Natural Resource Scarcity and Technological Change

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In this article, we examine trends in the real prices of nonrenewable natural resources to determine whether technological change is outpacing geophysical scarcity of these natural resources.

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In 1972, an interdisciplinary research group called the Club of Rome predicted worldwide catastrophe by 2050 (Meadows et al. 1972). They based their prediction on three trends they thought they observed: increasing scarcity of nonrenewable natural resources, increasing environmental degradation, and continuing population growth. They saw the combination of these trends as unsustainable and economic misery as inevitable.

The Club of Rome was not original in its pessimism about the future. English economist Thomas R. Malthus raised similar concerns in 1798. His analysis led him to conclude that misery was the inevitable state of humans (Malthus 1798). According to Malthus, if per capita income were above subsistence, population would expand until per capita income was reduced to subsistence level. (See the box entitled "An Overview of Malthus' Principle of Population.") At the time Malthus was writing—the early stages of the Industrial Revolution—poverty was widespread in English cities, so perhaps his pessimism was understandable.

Fortunately for us, Malthus was wrong. Since at least the late 1800s, per capita income in Western society has generally increased. Technological change occurred at a rapid pace, causing per capita income to rise even as the population grew. In fact, per capita income rose so much, the Club of Rome's pessimism seems hard to understand, except that Malthus' original analysis did not take into account natural resource scarcity or environmental degradation.

This essay examines whether the potential scarcity of nonrenewable natural resources is a reason for concern. Previous research (Barnett and Morse 1963, Jorgenson and Griliches 1967, Nordhaus 1973, Brown and Field 1978, Fisher 1979, Hartwick and Olewiler 1986, and Schmidt 1988) is mixed, but it generally has found that the economic evidence is inconsistent with the increasing scarcity of nonrenewable natural resources. In fact, technological change driven by free market forces has increased natural resource availability. Given the time elapsed since the previous research was conducted, however, it is appropriate to reexamine the evidence.

WHAT IS NATURAL RESOURCE SCARCITY?

Nonrenewable natural resources, such as aluminum and crude oil, exist in fixed amounts on Earth. When we use up all the crude oil on the planet, we will have no more of this resource. In addition, we tend to use the most easily obtainable natural resources first. Over time, natural resources become more difficult to extract. For example, at the beginning of the California gold rush, people were picking up gold off the ground. Toward the end of the gold rush, they were blasting the mountains with water, using much more capital and labor.

Geophysical scarcity may be irrelevant, however, if technological change increases resource availability. Consequently, economists prefer to measure scarcity in economic terms—that is, through market prices. Economists are interested in whether the prices of nonrenewable natural resources reflect increasing scarcity. In other words, are the real prices of natural resources rising to reflect increasing scarcity?

The economics perspective can be illustrated by examining a production function for the overall economy:

$$(1) \qquad Q = Q(K, L, NR),$$

where Q is output, K is capital, L is labor, and NR is natural resource use.[1] We expect normal economic conditions for production, which mean a positive marginal product for each input:

$$(2) \qquad \frac{\partial Q}{\partial K} > 0, \quad \frac{\partial Q}{\partial L} > 0, \quad \frac{\partial Q}{\partial NR} > 0.$$

For each input, output increases with its use, as is shown by the positive first derivative.

Normal economic conditions for production also mean a diminishing marginal product for each input:

$$(3) \qquad \frac{\partial^2 Q}{\partial K^2} < 0, \quad \frac{\partial^2 Q}{\partial L^2} < 0, \quad \frac{\partial^2 Q}{\partial NR^2} < 0.$$

For each input, output increases at a decreasing rate with increased use of the input, as is shown by the negative second derivative.

Economic theory also suggests how the increased provision of capital, labor, and natural resources affects the productivity of each other input. For instance, the productivity of capital and labor is expected to increase as natural resource use increases:

$$(4) \qquad \frac{\partial^2 Q}{\partial K \partial NR} > 0, \quad \frac{\partial^2 Q}{\partial L \partial NR} > 0.$$

In words, the marginal product of capital and the marginal product of labor increase when more of the natural resource is used.

Similarly, the productivity of the natural resources increases if either capital or labor increases:

$$(5) \qquad \frac{\partial^2 Q}{\partial NR \partial K} > 0, \quad \frac{\partial^2 Q}{\partial NR \partial L} > 0.$$

In words, the marginal product of natural resources is greater when either more capital or more labor is used.

If we take increasing natural resource scarcity to mean natural resource availability decreases over time, then as capital and labor grow the production conditions described above can explain the economic manifestation of natural resource scarcity and why it might be expected to limit economic growth. The conditions expressed in inequalities 4 and 5 show that if natural resource use declines while capital and labor grow, the marginal productivity of natural resources will rise and the marginal productivity of capital and labor will fall. Hence, increasing natural resource scarcity would imply that nat-

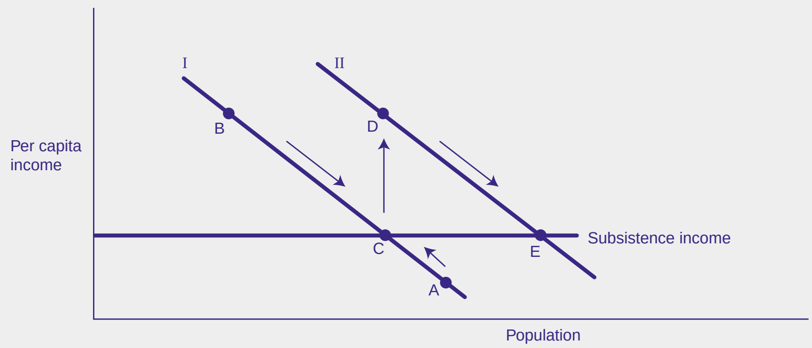
An Overview of Malthus' Principle of Population

Malthus thought an increase in population would reduce per capita income. His conclusion followed from the law of diminishing marginal productivity: as population increases, each worker has less land with which to work. Curve I in the figure represents this proposition for a given amount of land and level of technology. Curve II represents this proposition for a higher level of technology and/or greater acreage. The subsistence level of income is also represented in the figure.

