Lethality at Lower Prices: How the American System of Manufactures, Mass Production and the Red Queen Shaped Modern Warfare

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Summary

Why is it that the 20th century blessed by historically unparalleled improvements in the standard of living is also known as the century of horrors, vilified by politically induced famines killing millions, a holocaust aimed at exterminating an entire people, ethnic cleansing and interstate conflicts raging across the entire globe? The thesis offered by this paper is that the very combination of embodied and disembodied technological change raising the standard of living to unheard of heights also drive down the relative price of exerting military force, of unleashing lethality. In examining embodied technological change the emphasis of the paper is on inventions that improved the quality of capital yielding faster transportation, more rapid communications and more lethal firepower. In analyzing disembodied technological change the discussion focuses on the American system of manufactures, mass production exemplified by the assembly line coupled with mass distribution due to declining costs of transport and communications, and growth in knowledge within the fields of electronics and chemistry. In particular, the decline in the relative price of iron and steel products occurring in the latter half of the 19th century drove down the relative prices of lethality, military force more generally. A side effect of its decline was the growing ease with which challenges to state power could be sustained, thereby undermining the stability of many of the nation-states that came into existence after World War II.

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I Unprecedented Growth in Per Capita Income, Unprecedented Growth in the Means of Exerting Military Force

Why is the 20th century both cursed and praised? Why is it considered the most Janus faced period in human history? Simultaneously generating remarkable improvements in consumerism and wealth, yet scarred by unimaginable onslaughts on humanity, millions going to their deaths in wars, politically motivated famines and holocausts? Why is it graced by unprecedented growth in per capita income; and at the same time disfigured by the unprecedented horrors of violence launched by political organizations, the carnage of worldwide military conflicts, ethnic cleansing designed to exterminate entire peoples, confinement in concentration and/or labor camps, politically engineered famines backed up police or military personnel confining starving peoples in hunger zones where they perished in agony?

It is impossible to completely document this point. That said some estimates crude and imprecise as they may be, are revealing. Table 1 gives a glimpse, listing the bloodiest military conflicts of the 19th and 20th centuries, demonstrating the marked increase in potential of humans to exterminate one another on a mass scale. A more detailed accounting should include the conscious destruction of civilian populations in holocausts, in killing fields, in labor camps, as well as in gulags that slaughter through a deadly combination of undernourishment and overwork. [1]

The answer to the question posed at the outset of this paper is straightforward albeit incomplete given the complexity of the issues involved. Consider the following equation:

$$\textbf{[1]} \quad \mathbf{M = f(mY, p_{mf}) = f(myP, p_{mf})}$$

Where **m** is the rate that income is converted into military purposes (including the direct costs of arming military personnel and the opportunity cost of withdrawing population from the civilian labor force), **Y** is total income for a nation or sub-national group, **y** is its per capita income and $\mathbf{p_{mf}}$ is the relative price of exerting military force. The thesis is twofold: first per capita income has risen in the 20th century thereby increasing the capacity of populations to purchase through a combination of private market and governmental mechanisms the means of carrying out institutional violence; second, and more important, the price, the cost, of exerting organized military force has dropped precipitously relative to other prices, relative to the general consumer price index. Ultimately, technological progress that shape economic outcomes lies at the root of the 20th century's horrible paradox.

This paper documents the decline in the relative price of exerting military force and revealing its proximate technological sources. To this end a simple analytical framework is useful. The framework makes a basic distinction between augmenting the factors of production – improving their quality through long streams of invention and innovation – and total factor productivity growth due to disembodied technological progress. [2]

I characterize augmentation for each of the factors of production as follows: land is augmented through fertilization, irrigation, and selection and/or hybridization of seed varieties and domesticated animals used in farming; capital is improved through the embodying of technical advances in its construction; and labor is augmented by increases in hours worked and/or improvements in the efficiency of each hour worked. Employing formal algebra I define augmented land as:

$$\textbf{[2]} \quad \mathbf{La^* = (q_{La})\, La}$$

where **La*** is augmented land, $\mathbf{q_{La}}$ is land quality (taking into account biological inventions and enrichment through irrigation and fertilization embodied in it), and **La** is land area (in acres). Again, I define augmented capital as:

$$[3] \quad \mathbf{K^* = (q_K)K}$$

where **K*** is augmented capital, $\mathbf{q_K}$ is capital quality (the proxy I envision here is the average age of capital, its vintage), and **K** is the capital stock. Finally I define augmented labor **L*** as:

$$[4] \quad \mathbf{L^* = h\ e(h)\ W}$$

Where **L*** is augmented labor, **h** represents average hours worked per worker, e(h) is the efficiency of each hour worked, and **W** represents the number of workers. With these augmented factors of production I write a simple multiplicative Cobb-Douglas production function:

$$[5] \quad \mathbf{Q = A\ (K^*)^{\alpha}(L^*)^{\beta}(La^*)^{[1-(\alpha+\beta)]}}$$

where A is the index of total factor productivity (reflecting the introduction of general purpose technologies that are conceptual and are applied in a wide variety of applications and economies of scale like those realized with mass production methods of production) and the exponents for each augmented factor of production are the shares of the augmented factor in total income. Reconfiguring the equation in terms of growth rates for A and for each augmented factor or production yields the following equation for growth rates - the growth rate of each variable **x** is **g(x)** – relating growth in output to growth in total factor productivity and growth in the augmented factors of production, namely:

$$[6] \quad \mathbf{g(Q) = g(A) + \alpha\ g(K^*) + \beta\ g(L^*) + [1-(\alpha+\beta)]\ g(La^*)}$$

This equation will guide discussion throughout the rest of this paper.

In particular the quality of capital stock and total factor productivity are the focus of the analysis. The utility of the framework can be examined by explaining improvements in the lethality, the quality, of weapons, with two concrete illustrations: the evolution of muskets and rifles in the American Harpers Ferry Armory in the period 1800 to 1860 and the evolution of the machine gun from its origins in designs developed during the Civil War in the United States to the Kalashnikov AK-47 developed in the Soviet Union in the late 1940s. To do so we must differentiate between the theoretical lethality of guns and their operational lethality in conditions of warfare. We turn to this task in the next section.

II Lethality and Dispersion

In developing a metric for estimating the quality of weapons I use employ the distinction developed by Dupuy (1940), namely between the theoretical lethality of a weapon and the dispersion pattern of warfare stemming from improvements in the quality of the weapons themselves and the quality of equipment used in the transport of troops and the quality of the means of communications employed in coordinating their use. It is useful to give a sample of Dupuy's estimates for the theoretical lethality of various weapons (the theoretical lethality index **TLI**) which he divides by the dispersion pattern of warfare to arrive at a measure of the operational lethality (the operational lethality index, **OLI**) of each type of weapon in Table 2. Noteworthy in Panels B and C are: (1) the theoretical lethality of weapons has increased dramatically during the 19th and 20th centuries; (2) equally impressive is the increase in the dispersion pattern of warfare, the capacity of troops to occupy and control militarily territory (note the dramatic increase in the number of square meters per soldier illustrated in a comparison of the Napoleonic Wars and World War II); (3) hence there is a growing divergence between the theoretical lethality index of an individual weapon and its operational lethality index; and (4) a definite tendency of weapons to experience technological obsolescence in the sense that the operational lethality of a weapon like the late 19th century rifle declines over time as more advanced weapons come on-stream in the 20th century.

That the price of lethality has fallen relative to the general price level is largely based on using data for the United States which breaks the analysis into chronological periods: the period prior and leading up to the Civil War, 1800-1861; and the period thereafter, 1862-2000. My focus in mainly on the United States for two reasons: the availability of a wide range of data dating from 1800; the fact that the Civil War was a transitional war, not a modern industrial war in the fullest sense of the world but at the same time not a pre-industrial conflict like the Napoleonic Wars. Before the Civil War, technological progress in the manufacture of firearms largely stemmed from a steady stream of minor inventions embodied in the quality of arms produced and from applications of the American system of manufactures. After the Civil War, mass production, improvements in scientific knowledge especially in chemistry and electrical engineering relentlessly drove down the price of lethality.

To give some concreteness to the discussion of firearm quality it is useful to consider four guns: the French Charleville/Springfield 1795 muskets used in the late 18th century (the Springfield 1795 gun was largely modelled on the Charleville 1763 gun used by many Americans during the Revolutionary War); the Springfield Model 1840 rifle musket that was used during the decade of the 1850s and during the Civil War itself; the M1 Garand semi-automatic rifle developed by the US Army in the 1920s; and the AK-47 Kalashnikov put into mass production in the Soviet Union after World War II. The first two guns are typical examples of early industrial warfare, the last two of industrial mass production warfare embodying simplified designs for ease of manufacture. Selected characteristics of the guns appear in the following chart [3]:

Characteristic	French Charleville, Springfield 1795	Springfield Model 1840 Rifled Musket (1850-1865)	M1 Garand semi-automatic rifle	Kalashnikov AK-47 fully automatic
Weight	10 lbs.	8.4 lbs.	9.5 – 10.2 lbs.	8.4 lbs.
Rate of fire	2 -3 rounds/min	2 – 3 rounds/min	40 – 50 rounds a minute (trained soldier)	600 rounds/min (untrained soldier)
Action	Flinklock	Percussion cap	Gas operated rotating bolt	Gas operated rotating bolt
Feed system	Muzzle loaded	Muzzle loaded	8 – round *en bloc* clip	10 – 75 round detachable box
Caliber/cartridge size	.69 in. (.625 in. ball)	.69 in. (.65 in. minié ball)	7.62 × 63 mm.	7.62 × 39 mm.
Effective range	50 – 75 yds.	100 – 400 yds.	440 yds.	300 – 400 yds.
Muzzle velocity	1,500 ft./sec.	954 ft./sec.	2,800 ft./sec.	2,395 ft./sec.
Efficiency (foot pounds of muzzle energy per grain of propellant)	9.0 – 11.6	20.6	Not estimated	Not estimated
Recoil due to bullet velocity	8.83 ft./sec.	9.36 ft./sec.	2.7 lb./sec.	Not estimated (minimal)
Accuracy	Low (mainly used in volley fire)	High (trained soldier)	High (trained soldier)	Low (mainly used in volley fire)
Cleaning	Difficult [4]	Moderate (use of minié bullet reduced fouling)	Not estimated	Easy [5]
Danger in usage	High (might explode)	Low	Low	Low

The chart makes clear that increase in lethality over time derives from a wide variety of weapon characteristics. From an economist's perspective the ideal approach to estimating the relative price of a firearm begs for a hedonic price analysis; this is not something easily accomplished. Instead what I do here is use the theoretical lethality level of the various weapons as a gauge of weapon quality.

Panel A of Table 2 shows how weapon lethality has soared without significantly driving up unit costs. Combining various 2010 price quotations in US dollars for an AK-47 fully automatic assault rifle with the David-Solar price index for the United States given in Volume C of Carter et all (2006) I project backward to estimate the hypothetical price for the weapon in the period 1816-25 under the assumption that it could be purchased in that era. [6] I do this under a number of scenarios concerning the price of an AK-47 in 2010. A price of around $200 is most reasonable. [7] Given the likely level of the theoretical lethality index for an AK-47 – I actually use an estimate for a World War II machine gun that probably had a lower level of lethality than an AK-47 to make the calculations – I compute the ratio of the price of a unit of lethality technically possible after World War II to the price of a unit of lethality that was technically possible in the decade 1816-25. The implied ratios imply substantial gain in the relative price of lethality over time.

Most of the reduction in the relative price of a unit of lethality took place after the Civil War in the United States. To establish this I will show – exploiting data on the prices of muskets and musket rifles produced at Harpers Ferry Armory over the period 1800 to 1858 given in Appendix Table 1 in Smith (1977) – that the drop in the relative price of quality adjusted muskets was very gradual during that era.

During this period in the United States applications of the system of manufactures coupled with a slow moving yet steadily moving stream of quality improvements in individual muskets and riles pioneered at the Springfield and Harpers Ferry Armoires increased firearm lethality without appreciably driving up unit costs. Examples of the system of manufactures include the modularity principle, the assembling standardized interchangeable parts turned out with machine tools like lathes and milling machines into standardized manufacture products. Examples of the latter are modifications of inventions pioneered in Europe (especially France). What were not evident during this period were the major advances in steel-making stemming from a combination of technical advances in chemistry and scale economies that yielded impressive declines in the relative price of steel. In turn falling costs of steel dramatically cut the costs of manufacturing guns during the late 19th and 20th centuries.

