ECONOMICS Lecture 13
Production Theory: Technology

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Topics

- Malthusian Crisis
- Production Technology
- Factor Substitution
- Industrial Revolution
- The Future of Work

This lecture examines the role of technology revolution in economic history, models the technology factor in the production function, and connects the theory to future challenges of technology disruption.

Thomas Malthus: Population Crisis

It may safely be pronounced, therefore, that population, when unchecked, goes on doubling itself every twenty-five years, or increases in a geometrical ratio. The rate according to which the productions of the earth may be supposed to increase, it will not be so easy to determine. Of this, however, we may be perfectly certain, that the ratio of their increase in a limited territory must be of a totally different nature from the ratio of the increase of population. A thousand millions are just as easily doubled every twenty-five years by the power of population as a thousand. But the food to support the increase from the greater number will by no means be obtained with the same facility.

—Malthus. 1826. An Essay on the Principle of Population. Chapter 1
www.econlib.org/library/Malthus/malPop.html

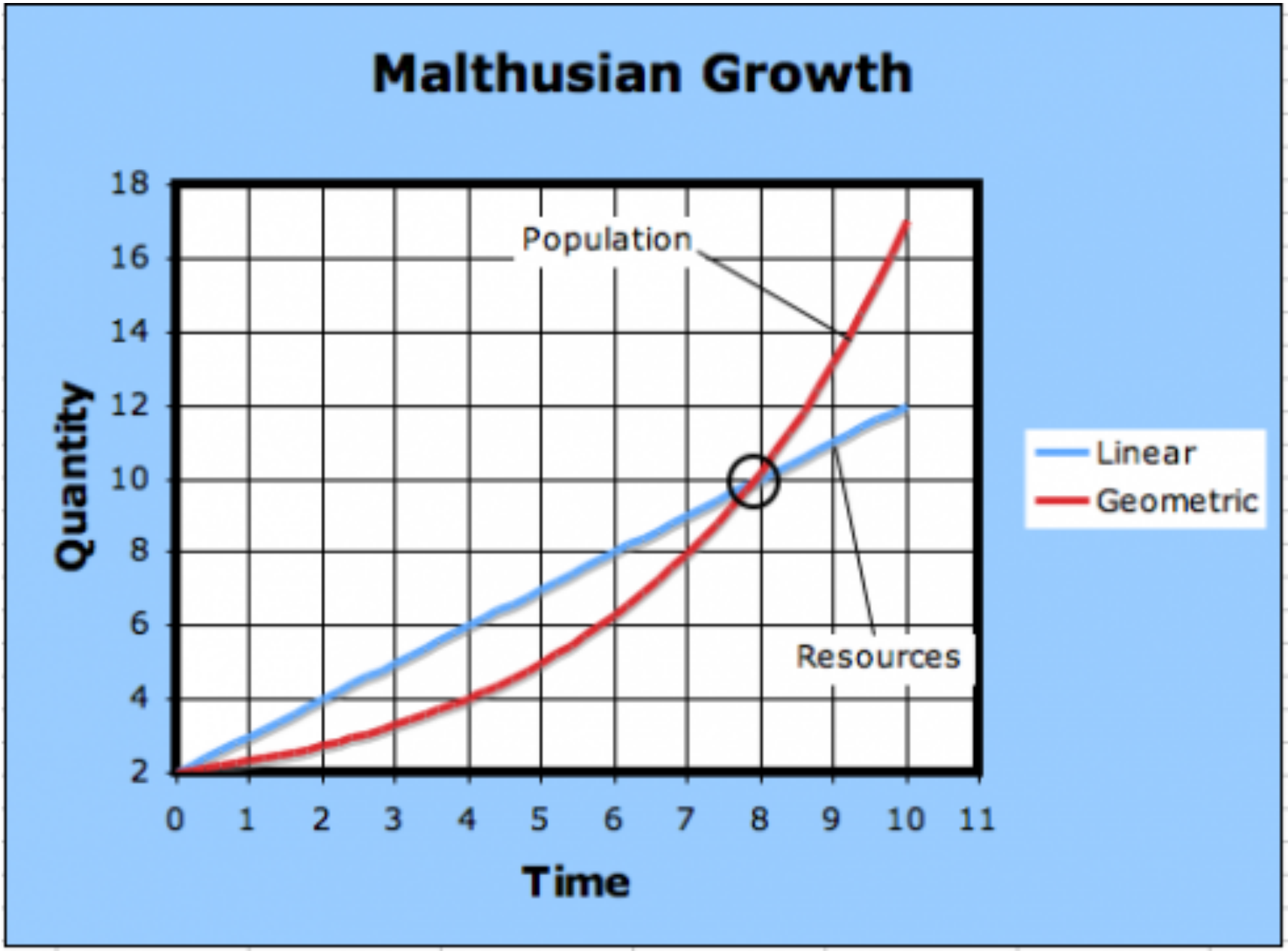
Thomas Malthus (1766-1834)

Thomas Robert Malthus was an English cleric and scholar, influential in the fields of political economy and demography.

He was interested in everything on populations. He collected figures on births, deaths, age of marriage and childbearing, and economic factors contributing to longevity. His main contribution was to highlight the relationship between food supply and population. His most important works:

- *An Essay on the Principle of Population (1798)*
- *Principles of Political Economy (1820)*