For a given amount of land and level of technology, Malthus argued that a population would tend toward a subsistence level of income. If per capita income were below the subsistence level (as illustrated by point A on curve I), starvation would reduce the population. If per capita income were above the subsistence level (as illustrated by point B on curve I), people would have more children and population would grow. In either case, population would adjust until income just reached the subsistence level (at point C on curve I). Therefore, he concluded that misery was the inevitable state of humankind. This conclusion is often referred to as the "dismal theorem" and may be the historical basis for calling economics "the dismal science."

Malthus' analysis is similar to that now made by ecologists studying animal populations and ecosystems. For example, if the deer population is smaller than a given ecosystem can support, the deer will reproduce and multiply in number. If the population is greater than the ecosystem can support, the weak will die off and the population will be reduced. The deer population tends toward a subsistence level of nutrition.

Malthus further argued that—without moral restraint in human reproduction—improved technology or increased resources would only increase human misery in the long run. An increase in technology or land temporarily increases well-being (as shown by a shift from point C on curve I to point D on curve II). Eventually, however, the increased capacity of the economy will lead to population growth, which will only be checked when per capita income reaches subsistence (point E on curve II). Hence, Malthus concluded that increased technology or land availability would result in more people living at subsistence, not an improvement in living conditions. This conclusion is often referred to as the "utterly dismal theorem."



ural resource prices rise relative to wages and the return to capital.

The economic conditions described above also suggest that in a world without technological change, output cannot keep pace with population growth unless natural resource use and capital grow at the same rate. In fact, if natural resource use grows more slowly than capital and labor—as greater natural resource scarcity would imply—output must grow more slowly than capital and labor unless there is technological change.

ANOTHER PERSPECTIVE ON NATURAL RESOURCE SCARCITY

Hotelling (1931) develops a model to explain how the prices of nonrenewable natural resources—such as oil, natural gas, coal, copper, nickel, bauxite, zinc, and iron—would evolve over time in the absence of technological change. Hotelling's analysis exploits the proposition that the quantity of nonrenewable resources is fixed. The consumption of the resource today reduces the amount available for future consumption, and the owner of such a resource must decide how to distribute its use over time.

In an economy in which other investments earn a market rate of interest, individuals saving nonrenewable natural resources for future periods also must expect to earn the market interest rate (including the appropriate risk premium). If the expected return to saving a nonrenewable natural resource for future periods is less than the market interest rate, managers of that resource will save less of it for the future. This will make the resource more plentiful today and less plentiful in the future, which will lower today's price, raise future prices, and increase the expected return to saving the resource for future periods.

On the flip side, if the expected return is greater than the market interest rate, managers will save more of the resource for future periods, making it less plentiful today and more plentiful in the future. This will raise today's price, lower future prices, and decrease the expected return to saving the resource for the future. Only when the expected return is equal to the market interest rate will managers of the resource consider their production plans finalized. Under these conditions, the difference between the price and marginal cost of producing a nonrenewable natural resource will rise at the market interest rate unless production costs are affected by resource depletion (Solow 1974):

$$P_{NR,t} = C_{NR,t} + \lambda e^{rt}, \quad (6)$$

where $P_{NR,t}$ and $C_{NR,t}$ are the price and marginal cost of producing the natural resource at time t, respectively, r is the market interest rate, and λe^{rt} is the value of holding an additional unit of the resource off the market until a future period (a practice economists call "user cost"). The relationship described by Equation 6 is commonly called the "Hotelling rule."

With $C_{X,t}$ representing the effects of cumulative production on the cost of producing the natural resource at time t, Peterson and Fisher (1977) show

$$\dot{\lambda} = -e^{-rt} C_{X,t}, \quad (7)$$

which means λ is constant over time and the user cost grows at the interest rate unless production costs change with cumulative extraction ($C_{X,t} \neq 0$). If production costs rise with cumulative extraction ($C_{X,t} > 0$), the user cost rises more slowly than the interest rate.[2] The price of the natural resource is expected to rise over time, however, whether or not production costs rise with cumulative extraction ($C_{X,t} \geq 0$).[3]

Financial markets and forecasts of future prices are generally consistent with theory reflecting expectations that prices for nonrenewable natural resources will rise over long periods of time.[4] In fact, the Hotelling rule is best interpreted as a market efficiency condition describing how current and expected future prices for these resources are simultaneously determined by current market conditions and expectations about future market conditions. For nonrenewable natural resources, current prices and expectations about future prices depend on the information and technology available at the time.

MARKET-INDUCED TECHNOLOGICAL CHANGE

As demonstrated above, if a nonrenewable natural resource is expected to become more scarce in an economic sense, its price will be expected to rise. In a market system, expectations of higher prices increase the incentive to find new technology that will offset geophysical scarcity. When they expect higher prices, consumers have an incentive to look for new technology that lets them use less of a natural resource. When they anticipate higher production costs, producers have an incentive to develop new technology to lower costs. In short, the very mechanism that signals increasing economic scarcity of a nonrenewable resource helps