Our story begins with Thomas Jefferson. As Minister to France between 1785 and 1789, Jefferson deepened his knowledge of French and British innovations stemming from the practical application of science. In 1785, in Paris, he visited the workshop of Honoré Blanc, a military blacksmith working in an experimental workshop that was attempting to substitute interchangeable parts for craft manufacture. Blanc's job was developing a novel method of turning out muskets in a standardized fashion. Enjoying the support of the French artillery service interested in reducing the costs of manufacturing flintlock muskets, Blanc was assembling flintlock mechanisms, drawing components – tumblers, cocks, screws, and springs – out of bins each devoted to one component. What impressed Jefferson was the principle of modular assembly: creating large volumes of interchangeable parts that later on would be fit together, reducing costs through scientifically informed engineering while simultaneously enforcing product standards. Before returning to the United States, Jefferson shipped a bundle of gunlocks to the newly founded republic; arriving home he became a fervent advocate for the employ of interchangeable parts in the manufacture of small arms. Indeed soon after Jefferson's return, the army's Ordnance Department underwrote the application of Blanc's principles in its Springfield and Harpers Ferry arsenals. [8]

As for technical breakthroughs largely independent of the American system of manufactures one should include experiments in creating a breech loading firearm as opposed to a muzzle loaded firearm, the introduction of the percussion cap as a substitute for the flintlock, and the use of the minié bullet that reduced fouling especially in rifled barrels. An additional invention was the Spencer carbine that employed a seven round magazine allowing a member of the Union cavalry to outshoot his Confederate opponent (getting off seven shots in the time a musket using Confederate could get off two).[9]

In the long run, advances in the application of the American system of manufactures that was to yielded the important gains for weapons production. It set the stage for the mass production of weapons using standardized interchangeable parts turned out by specialist industrial workers employing machine tools. [10] The first fully manufactured gun assembled by interchangeable parts was produced at the Springfield Armory in 1844 and in 1845 at Harpers Ferry: this was the US Model 1842 percussion musket. Earlier experiments aimed at reducing all steps in production to only those based on manufacturing standardized parts, most notable were those carried out by John H. Hall who introduced cutting machines that even young boys could operate during the 1810s and 1820s. [11] Nash patented a lathe for turning out musket barrels in 1818; Blanchard created a lathe for turning out gun stocks; indeed, he invented thirteen different woodworking machines to make gunstocks. Between 1845 and 1854 twenty five structures were built at Harpers Ferry, many designed specifically to house machine tools used in interchangeable parts production. These included a two-story boring mill; a forging and smith's shop; a grinding mill; and a stocking and machine shop. [12] A complete catalogue displaying pictures of the machine tools employed at the two arsenals, Springfield and Harpers Ferry that operating under the control of the US Army Ordnance Department after the War of 1812, is given in Benton (1970). In sum, much of the advance in the quality of weaponry manufactured in the United States to the specification of the US Army stemmed from intensification in the application of the American System of Manufactures and inventions in the machine tool sector.

The implications of these advances in manufacturing for the relative price of quality adjusted manufacture can be gauged by adjusting figures on the nominal cost of producing muskets at Harpers Ferry for the quality of weapons produced there and by deflating the resulting nominal figures by the David-Solar consumer price index. My estimates serve as the basis for Charts 2, 3 and 4. However, something should be said about using the consumer price index. It might be better to use a wholesale price index but that index was unavailable prior to 1890. In any case, as is shown in Chart 1, the wholesale price index and the consumer price index in the United States move fairly closely with one another over the period 1890 to 1997, the World War I period being the sole exception.

Two methods were used to estimate quality of the firearms. The first was to assume that quality advance was discontinuous largely taking place in the 1840s (when the Springfield Model 1840 using only interchangeable parts was put into production) and 1950s (when the minié bullet was introduced making the rifling of gun barrels more attractive). In this case I divided the gain in theoretical lethality evident in the comparison of an early 19th century rifle with the late 19th century rifle used during the Civil War (see Panel C of Table 2) into two equal gains, the first made in 1940 and the second achieved in 1850. [13] Justification for this approach is based on the fact – evident in Chart 2 – that there were two dips in the number of muskets produced per worker at Harpers Ferry, the first in the early 1840s when the system of interchangeable parts was fully embraced (and new workshops were being built at the facility to house the new machine tools being brought on line) and the second during the mid-1850s when rifling was fully embraced due to the use of the minié bullet. The series created in this manner appears in Chart 3. The other method assumes that the gain in lethality took place continuously between 1802 and 1858. This series is graphically represented in Chart 4.

While the two charts tell a fairly similar story – namely modest decline in the relative cost, the real cost, of producing quality adjusted firearms – Chart 3 shows the biggest gains for the post-1840 period, not surprising given the assumption employed in its construction that emphasizes a sharp break in the early 1840s.

Several points flowing from the discussion in this section are interesting. First, massive declines in the real price of lethality occurred between the early 18th century and the late 20th century. The second is that most of this decline must have happened after 1865 when mass production emerged out of the American system of manufactures that extended standardization/interchangeable parts principles into the design of assembly line production took hold. Coupled with scientific knowledge that was increasingly brought to bear in improving the quality of machinery and reorganize the nature of production - and especially when advances in iron and steel manufacturing dramatically reduced the real price of iron and steel bars and plate – mass production revolutionized the manufacture of military equipment.

III Mass Production and Disembodied Technological Change

During the 19th century, improvements in the design of ships and railroads and applications of electricity to communications – most notably the telegraph – dramatically cut the real price of transporting goods and coordinating production. This development has been widely discussed in the literature and is evident here, albeit incompletely, with Charts 5 and 6 and Panels A and B of Table 3. [14] As more modes of transportation burst into the competitive fray in the 20th century – airplanes, trucks and buses employing the internal combustion engine for instance – transport costs continued to plummet and quality, measured by speed, improved. The same held for communications: radio, television, the telephone, more recently the Internet increasing speed of transmitting information while at the same time reducing real costs. In the case of communications, the importance of disembodied technical change due to advances in knowledge about electricity loomed large.

`The fall in the real price of transporting goods and sending information promoted scale economies in production and distribution. Some of these savings were internal to firms – the reach of markets expanded encouraging firms to ramp up production that hitherto had been too expensive to tap; but most were external to firms, taking the form of geographical scale economies due to concentration of specific industries in specific regions. For instance in the latter half of the 19th century an industrial belt stretching from Pennsylvania through Ohio and the Northeast of the United States into southern Ontario arose because industries concentrated in specific locales (perhaps due to historical accident) that were near other locales specializing in related fields of manufacturing. A good example of such a regional center is Pittsburgh that evolved from "Iron City" into "Steel City" during the latter half of the 19th century. It should be noted that clustering of populations in nascent industrial belts increased the demand for transportation linking expanding conurbations to one another, encouraging boosters of freshly arisen cities to offer low business taxes, later on low electricity rates.

Technological advance in the iron and steel sector was crucial because iron and steel was widely used in the construction of transport equipment – railroads and steamships for instance – and in the manufacture of machines that built transportation equipment, in particular machine tools. With the decline in the price of steel in particular, the real cost of employing and expanding on the reach of the American system of manufactures in production plummeted.

Again decline in the real costs of producing iron and steel is well known and need not be recounted here. [15] The key advances were pioneered by Henry Bessemer in the 1850s (the Bessemer converter reduced the cost of producing steel which had hitherto been produced by heating wrought iron in the presence of carbon thereby adding carbon into the mix to generate "blister steel"); Charles William Siemens, trained in science, developed the open hearth process during the 1860s that vastly increased the level of heat that could be used to melt iron (a major reason for the expansion of heating capacity was recycling gases that had been wasted in iron and steel making before); and, Sidney Gilchrist Thomas who applied his knowledge of chemistry to develop a method of eliminating phosphorus from pig iron in the late 1870s that expanded the diversity of iron ores that could be economically processed into iron and steel products. It is important to keep in mind that as in many other fields of industry, scientific knowledge was becoming increasingly important in promoting cost reducing technological progress in the iron and steel sector in the latter half of the 19th century.

This point is amply demonstrated in Charts 7, 8, 9 and 10 for the United States. [16] The real price of iron and steel products fell sharply, relative to the general price level, relative to the costs of coal one of the key inputs into production. For the United Kingdom, the dominant producer of iron and steel products prior to the 1870s, the story is a bit more complicated. The United Kingdom was a major exporter of coal, and as real prices for coal increased in the period 1880 to 1936 so did the prices of common bar iron in the country.[17] This point is apparent from Chart 11. Still, relative to coal prices, the price of Scottish pig iron did decline due to technical advances in the industry, as is clear from Chart 12. Of course the problem was that the real price of coal was sharply increasing in the United Kingdom.

The case of Sweden, home to highly prized iron ores that were heavily imported into Great Britain prior to the technical advances in the iron and steel sector is informative. [18] As can be seen from Chart 13, pig iron prices rose relative to iron ore prices in the period before the major advances in iron and steel manufacturing – presumably because of growing demand from Great Britain – only to fall in the wake of the technological advances in iron and steel manufacturing which, among other things, reduced the demand for Swedish iron bars abroad. This logic also applies to the series displayed in Chart 14. [19]

The period from 1870 to 1900 is justifiably called the "age of steel". More and more steel was replacing iron in the manufacture of buildings, bridges, railroads and ships. And – not surprisingly given the fact that steel was less likely to break under stress than was the case with iron – into the manufacture of firearms. For instance Benton (1970 reprint of 1878 original: page 165) reports as follows:

> "Since 1873 all small arm barrels have been made of decarbonized steel (Bessemer) and about one in six hundred only have been found to burst in proof."

As steel prices fell, steel became competitive with iron in the manufacture of weapons. In turn the quality of weapons at any given price was increased, simply because they were less likely to be revealed faulty when tested and/or used in combat, less likely to require extensive repair before being added to battlefield ready stocks of weapons.

Troops need to be moved to arrive at battlefields. Supplies – ammunition, food, clothing, and medical assistance – need to be brought to them. To expand dispersion on the battlefield, to support their movement and to sustain large bodies of troops in the field, communications become crucial. Declining costs of transport and communications, brought on partly be falling real costs of producing steel, partly by advances in scientific knowledge, partly by scale economies internal to firms - mass production using assembly lines – reduced the relative price of exerting military force $\mathbf{p_{mf}}$. So did falling prices for firearms. By the turn of the 20th century the relative price of exerting military force had dropped tremendously. It is difficult to put a precise estimate on this because one needs to weight together the real price of transport, the real price of communications, and the real price of military equipment including ammunition. [20] In doing so one would like to avoid simply taking the sum of real price declines in each sector as price declines in one generate price declines in the others. For instance declines in transport and communications tended to promote declines in iron and steel prices (by driving down the costs of getting ores to blast furnaces) that in turn promoted declines in the cost of constructing transport equipment. The carnage of World War I is not surprising in light of the decline in the relative price of exerting military force that took place during the late 19th century.[21

IV The Red Queen

The Red Queen principle is simple: you have to run fast just to stay in place. There is no better illustration of this then military competition. Beginning with World War I this principle increasing loomed over field of international geopolitics.

The reason lies in the logic of equation #1, namely

$$\mathbf{M = f(mY, p_{mf}) = f(myP, p_{mf})}$$

the potential of an individual country to exert military force depends on economic size (the product of its per capita income and population size) and the relative price of exerting military force. As the cost of equipping and transporting an individual soldier fell it became possible for the relative sizes of armies and navies – later on air forces – to attain heights never imagined in past wars including the Napoleonic Wars that ravaged Europe for over fifteen years. For the countries of Europe (including Russia), North America, and Japan that embraced heavy industrialization by the late 19th century the potential to carry on a sustained "total war" that punished both armed forces and civilians alike expanded with remarkable force.

Out of this state of affairs emerged a remarkable paradox: the unit cost of exerting military force fell; at the same time the cumulative cost of carrying on warfare for an major industrial economy actually escalated since larger and larger military organizations could be funded and longer conflicts could be sustained before economic collapse, not only larger in absolute terms, but also in relative terms. Consider the United Kingdom, France, Germany and Italy. Over most of the period 1860 – 2000 the proportion of their populations serving as military personnel fell short of 15 persons per members of their national 1,000 populations. In the case of Germany and France that fought a brief war in 1870-1871 the rations rose somewhat (in the case of France the ratio rose from 12.7 for the 1860s to 14.7 per 1,000 for the 1870s; in the case of Germany the ratio was 11.8 in the 1870s, dropping to 10.5 in the 1880s). By comparison the ratios for 1915-1920 were as follows: the United Kingdom, 69.2; France, 103.2; Germany, 55.9; and Italy 68.3. In the period 1940-45, the ratios rose even more dramatically for the two countries that fought the longest: the ratio for the United Kingdom was 71.2; the ratio for Germany was 85.5.[22] Moreover these estimates understate the actual burden imposed on the civilian economy by the military economy: for every soldier in the field, workers in the homeland were spewing out weapons and foodstuffs to support that soldier. On the heels of the "age of steel" World War I ushered in a new era, the era of "total war."

The lethality of weapons has increased dramatically, especially in the period after 1870. Older weapons become obsolete at an increasingly fast pace. This point is underscored by the decline in the operational lethality of weapons used in an earlier war that are stored up for use in a subsequent conflict, for instance rifles used in World War I that are recycled for use in World War II. The problem with storing them up is that they quickly that they lose their operational lethality for future wars. In other words compared to what is then available they become obsolete. With the acceleration in lethality of weapons the relevant length of the period before they become completely obsolete shrinks. In an era in which another total war is possible the incentive of military organizations in the great powers – those enjoying relatively large national incomes and relatively low unit costs of exerting military force - is to accelerate their research and development aimed at producing new weapons and weapon delivery systems. In an era in which the internal combustion engine was revolutionizing transport on land and in the air this meant turning out prototypes for combat aircraft, for bombers; creating prototypes for aircraft carriers and destroyers; creating prototypes for tanks; and developing new firearms. For example the United States Army began developing the M1 Garand semi-automatic rifle in the early 1920s. Ironically restrictions on the volume of battleships, bombers and other military equipment arrived at in the Peace of Paris in 1919 and in the Washington Conference of 1922 actually stimulated experimentation in armaments manufacture as great powers scrambled to find ways to work within the restrictions that they imposed on one another.

