Progress

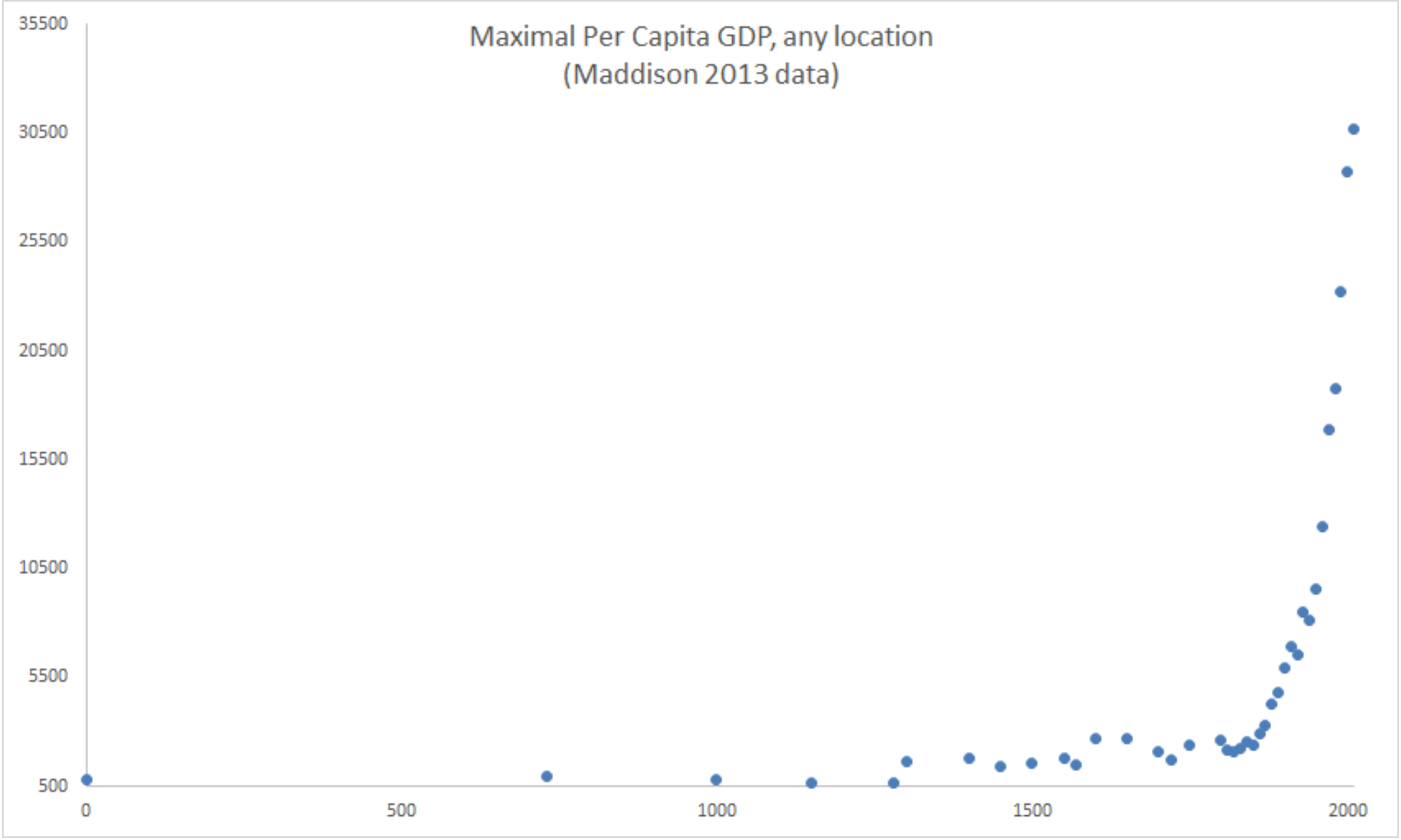
Class 2 - Industrial Revolution

Kevin A. Bryan - Toronto Rotman - Sep 23, 2025

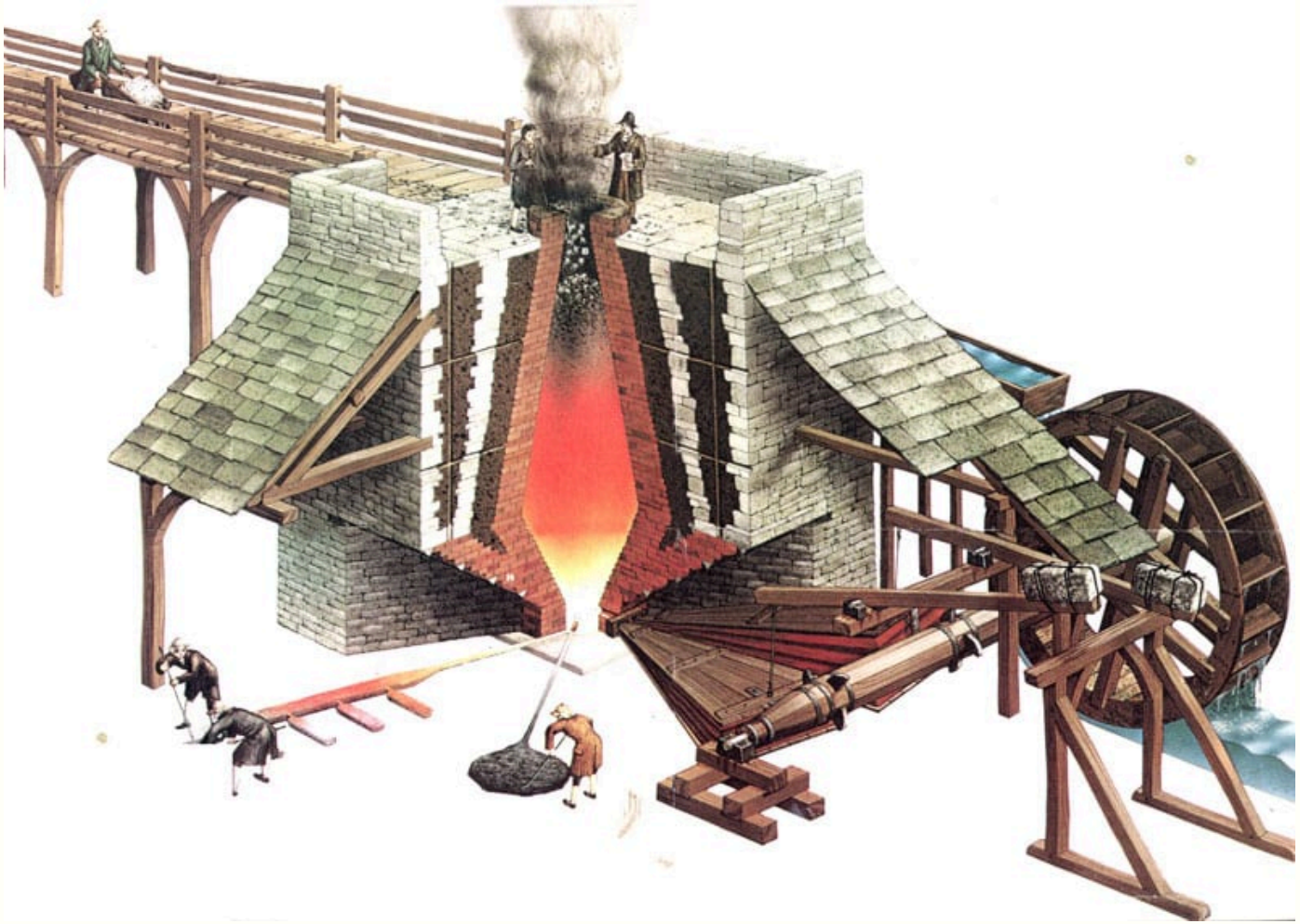
Notes after class are in red

Moreover, a mass of children work the whole week through in the mills or at home, and therefore cannot attend school. The evening schools, supposed to be attended by children who are employed during the day, are almost abandoned or attended without benefit. It is asking too much, that young workers, who have been using themselves up twelve hours in the day, should go to school from eight to ten at night. - Engels, Condition of the Working Class

So yes, I know we have a lot of reading, but in perspective!



As we saw last week, this chart shows incomes per capita for the richest places in the world by year. These estimates are rough, but 3-4 times bare subsistence for average worker was about as rich as anywhere got until the mid-1800s, when we see the "hockey stick". That is, the Industrial Revolution is the most important period of progress ever!



Tell me what you notice?

This is a medieval blast furnace. Known for long time in China then to Scandinavia by 1100s. Uses charcoal (trees!) to remove impurities in mined iron and make it usable. The carbon both acts as fuel to heat the furnace, and as a chemical reactant: the oxygen in the air reacts with carbon in the coke to form carbon dioxide, which in the heat of the furnace quickly becomes carbon monoxide. The carbon monoxide, in