Table 1

Natural Resource Prices Deflated by the Consumer Price Index

Commodity	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	1998
Aluminum	*	*	*	55.71	33.92	23.21	20.27	18.96	10.46	12.48	10.51	13.12	8.20	5.87
Anthracite coal	100.00	87.95	91.90	103.42	117.74	140.26	177.33	164.84	214.19	152.98	161.58	298.63	177.85	122.07
Bituminous coal	100.00	81.90	69.67	79.04	76.00	118.75	64.60	86.40	128.07	100.89	102.92	224.38	135.58	96.32
Copper	100.00	132.27	103.56	116.08	82.45	52.28	47.43	49.21	53.65	65.35	89.50	73.52	57.43	29.64
Iron	100.00	112.49	79.15	91.99	71.52	93.41	47.98	71.10	86.47	98.13	83.42	113.36	NA	NA
Lead	100.00	105.67	102.15	107.87	96.31	81.72	67.42	75.88	113.06	82.23	82.74	105.46	73.34	58.38
Natural gas	*	*	*	*	*	97.78	94.86	66.87	56.26	98.50	91.76	401.75	277.63	257.20
Nickel	100.00	97.25	71.47	59.38	42.41	20.78	20.78	24.74	18.53	24.77	32.93	35.58	31.05	13.11
Oil	100.00	31.91	28.08	46.86	21.45	50.37	23.43	23.91	34.27	31.96	26.92	86.05	51.30	22.52
Silver	100.00	113.30	111.11	70.86	55.10	48.57	21.71	23.81	29.32	29.31	43.48	238.64	35.83	30.64
Steel	*	*	*	162.63	128.97	125.84	87.37	129.27	121.53	161.71	151.56	165.62	134.21	99.56
Tin	*	100.00	110.51	166.75	169.80	112.24	88.39	165.32	184.67	159.39	208.72	477.54	140.11	109.43
Zinc	100.00	102.96	110.58	95.54	104.69	70.57	49.94	81.43	104.66	79.56	71.42	82.20	105.35	58.67

* All commodities indexed to 1870 = 100 except aluminum (1895 = 100), natural gas (1919 = 100), steel (1897 = 100), and tin (1880 = 100).

SOURCE: Authors' calculations using data from Bureau of Labor Statistics, Department of the Interior, Department of Energy, and Manthy (1978).

stimulate the technological change that will offset that scarcity.[5] Whether technology advances rapidly enough to prevent a rise in the prices of the resources, however, is a question best left to the evidence.

WHAT IS THE EVIDENCE?

The conditions described above form a basis to test whether nonrenewable natural resources are becoming more scarce in an economic sense or whether technological advance is making them more plentiful. Rising real prices for nonrenewable natural resources would provide evidence that technological advance has not offset increased geophysical scarcity; constant real prices would indicate that technological advance has just offset increased scarcity; and falling real prices would signify that technological advance has more than offset increased geophysical scarcity.

In this article, we examine trends in the real prices of twelve nonrenewable natural resources—aluminum, anthracite coal, bituminous coal, copper, iron, lead, natural gas, nickel, crude oil, silver, tin and zinc—and one basic manufactured product, steel, to determine whether technological change is outpacing geophysical scarcity for nonrenewable natural resources. To obtain real prices from the nominal ones, we deflate the time series in two ways. The first method, suggested by the Hotelling rule and used by Fisher (1979) and Hartwick and Olewiler (1986), uses an overall price index, such as the U.S. Consumer Price Index (CPI), to deflate the prices of individual natural resources. This approach is the standard method for converting nominal prices to real prices and provides a conservative estimate of the extent to which technological progress has reduced the scarcity of nonrenewable natural resources.

The second method, suggested by the production function and used by Nordhaus (1973), deflates the prices of individual natural resources with the average manufacturing wage. This approach shows how much human effort is required to produce a given commodity and provides an aggressive estimate of the extent to which technological progress has offset resource scarcity.

An Overview of the Price Data

Under the conservative approach of deflating natural resource commodity prices by the CPI, most series generally decline, as shown in Table 1.[6] All but three of the commodities—anthracite coal, natural gas, and tin—had lower real prices in 1998 than they did in the first year for which data are available. In 1998, the prices of anthracite coal and tin were 22.07 percent and 9.43 percent above their respective initial values. The price of natural gas was 157.2 percent above its 1919 value. The prices of steel and bituminous coal were 0.44 percent and 3.68 percent below their initial values, respectively. The prices for the remaining eight commodities declined by more than 40 percent from the first year for which we have data to 1998. Most notable are nickel and aluminum prices, which in 1998 were 13.11 percent and 5.87 percent of their initial real prices, respectively.

Under the more aggressive approach of deflating natural resource commodity prices by manufacturing wages, we see stronger evidence of downward trends, as shown in Table 2. By

Table 2
Natural Resource Prices Deflated by Manufacturing Wages

Commodity	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	1998
Aluminum	*	*	*	55.71	29.99	15.19	11.06	7.24	3.14	2.94	2.19	2.67	1.75	1.24
Anthracite coal	100.00	67.12	65.30	68.04	68.49	60.40	63.64	41.41	42.33	23.70	22.14	40.05	24.92	16.98
Bituminous coal	100.00	62.50	49.50	52.00	44.21	51.14	23.18	21.70	25.31	15.63	14.10	30.09	19.00	13.39
Copper	100.00	100.94	73.58	76.37	47.96	22.51	17.02	12.36	10.60	10.12	12.26	9.86	8.05	4.12
Iron	100.00	85.85	56.24	60.52	41.61	40.22	17.22	17.86	17.09	15.20	11.43	15.20	NA	NA
Lead	100.00	80.65	72.58	70.97	56.03	35.19	24.19	19.06	22.35	12.74	11.34	14.14	10.28	8.12
Natural gas	*	*	*	*	*	96.78	78.25	38.61	25.56	35.08	28.90	123.85	89.41	82.21
Nickel	100.00	74.22	50.78	39.06	24.67	8.95	7.46	6.21	3.66	3.84	4.51	4.77	4.35	1.82
Oil	100.00	24.35	19.95	30.83	12.48	21.69	8.41	6.01	6.77	4.95	3.69	11.54	7.19	3.13
Silver	100.00	86.47	78.95	46.62	32.05	20.92	7.79	5.98	5.80	4.54	5.96	32.00	5.02	4.26
Steel	*	*	*	162.63	114.04	82.37	47.66	49.36	36.51	38.08	31.57	33.76	28.58	21.04
Tin	*	100.00	102.88	143.75	129.43	63.33	41.56	54.41	47.83	32.36	37.48	83.92	25.72	19.94
Zinc	100.00	78.57	78.57	62.86	60.90	30.39	17.92	20.45	20.68	12.33	9.79	11.02	14.76	8.16

* All commodities indexed to 1870 = 100 except aluminum (1895 = 100), natural gas (1919 = 100), steel (1897 = 100), and tin (1880 = 100).