But this raises the problem of what to do with the older arms that are likely to become increasing obsolete as research and development in military matters intensifies amongst the great powers. Historically before the advent of total war the primary determinant of the speed at which new firepower was improved, and its unit costs reduced, was the frequency of warfare itself. As shown for pre-industrial wars by Hoffman (1998) the more frequent conflicts are between countries within a region, the greater is the pressure to drive down the relative price of military hardware through research and development. Since European states were prone to fight each other after they emerged out of the decentralized political units of the late Middle Ages it was in Europe that the relative price of quality adjusted firepower fell the fastest. Wars being frequent, and the pace of technological change in weapons production modest, weapons used in one war could be recycled for use in the next. This trend changed with the era of total war since the number of weapons produced to fight the conflict were very large and had to be stockpiled or simply scrapped after the war ended as the number of military personnel plummeted. However as noted earlier, many of these stockpiled weapons were likely to become obsolete in the near future.

Complicating the problem of weapons going obsolete is the disparity between the evolution of weapons and the evolution of military strategy. There are many instances when battlefield tactics do not keep up with the quality of weapons that can and are employed in a conflict: the weapons have not been tested on the field of conflict; and military commanders tend to develop their tactics for future wars on the basis of the last war they were involved in, one exclusively using earlier weapons, not the latest available. The result is that many weapons may be used incorrectly, say as artillery weapons rather than weapons designed to advance an infantry position. This was the case with the early machine guns, the Gatling and later the Maxim gun, which were first employed as components of the artillery rather than as guns which could be effectively used in infantry assault, or to hold defensive positions against an infantry assault. [23] Another good example is the submarine which had a bad reputation for years before an effective usage could be found for it. While the particular weapon may have a bad reputation in one country it does not necessarily have a bad reputation in other countries. As a result once a war between countries breaks out, a nation's military may find itself at considerable disadvantage relative to its enemy, thereby being forced to "run much faster than expected" to catch up, closing the gap, ideally matching or surpassing the lethality of the opponent's weaponry. It is hardly surprising to observe that periods of sustained warfare are periods when research and development of new weapons is the most intense.

Applied to warfare the Red Queen principle suggests that technological progress in war making material tends to outstrip technological progress in other fields simply because the pace of progress made by a potential adversary is typically unknown or at least imperfectly unknown to the military planners elsewhere. During a war or in a crisis period leading up to a war military planners worry about falling behind their potential enemies, thereby stepping up their campaigns to develop and test improved weapons. Perhaps this may not be true at all times. It is true in the era of total war for the simple reason that an advantage in one field – say airpower – can translate into a huge advantage in quickly defeating a country whose political center is a capital city vulnerable to aerial bombing.

In short, the improvements in transport and communications commenced in the 19th century and intensified in the 20th century with the growing use of the internal combustion engine on land and in the air led to a decided bifurcation in the field of military equipment manufacture. On the one hand firearms of increasing lethality and the ammunition they employed were being produced at lower and lower prices (relative to the general price level), partly because larger and larger volumes of firearms were being stockpiled. On the other hand the cost of securing "state of the art" equipment for delivering firepower – aircraft, missiles, aircraft carriers – was soaring, in part because production of the new delivery methods required heftier investment in research and development, including the mobilization of engineers and scientists. [24] In my opinion this has led some experts on military matters to conclude – incorrectly I would assert - that the relative price of exerting military force has skyrocketed for warfare in general, especially in the post-World War II era. [25] The fact is that big capital acquisition projects tend to last a long time, for instance twenty to thirty years. Properly depreciated they are dwarfed by the flow costs of acquiring and sustaining personnel and maintaining and operating the capital equipment.

This bifurcation profoundly influenced the interwar international trade in firearms. Major industrial powers unconstrained by the Paris Peace Conference in their arms development programs like France, Italy and the United Kingdom took the dominant position in exporting tanks and warships. The United States – exploiting learning curve advantages stemming from the massive size of its domestic market for aircraft – took the lead in exporting combat aircraft. [26] By contrast Germany, rearming during the 1930s from a position in which military stocks particularly those required to carry out total war were low, exported firearms that were rapidly becoming obsolete. An excellent example of the latter trade is German barter trade with Yugoslavia, Germany acquiring mineral imports like bauxite from Yugoslavia in exchange for firearms. The German dealers were careful to select for export stockpiled arms likely to go obsolete soon, not surprising given the fact that Hitler had designs on the Balkans. Indeed Germany invaded Yugoslavia in 1941, weeks before it invaded the Soviet Union in June of 1941. The Germans were astute in securing minerals and foodstuffs for weapons that they suspected would be of very little use to the military organizations of states that they had designs on. If you are going to arm a potential enemy, do it with weapons whose effectiveness you can easily destroy with your own.

V Exporting Low Cost Lethality to the Developing World

In the aftermath of World War II, during the late 1940s, the Soviet Union developed and tested two military weapons of paramount significance for the postwar period. One, the atomic bomb exploded in August 1949 in response to the United States possession of atomic weapons was a strategic total war weapon. The other was a firearm of great lethality, the AK-47. This ferocious weapon incorporated earlier improvements in machine gun design. It utilized the basic principles of rapid fire realized with the Gatling gun. It exploited Maxim's ingenious idea of recycling hot gases emitted from the muzzle of a gun to expel mechanically the spent cartridge just fired and load a fresh cartridge for firing. These ideas had already been incorporated to a degree in the M1-Garand and the German *sturmgewehr* (storm rifle) that came online at the close of World War II. Working with a team of engineers, mechanics, and scientists, Mikhail Kalashnikov developed a light weight assault rifle in 1947 usable in incredibly cold climates that was put into mass production during the same year the Soviet Union tested its first atomic bomb. [27]

The mass production of AK-47 was a perfect example of how the Soviet Union achieved technological progress. Stalin established a competition, bidding various teams to submit prototypes for an fully automatic rifle that could be used in cold climes, thereby mandating loose tolerances in the mechanics of the gun. The head of the successful team Kalashnikov was awarded the Stalin Prize, receiving a huge bonus that allowed him to purchase a refrigerator, a vacuum cleaner and a *Pobeda* automobile. In short, he was raised into the ranks of an elite that called the shots in Soviet society, who received the benefits in terms of a standard of living denied the great mass of the population. This was no accident. Despite their claim to creating a mass democracy based on the dictatorship of the proletariat, Communist countries were run by a miniscule elite of bureaucrats, politicians, technical experts, and high ranking military figures who directed command and control economy operating under hierarchical principles common to military organizations, yet indulged in myth making about how masses of average Soviet citizens, even those born into poverty like Kalashnikov, could rise to the pinnacle of success. While the Communist countries had difficulty competing with the Western bloc countries in the production of market oriented consumer durables due to a lack of competition and work incentives in their manufacturing sectors, they could innovate in areas where the state could and did set standards in the mass production of weapons whose primary use was to arm state organizations.

Shared with its Communist bloc partners – whose combined populations far outnumbered the populations of those countries closely allied with the United States – the technology for making knockoffs or improved versions of the AK-47 rapidly spread globally during the 1960s, 1970s and 1980s. [28]

It was a perfect weapon for suppressing rebellions of those discontented with the low standards of living and lack of civil rights accorded to the mass of the population. The AK-47 was used to suppress rebellions throughout those countries living behind the Iron Curtain, in East Germany in 1953, in Hungary in 1956. As a means of suppressing domestic dissidence in its Communist allies by beefing up their police and security forces the Soviets transferred the technological specifications for the AK-47 along with samples throughout Eastern Europe and to China and North Korea. Thus a host of slightly modified AK-47 weapons were developed in the 1950s and 1960s, Chinese variants, Albanian variants, Czech variants. It is estimated that the number of AK-47 type rifles manufactured lies somewhere between 75 and 100 million weapons. This number reflects several facts: the low cost of producing the weapon; the fact that its crudeness of construction renders it useful in virtually all climatic conditions, in the tropics as well as places like Siberia; and the fact that before the Cold War ended the cumulative population size of those living under Communist rule far exceeded those in North America, Western Europe and Japan.

Moreover the Communist countries were committed to promoting wars of national liberation in the colonial world. What better way to make allies in Africa and South East Asia than grant them AK-47s on favourable terms? What better way to force the capitalist world allied with the United States to expend its military capital on fighting off Communist inspired insurgencies and guerrilla wars in the developing world? What better way to keep up in a global strategic contest with the West? Given the high research and development costs of creating new Total War technology why not pursue comparative advantage, producing huge stockpiles of low cost weapons that could challenge the West in the developing world? Indeed in the developing world the AK-47 was a perfect weapon: it was easy to use; light weight; and it could be quickly cleaned. Testifying to the low training costs required of those learning to fight with an AK-47 is the fact that child soldiers like those abducted to fight in the Lord's Resistance Army in Uganda rapidly learn to kill - and kill over again - with the weapon. [29] True, use of the machete and fire dwarf the use of AK-47s in conflicts in Africa. But these weapons can also be wielded by children.

Indeed it is this feature of the AK-47 that has rendered its role in the developing world so insidious. In newly established nation states where political differences are still being ironed out the potential for civil unrest is unusually great. Table 4 speaks to this problem pointing out that newly established nation-states are unusually vulnerable to falling into an apparently unending sequence of civil wars and coups that retard economic growth. [30] There is no doubt that political problems associated with nation building – particularly in countries where ethno-linguistic fragmentation is extensive, where rival groups compete for land, where control over diamond mining or contracts with foreign oil companies is fought over – are partly to blame for this state of affairs. But so is the fact that lethal low cost weapons are abundantly available in these countries, making it easier to recruit untrained guerrilla fighters, to force teenagers to join the ranks of militants many motivated by not by high-minded idealism but rather by naked greed directed at accumulating power and riches.

V Conclusions

Historians of the 19th and 20th centuries rightly document the great improvement in living standards achieved for greater and greater proportions of global population. By the closing decades of the 20th century poverty rates were falling throughout Asia – particularly China and India – the Middle East and Latin America. Taking a long run view we can attribute this to improvements in the quality of capital goods and land, increasing work intensity, and total factor productivity growth. At the same time the potential to carry out systematic ethnic cleansing and to kill large numbers of people in the time it takes to develop a new computer game has also increased. The real cost of lethality has plummeted for the same reason that middle class households the world over enjoy refrigerated foods, high speed internet services, and daily drives in their air conditioned automobiles. Out of this enhanced lethality has jumped the genie of total war. And out of this enhanced lethality has leapt the genie of revolution, rebellion against the state, and civil war. This is the great paradox buried in the economic history of the modern world.

Footnotes

[1] Some rough estimates of 20th century civilian and battle field deaths brought on as an indirect result of military and/or politically motivated campaigns are:

(a) Non-battle deaths occurring between 1932 and 1945 in the “bloodlands” region stretching from the German-Polish border through the Ukraine and the western Soviet Union are given by Snyder (2010: pg. 411): in the Soviet Ukraine in 1932-33 largely due to starvation, 3.3 million; during the Great Terror in the Soviet Union between 1937 and 1938, 0.3 million (0.7 million total in the Soviet Union); killed in the Soviet/German occupation of Poland between 1939 and 1941, 0.2 million; Soviet citizens starved by the Germans between 1941-44, 4.2 million; Jews killed by gassing or shooting by Germans in the Shoah taking place between 1941 and 1944, 5.4 million; and civilians shot by Germans as “reprisals” mainly in Belarus and Warsaw between 1941 and 1944, 0.7 million; total 14.1 to 14.5 million.

(b) Famine deaths during the Great Famine in Maoist China given in Mosk (2010: pg. 187): low estimate 16.5 million; high estimate 29.5 million.

(c) Holocaust estimates given in Tooze (2006: pg. 523): low estimate of workers killed by Germans, 4.8 million, high estimate 7 million.

(d) Deaths taking place in Communist countries reported in Besançon (2007, xiv): low estimate of 85 million, high estimate of 100 million.

(e) Estimates of major interstate wars: World War I, 9 million; World War II, 15 million; Korean War, 2 million; Sino-Japanese War between 1937 and 1941, 1 million; Vietnam war, low estimate 3.2 million, high estimate 5.7 million ; total, low estimate 30 million; high estimate 32.7 million.

(f) Totals excluding minor interstate wars and civil wars occurring during the 20th century: low, 121.1 million; high 138.8 million.

[2] These equations are discussed in more detail in Mosk (2010, 2011).

[3] The data used in this chart is largely drawn from various pages in Butler (1971).

[4] Cleaning a musket of this type required use of a kit that typically contained picks, screwdrivers, wrenches, and in the case of an officer's kit a spring vise.

[5] Teenagers in high schools in the Soviet Union were tested on their ability to take apart an AK-47 and reassemble it. In a recorded testing at School No. 1 Pripyat in April of 1986 the fastest time recorded for a student was 22 seconds, the slowest 75 seconds. See page 360 in Chivers (2010). It should be kept in mind that compulsory conscription was the price every male in the Soviet Union paid for being a citizen of the country.