https://www.econlib.org/library/Enc/bios/Malthus.html



https://montessorimuddle.org/2011/06/30/malthusian-growth/

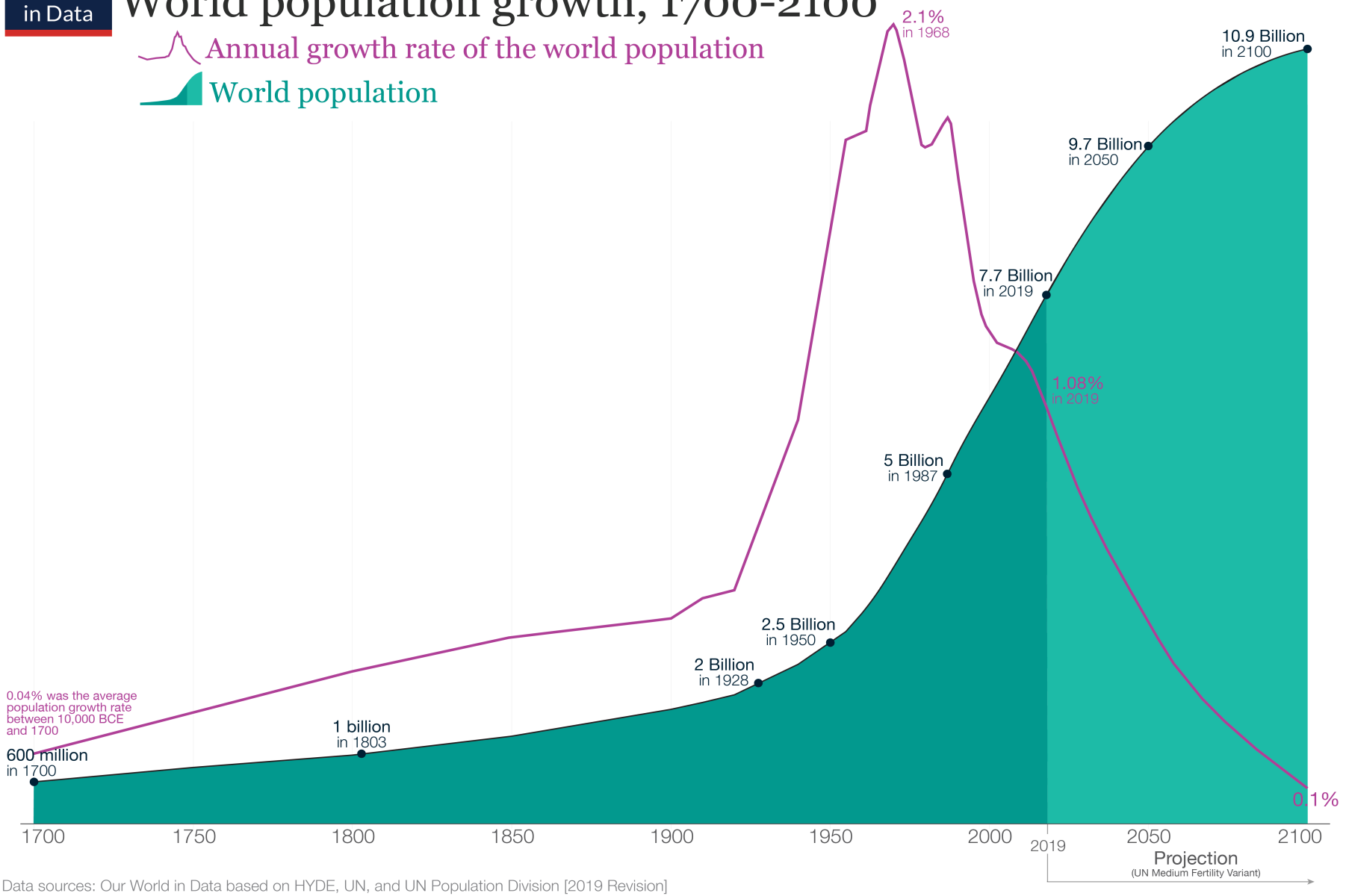
Malthus: Population Growth and Crisis

- Noting that while food production tends to increase arithmetically, population tends to increase naturally at a (faster) geometric rate, Malthus argued that it is no surprise that people thus choose to reduce (or "check") population growth.
- Malthus is arguably the most misunderstood and misrepresented economist of all time. *The adjective "Malthusian" is used today to describe a pessimistic prediction of the lock-step demise of a humanity doomed to starvation via overpopulation.*
- Malthus was fascinated not with the inevitability of human demise, but with why humans do not die off in the face of such overwhelming odds. Malthus's actual conclusion is that because humans have *not* all starved, economic choices must be at work, and it is the job of an economist to study those choices.

https://www.econlib.org/library/Enc/bios/Malthus.html

Our World in Data

World population growth, 1700-2100



Data sources: Our World in Data based on HYDE, UN, and UN Population Division [2019 Revision]
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing.

https://ourworldindata.org/world-population-growth

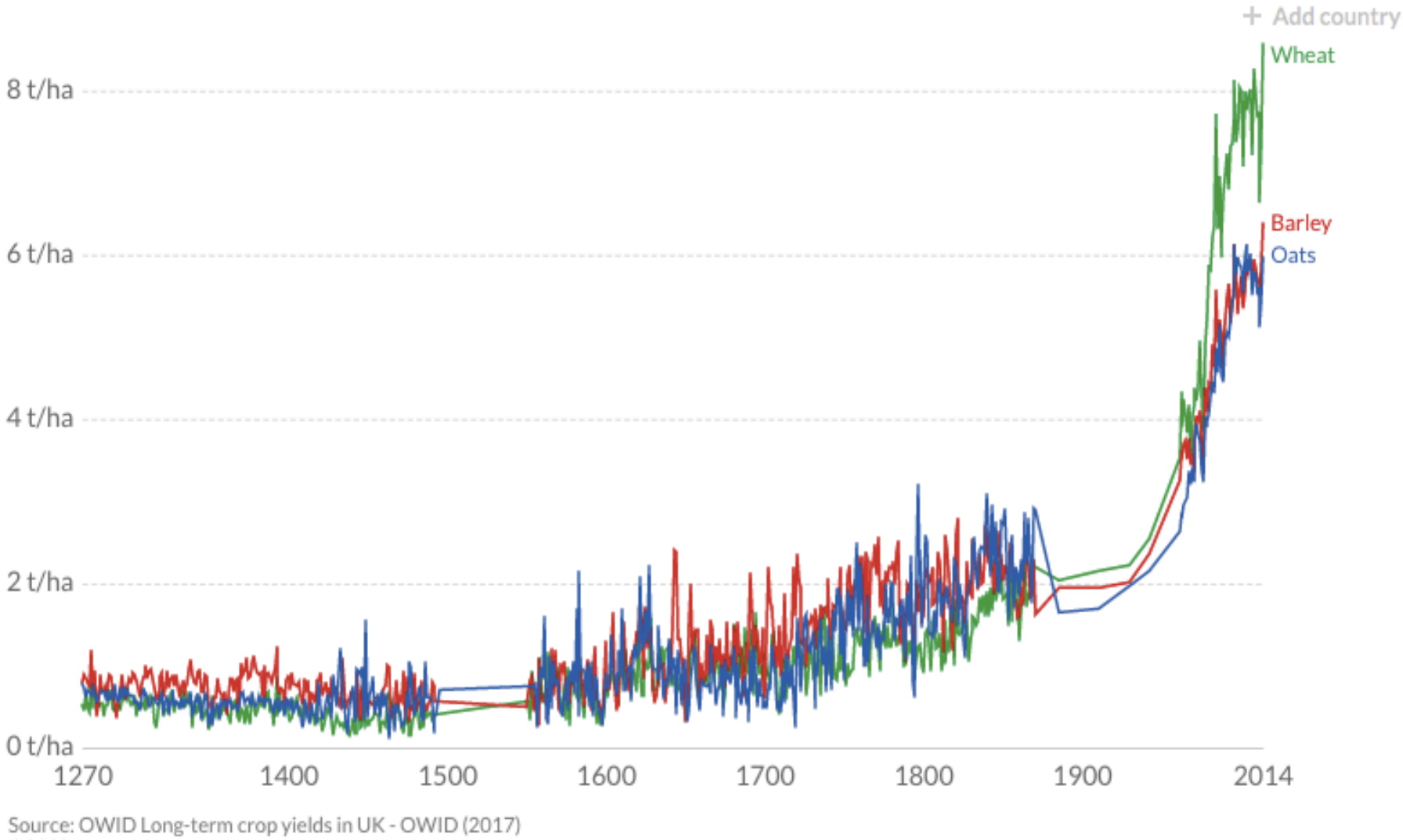
Agricultural Consumption in England

	1700-9	1760-9	1860-9
Population (millions)	5.16	6.25	19.97
English Farm net output (£ m. 1860-9)	64.7	71.4	114.3
Net Food Imports (£ m. 1860-9)	1.7	3.2	79.8
Net Raw Material Imports (£ m. 1860-9)	-2.1	-4.6	61.4
Domestic Coal Consumption (£ m. 1860-9)	1.7	7.9	48.3
Total Food, Energy and Raw Material Consumption (£ m. 1860-9)	66.0	79.3	303.8
Consumption per Person (£. 1860-9)	12.8	12.7	15.2
Predicted Consumption (£. 1860-9)	12.8	13.3	15.1