turn, reacts with the iron oxide to form iron and CO2 (called “reduction” of the ore). The iron absorbs carbon, which lowers its melting point and causes it to melt as it descends into the hotter parts of the furnace. The now-liquid iron drips down to the bottom of the furnace where it’s drained out (called “tapping” the furnace).

Producing a single kilogram of iron required perhaps 6 kilograms of iron ore, and 15 kilograms of charcoal. That charcoal, in turn, required perhaps 105 kilograms of wood. Turning a kilogram of iron into steel required another 20 kilograms of charcoal (140 kilograms of wood). https://www.construction-physics.com/p/the-blast-furnace-800-years-of-technology.

Need heat, need something to burn, need iron, need some energy to push that heat in. Iron, the crucible for steel, the steam engine for power not next to water, the loss of forests, rail and ships to export this, plus minor improvements in the height of the blast furnace, urbanization, education. We hugely dropped energy requirements for making iron (15x drop) over the 1800s.

How? Small improvements. Trial and error. People willing to keep trying even when it doesn't work at first for small reasons (as in my example of the holding up cardboard with an upsidedown cup of water - sometimes it doesn't work because of small changes in setup you would barely notice, but the physics of atmospheric pressure are always the same!)

The Iron Bridge of Shropshire, 1781. With cheap iron, we can do some pretty beautiful things!