[6] Specifically I use the ratio of the David-Solar consumer price index in 1996-2000 to the consumer price index for the period 1916-25 to make the calculation.

[7] Local prices for AK-47s vary depending on supply and demand for the weapons (supply includes the degree of regulation concerning the acquisition of the weapon). In Iraq in 2003 an AK-47 typically sold for $150 or less; in eastern Uganda in the late 1980s an AK-47 could be purchased for around $200 or – in trade – commanded a barter price of three to four head of cattle. See pages 381ff in Chivers (2010). In many ways arms dealers in the developing world operate like drug dealers, hooking their clients on the latest equipment just as a drug dealer hooks his or her clients on the newest products guaranteed to give a high.

[8] For a more lengthy discussion of Jefferson's interest in developing technology in the United States and the importance of the insertion of an article concerning patents in the Constitution of the United States, see Mosk (2010a). Alder (1997) discusses Jefferson's visit to

French military arsenals and his interest in bringing the system of interchangeable parts back to the United States.

[9] Details concerning advances in weaponry between 1795 and the Civil War in the United States are given in Butler (1971), Fuller (1968), Parsons (1950) and Smith (1977). Highlights include development of the US Musket 1816 – designed to tackle defects in American weapons used in the War of 1812 – the US percussion musket of 1842 that not only abandoned the flinklock but also introduced improvements in the breech, and the muskets manufactured in the 1850s that were designed to fire a minié bullet (which expanded as it was fired out of the barrel hugging the sides of the barrel as it travelled along its channel). As far as these improvements were concerned most came in the 1840s and the 1850s. Full conversion to breech loading did not occur until after the Civil War. Butler (1971) argues that successive models of the Springfield Model yielded gains in efficiency measured as muzzle energy by grain of propellant. His figures show the following for efficiency: Model 1795, 11.6; Model 1822, 13.4; Model 1840 in use from 1840-45, 16.5; Model 1840 in use from 1845-50, 18.2; and Model 1840 in use from 1850 to 1860, 20.6. For a general discussion of the disadvantage in gun production experienced by the armies of the Confederacy in comparison to the Union Army see Collins (1999).

[10] On the overwhelming advantage in weapons manufacture secured by the United States in the early 20th century see pages 26-7 in Crowell (1919). To some extent the American emphasis on mass production using totally standardized practices may have come at the expense of quality. For a discussion of the contrast between the approach of the American military that emphasized quantity over quality of weaponry and the approach of its Axis opponents that tended to favor quality over quantity during World War II see Harrison (1998).

[11] See page 222 ff. in Smith (1977).

[12] See pages 276 ff. in Smith (1977).

[13] It should be noted that the ratio of the theoretical lethality of a late 19th century rifle to an early 19th century rifle (4.25 = 153/36) is almost identical to the ratio of the operational lethality of a late 19th century rifle to an early 19th century rifle (4.36 = 6.1/1.4). For this reason I feel confident that employing the theoretical lethality index ratio to estimate the gain in quality is comparable to employing the operational lethality index.

[14] The literature on this is huge. See inter alia Field (1992), Findlay and O'Rourke (2007) and Harley (1988, 1998).

[15] See Carr and Taplin (1962), Hyde (1977), Temin (1964), Tweedale (1987) and Warren (1973). The American iron and steel industry, relatively small in the period before the Civil War when imports from Great Britain loomed large in meeting domestic demand, grew rapidly in the latter part of the century partly because the technical improvements in the industry made economically feasible use of American ores. Bessemer and Open Hearth production promoted increases in the scale of iron and steel making plants, thereby promoting scale economies.

[16] The data underlying these charts is taken from various tables and volumes in Carter et al (2006).

[17] On the export of coal from the United Kingdom see Harley (1989). The British statistics upon which the estimates in Charts 11 and 12 are based are drawn from Mitchell and Deane (1962) and Mitchell and Jones (1971).

[18] Sheffield, which specialized on producing "blister steel" from wrought iron bars was a major importer of Swedish iron bars. See Tweedale (1987).

[19] The data underlying Charts 13 and 14 is taken from Jörberg (1972).

[20] For the interest of the US Army in transport and communications technologies see *inter alia* Yeang (2004). During the period before the Civil War a substantial number of US Army officers were sent to advise private railroads on their construction. The argument was that this would bolster military security making it easier to move troops to repel foreign invaders, to defeat Indian tribes, and to suppress slave rebellions should they occur.

[21] One simple indicator of this is given by Crowell (1919: page 27). It is his estimate of the number of rounds of ammunition expended in modern battles that involved artillery preparation for assault on defensive. Putting his figures on a daily basis they are as follows: Chickamauga, Union forces, 1863, 3,663 rounds; Gettysburg, Union forces, 1863, 10,927 rounds; St. Privat, German forces,1870, 39,000 rounds, Nan Shan, Japanese forces, 1904, 34,047 rounds; and Somme, British forces, 1916, 571,429 rounds. Had the relative price of the artillery ammunition used in 1916 been as high as it was in 1863, it is difficult to imagine that the British would have used as many rounds as they did in 1916.

[22] These figures are drawn from Maddison (2006) and the Correlates of War website www.correlatesofwar.org (Version 3.02 of National Material Capabilities file accessed in October 2009).

[23] On this point, see Armstrong (1982) and Chivers (2010). A comparison of France and Germany in the period after 1871 is instructive in this regard. In the 1860s the French army began experimenting with a multi-barrel Montigny *mitrailleuse* gun that had some of the features of the Gatling gun. They used it as part of their artillery equipment in the Franco-Prussian war of 1870, realizing it was ineffective against German artillery barrages beyond 500 yards. Even though it was a French chemist who invented a smokeless powder that was of special value to

designers of machine guns like the Maxim gun – because it leaves the bore of the gun relatively free of residue and it allows machine gun units to avoid observation more easily than they could in the past – the French military lost its interest in employing machine guns, only switching policy, finally embracing use of the gun in 1899. By contrast the German army showed keen interest in using the machine gun, the gun works at Spandau cranking out thousands of Maxim gun knock-offs in the years leading up to World War I.

[24] On this point see Laurence (1992).

[25] See, for instance, Kirkpatrick (2004).

[26] Remarks based on exports in 1930 given in page 4-3 of Laurance (1992). During the interwar period there was a slow drift away from the laissez-faire "Merchants of Death" era in which the arms trade was dominated by private manufactures like Vickers-Armstrong and Krupp, toward an era in which geopolitics began to play an important role, especially in the late 1930s as countries were girding for war. On the arms trade in the "Merchants of Death" era see Laurance (1992). On the importance of mass production learning curve cost reduction in the manufacture of combat aircraft see Stockholm International Peace Research Institute (1971).

[27] This section draws heavily on Chivers (2010) that provides a detailed account of the development of the AK-47 and the role of Kalashnikov in coming up with some of the key ideas for its design. The main thrust of the account in Chivers (2010) is that Kalashnikov's innovative thinking, while important, was only one input into a gun built by committee, modified every step of the way by other experts and by production teams that put the weapon into mass production.

[28] For population figures see Table 7.1, pp. 224-225 in Mosk (2008).

[29] See Chivers (2010: pg. 372 ff.)

[30] On the conflict trap – the tendency of the incidence of a civil war to generate subsequent civil wars retarding economic development – see Collier (2007).

Table 1

Unprecedented Rise in the Standard of Living, Unprecedented Increase in Violence (1816-1998)

Panel A: Per Capita Income in 1990 International Geary-Khamis Dollars, 1820-1998

Region	***1820***	***1998***	***Compound Annual Growth Rate, 1820-1998 (%)***
World	667	5,709	1.21%
Western Europe	1,232	17,921	1.51
Western Offshoots [a]	1,201	26,146	1.75
Japan	1,130	21,470	1.93
Latin America	665	5,795	1.22
Eastern Europe & Former USSR	667	4,354	1.06
Asia (Excluding Japan)	575	2,936	0.92
Africa	418	1,368	0.67

Table 1 [Continued]

Panel B: The Top Nine International Interstate Wars Ranked in Terms of Severity (Total Number of Battle Deaths), 1816-1980 [(b)]

War	Rank			Magnitude in Terms of Nation Months	Battle Deaths		
	Severity	Battle Deaths per Nation Month	Battle Deaths per Capita		Total	Per Nation Month	Per 1000 Armed Forces
World War II (1939-45)	1.0	2.0	4.0	875.6	15,000,00	17,318.8	1,953.9
World War I (1914-18)	2.0	5.0	3.0	607.8	9,000,000	14,076.7	1,519.7
Korean War (1950-53)	3.0	19.0	15.0	514.0	2,000,000	3,681.1	201.6
Vietnamese (1965-75)	4.0	35	6.0	n.e.	n.e.	n.e.	n.e.
Sino-Japanese (1937-41)	5.0	11.0	16.0	106.2	1,000,000	9,416.2	1,428.6
Lopez [(c)] (1864-70)	6.0	36.0	2.0	n.e.	n.e.	n.e.	n.e.
Russo-Turkish (1877-78)	7.0	3.0	12.0	17.6	285,000	16,193.2	306.5
Crimean (1853-56)	8.0	25.0	19.0	116.3	264,200	2,267.8	191.4
Franco-Prussian (1870-71)	9.0	13.0	11.0	27.0	187,500	6,944.4	189.4

Table 1 [Continued]

Panel C: The Top Ten Civil Wars Ranked in Terms of Severity (Total Number of Battle Deaths), 1816-1980

Country/Period	Rank in Terms of:			
	Battle Deaths	Nation Months	Battle Deaths per Nation Month	Battle Deaths per Capita
China (1860-64)	1.0	17.0	3.0	21.0
China (1946-50)	2.5	18.0	5.0	28.0
Nigeria (1967-70)	2.5	29.0	4.0	9.0
United States (1861-65)	4.5	20.0	10.0	8.0
Spain (1936-39)	4.5	28.0	6.0	2.0
USSR/Russia (1917-20)	6.5	24.0	8.0	23.0
Pakistan (1971)	6.5	60.0	2.0	22.0
Columbia (1949-62)	8.5	1.0	30.0	1.0
Vietnam (1960-65)	8.5	12.0	17.0	7.0
Mexico (1910-20)	10.5	4.0	28.0	11.0

Notes: (a) The Western Offshoots consist of Australia, Canada, New Zealand and the USA.

(b) There is a three way tie for the tenth spot in the ranking (the next three wars in terms of severity each get a rank of 11.0).

(c) War of the Triple Alliance pitting Paraguay against Brazil, Argentina and Uruguay.

n.e. = not estimated.

Sources: Page 30 in Maddison (2006); Table 4.2 (pp. 60-69) in Singer and Small (1972); and various pages in Small and Singer (1982).

Table 2: Relative Price of Kalashnikov AK-47 circa 1820, Historical Dispersion Patterns in Various Modern Wars, Theoretical Lethality Indices (TLIs) and Comparative Operational Lethality Indices (OLIs), 17th century to World War II

Panel A: Relative Cost of Lethality Circa 1816-25 in the United States: Musket Compared to AK-47 [(a)]

Price (1816-1825 US dollars)	Theoretical Lethality Index (TLI)	Theoretical Lethality Units per 1816-1825 $	Ratio of Lethality per 1816-1825 $ (musket = 1)
Musket (Harper's Ferry) unit cost $15.75	40	2.54	1
AK-47 purchased in 1996-2000 for $200	4973	24.87	9.79
AK-47 purchased in 1996-2000 for $300	4973	16.58	6.52
AK-47 purchased in 1996-2000 for $400	4973	12.43	4.90
AK-47 purchased in 1996-2000 for $500	4973	9.95	3.92

Panel B: Dispersion Patterns (Army or Corps of 100,000 Troops)

Measure of Dispersion	Napoleonic Wars	American Civil War	World War I	World War II
Area Occupied by Deploying Force 100,000 Strong (sq. km)	20.12	25.75	248	2,750
Soldiers per sq. Km	4,970	3,883	404	36
Square meters/soldier	200	257.5	2,475	27,500

Table 2: [Continued}

Panel C: Theoretical Lethality Indices (TLIs) and Operational Lethality Indices (OLIs) in Various Periods, 17th Century Warfare to World War II

Weapon	Theoretical Lethality Index (TLI)	Operational Lethality Indices (OLI) (b)					
		17th century	18th century	Napoleonic Wars	US Civil War	World War I	World War II
17th century musket	19	3.8					
Early 19th century rifle	36		3.6	1.8	1.4		
Late 19th century rifle	153				6.1	0.61	0.05
WWI machine gun	3,463					14.0	1.15
WW II machine gun	4,973						1.66
WW I tank	34,636					139	12
WW II medium tank	935,458						312
WW I fighter bomber	31,909					128	11
WW II fighter bomber	1,245,789						415

Table 2: [Continued]

Notes: (a) AK-47 prices found on the internet in December 2010 and in Chivers (2010) deflated by the David-Solar price index; the theoretical Lethality Unit for a World War II machine gun used to estimate the TLI for an AK-47 is an underestimate of the TLI for an AK-47 that improved on machine gun design in the aftermath of World War II.
(b) Estimates of TLIs made by Dupuy take into account a variety of characteristics including rate of fire, number of potential targets per strike, relative incapacitating effect, effective range (or muzzle velocity), accuracy, reliability, battlefield mobility, radius of action and vulnerability. The OLI is computed by dividing the TLI by the dispersion factor thereby estimating the relative battlefield values of weapons in different periods and different wars.