Clark (2002), The Agricultural Revolution and the Industrial Revolution: England, 1500-1912
http://faculty.econ.ucdavis.edu/faculty/gclark/papers/prod2002.pdf

Long-term cereal yields in the United Kingdom

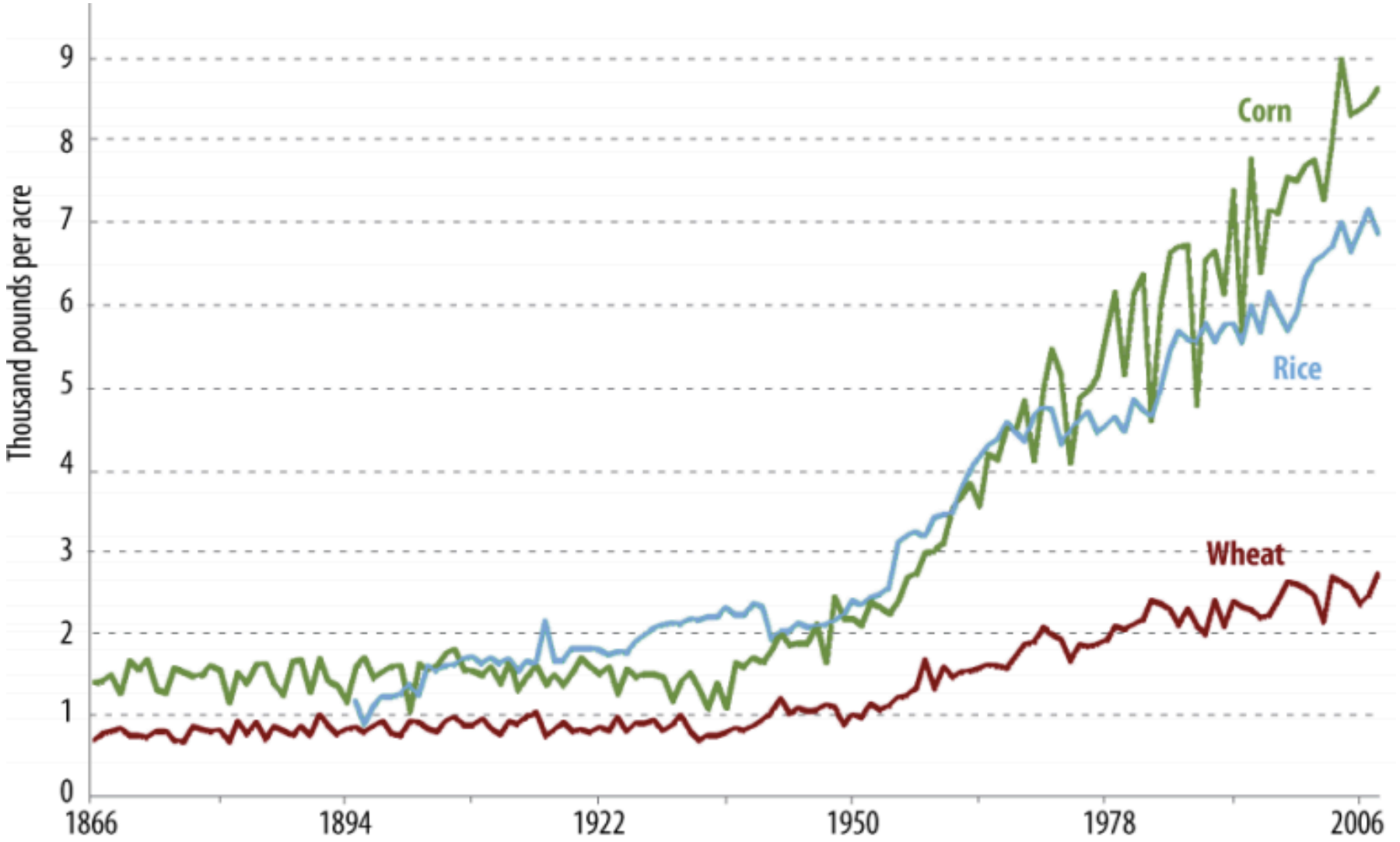
Average agricultural yields in key crops in the United Kingdom from 1270-2014, measured in tonnes per hectare.



Source: OWID Long-term crop yields in UK - OWID (2017)