SOURCE: Authors' calculations using data from Bureau of Labor Statistics, Department of the Interior, Department of Energy, and Manthy (1978).

1998, all the commodities had lower real prices than they did in the first year for which data are available, and over half the commodities had prices that were less than one-tenth of their initial values. The 1998 prices of anthracite coal, natural gas, and tin, which show gains in the CPI-adjusted series, were 16.98 percent, 82.21 percent, and 19.94 percent of their initial values, respectively. The real 1998 prices of steel and bituminous coal stood at 21.04 percent and 13.39 percent of their initial values, respectively. The prices of nickel and aluminum were 1.82 percent and 1.24 percent of their first reported prices.

Because commodity prices vary over the business cycle, we also analyze data that coincided with peaks of both U.S. and world business cycles. We find substantially similar price trends to those reported in Tables 1 and 2.

Econometric Tests of Resource Scarcity: 1870–1998

Although prices for most nonrenewable natural resources generally fell from the first year for which data are available, they also exhibited considerable volatility. Over short periods, price data may reflect a number of market conditions other than resource scarcity and technological advance, such as monopolization, cartelization, taxation, and regulation. To abstract from possible short-term fluctuations, we test for time trends in the prices of resources, using annual data from 1870 through 1998 as follows:[7]

$$\ln P_i = \alpha_i + \beta_i t + e_{t,i} \quad (8)$$

for each nonrenewable natural resource i, where P_i is the real price of resource i, t is time, α_i and β_i are parameters to be estimated, and $e_{t,i}$ is a normally distributed error term. As before, we measure real prices for each of the thirteen commodities by two methods—deflating with the CPI and deflating by average U.S. manufacturing wages.

Estimating Equation 8 for the more conservative, CPI-adjusted data yields mixed results, as shown in Table 3. Prices for five of the commodities—anthracite coal, bituminous coal, natural gas, steel, and tin—show significant positive annual trend rates of growth, varying from a low of 0.2 percent for steel to a high of 2 percent for natural gas. Prices for iron and crude oil show no significant trends. Prices for the other six commodities—aluminum, copper, lead, nickel, silver, and zinc—show significant negative annual trend rates of growth, varying from –0.3 percent for lead and zinc to –2.2 percent for aluminum.

Estimating Equation 8 for the more aggressive, wage-adjusted data yields stronger declines in commodity prices, as shown in Table 4. With the exception of natural gas, all the commodity price indexes show significant negative trends. Annual rates range from –1.2 percent for anthracite and bituminous coal to –4.1 percent for aluminum. Natural gas has no significant trend.

To control for potential variation of commodity prices over the business cycle, we also estimate Equation 8 by including measures of world and U.S. GDP. Although business cycles are shown to be significant in a few of the real commodity prices, the signs and significance of the trend coefficients are substantially similar to those in Tables 3 and 4.

Econometric Tests of Resource Scarcity: Subperiods

When working with such a long time series, breaks in the trends are possible. Casual observation suggests the possibility of such breaks for most price series around the end of World War II. To test formally for breaks in the individual series, we conduct Chow tests using data from 1870 through 1945 in the first period and 1946 through 1998 in the second period.[8] The results show that at the 95 percent confidence level every price series, except lead and tin deflated by manufacturing wages only, has a significant break between 1945 and 1946.

Armed with this information, we repeat the econometric exercises described in Equation 8 for two periods—from 1870 through 1945 and from 1946 through 1998. For most of the commodities, strong downward trends in prices are found from 1870 through the end of World War II, but price declines moderate or reverse in the postwar era.

With the CPI-deflated commodity prices, ten of the thirteen pre-1946 series trend downward (*Table 5*). Anthracite coal and tin trend upward, and bituminous coal shows no price trend. After 1945, however, price declines moderate. Five of the commodity price series show significant positive trends, four show no significant trend, and four show significant negative trends.

With the wage-deflated commodity prices, all eleven of the pre-1946 series trend downward (*Table 6*). As with the CPI-adjusted data, price declines moderate after 1945. Four of the commodity price series show no significant trend, and six show significant negative trends. Only natural gas shows a significant positive trend after 1945.

As we did for the entire sample period, we control for potential variation of commodity prices over the business cycle in the subperiods using measures of both world and U.S. GDP. Although business cycles are significant in a few commodity prices, the signs and significance of the trend coefficients are substantially similar to those in Tables 5 and 6.

Table 3

Estimated Trends in Natural Resource Prices Deflated by the CPI, 1870–1998

Commodity	Constant	Trend growth rate
Aluminum	.73**	–.022**
Anthracite coal	1.75**	.007**
Bituminous coal	1.26**	.006**
Copper	–.54**	–.007**
Iron	4.65**	.001
Lead	–1.75**	–.003**
Natural gas	–3.34**	.020**
Nickel	.98**	–.012**
Oil	1.16**	.001
Silver	1.05**	–.007**
Steel	1.50**	.002**
Tin	–.26**	.006**
Zinc	–1.67**	–.003**

** Denotes significance at the 95 percent confidence level.

SOURCE: Authors' estimates using data from the Bureau of Labor Statistics, Department of the Interior, Department of Energy, and Manthy (1978).

Table 4

Estimated Trends in Natural Resource Prices Deflated by Manufacturing Wages, 1870–1998

Commodity	Constant	Trend growth rate
Aluminum	1.71**	–.041**
Anthracite coal	2.66**	–.012**
Bituminous coal	2.18**	–.012**
Copper	.38**	–.025**
Iron	5.65**	–.019**
Lead	–.83**	–.022**
Natural gas	–2.64**	.004
Nickel	1.89**	–.031**
Oil	2.08**	–.017**
Silver	1.97**	–.025**
Steel	2.48**	–.017**
Tin	.67**	–.013**
Zinc	–.75**	–.021**

** Denotes significance at the 95 percent confidence level.

SOURCE: Authors' estimates using data from the Bureau of Labor Statistics, Department of the Interior, Department of Energy, and Manthy (1978).

