917–2000 period*

The benchmark results for the 1870–2000 period have so far survived the robustness tests made, except for the attempt to control for market interventions, which was inconclusive. There is, however, a serious concern that the CPI data available for the years 1870–90, especially, but also 1890–1912, are uncomfortably unreliable. An official CPI estimate for the United States was first compiled by the BLS for 1917 (and stretched back to 1913). The numbers for earlier years “are based on the efforts of economists and economic historians who have created CPI estimates and linked them to the modern series” (McCusker, 2001). According to Sahr (2002), “[o]bviously extreme caution should be used concerning all (price) data before 1913.”

The various consumer price estimates for 1870–90 are based almost exclusively on food price data and are hence fragmentary and unreliable. Rees (1961) undertook an ambitious revision and extension of earlier price estimates for the 1890–1914 period in a study for the NBER. Rees’ revised index included many more non-food good and used retail prices for these goods (while previous price series were based on wholesale prices). By also including the prices of some services (medical care and insurance) he demonstrated that previous (food-dominated) indexes had seriously overestimated consumer price inflation.¹⁶ The numbers derived by Rees for this period are close to those reported in the Historical Statistics of the United States (USBC, 1975), which were used in this study and by Costa (2001). As Rees (1961, p. 119) concludes, “[o]ur cost-of-living index [for 1890–1914] in general is certainly less accurate than official indexes for more recent years.”

These problems with the CPI data for 1870–1916 suggest examining to what extent, if any, our findings are altered when the years before 1917 are excluded. The results, also reported in Table 6, reinforce the doubts raised earlier about the widespread belief that real copper prices have fallen over the long run. Even when no adjustment is made to the deflator, the copper price trend for the 1917–2000 period is flat, rather than significantly negative as was found for the entire 1870–2000 period. Moreover, adjusting the deflator by 1% point a year (the base case) pro-

duces an upward trend in copper real prices that is significant and trend stationary.

6. CONCLUDING REMARKS AND FURTHER RESEARCH

Growing evidence indicates that the US CPI and other standard deflators have overestimated inflation. The magnitude of the bias is uncertain; the point estimates range from 0.9% to over 2.0% points a year, and vary somewhat with the time period covered. Though most of the evidence applies to the period after World War II, there are good reasons to believe that consumer price series for earlier years, all the way back to the 1870s, are biased as well.

When the nominal price of copper is converted to a real price using the CPI with no correction for the overestimation of inflation, the linear trend over the 130-year period, 1870–2000 is downward and statistically significant. When the CPI is reduced by 0.5%, 1.0%, and 1.5% points a year to correct for its upward bias, this finding is called into question. With the two higher adjustments, the estimated trend is upward and with the 1.5% point adjustment, it is statistically significant at the 1% level.

Moreover, this finding is quite robust. It holds whether nominal copper prices are those reported by the North American producers or the LME. It holds if the PPI is used to deflate nominal prices instead of the CPI. It holds if one assumes the true trend in real prices follows an inverse relationship rather than a linear one. It holds, though with much less statistical certainty, when periods of market manipulation are excluded from the analysis.

The results derived here do presume that the price of copper has followed one constant secular trend over the past 130 years. While our tests for trend stationarity provide some support for this assumption, there are reasons to suspect that the long-run trend in copper prices has changed from time to time as important new end uses for copper have arisen, as close substitutes have been developed, as major innovations have reduced copper production costs, and as the world economy itself has experienced structural changes. In particular, Figure 2 suggests that the trend the price of copper followed was more or less constant between 1870 and World War I, then fell over the following two decades, rose from the mid-1930s until the early 1970s, and has since once again fallen.

If the long-run trend in copper prices has changed from time to time, this provides yet another reason to question the widespread belief that the price of copper has persistently, for a century or longer, been following a downward trend. Moreover, whether the long-run trend has or has not been following a single long-run trend does not alter the fact that the actual path of real copper prices properly deflated for inflation has remained constant or risen (depending on the assumed size of the inflation bias), rather than fallen, over the past 130 years.

Two main themes for further research are suggested by our study. The first is to examine to what extent our finding for copper can be generalized to other mineral commodities. Comparing copper price trends as conventionally estimated with those for other mineral commodities provides some tentative indications. In the case of petroleum, lead, zinc, and tin, long-run real price trends, when estimated with an unadjusted deflator, are more or less constant, neither rising nor falling significantly. Adjusting the deflator, as we have done in the case of copper, would most likely convert the trends for these commodities from stationary to rising (though with quite pronounced short-term fluctuations). For another group of mineral commodities, including aluminum, nickel, and silver, the decline in the unadjusted price series is greater than for copper, and may be sufficiently large to persist even after adjusting the deflator. Further detailed investigation is clearly needed to determine which other mineral commodities have experienced rising long-run price trends.