https://ourworldindata.org/crop-yields

US Farm Yields, 1866-2008

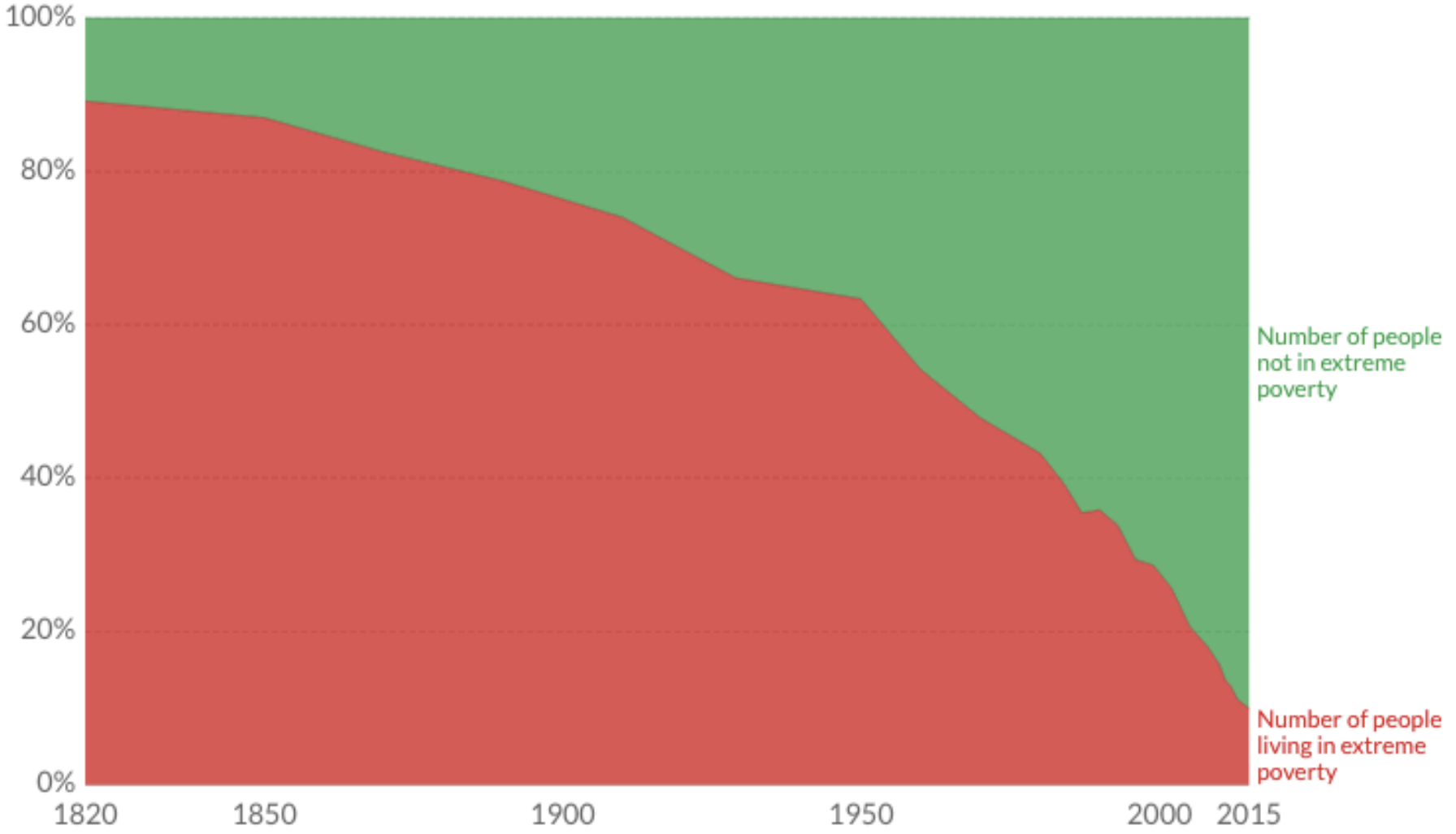


Philip Pardey, "Putting U.S. Agricultural R&D and Productivity Developments in Perspective," Farm Foundation Conference, 2009 https://fas.org/sgp/crs/misc/R40819.pdf

World population living in extreme poverty, 1820–2015

Extreme poverty is defined as living on less than 1.90 international-$ per day. International-$ are adjusted for price differences between countries and for price changes over time (inflation).

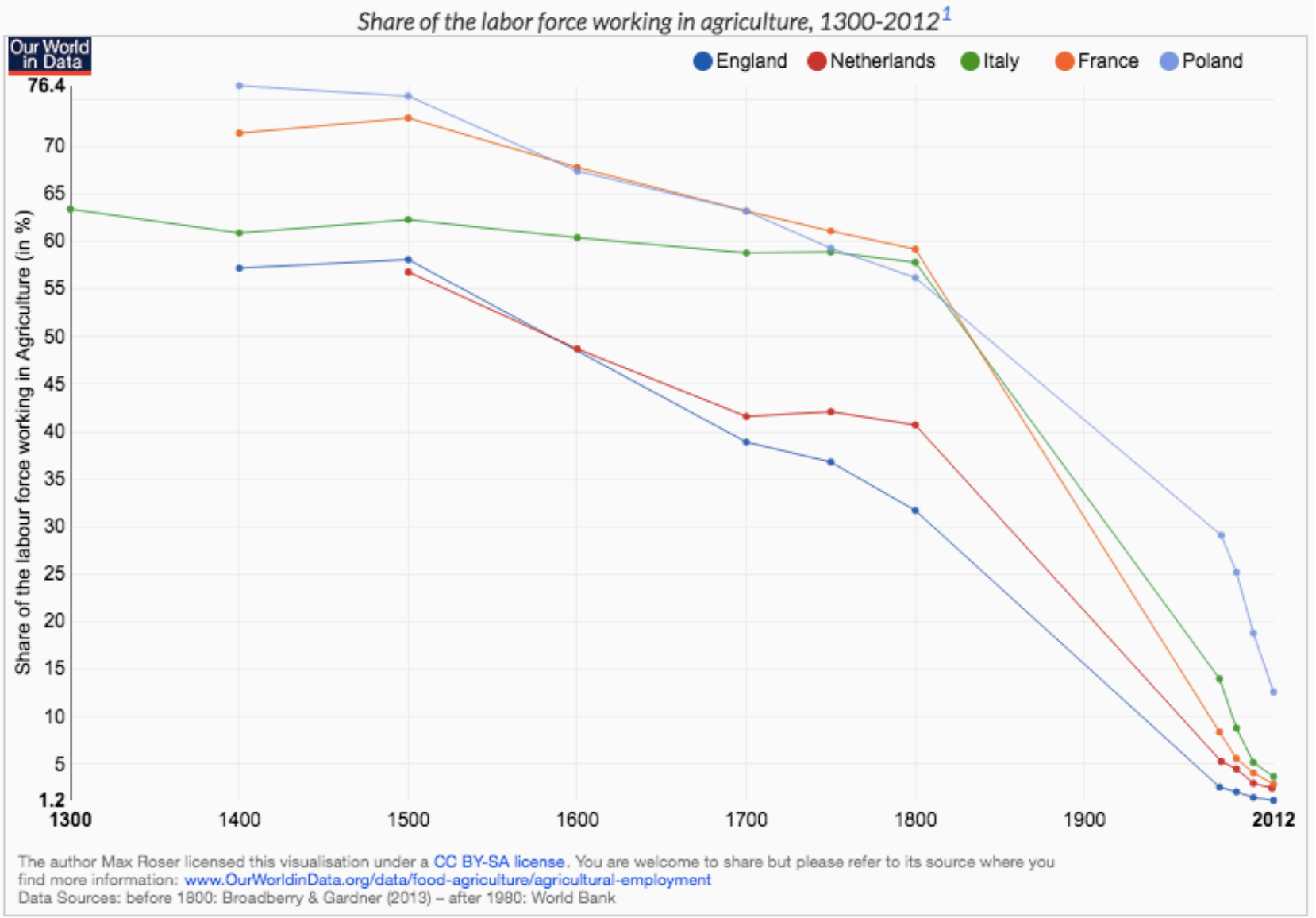
Our World in Data



Source: OWID based on World Bank (2019) and Bourguignon and Morrisson (2002)