From Witney to Canada

And of course the famous Hudson's Bay blanket, as Allen notes, only makes it to Canada because of cheaper wool in the 1700s in England due to Industrial Revolution innovations.

About 1760 a wave of gadgets swept over England.

(A famous schoolboy's description of the Industrial Revolution in historian T.S. Ashton's account)

Iron and steam and watches and modern textiles and the railroad and silk and machine tools and great factories and huge spikes in urbanization

Embedded Website:

https://www.youtube.com/embed/xEimbZfrgOI?si=MlYGYGzIwTgoKN4G&start=609

Mike Myers, the industrial revolution was neither industrial nor a revolution. Good point!
https://www.youtube.com/embed/xEimbZfrgOI?si=MlYGYGzIwTgoKN4G&start=609

And so - why do we care about the IR? Was it in fact "neither industrial nor a revolution"?

Maybe Mike Myers is right! The "revolution" took almost a century, as we'll see, and even if the *result* is a bunch of new industrial inventions spreading through society, that is not the *cause*.

Why do we care about the Industrial Revolution?

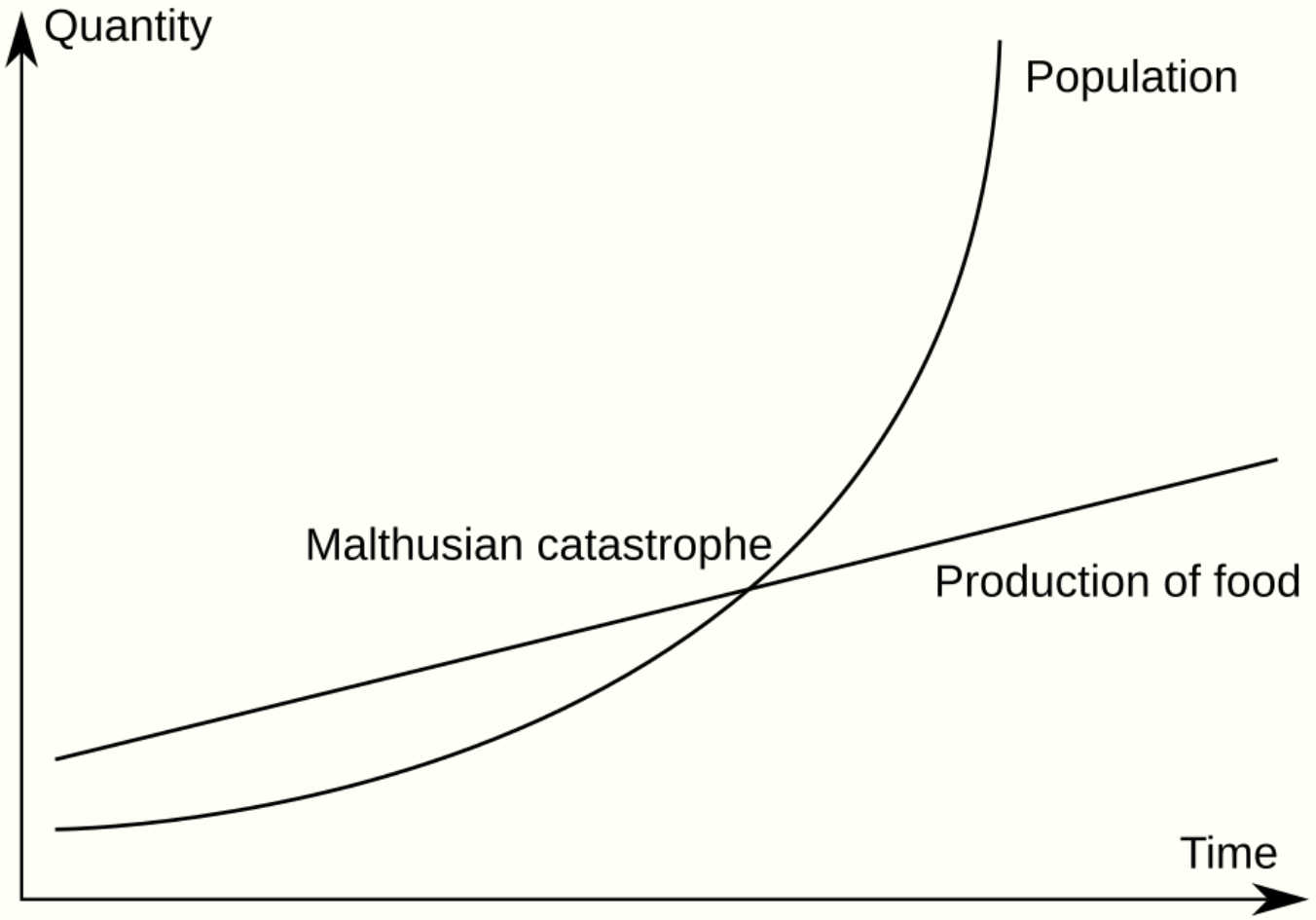
This isn't just about history...

Because if we care about how to make "progress happen in rare times, rare places, rare orgs", we better understand the most consequential era of progress in human history happened, and what lessons we can draw from that for today.