It is important, however, to keep our results and those of future studies in perspective. Even if mineral commodity prices and hence mineral scarcity in general are rising, what is truly surprising is that the increases have not been greater. Given the sharp growth in per capita incomes, particularly in the developed countries, and also in world population, the consumption of all mineral commodities over the past 130 years has exploded. Despite the huge increases in production that have made this possible,¹⁷ the real prices of mineral commodities have not increased greatly. Moreover, the increases that have occurred have clearly not prevented the world economy from growing more strongly over the past century than during any previous period (Maddison, 2003).

A second intriguing avenue for further research, raised by our findings, is the possibility

that the barter terms of trade for countries exporting mainly primary commodities and importing manufacturing products have declined less than the available estimates suggest, or perhaps not at all. The price trends for primary commodities, as measured by the standard price indexes, are largely free of the biases that beset the price trends of imported manufactured goods, as quality change and the delayed introduction of new products, are much less of an issue.

One cannot, however, use the estimated bias in the US CPI (or PPI) as a measure of the bias in the price of the manufactured imports of primary product exporting countries. The biases, which Boskin *et al.* and others listed in Table 2 have estimated, are derived on the basis of all goods and services, both tradables and non-tradables, that enter the CPI index. Services account for more than 50% of the CPI, and the estimated biases due to quality improvements are much smaller (and more difficult to estimate) for services than for manufacturers (Boskin *et al.*, 1996). The predominance of manufactured goods in developing country imports hence suggests that the adjustment for inflation bias should be higher when adjusting the terms of trade than when adjusting the CPI. This and many other measurement intricacies have to be confronted when attempting to gauge the extent to which terms of trade estimates are biased.

While the share of primary products (excluding fuels) in low- and middle-income countries' exports has generally declined over the years, these products continue to dominate exports for some 50 of the poorest countries. Though the data are incomplete, in almost all sub-Saharan African countries, food, agricultural raw materials, and ores and metals account for more than half of the exports, and in most cases, for more than two-thirds. With a few exceptions, manufactured goods make up more than 60% of these countries' imports (World Bank, 2003). If commodity prices, properly deflated, are on the increase, rather than declining as widely assumed, this may well affect the allocation of investments in the commodity-dependent countries.

Long-term trends in the terms of trade are also of significance for net-importers of minerals, including many of the developed countries as well as populous and rapidly growing China and India. Rising commodity prices, to a large extent driven in recent years by the growth of demand in these countries, could influence

unfavorably their future growth prospects. So, the terms of trade issue is still of high relevance, for both exporting and importing

countries, and a challenging area for future research that this study suggests is in need of attention.

NOTES

1. The London Metal Exchange copper price, for example, was for Trough Copper (fire-refined averaging 99.25% copper) from 1780 to 1879, for Best Selected Copper (fire-refined averaging 99.75% copper) from 1880 to 1914, and for electrolytic wirebars after 1914 (averaging 99.99% copper). In the absence of these quality improvements, the price of copper presumably would have fallen slightly more or risen slightly less. However, some changes in copper trading have had the opposite effect. For instances, for technical reasons, sellers since 1981 have been able to deliver cathode copper instead of wirebar. This has eliminated a step in the production process and reduced costs. The US producer price for copper reflects similar developments. For more on the changes over time in the specifications of the copper products sold on commodity markets, see Crowson (2003, p. 43).

2. Howie (2002, chap. 4) corrects for price distortions introduced by subsidization and the exercise of market power over the 1900–97 period, and finds that this produces less of a decline in the long-run trend in real copper prices.

3. It is worth noting that: (a) Short-run fluctuations in mineral commodity prices, which are quite pronounced, are often driven by factors unrelated to long-run trends in availability, such as economic booms and recessions. (b) Two other economic measures of mineral commodity availability are user costs (which reflect the value of mineral resources in the ground) and the marginal costs of extraction and processing mineral commodities. The latter measure suffers from the fact that it does not consider the cost of discovering mineral resources. In addition, reliable information on the marginal costs of extracting and processing mineral commodities is often unavailable. User costs provide a good indication of trends in the availability of mineral commodities in the ground. In contrast, mineral commodity prices reflect availability after mineral resources are extracted and processed. While both are useful indicators, they measure availability at different stages in the production process. Because reliable data on user costs are seldom readily available, mineral commodity prices are much more widely used. (c) Reserves (which measure the amount of a mineral commodity found in deposits that are known and currently profitable to exploit) and other physical measures are also at times used to measure the availability of mineral commodities. However, these

measures all suffer from serious deficiencies as measures of the long-run availability of mineral commodities. For more on measuring long-run trends in mineral commodity availability, see Tilton (2003, chap. 3).