www.ourworldindata.org/a-history-of-global-living-conditions-in-5-charts

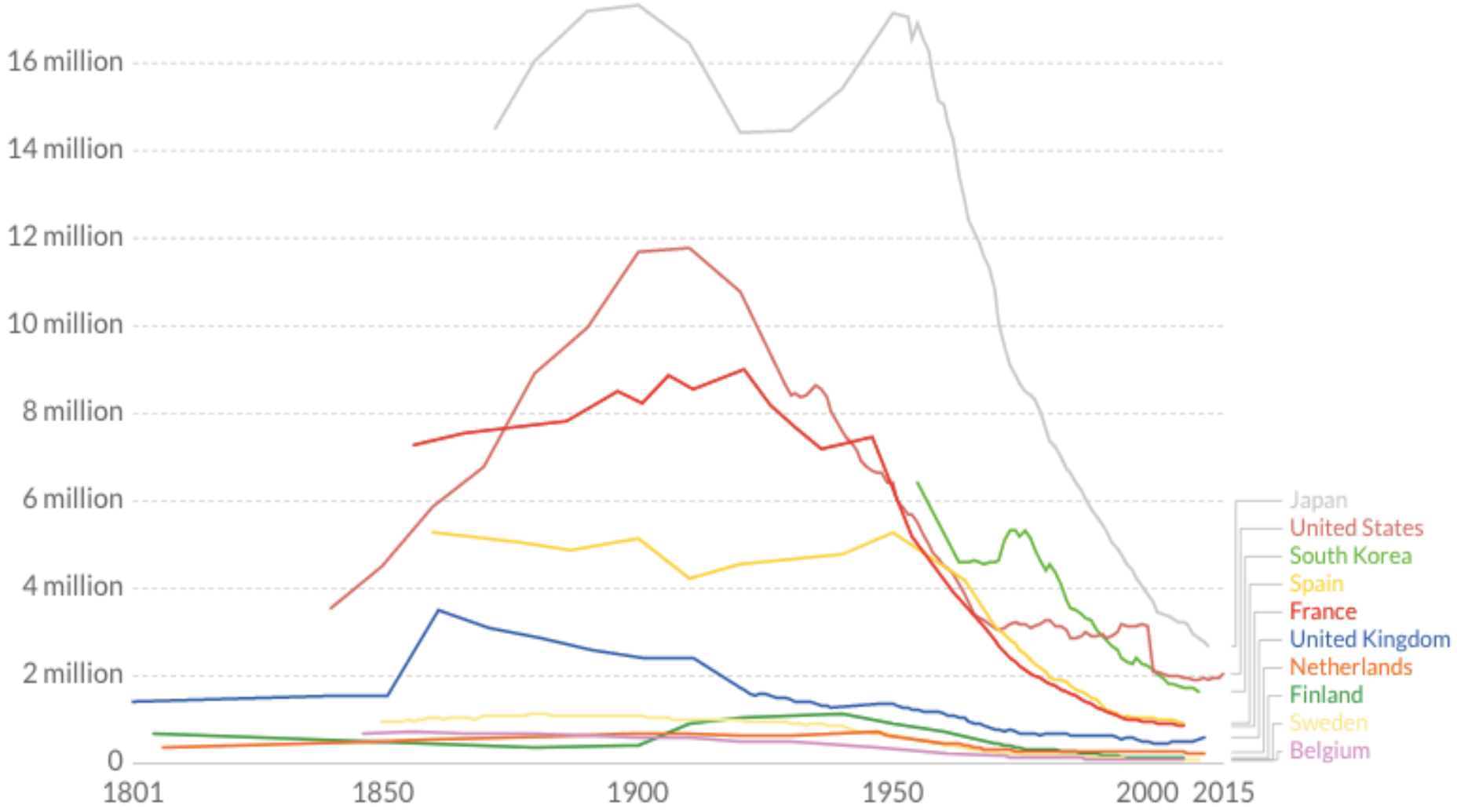
Share of Agricultural Labor Force



https://ourworldindata.org/employment-in-agriculture

Number of people employed in agriculture since 1800

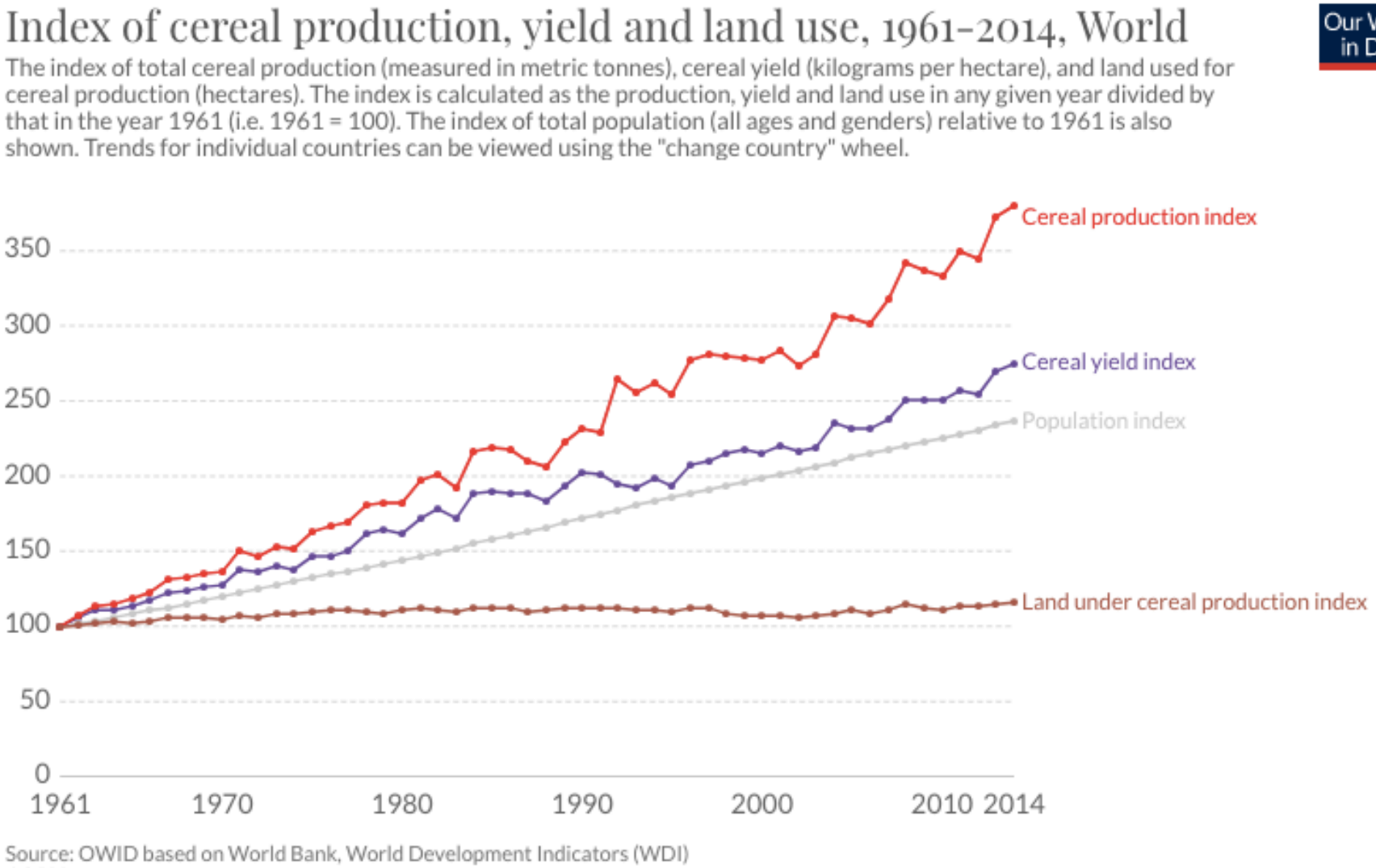
The total number of individuals in agricultural employment across select countries from the year 1800.