Examining British economic history in the period 1760-1830 is a bit like studying the history of Jewish dissenters between 50 B.C. and 50 A.D. At first provincial, localized, even bizarre, it was destined to change the life of every man and women…beyond recognition.

Mokyr

We care about the IR because its *impact* was breaking humanity out of the nasty, brutish and short life of poverty we lived in for all time. It may not have been obvious that would happen in the mid-1800s!



The Malthusian mechanism

In Malthus, population grows geometrically. Innovation or other shock to income -> more kids -> move to farm marginal land -> we get poorer. These Malthusian cycles take time, but when food is most of what we consume, this Malthusian mechanism makes sustained growth very hard. Consider the cycle around the Black Death. Allen: Real wages were similar across Europe after the Black Death, but then a great divergence emerged. Wagesin London and Amsterdam remained high. Workers in those cities could buy several subsistence basketsfor their families (although typically they upgraded their spending on food to include more meat, beer,etc.). In contrast real wages fell in Florence and Vienna.
By the 18th century labourers there could barely afford one subsistence basket. Workers in Beijing and Delhi received similarly miserable earnings. Thedifference between these cities was due to international trade. London and Amsterdam were boomingports and wages were very high. The population was growing rapidly as migrants were drawn in from thecountryside. The demand for labour grew rapidly enough to sustain the high wage.

Some Explanations

Marx (?!): Capitalism was the only economic system in which incentives led to economic growth.

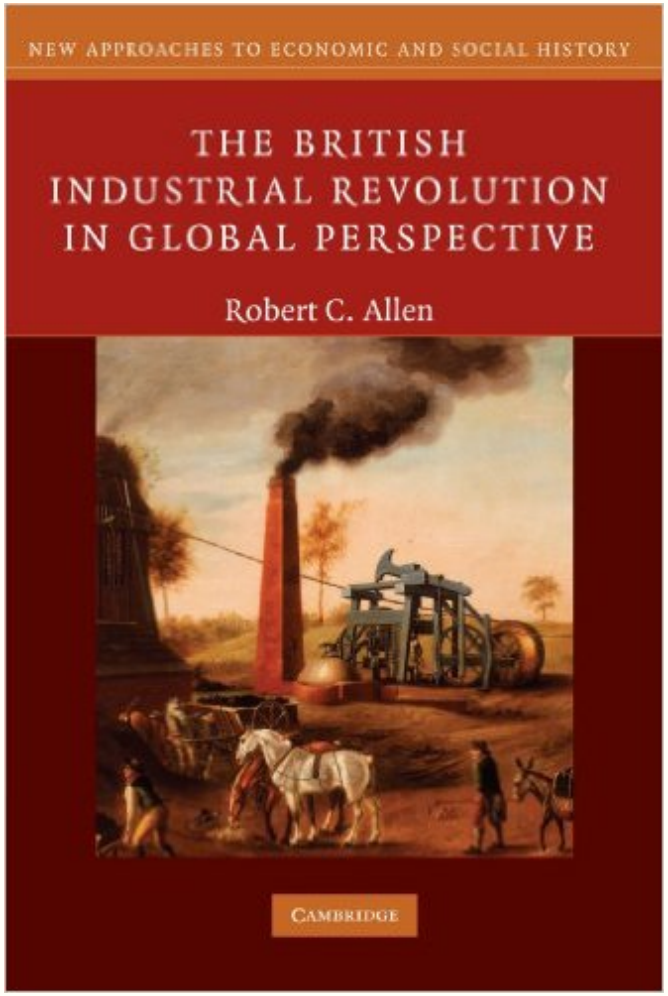
Allen: High English wages, cheap English coal

Mokyr: "Culture of Tinkerers"

McCloskey: "Bourgeois Dignity"

Crafts: Improvements in few areas outrun Malthus

Others: institutions, colonialism/market size, etc.



A "things" theory of the Industrial Revolution

Bob Allen is a "historian of production". His theory of the IR: we became more productive at making things. Why? Raw incentives. High wages and cheap energy in Britain -> more invention. Why high wages? Many reasons - growth from 1600, colonial trading relationships, democratic reform, and so on.

"Necessity is the mother of invention"

Is invention "induced" by "expensive" factors? That is, did England innovate in saving human energy by using coal simply because...coal was cheap and labor was expensive?

Production uses energy and labor: $Y = AE^{\alpha}L^{1-\alpha}, \quad A > 0, 0 < \alpha < 1$

So profit (normalize price to 1): $\pi(E, L) = AE^{\alpha}L^{1-\alpha} - p_E E - wL$