4. Also see Gordon (1990, pp. 8–14). Among the areas listed, the question of whether the slowdown in productivity growth in the United States since the mid-1970s is overestimated has attracted the most attention. See, for example, Jorgenson and Stiroh (2000), Onliner and Sichel (2000), and Gordon (2000).

5. Hausman (1997) has suggested a simple, but ingenious method for dealing with the consumer surplus omission. There are other sources of bias in the CPI that are quantitatively small and hence not detailed here, for example, the switch to discount stores and spurious weights used to aggregate the CPI (Lebow & Rudd, 2003).

6. It is important to note that the quality improvements estimated by Gordon (1990) exclude intangible quality changes, such as better sound in video recorders.

7. For further discussions of the choice of indexes, see Boskin *et al.* (1998), Gordon and Griliches (1997), Deaton (1998), Moulton (2000), Schultze and Mackie (2002), and Abraham (2003).

8. The methods used by the BLS to adjust for quality changes are described in Moulton and Moses (1997). Moulton (2000) acknowledges that quality change is insufficiently incorporated into the official indexes, that improvement is warranted, and that this is underway.

9. The main exchanges in this debate can be consulted in the May issues (Papers and Proceedings) of the *American Economic Review* for 1997, 1999, and 2000; the *Brookings Papers on Economic Activity*, 1997:1; and the *Journal of Economic Perspectives*, Winter 1998 and Spring 2003. To our knowledge, Boskin and his co-authors have not yet responded to the Schultze and Mackie (2002) report.

10. According to Bosworth (1997), the quality adjustment made by the BLS lowered the official CPI by between 0.28% and 1.76% points (with a mean of about 1.0) for the year 1995. However, these quality

adjustments are for selected goods only and the average is derived on the assumption that all other products had no quality change. This introduces an overall downward bias of unknown size. This estimate nevertheless suggests that unadjusted quality changes in the years before the early 1990s were notable, providing further support for the quality bias estimates of the Boskin Commission.

11. For assessments of the UK retail price index, see Sliver (2003) and Fenwick (2003) and for the OECD countries more generally (OECD, 1994, 1999). For a description and assessment of the UK inflation indexes for the 1860–1932 period, see Bowley (1937).

12. Although we believe that the CPI is a more appropriate deflator than the PPI for our purposes, given our ultimate interest in the impact of copper price trends on the welfare of society in general, many earlier studies, as Table 1 shows, have used the PPI. The US PPI has only existed since 1978, when it replaced the earlier WPI, which contained almost no producer goods before 1947 (Gordon, 1990, p. 15). We have nevertheless re-estimated all of the equations for which results are presented in Tables 3–6 using prices deflated by the PPI. The results, available upon request, do not change any of our conclusions.

13. A stationary variable has a constant mean and variance over time. A trend stationary variable has a constant mean and variance once its trend is removed. A

differentiated stationary variable has a constant mean and variance in its first differences. A variable that is not trend stationary may not follow the same trend over time. This means that the true β 's in Eqns. (1)–(3) may not be constants, but instead may vary over the period examined. In this case, the estimated β 's reflect some hybrid average of the true β 's, and as a result are unlikely at any point in time to represent the true long-run trend in prices.

14. It is worth noting that Gordon (1990) found the bias in the price index for producer durables to be much higher than for consumer durables (3.0% vs. 1.5% points, respectively) over the 1947–83 period.

15. We also tried the GDP deflator, but it does not produce a copper price series that is stationary, perhaps because it goes back only to 1929 and so generates a shorter series.

16. For the 1890–1914 period, inflation as measured by an index dominated by food was estimated at a cumulative rate of 30% (Douglas, 1930). Rees' extension of this index to include many more products showed a cumulative inflation of 10%, or one-third of the previous estimate (Rees, 1961, Table 22).

17. World copper mine output, for example, rose from under 0.5 million tons in 1900 to 13.2 million tons in 2000 (Porter & Edelstein, 2003).

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