Source: Our World In Data based on Herrendorf et al. (2014)

https://ourworldindata.org/employment-in-agriculture

Yields vs Land Use during the Green Revolution

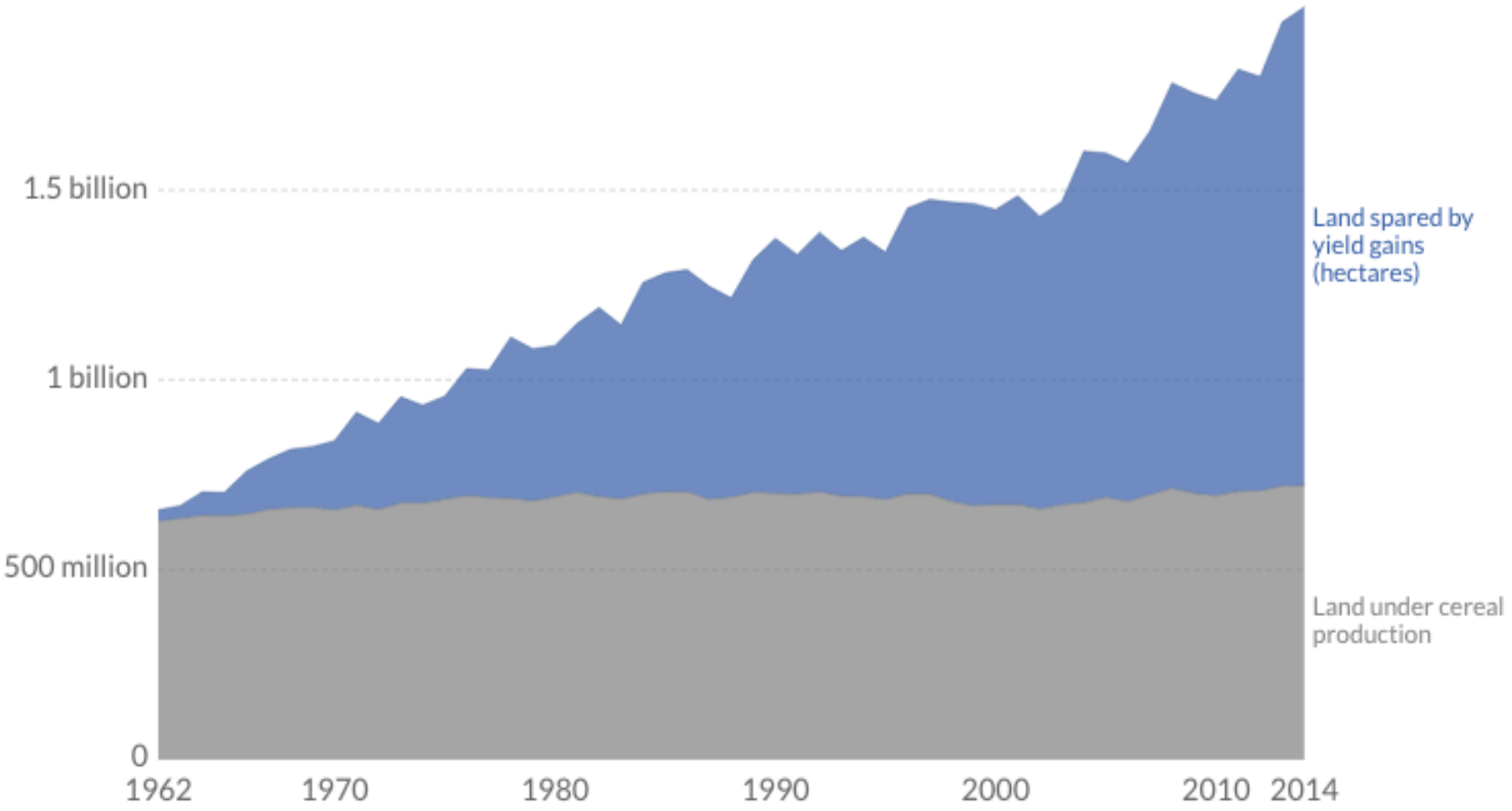


https://ourworldindata.org/yields-vs-land-use-how-has-the-world-produced-enough-food-for-a-growing-population

Global land spared as a result of cereal yield improvements

Global area of land spared from agricultural production as a result of improvements in cereal yield, measured in hectares. This has been calculated as the area of land which would have been necessary to maintain global cereal production at actual output rates, assuming average cereal yields had remained constant since 1961.