The first order conditions give us

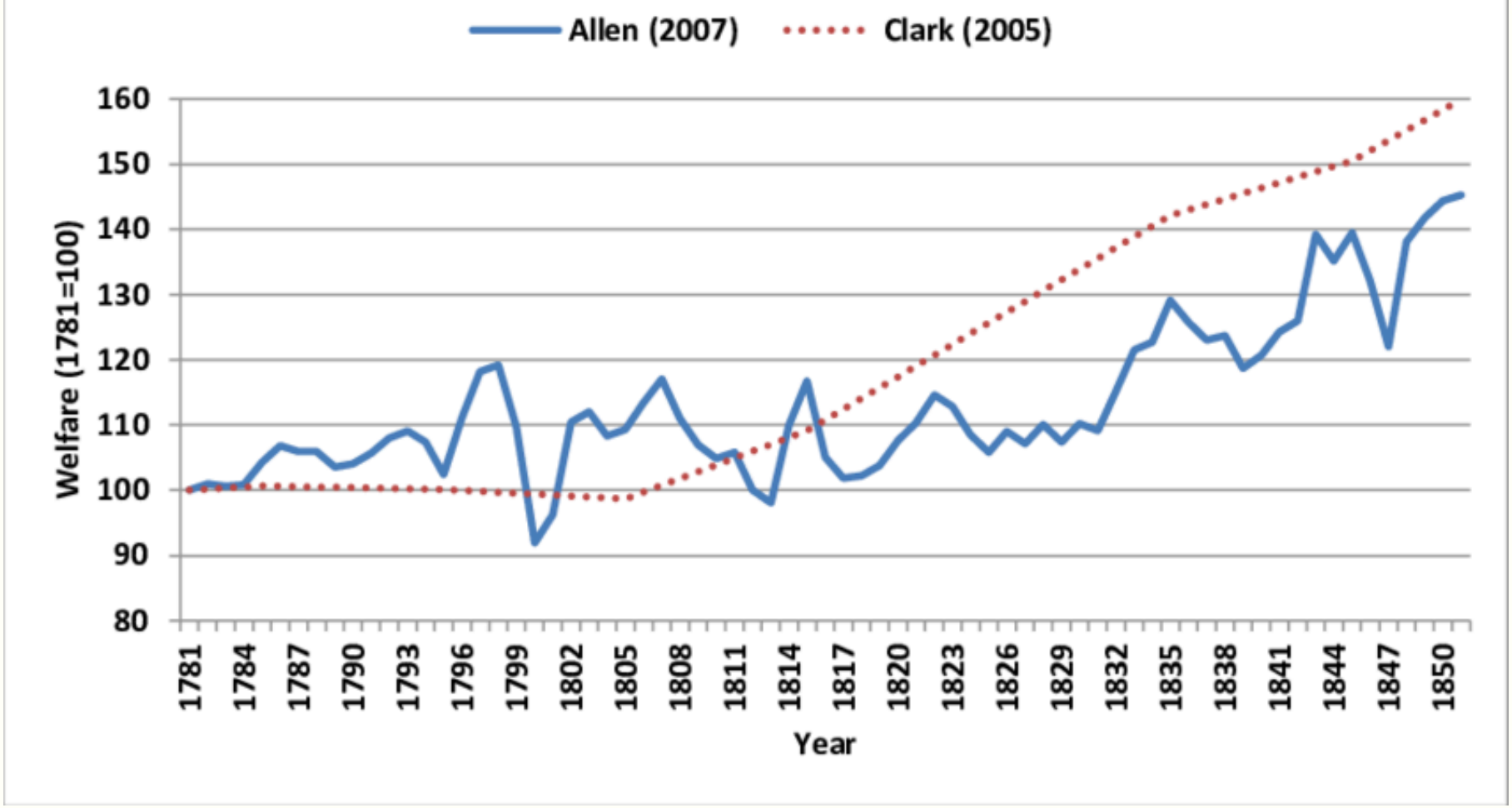
$$\frac{\partial \pi}{\partial E} = \alpha A E^{\alpha-1} L^{1-\alpha} - p_E = 0 \Rightarrow MP_E = p_E$$

$$\frac{\partial \pi}{\partial L} = (1-\alpha) A E^{\alpha} L^{-\alpha} - w = 0 \Rightarrow MP_L = w$$

So do I care about "saving" labor or energy more?

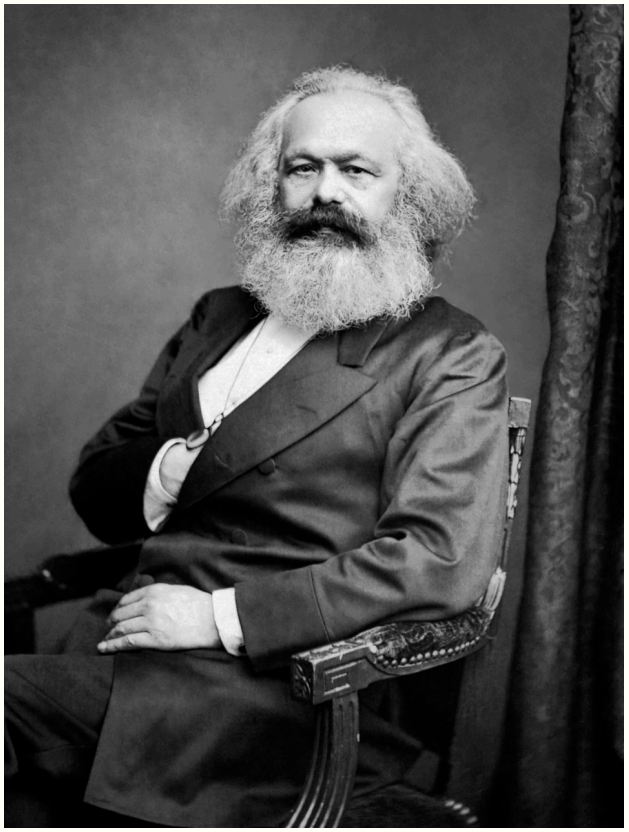
There are no expensive factors of production! Everyone is paid their marginal product. Now, Acemoglu (2012) and similar give more sophisticated arguments about how invention works, but the basic idea that "labor is expensive" - no, labor is hired until MPL=w.