Econometric Tests of Resource Scarcity Reconsidered

Econometric tests conducted for the entire period or subperiods generally suggest similar results for samples that include the post–World War II data. Using the more conservative CPI-adjusted data, we find that real prices for some nonrenewable natural resources have positive trends while others have negative trends. Using the more aggressive wage-adjusted data, we find no significant upward trends in commodity prices. Breaking the series into two periods, however, we find evidence that price declines for nonrenewable natural resources may have moderated (or reversed for some CPI-adjusted price series) since World War II.[9] Predicting future price increases from this moderation is unwarranted, however.[10]

At issue is whether the more conservative or the more aggressive approach to analyzing the price data is more appropriate for assessing resource scarcity. The CPI-deflated price data measure the scarcity of the nonrenewable natural

Table 5

Estimated Trends in Natural Resource Prices Deflated by the CPI, 1870–1945 and 1946–1998

1870–1945 Commodity	Constant	Trend growth rate	1946–1998 Commodity	Constant	Trend growth rate
Aluminum	1.32**	–.033**	Aluminum	–.48**	–.010**
Anthracite coal	1.64**	.010**	Anthracite coal	2.39**	0
Bituminous coal	1.43**	0	Bituminous coal	1.29**	.006**
Copper	–.26**	–.016**	Copper	–.41*	–.007**
Iron	4.92**	–.008**	Iron	3.82**	.012**
Lead	–1.71**	–.006**	Lead	–.37*	–.016**
Natural gas	–.22	–.028**	Natural gas	–5.55**	.041**
Nickel	1.54**	–.030**	Nickel	–.51*	.003
Oil	1.52**	–.010**	Oil	.49	.009**
Silver	1.60**	–.024**	Silver	–.50	.009**
Steel	1.84**	–.006**	Steel	1.80**	–.001
Tin	–.25**	.005**	Tin	.50	–.001
Zinc	–1.54**	–.007**	Zinc	–1.53**	–.004**

** Denotes significance at the 95 percent confidence level.
* Denotes significance at the 90 percent confidence level.

SOURCE: Authors' estimates using data from Bureau of Labor Statistics, Department of the Interior, Department of Energy, and Manthy (1978).

Table 6

Estimated Trends in Natural Resource Prices Deflated by Manufacturing Wages, 1870–1945 and 1946–1998

1870–1945 Commodity	Constant	Trend growth rate	1946–1998 Commodity	Constant	Trend growth rate
Aluminum	2.59**	–.057**	Aluminum	–.71**	–.017**
Anthracite coal	2.58**	–.008**	Anthracite coal	2.16**	–.007**
Bituminous coal	2.36**	–.017**	Bituminous coal	1.07**	–.001
Copper	.68**	–.034**	Copper	–.64**	–.014**
Iron	5.85**	–.026**	Iron	4.32**	–.003
Lead†			Lead†		
Natural gas	1.37**	–.057**	Natural gas	–5.78**	.033**
Nickel	2.48**	–.048**	Nickel	–.74**	–.004*
Oil	2.45**	–.028**	Oil	.26	.001
Silver	2.53**	–.042**	Silver	–.73*	.002
Steel	3.14**	–.030**	Steel	1.57**	–.008**
Tin†			Tin†		
Zinc	–.61**	–.025**	Zinc	–1.75**	–.011**

** Denotes significance at the 95 percent confidence level.
* Denotes significance at the 90 percent confidence level.
† Authors chose not to estimate this series in two periods because there was no break in trend.

SOURCE: Authors' estimates using data from Bureau of Labor Statistics, Department of the Interior, Department of Energy, and Manthy (1978).

resources relative to a given basket of goods. Because improved technology increases the availability of all goods, the CPI-deflated measures of prices tend to underestimate the effect of technological change in increasing the availability of the resources.[11]

Deflating the price data with manufacturing wages captures technological change that increases the availability of all goods, but it also reflects the rising educational attainment of manufacturing workers from 1870 to 1998. As such, the wage-deflated price measures tend to overestimate the effect of technological change in increasing the availability of nonrenewable natural resources. The relevant real price—and the correct assessment—lies somewhere between those found with the two measures. Table 7 presents a summary of what we can conclude from the relevant measures of the real prices of the nonrenewable natural resources in question. (Also, see the appendix.)

SUMMARY AND CONCLUSIONS

Some observers remain concerned that increasing natural resource scarcity will limit future economic growth and human well-being, while others remain optimistic that technological change will overcome geophysical scarcity. Reliance on free markets can promote the requisite technological change. The increasing scarcity of a natural resource increases its price. When they expect higher prices, consumers look for technology that lets them use less of a natural resource. Producers turn to technology that lowers production costs in expectation of higher profits.

The question is whether technological change can outpace geophysical scarcity, and economic theory suggests a test. Rising real prices for nonrenewable natural resources would provide evidence that technological advance has not offset increased geophysical scarcity; constant real prices would indicate that technological advance has just offset increased geophysical scarcity; and falling real prices would signify that technological advance has more than offset increased geophysical scarcity.

Using econometric tests to examine the trends in the real prices of thirteen commodities, we find little evidence of increased natural resource scarcity from 1870 through 1998. For none of these commodities do we find conclusive evidence that the relevant real price has risen. Our results indicate that the relevant real prices could have risen or remained unchanged for natural gas; could have risen or fallen for anthracite coal, bituminous coal, steel, and tin; could have remained unchanged or fallen for iron and crude oil; and have fallen for aluminum, copper, lead, nickel, silver, and zinc.