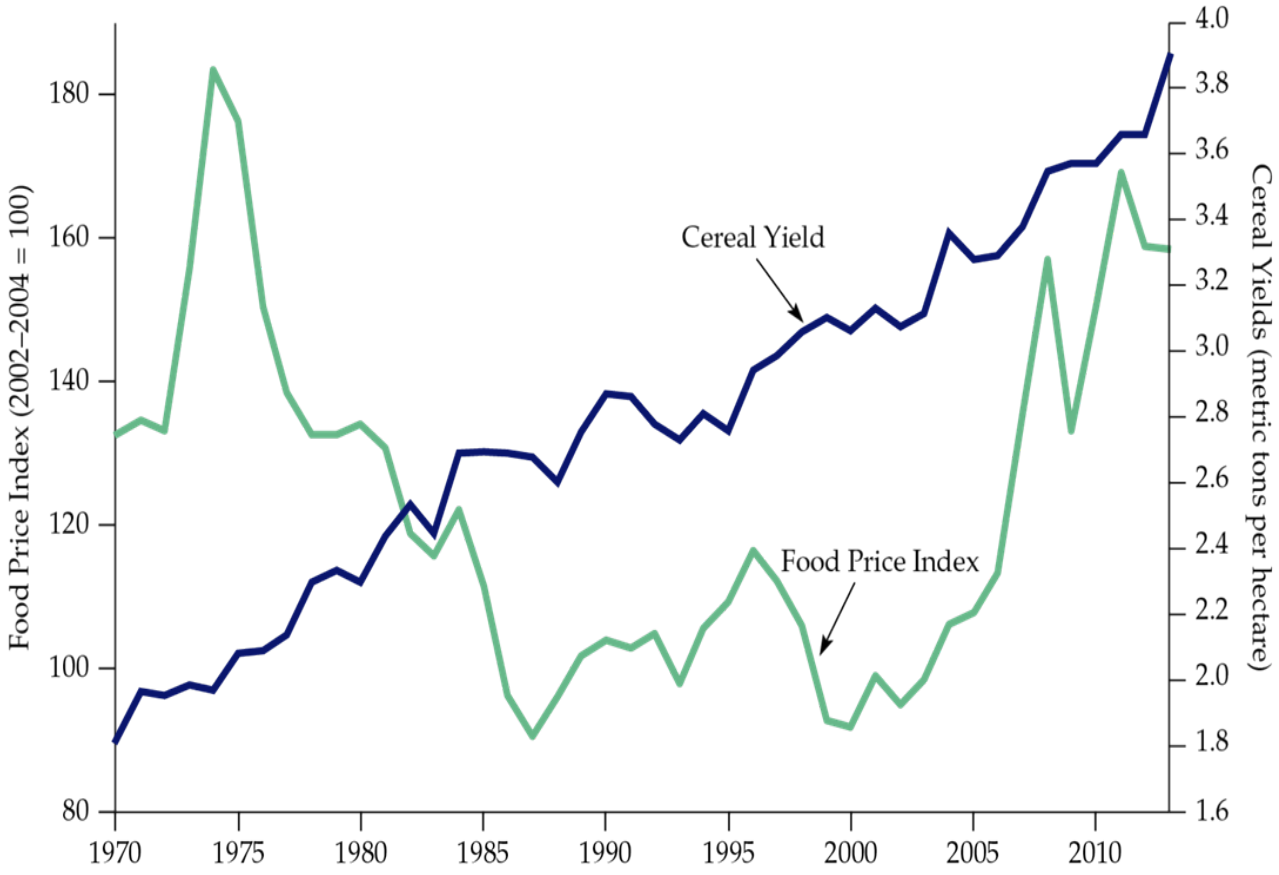
Our World in Data



Source: OWID based on UN Food and Agriculture Organization

https://ourworldindata.org/crop-yields

Cereal Yields and Food Production Index



YEAR	INDEX
1961–64	100
1965	101
1970	105
1975	106
1980	109
1985	115
1990	117
1995	119
2000	127
2005	135
2010	146
2013	151

Cereal yields have increased. The average world price of food decreased in the latter part of the 20th century but has been generally increasing in the 21th century.

Malthusian Economics: Dismal Science

- Malthus predicted that as the marginal and average productivity of labor fell and there were more mouths to feed, mass hunger and starvation would result. Economics thus becomes a dismal science.
- Writing before the industrial revolution, he did not fully appreciate the impact of technology improvements (i.e., pesticides, refrigeration, mechanized farm equipment, and increased crop yields) on food production.
- Over the past century, agricultural revolution has dramatically altered food production in most countries (including developing countries, such as India). As a result, the average product of labor and total food output have increased, though hunger still remains a severe problem in some areas, in part because of the low productivity of labor there.

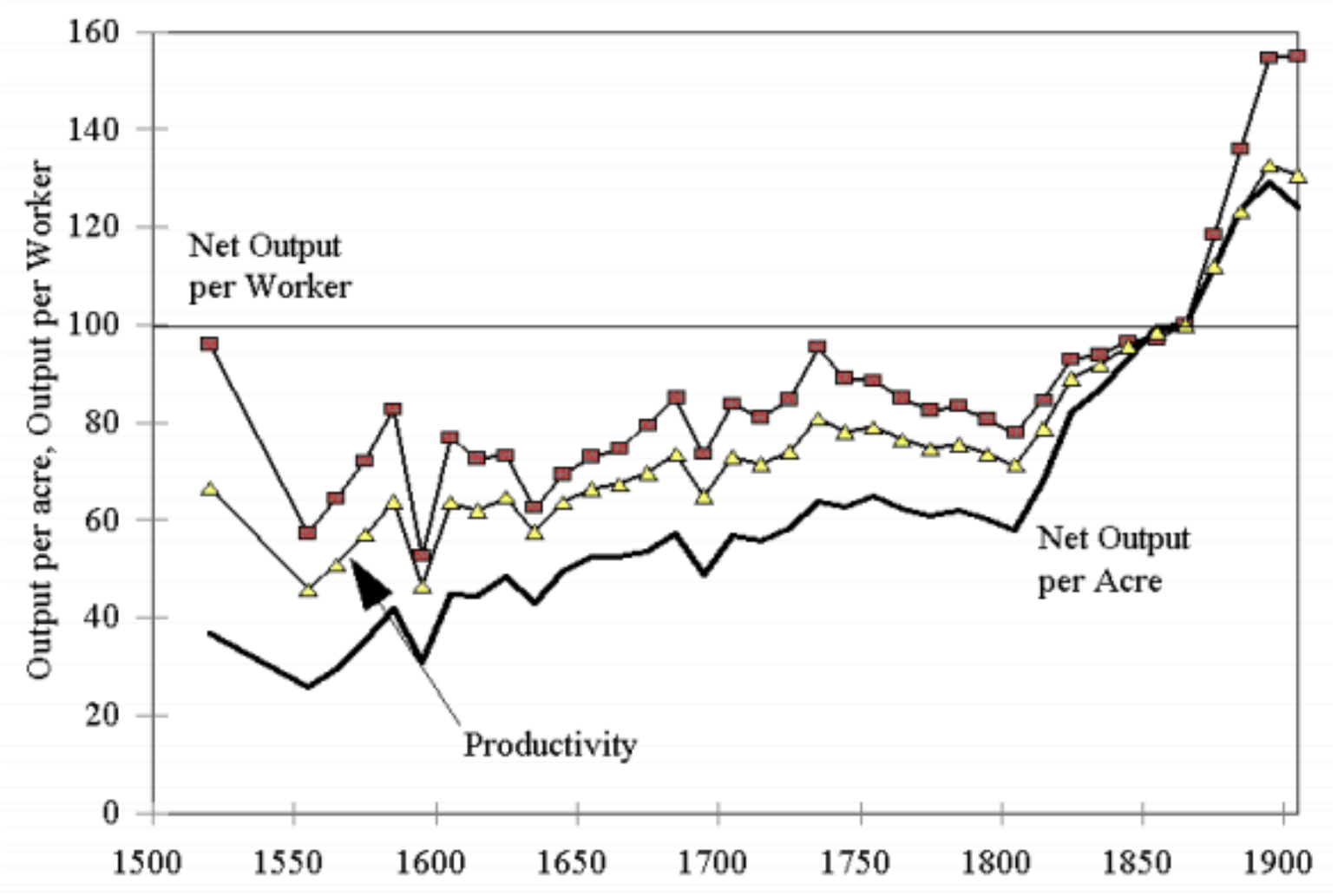
https://www.econlib.org/library/Enc/bios/Malthus.html