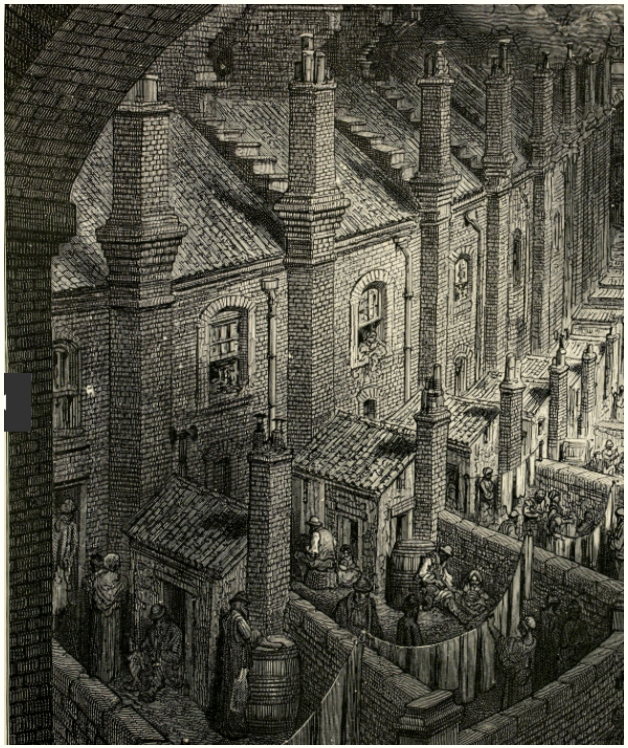
And likewise, did America have a lot of innovation because land "abundant" and labor "dear" (workers just moved West unless you paid them)? For a firm, we hired workers until MPL=wage, and we used capital until its marginal cost equalled its marginal product. So *in equilibrium* neither is expensive and something to economize on, unless we want to



Hitherto it is questionable if all the mechanical inventions yet made have lightened the day's toil of any human being...(Mill, 1871)

Even John Stuart Mill in 1871 wasn't sure the IR was good for workers! You can see in the graph: first 50-80 years after Industrial Revolution really kicks off in mid-1700s, hardly any change in British regular worker wages (and cities were disgusting and unhealthy, so living standards may have been outright worse in 1840 than 1760 - no wonder Marx and Engels had success!)





Marx and Engels

The food of the labourer, indigestible enough in itself, is utterly unfit for young children, and he has neither means nor time to get hischildren more suitable food. Moreover, the custom of giving children spirits, and even opium, is very general

Engels, Condition of the Working Class

This is 60-80 years into the Industrial Revolution productivity rise!

Why, then, did anyone move to the factory towns?

Little open land w/ pop growth and enclosure of grazing land, mechanization makes it hard to do cottage industry like fabric production at home

Mechanization meant that 'the masters and the fabric may flourish, but it cannot be contended that the labouring hands do the same.' The employment of weavers was cut in half.

Ok, so we need society to overcome the *dislocation* of progress. But also: we need technical progress to outrun Malthus. The Song Dynasty in China saw *inventions*: the gun, movable type, a primitive Bessemer process, a modern canal lock system, the steel curved moldboard plow, and a huge increase in arable land following public works projects. But what of *improvements*?

That is, inventions happened in many places. But using the very very very most elite of society, many of whom were "scientists" not tinkerers or engineers, with little interest in practical application, and many of whom have their roles because of family connections not skill. To get small, cumulative improvements in a technology, you need to use a broader set of talent.

"Thrifty self-discipline and violent expropriation have been too common in human history to explain a revolution utterly unprecedented in scale and unique to Europe around 1800"

McCloskey

That is, we need more than just exploitation to explain the IR because exploitation happened many times. The Mongols did not have an Industrial Revolution...or even more relevant, Spain and Portugal have incredibly exploitative empires, and literally just funnel gold and silver back home, but do not see anything close to an IR.

"From the hour of their birth, some are marked out for subjection, others for rule"