Sources: Table Cc 1-2 (pp. 3-158-9) in Volume C of Carter et al (2006) Chivers (2010), various pages in Dupuy (1980) and Table 1 (appendix table without pagination) in Smith (1977).

Table 3: Real Freight Rates per Ton-Mile on Canal and on Railroad (Nominal Rates Deflated by the David-Solar Consumer Price Index), Real Revenue per Passenger on International Flights and Average Speed of Aircraft (Miles per Hour) in the United States

Panel A: Real Freight Rate Fares per Ton-Mile on Canals (Nominal Rates Divided by the Consumer Price Index), 1802-1880

Year	**Rate**	**Year**	**Rate**	**Year**	**Rate**
1802	775.2	1848	105.3	1866	87.7
1817	429.7	1852	94.1	1870	71.7
1831	601.0	1856	128.7	1872	85.0
1840	216.4	1858	101.0	184	73.0
1844	152.8	1864	92.6	1880	52.9

Panel B: Real Freight Rates on Railroads (Nominal Revenue per Ton-Mile Divided by the Consumer Price Index), 1833-1900

Year	**Rate**	**Year**	**Rate**	**Year**	**Rate**
1833	219.2	1860	100.0	1874	61.3
1848	206.8	1862	79.7	1876	55.4
1852	119.1	1864	56.7	1882	33.4
1854	109.6	1866	61.7	1888	31.3
1856	119.1	1868	70.5	1890	29.5
1858	111.8	1872	58.3	1900	25.8

Panel C: Average Revenue per Passenger on International Flights and Average Speed of Aircraft (United States)

Years	Average Revenue per Passenger		Average Speed of Aircraft	
	Relative to Average Revenue on Domestic Flights	Relative to the Consumer Price Index (1967=100)	Miles per Hour	Relative to Speed of Domestic Travel = 100
1940-1949	159.0	304.9	177.2	107.0
1950-1959	122.8	167.5	240.8	118.2
1960-1969	90.7	112.7	432.6	138.5

Sources: Various tables in volumes 3 and 4 of Carter et al (2006) and Table 5.1, pg. 95, in Mosk (2005).

Table 4

Growth Rates for Income per Capita (g_y) and Percentage of Years with Negative Income per Capita Growth Rates (yng%): Countries Classified According to the Number of Years Prior to the First Year of the Observation Period When Current Nation State Established (yes)
Panel A: Countries for which "yes" is less than or equal to 1

Country	g_y		yng%		Number and Nature of Crises
	Crisis period	Non-Crisis Period	Crisis period	Non-Crisis period	
Algeria	-2.27%	3.14%	66.7%	27.6%	2 (1962, 1991-98) Complex
Angola	-2.95	1.99	63.6	9.1	1 (1975-98) Complex
Bangladesh	5.19	1.12	50.0	19.2	1 (1974-5) Regime transition
Benin	2.66	1.20	30.0	41.4	1 (1963-72) Regime transition
Burkina Faso	-3.92	0.66	100.0	52.6	1 (1980) Regime transition
Burundi	4.93	-0.62	36.4	61.5	2 (1963-73; 1988-98) Complex
Chad	0.06	0.34	56.3	33.3	1 (1965-96) Complex
Comorus	-7.16	-1.21	100.0	54.6	1 (1995-6) Complex
Cyprus	1.82	5.23	28.6	20.0	2 (1963-8; 1974) Complex
The Gambia	-2.35	0.78	100.0	57.6	1 (1994) Regime transition
Ghana	1.83	0.74	75.0	42.1	2 (1972; 1978-84) Regime transitions
Guinea-Bissau	-28.22	4.84	100.0	45.8	1 (1998) Complex
Guyana	-2.04	2.32	33.3	36.7	1 (1978-80) Regime transition
Kenya	-2.24	1.76	100.0	42.4	1 (1991-93) Ethnic war
Lesotho	2.16	2.28	33.3	40.6	2 (1970; 1994-8) Regime transition-1; Complex-2
Madagascar	-1.52	-.97	75.0	64.7	1 (1974-5) Regime transition
Mali	-1.59	0.07	75.0	50.0	1 (1990-3) Ethnic war
Morocco	2.93	2.51	27.8	28.0	2 (1963-5; 1975-89) Regime transition-1; Ethnic war-2
Mozambique	-3.44	0.07	62.5	62.5	1 (1976-92) Revolution
Niger	-3.23	-1.51	100.0	59.5	1 (1996) Regime transition
Nigeria	0.21	1.05	61.6	38.5	2 (1964-70; 1980-5) Complex
Papua New Guinea	-022	-1.21	54.6	69.2	1 (1988-98) Ethnic war
Rwanda	-2.20	1.93	46.2	33.3	2 (1963-66; 1990-8) Complex

Table 4 [Continued]

Panel A: Countries for which "yes" is less than or equal to 1 [Continued]

Country	g_y		Yng%		Number and Nature of Crises
	Crisis period	**Non-Crisis** Period	Crisis period	Non-Crisis Period	
Senegal	-0.44%	-0.30%	45.5%	48.2%	2 (1962-4; 1991-8) Regime transition-1; Ethnic war-2
Sierra Leone	-1.78	0.52	54.6	45.8	2 (1967-71; 1991-8) Regime transition-1; Complex-2
Uganda	1.67	1.93	39.4	25.0	1 (1966-98) Complex
Zambia	0.71	-1.30	66.7	69.0	2 (1968-72; 1996) Regime transitions
Zimbabwe	1.26	2.62	56.3	31.3	1 (1972-87) Complex

Panel B: Countries for which "yes" is greater than 1

Country	g_y		Yng%		Number and Nature of Crises
	Crisis period	**Non-Crisis** Period	Crisis period	Non-Crisis period	
Argentina	1.62	1.52	40.0	35.3	2 (1966; 1973-80) Regime transition-1; Complex-2
Brazil	2.23	1.22	16.7	21.0	1 (1964-5) Regime transition
Chile	-4.38	3.22	50.0	15.9	1 (1973-6) Complex
Columbia	1.94	1.87	7.1	23.3	1 (1984-8) Revolution
Dominican Republic	1.13	3.28	33.3	16.7	1 (1961-6) Complex
Ecuador	6.33	1.54	0.0	31.0	1 (1970-2) Regime transition
Egypt	2.77	2.50	25.81	2.39	1 (1986-1998) Revolution
El Salvador	-1.66	2.09	46.7	10.3	1 (1977-92) Complex
Ethiopia	0.13	0.80	35.3	30.0	1 (1961-94) Complex
Greece	4.05	3.53	0.0	20.9	1 (1967) Regime transition
Guatemala	1.36	1.34	25.8	25.0	1 (1966-96) Complex
Haiti	11.56	3.16	0.0	53.3	1 (1991) Regime transition
India	2.54	-	27.3	-	1 (1952-98) Ethnic war
Indonesia	3.04	5.08	22.2	9.1	3 (1956-66; 1975-92; 1977-98) Complex (all three)
Iran	0.64	5.58	40.9	19.1	3 (1952-5; 1963; 1977-98) Regime transition-1; Revolution-2; Complex-3
Israel	2.83	4.35	21.9	8.3	1 (1967-98) Ethnic war
Jordan	-3.71	3.47	50.0	34.2	2 (1957; 1967-71) Regime transition-1; Revolution-2

Table 4 [Continued]

Panel B: Countries for which "yes" is greater than 1 [Continued]

Country	g_y		yng%		Number and Nature of Crises
	Crisis period	**Non-Crisis** Period	Crisis period	Non-Crisis Period	
Korea, South	4.43	5.56	25.0	12.5	2 (1961-3; 1979) Regime transition-1; Revolution-2
Mexico	2.27	2.04	0.0	18.6	1 (1994) Ethnic war
Nicaragua	-5.28	0.81	83.3	43.8	1 (1978-90) Complex
Pakistan A	-3.16	3.49	50.0	7.1	1 (1958-61) Complex
Pakistan B	2.37	3.52	13.6	33.3	2 (1971-7; 1983-98) Complex-1; Ethnic war-2
Panama	4.23	2.52	0.0	26.2	1 (1968-9) Regime transition
Peru	-0.35	2.21	41.2	22.2	2 (1968; 1982-97) Regime transition-1; Complex-2
Philippines	1.13	2.44	26.7	7.1	1 (1969-98) Complex
Romania	-5.48	5.02	100.0	21.6	1 (1989) Revolution
South Africa	-0.46	2.03	60.0	10.4	2 (1976-7; 1984-96) Revolution-1; Complex-2
Sri Lanka	2.80	1.56	5.9	11.1	2 (1971; 1983-98) Revolution-1; Complex-2
Syria	8.73	2.84	20.0	30.3	2 (1958-63; 1981-2) Revolution; Complex-2
Thailand	4.40	4.98	7.7	11.1	3 (1957; 1967-83; 1991-8) Regime transition-1; Complex-2 & 3
Turkey	2.30	3.02	30.0	16.7	2 (1971: 1980-98) Regime transition-1; Complex-2
United Kingdom	1.97	2.49	23.1	0.0	1 (1969-94) Ethnic war

Notes: The State Failure Taskforce Report (Phase III) divides "state failure events" into the following five categories:
(1) Revolutionary wars – episodes of sustained violent conflict between organization and politically organized challengers that seek to overthrow the central government, to replace its leaders, or seize power in one region.
(2) Ethnic wars – episodes of sustained violent conflict in which national, ethnic, religious, or other communal minorities challenge governments to seek major changes in status.
(3) Adverse regime changes – major, abrupt shifts in patterns of governance, including state collapse, periods of severe elite or regime instability, and shifts away from democracy toward authoritarian rule.

Table 4: Notes [Continued]

(4) Genocides and politicides – sustained policies by states or their agents, or, in civil wars, by either of the contending authorities that result in the deaths of a substantial portion of a communal or political group.
(5) Complex – complex events are made of two or more temporarily linked wars and crises. If events overlap or if four years or less separate the end of one event and the onset of the next, they are combined into complex events

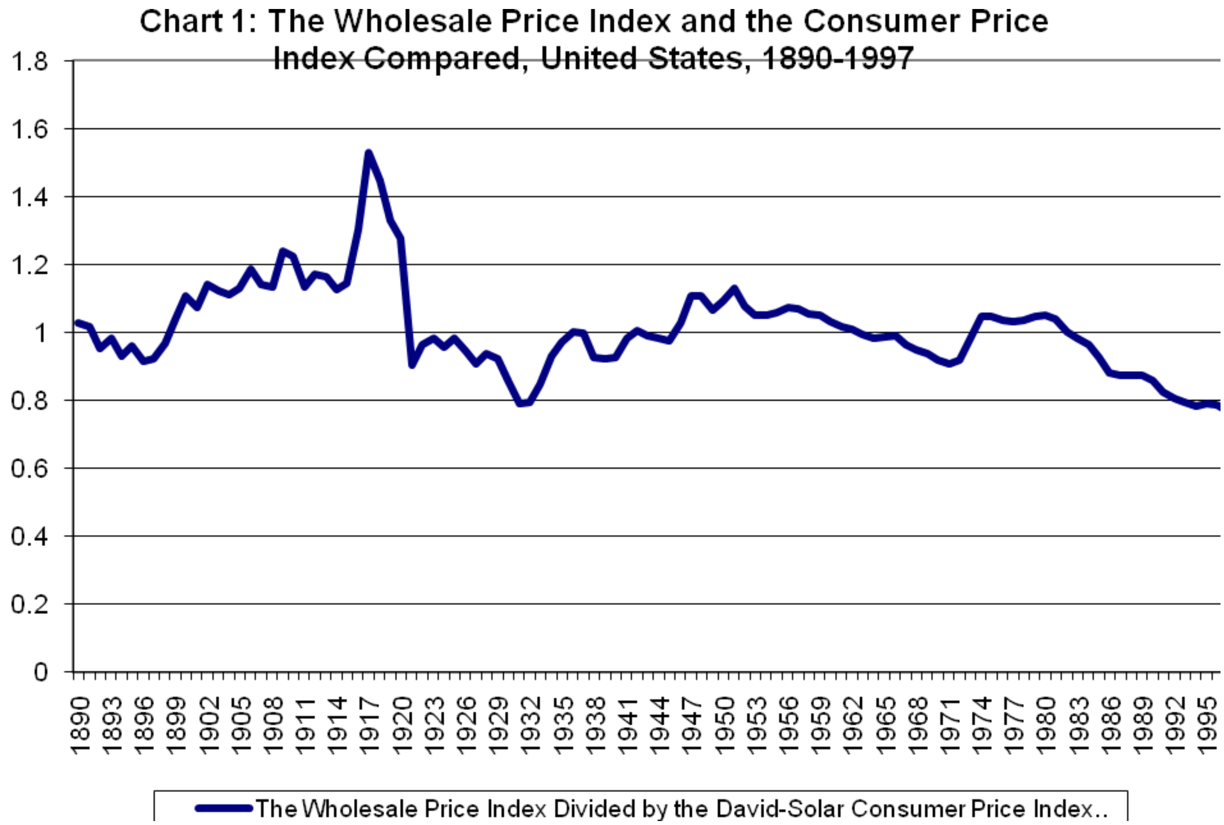


Chart 1: The Wholesale Price Index and the Consumer Price Index Compared, United States, 1890-1997
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1890
1893
1896
1899
1902
1905
1908
1911
1914
1917
1920
1923
1926
1929
1932
1935
1938
1941
1944
1947
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
The Wholesale Price Index Divided by the David-Solar Consumer Price Index..