Although we find evidence that price declines for nonrenewable natural resources may have moderated (or reversed for some CPI-deflated price series) since World War II, we find little evidence of increased scarcity. For only one of the thirteen commodities—natural gas—do we find conclusive evidence that the relevant real price has risen. The real price of tin could have risen or fallen. The real prices could have risen or remained unchanged for bituminous coal, iron, crude oil, and silver; could have remained unchanged or fallen for anthracite coal, nickel, and steel; and have fallen for aluminum, copper, lead, and zinc.

In short, the evidence suggests that over the past century, new technology driven by free market forces has overcome the geophysical scarcity of nonrenewable natural resources. Increased reliance on markets during the closing decades of the twentieth century is cause for optimism that these trends will continue in the twenty-first.

Table 7

Summary of Trends in the Real Prices of Nonrenewable Natural Resources

Commodity	Whole period (1870–1998)	Post–World War II
Aluminum	Falling	Falling
Anthracite coal	Rising to falling	Unchanged to falling
Bituminous coal	Rising to falling	Rising to unchanged
Copper	Falling	Falling
Iron	Unchanged to falling	Rising to unchanged
Lead	Falling	Falling
Natural gas	Rising to unchanged	Rising
Nickel	Falling	Unchanged to falling
Oil	Unchanged to falling	Rising to unchanged
Silver	Falling	Rising to unchanged
Steel	Rising to falling	Unchanged to falling
Tin	Rising to falling	Rising to falling
Zinc	Falling	Falling

SOURCE: Authors' estimates using data from the Bureau of Labor Statistics, Department of the Interior, Department of Energy, and Manthy (1978).

NOTES

The authors would like to thank W. Michael Cox for providing manufacturing wage data.

1 For illustrative purposes, we assume constant returns to scale for the world economy—that is, a doubling of all inputs doubles output.

2 If $C_{X,t}$ is negative, the user cost rises more rapidly than the interest rate.

3 For extremely high values of $C_{X,t}$, the user cost and price of the natural resource would fall over time. These conditions do not generally exist. See Dasgupta and Heal (1979).

4 Futures markets for nonrenewable natural resources occasionally go into backwardation, reflecting short-term supply constraints and the cost to users of stocking out.

5 Of course, technological advance may occur without such stimulation, but a historical comparison of the rates of technological growth in free market economies with those occurring in the Communist-bloc countries demonstrates the importance of incentives to technological change.

6 The 1980 prices show evidence of the commodity price explosion in the 1970s, as prices for most commodities rise dramatically, then begin to fall.

7 Price data for aluminum, iron, natural gas, steel, and tin cover the periods 1895–1998, 1870–1981, 1919–98, 1897–1998, and 1880–1998, respectively.

8 The data may show additional or more-optimal breaks than between 1945 and 1946, but exhaustive testing of breaks is of relatively low power econometrically.

9 The commodity price explosion in the 1970s may have contributed to the break in trend. Residuals for trends estimated over the entire period and the 1870–1945 subperiod are white noise, but residuals

for most trends estimated over the 1946–98 period are not.

[10] Using CPI-adjusted data, Slade (1982) uses a quadratic time-trend to predict that prices for nearly all nonrenewable natural resources would eventually begin rising. Berck and Roberts (1996) show that other specifications are preferred and that Slade's conclusions are unwarranted.

[11] Consider the case in which technology changes in such a way that all goods and services, including nonrenewable natural resources, could be produced with half as much effort. The CPI-deflated measure of prices for nonrenewable natural resources would suggest no change in availability.

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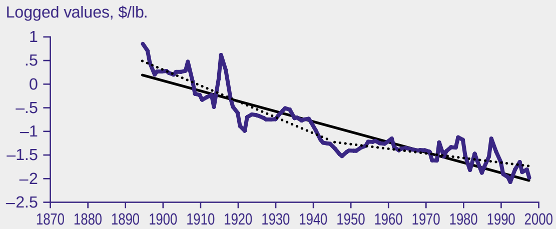
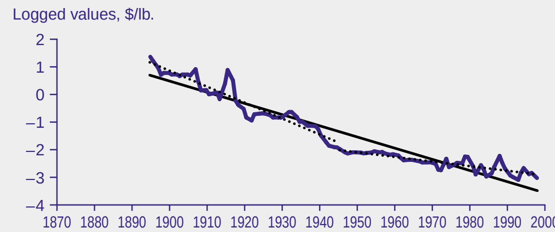
Appendix

Trends in Natural Resource Prices

Deflated by the CPI | **Deflated by manufacturing wages**

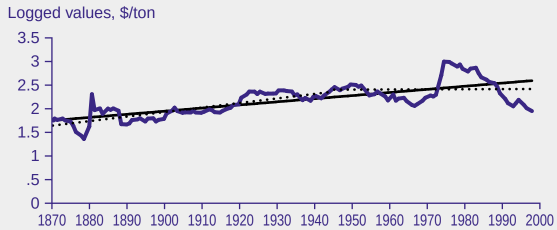
Aluminum

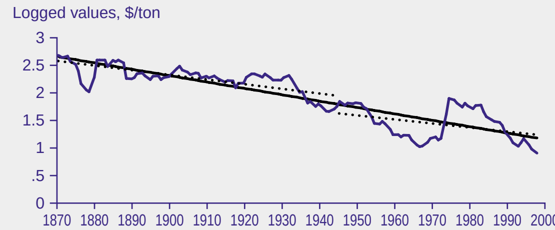




By all measures, relevant real price fell during entire period, as well as after World War II.

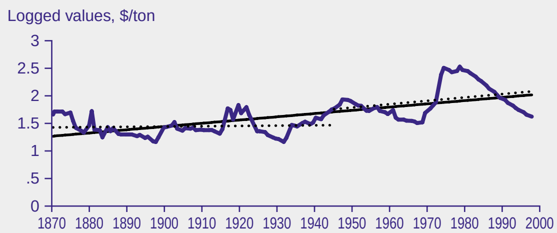
Anthracite coal

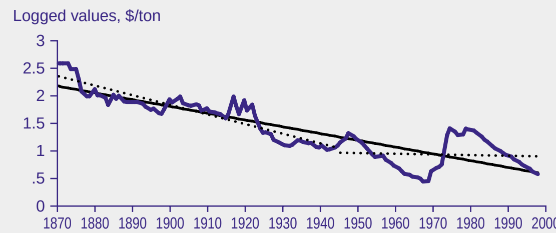




Relevant real price could have risen or fallen during entire period but has remained unchanged or fallen since World War II.