Aristotle, Politics

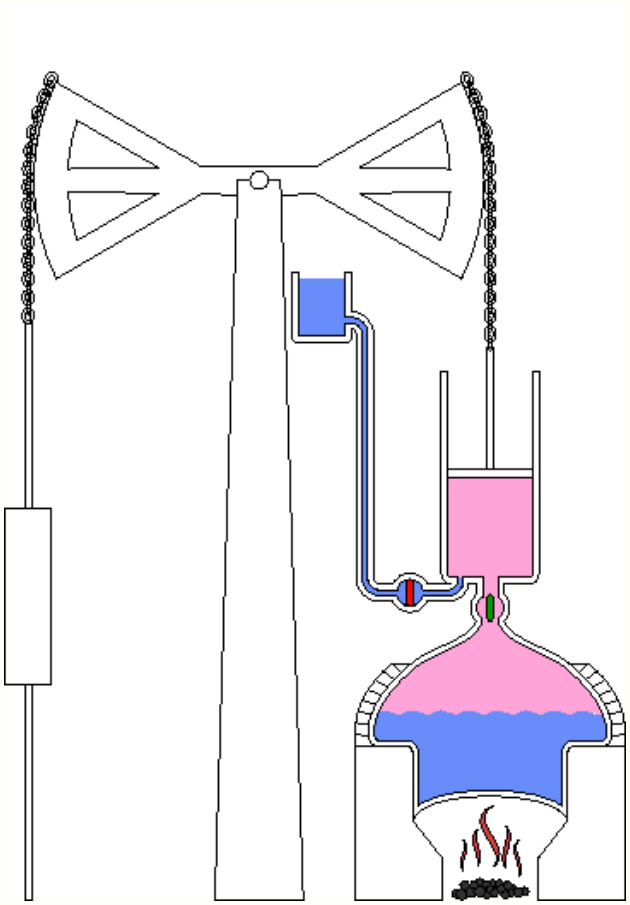
Inherited wealth was long thought blameless compared with earned wealth, about which suspicion hung.

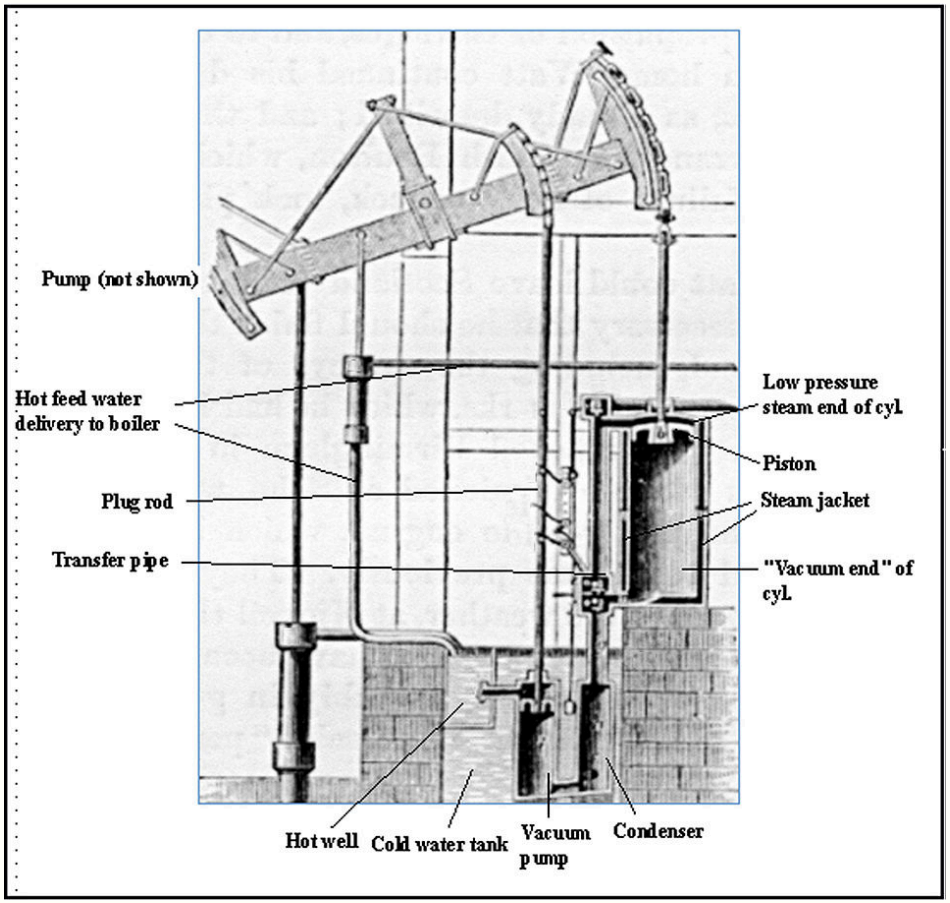
McCloskey

Britain in 1700s -> more dignity for common workers -> their ideas are seen as having value as well as their persons -> Watt (steam engine), son of shipwright. Arkwright (loom): barber with no education. Trevithick (railroad): son of mine foreman.

The important “institutions” were ideas, words, rhetoric, ideology. And these did change on the eve of the Great Enrichment.