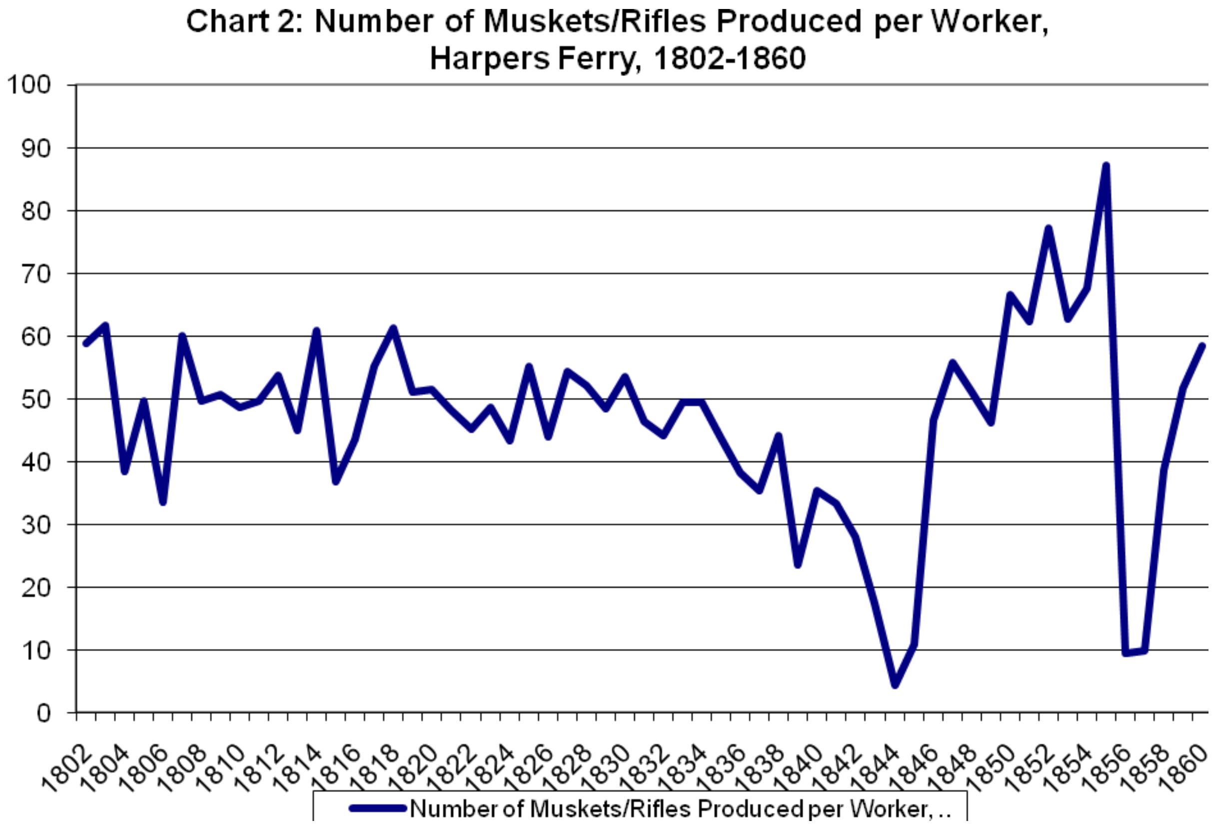
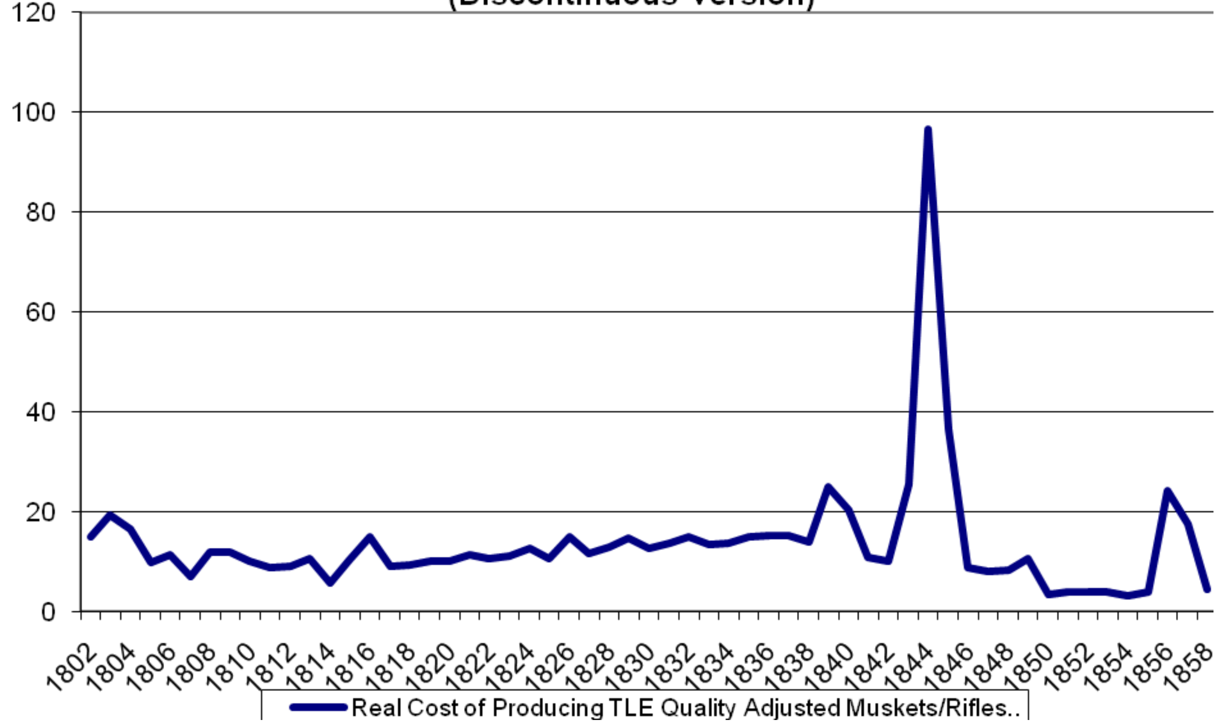


Chart 2: Number of Muskets/Rifles Produced per Worker, Harpers Ferry, 1802-1860
100
90
80
70
60
50
40
30
20
10
0
1802
1804
1806
1808
1810
1812
1814
1816
1818
1820
1822
1824
1826
1828
1830
1832
1834
1836
1838
1840
1842
1844
1846
1848
1850
1852
1854
1856
1858
1860
Number of Muskets/Rifles Produced per Worker, ..

Chart 3: Real Unit Cost of Producing Theoretical Lethality Index Adjusted Muskets/Rifles at Harpers Ferry, 1802-1858 (Discontinuous Version)



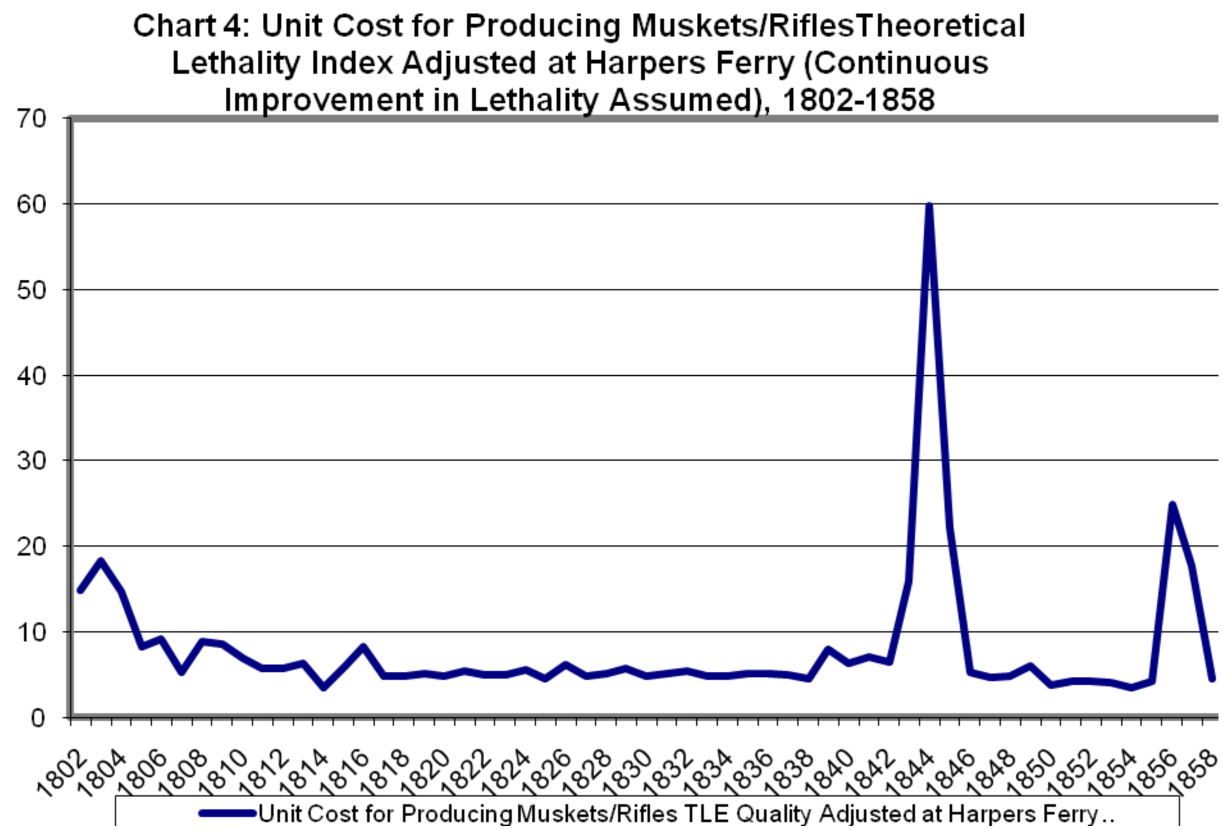


Chart 4: Unit Cost for Producing Muskets/RiflesTheoretical Lethality Index Adjusted at Harpers Ferry (Continuous Improvement in Lethality Assumed), 1802-1858
70
60
50
40
30
20
10
0
1802
1804
1806
1808
1810
1812
1814
1816
1818
1820
1822
1824
1826
1828
1830
1832
1834
1836
1838
1840
1842
1844
1846
1848
1850
1852
1854
1856
1858
Unit Cost for Producing Muskets/Rifles TLE Quality Adjusted at Harpers Ferry..

Chart 5: Relative Level of Ocean Shipping Freight Rates (Relative to Consumer Price Index), United States, 1814-1860

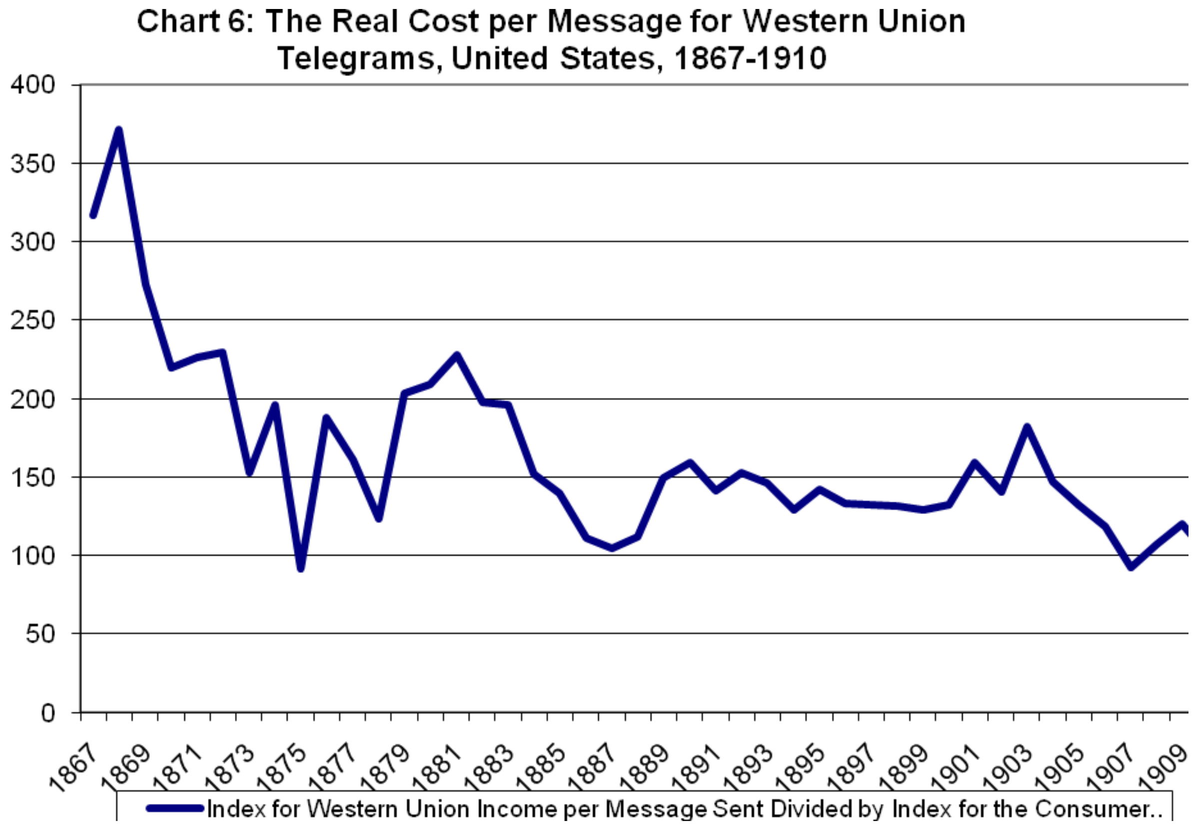


Chart 6: The Real Cost per Message for Western Union
Telegrams, United States, 1867-1910
400
350
300
250
200
150
100
50
0
1867
1869
1871
1873
1875
1877
1879
1881
1883
1885
1887
1889
1891
1893
1895
1897
1899
1901
1903
1905
1907
1909
Index for Western Union Income per Message Sent Divided by Index for the Consumer..