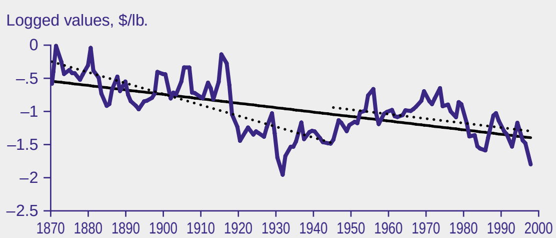
Bituminous coal

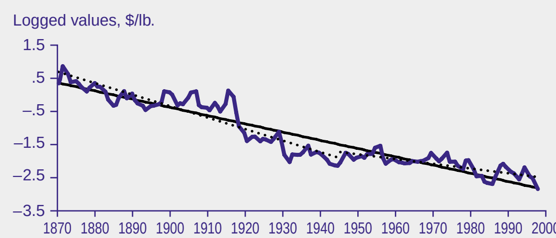




Relevant real price could have risen or fallen during entire period but has risen or remained unchanged since World War II.

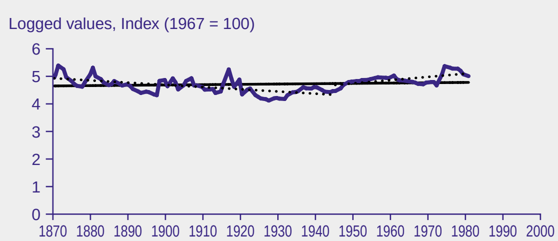
Copper

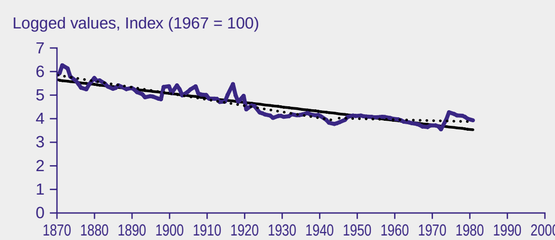




By all measures, relevant real price fell during entire period, as well as after World War II.

Iron





Relevant real price could have remained unchanged or fallen during entire period but has risen or remained unchanged since World War II.

Actual price — Trend whole period ······ Trend pre-1946 and post–World War II

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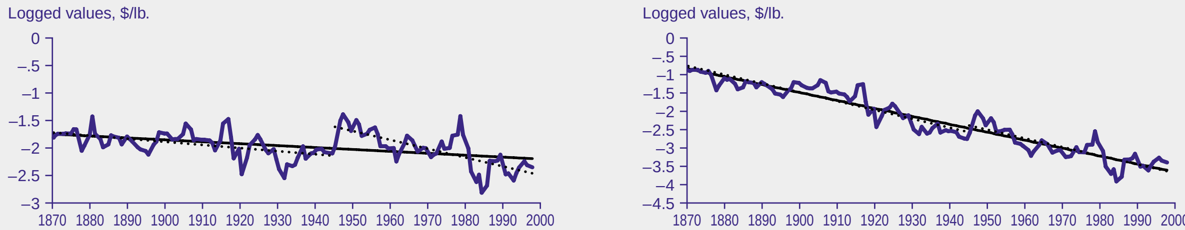
Appendix *(continued)*

Trends in Natural Resource Prices

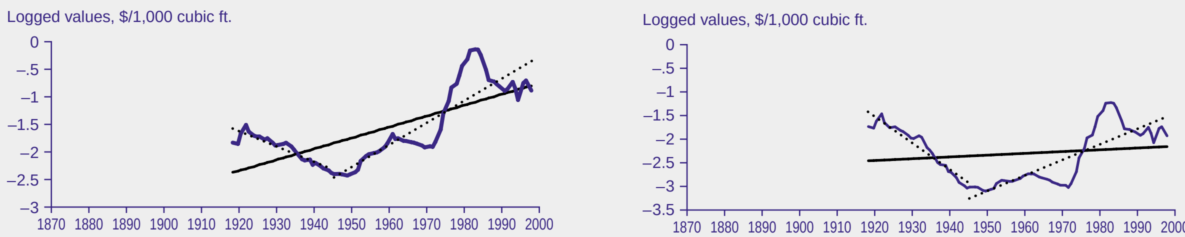
Deflated by the CPI | **Deflated by manufacturing wages**

Lead



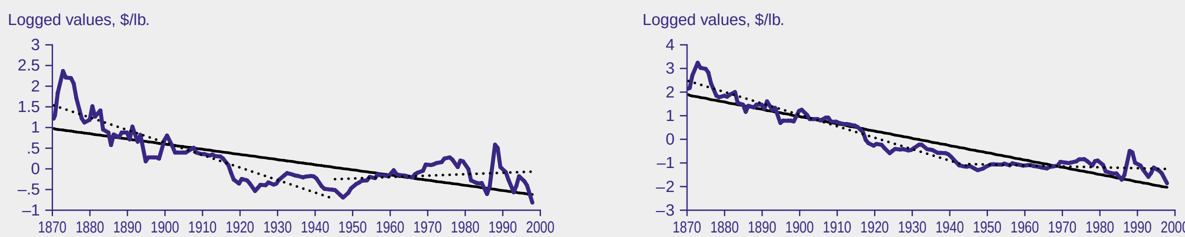
By all measures, relevant real price fell during entire period, as well as after World War II. Chow test indicates price data deflated by manufacturing wages should not be split into the two periods 1870–1945 and 1946–1998.