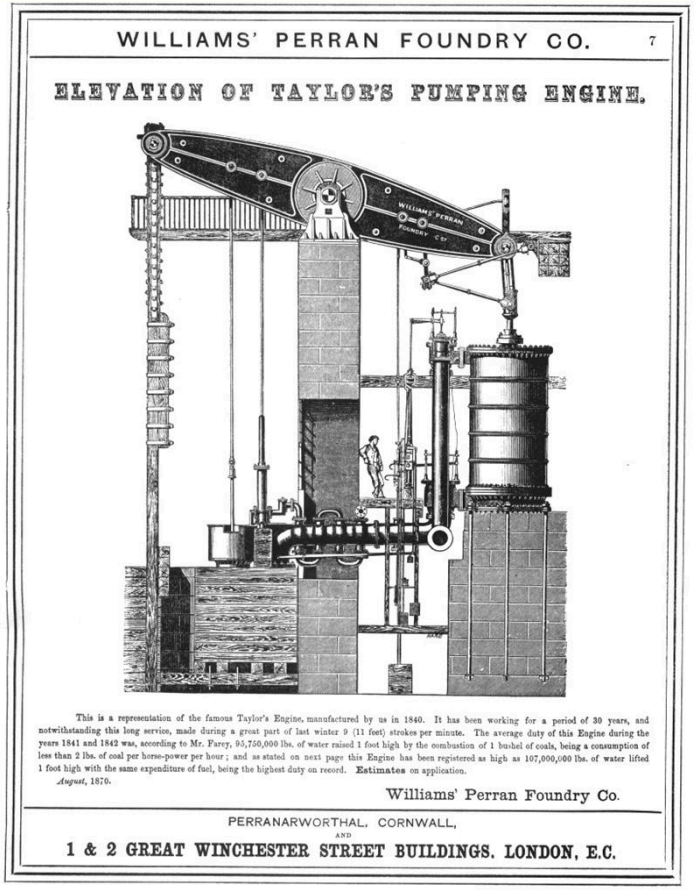
McCloskey, we had property rights in Rome and the Ottoman Empire, but no Great Enrichment. China was commercial, no great enrichment.





Newcomen vs Watt

Some science came to Newcomen from Italy. But energy needed to do work with steam fell from 44 lbs of coal to 3 lbs of coal per HP-hour over a century after Newcomen! The steam engine was invented by Newcomen, a Dartmouth ironmonger. Fuel consumption fell from 44 lbs per HP-hour in 1727 to 30 lbs per HP-hour in 1769, probably because ofcollective invention as operators shared their results and built on each other's experience. Consumption dropped again from 30 lbs to 17 lbs. This was the result of research by John Smeaton. Smeaton collected the records of fifteen engines—their owners did not keep them secret—and analysed them to determine the most efficient design. The next advance was due to James Watt, FRS, whose famous separate condenser cut fuel consumption from 17 to 9 lbs. The first engine with a separate condenser went into service in 1776. And so on - tinkerers!



WILLIAMS' PERRAN FOUNDRY CO. 7

ELEVATION OF TAYLOR'S PUMPING ENGINE.

This is a representation of the famous Taylor's Engine, manufactured by us in 1840. It has been working for a period of 30 years, and notwithstanding this long service, made during a great part of last winter 9 (11 feet) strokes per minute. The average duty of this Engine during the years 1841 and 1842 was, according to Mr. Farey, 95,750,000 lbs. of water raised 1 foot high by the combustion of 1 bushel of coals, being a consumption of less than 2 lbs. of coal per horse-power per hour; and as stated on next page this Engine has been registered as high as 107,000,000 lbs. of water lifted 1 foot high with the same expenditure of fuel, being the highest duty on record. **Estimates** on application.

August, 1870.

Williams' Perran Foundry Co.

PERRANARWORTHAL, CORNWALL,
AND
1 & 2 GREAT WINCHESTER STREET BUILDINGS, LONDON, E.C.

Lean's Engine Reporter and the *Lunar Society*

Lean's Reporter and similar periodicals provided information in real time about advances in various industries. Societies like the Lunar Society and SDUK spread scientific and engineering ideas beyond just the very elite Royal Society types. For Mokyr, you have 2-5% of society ("right-tail human capital") able to and willing to contribute to progress.

Britain's enormous wealth is because of the 'wonderful practical skills of her adventurers in the useful application of knowledge and the superiority of her workmen

Jean-Baptiste Say

It was evident to other Europeans like the famous Frenchman Say that something was happening uniquely in England.

The invention "of the method of invention". Either via incentives or culture...

Consider the link to AI

AIs big improvement will be if it creates a large speedup in how quickly innovation can happen. How? AI writes code to improve AI which writes code to run automated labs which run studies to improve robotics which allow for more automated labs and so on.

Ideas we'll see all term: culture (McCloskey), incentives (Allen), science (incl. "low" science of tinkering - Mokyr), cities, liberty...

Some truth in all these ideas. So why the Industrial Revolution in Britain? It was rich enough due to growth from 1600 to 1750 that there was a large group of folks who could work on tasks beyond agriculture; democracy and cultural changes give dignity to at least some section of common people and respect to those who are not the landed gentry; these newly respected folks due to ideas since Bacon both care about continual improvement, have just enough science to actually do it, have institutions where good ideas spread quickly, and are incentivized via industry and patents to care about making new things; and cheap coal with high wages a la Allen means that innovations using coal-generated industry in particular to reduce human labor have a high return.

Which of those factors matters most? An argument for historians. My read of the evidence, though, is that at least within Europe in the 1700s, the engineering/tinkering culture in Britain, and the fraction of the population which took part, was unique in human history.

Next Week

Is Science Necessary?

We've seen the tinkerers and the improvements, much of which were not linked to science (which was stronger on the Continent!). So what role does scientific knowledge play in progress?