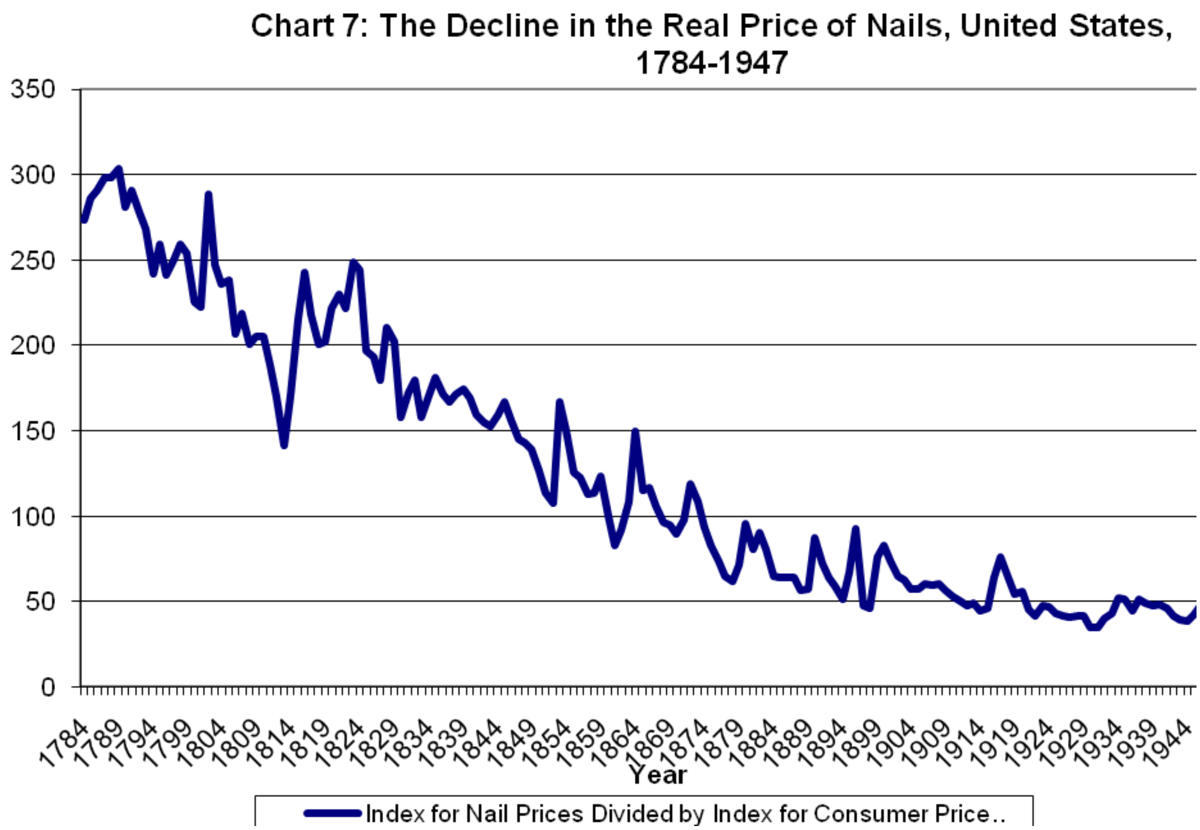


Chart 7: The Decline in the Real Price of Nails, United States, 1784-1947
350
300
250
200
150
100
50
0
1784
1789
1794
1799
1804
1809
1814
1819
1824
1829
1834
1839
1844
1849
1854
1859
1864
1869
1874
1879
1884
1889
1894
1899
1904
1909
1914
1919
1924
1929
1934
1939
1944
Year
Index for Nail Prices Divided by Index for Consumer Price..

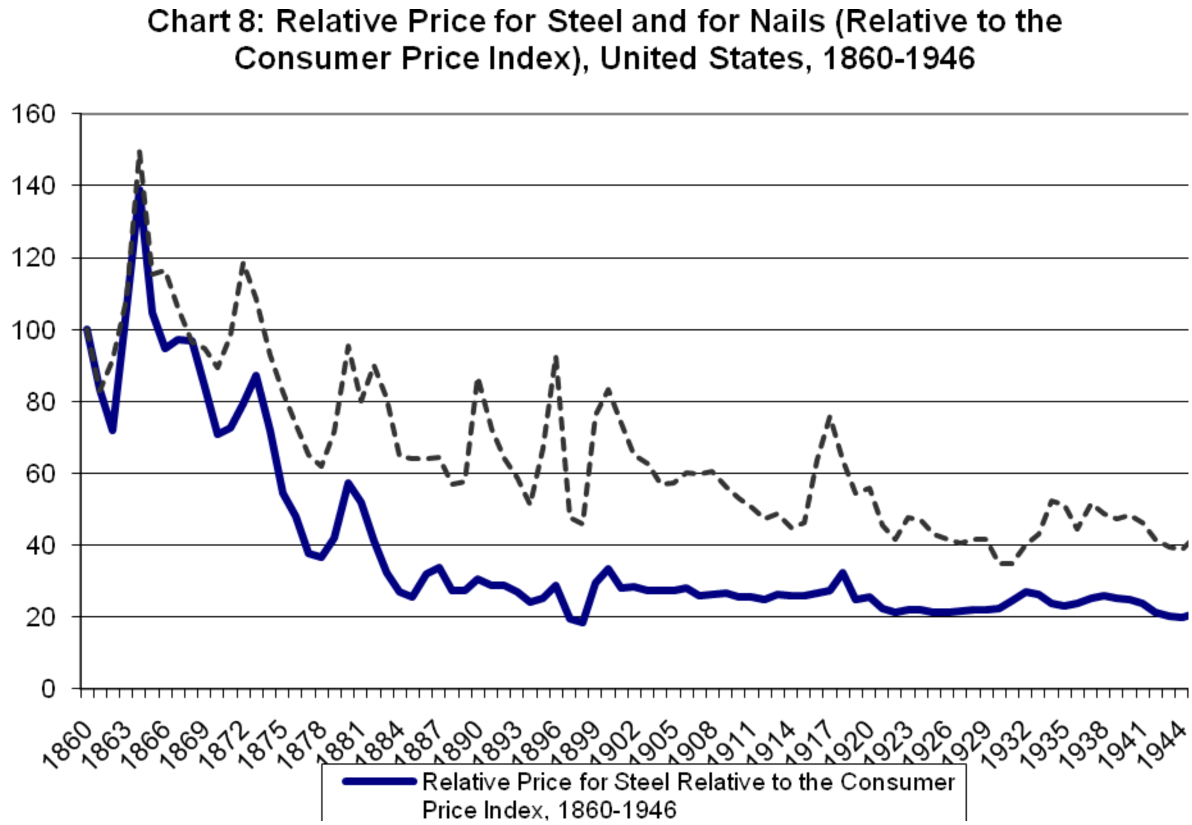


Chart 8: Relative Price for Steel and for Nails (Relative to the Consumer Price Index), United States, 1860-1946
160
140
120
100
80
60
40
20
0
1860
1863
1866
1869
1872
1875
1878
1881
1884
1887
1890
1893
1896
1899
1902
1905
1908
1911
1914
1917
1920
1923
1926
1929
1932
1935
1938
1941
1944
Relative Price for Steel Relative to the Consumer Price Index, 1860-1946

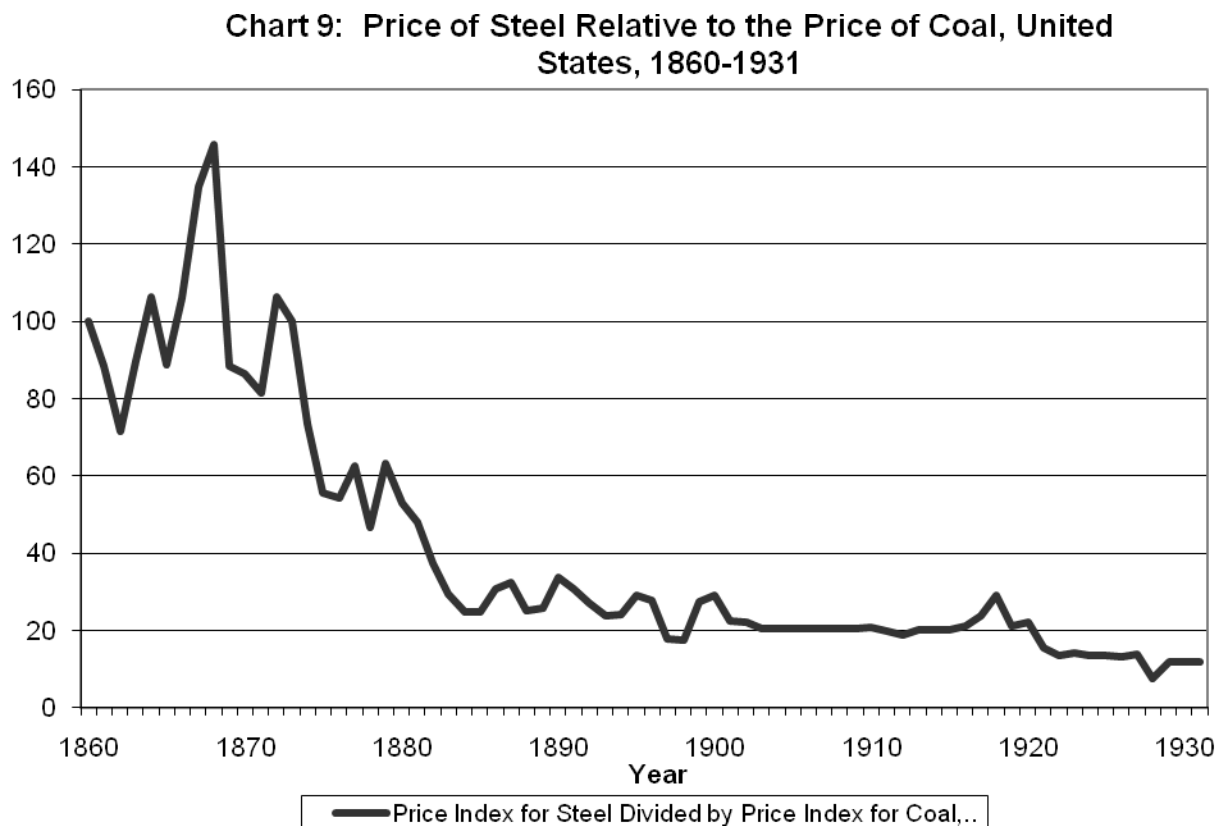


Chart 9: Price of Steel Relative to the Price of Coal, United States, 1860-1931
160
140
120
100
80
60
40
20
0
1860
1870
1880
1890
1900
1910
1920
1930
Year
Price Index for Steel Divided by Price Index for Coal,..