Natural gas



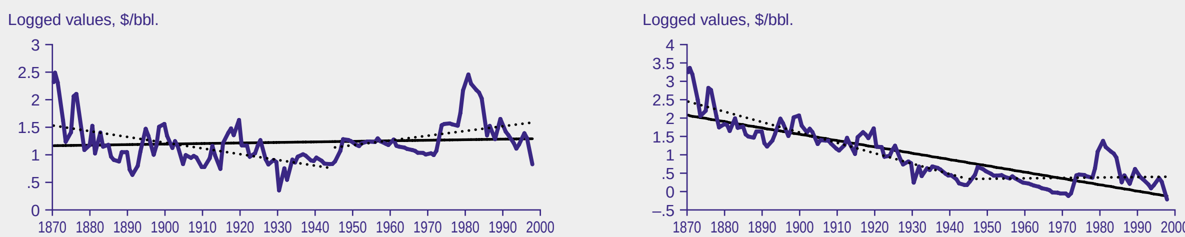
Relevant real price could have risen or remained unchanged during entire period but, by all measures, has risen since World War II.

Nickel



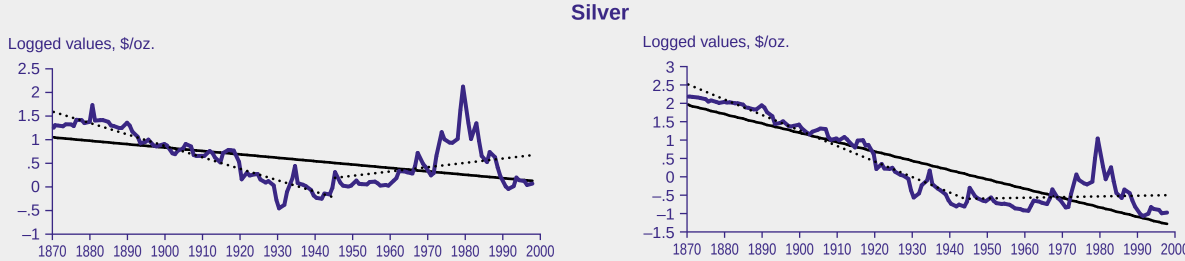
Relevant real price fell during entire period but has remained unchanged or fallen since World War II.

Oil



Relevant real price could have remained unchanged or fallen during entire period but has risen or remained unchanged since World War II.

Silver



Relevant real price fell during entire period but has risen or remained unchanged since World War II.

Actual price — Trend whole period ······ Trend pre-1946 and post–World War II

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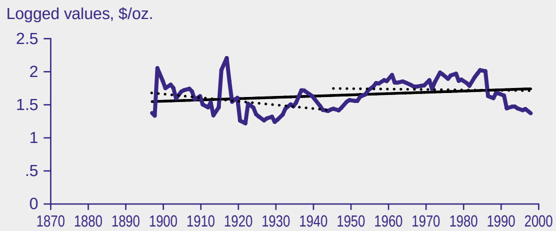
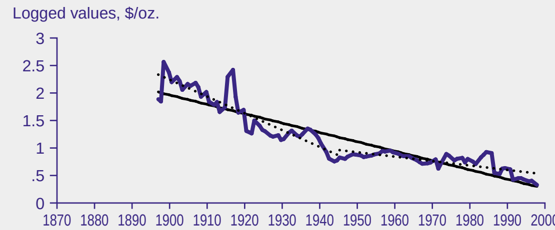
Appendix *(continued)*

Trends in Natural Resource Prices

Deflated by the CPI | **Deflated by manufacturing wages**

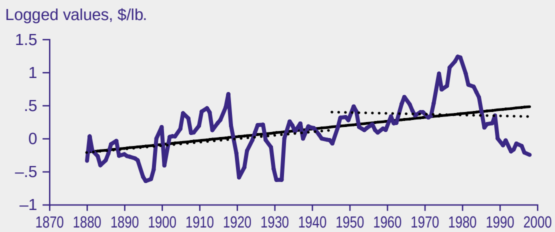
Steel

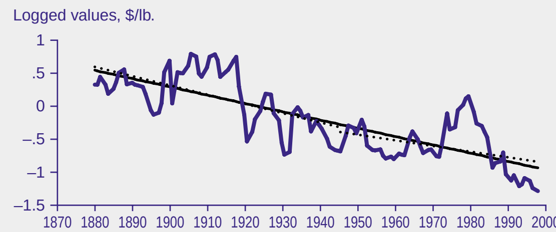




Relevant real price could have risen or fallen during entire period but has remained unchanged or fallen since World War II.

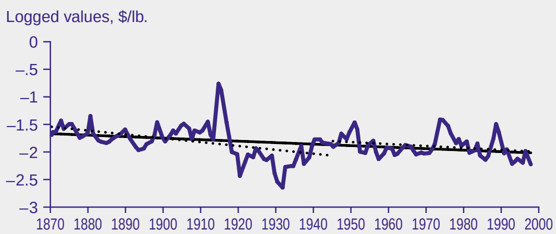
Tin

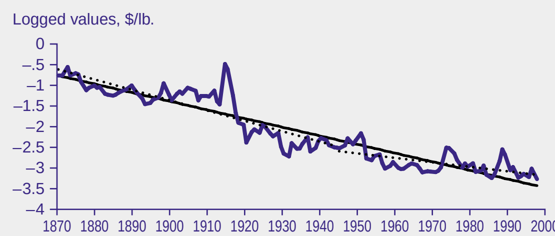




Relevant real price could have risen or fallen during entire period, as well as since World War II. Chow test indicates price data deflated by manufacturing wages should not be split into the two periods 1870–1945 and 1946–1998.

Zinc





By all measures, relevant real price fell during entire period, as well as after World War II.

Actual price — Trend whole period ······ Trend pre-1946 and post–World War II

SOURCE: Authors' calculations and estimates using data from the Bureau of Labor Statistics, Department of the Interior, Department of Energy, and Manthy (1978).