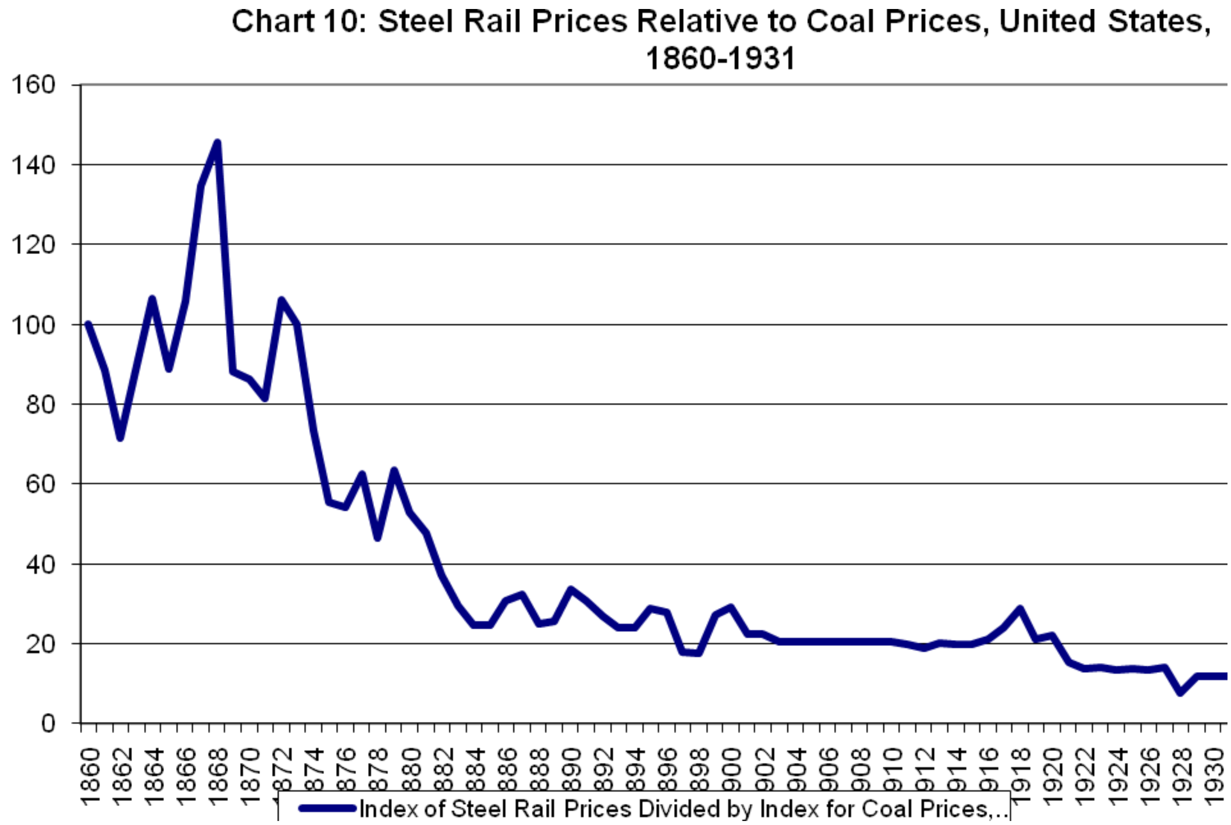


Chart 10: Steel Rail Prices Relative to Coal Prices, United States, 1860-1931
160
140
120
100
80
60
40
20
0
1860
1862
1864
1866
1868
1870
1920
1922
1924
1926
1928
1930
Index of Steel Rail Prices Divided by Index for Coal Prices,..

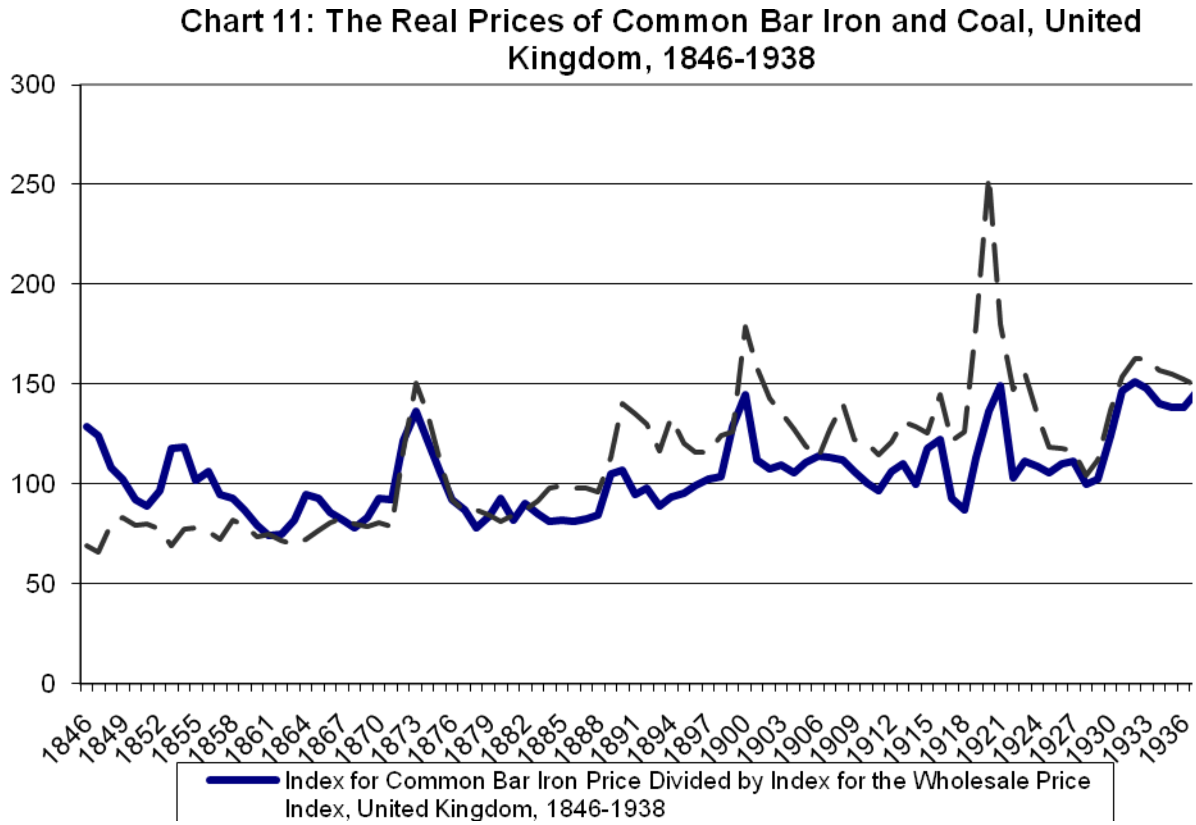


Chart 11: The Real Prices of Common Bar Iron and Coal, United Kingdom, 1846-1938
300
250
200
150
100
50
0
1846
1849
1852
1855
1858
1861
1864
1867
1870
1873
1876
1879
1882
1885
1888
1891
1894
1897
1900
1903
1906
1909
1912
1915
1918
1921
1924
1927
1930
1933
1936
Index for Common Bar Iron Price Divided by Index for the Wholesale Price Index, United Kingdom, 1846-1938

Chart 12: The Price of Scottish Pig Iron Relative to Coal Price and the Real Price of Coal, United Kingdom, 1831-1938

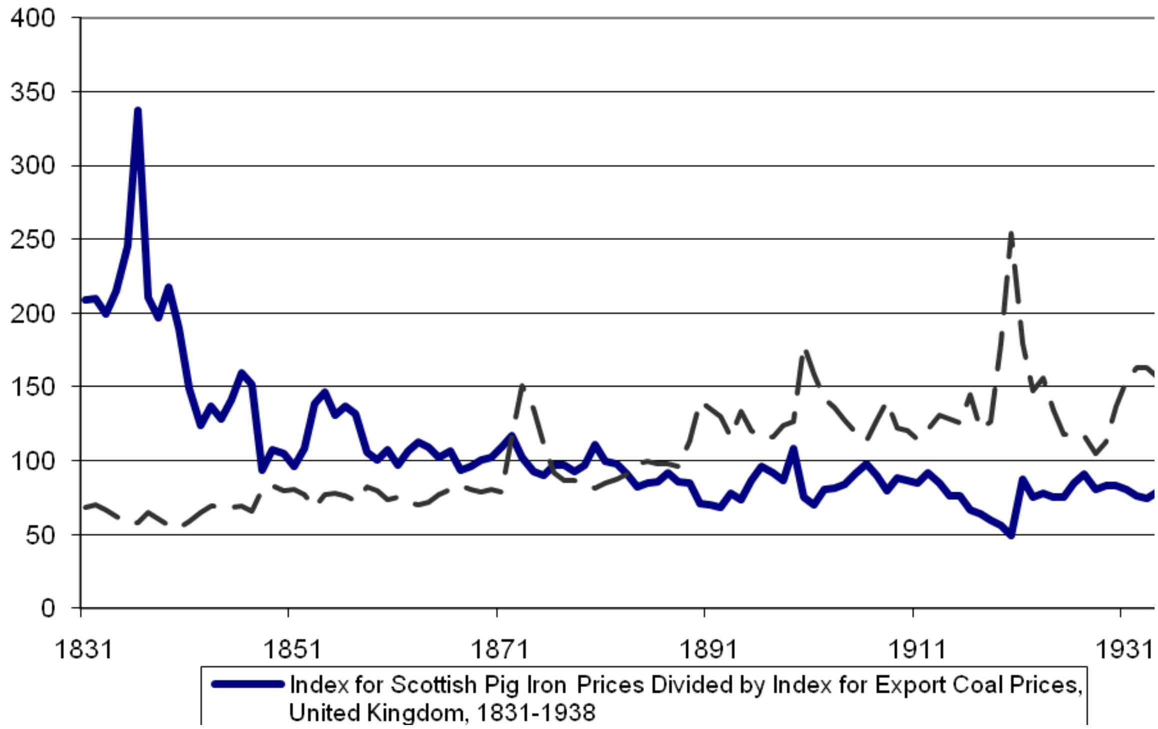


Chart 13: Relative Price of Pig Iron (Relative to Iron Ore Price), Sweden, 1732-1914

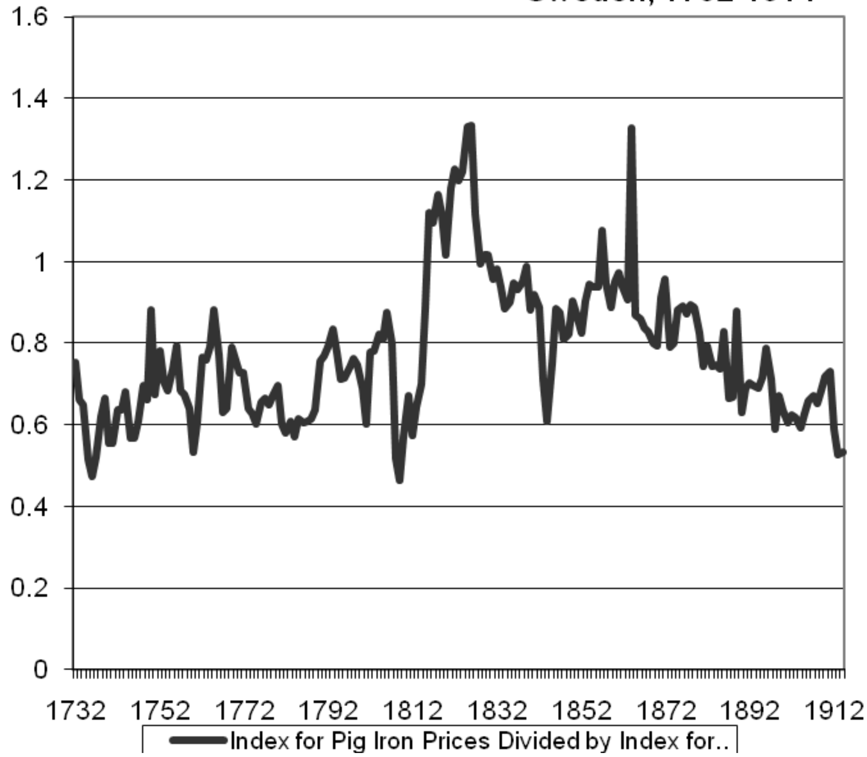
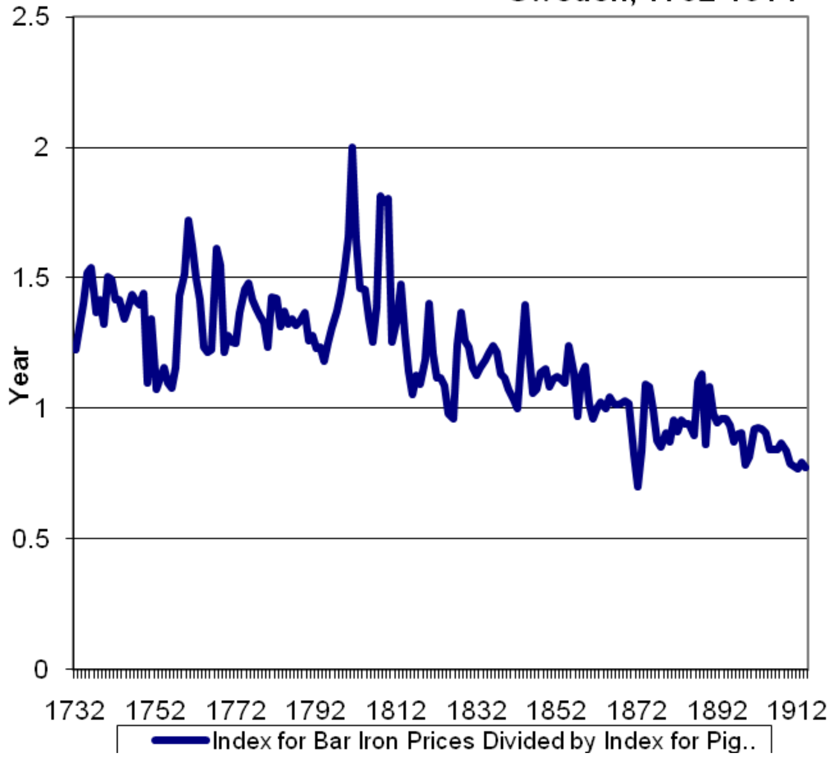


Chart 14: Relative Price of Bar Iron Relative to Pig Iron Price, Sweden, 1732-1914



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