The Agricultural Revolution

- The Agricultural Revolution was the unprecedented increase in agricultural production in Britain due to increases in labor and land productivity between the **mid-17th and late 19th** centuries, which was linked to such **new agricultural practices** as crop rotation, selective breeding, and **a more productive use of arable land**.
- Agricultural output grew faster than the population over the century to 1770 and thereafter productivity remained among the highest in the world. This increase in the food supply contributed to the rapid growth of population in England and Wales, from 5.5 million in 1700 to over 9 million by 1801, although domestic production gave way to food imports in the 19th century as population more than tripled to over 32 million. **The rise in productivity accelerated the decline of the agricultural share of the labor force, adding to the urban workforce on which industrialization depended.**

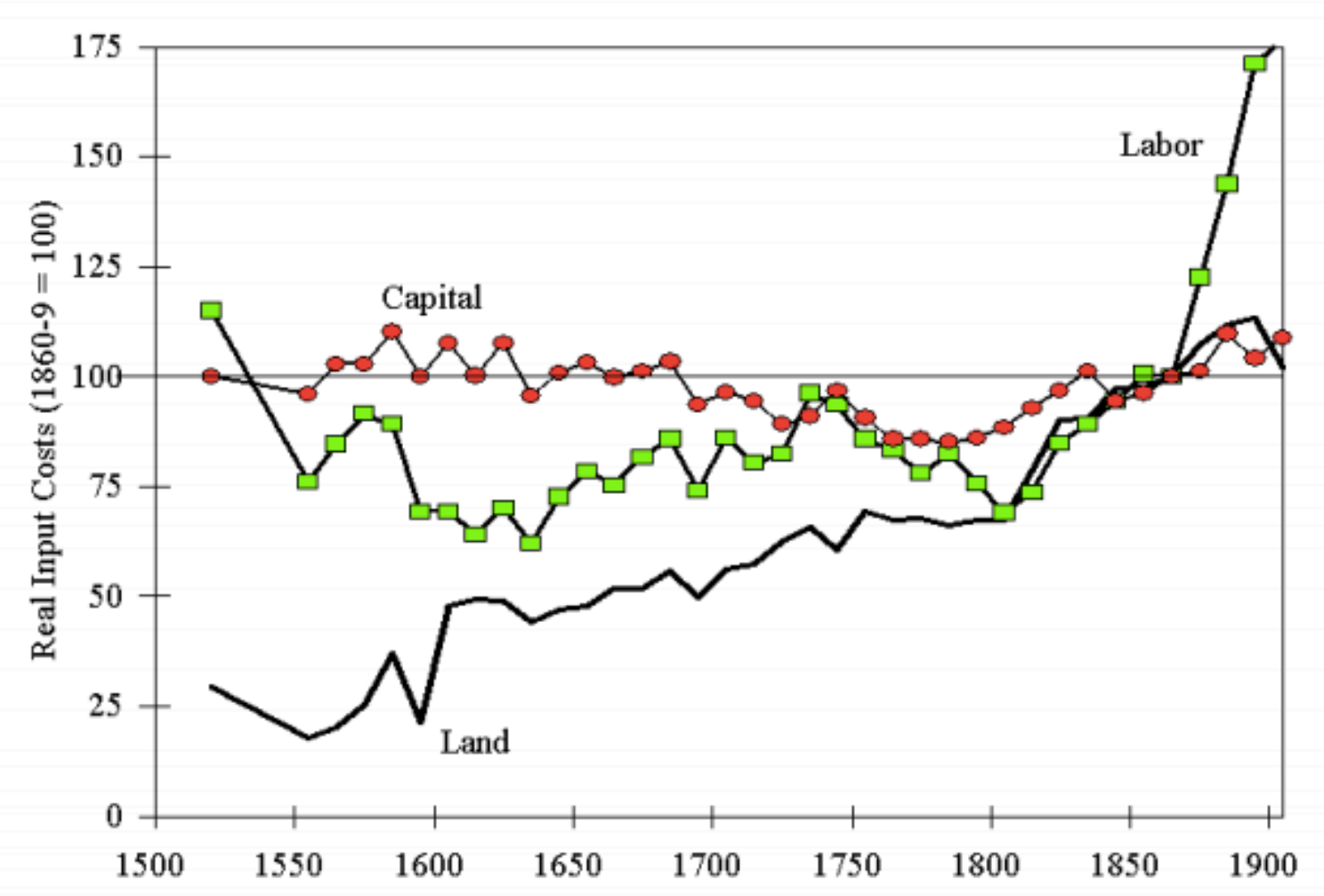
https://courses.lumenlearning.com/boundless-worldhistory/chapter/the-agricultural-revolution/

Agricultural Productivity Estimates



Clark (2002), The Agricultural Revolution and the Industrial Revolution: England, 1500-1912
http://faculty.econ.ucdavis.edu/faculty/gclark/papers/prod2002.pdf

Agricultural Factor Cost Estimates



Clark (2002), The Agricultural Revolution and the Industrial Revolution: England, 1500-1912
http://faculty.econ.ucdavis.edu/faculty/gclark/papers/prod2002.pdf

Living Standards and Productivity

- What is the most crucial of people's living standard in the long run?
- Living standards can be measured by the goods and services people can purchase from the market place. Since production provides the source of income. The level of income further determines workers' purchasing power and living standards.
- Total output is the goods and services produced by all workers for consumption or investment purposes. Average product of labor is the quantity of output per worker or per working hour.
- Marginal product of labor is the quantity of output produced by utilizing last unit of labor. Labor productivity can be measured by either average product or marginal product of workers for an entire industry or for the economy as a whole.

Labor Productivity and Living Standards

Country	UNITED STATES	JAPAN	FRANCE	GERMANY	UNITED KINGDOM
	GDP PER HOUR WORKED (IN 2010 U.S. DOLLARS)	GDP PER HOUR WORKED (IN 2010 U.S. DOLLARS)	GDP PER HOUR WORKED (IN 2010 U.S. DOLLARS)	GDP PER HOUR WORKED (IN 2010 U.S. DOLLARS)	GDP PER HOUR WORKED (IN 2010 U.S. DOLLARS)
	$62.41	$39.39	$60.28	$58.92	$47.39
YEARS	ANNUAL RATE OF GROWTH OF LABOR PRODUCTIVITY (%)	ANNUAL RATE OF GROWTH OF LABOR PRODUCTIVITY (%)	ANNUAL RATE OF GROWTH OF LABOR PRODUCTIVITY (%)	ANNUAL RATE OF GROWTH OF LABOR PRODUCTIVITY (%)	ANNUAL RATE OF GROWTH OF LABOR PRODUCTIVITY (%)
1970-1979	1.7	4.5	4.3	4.1	3.2
1980-1989	1.4	3.8	2.9	2.1	2.2
1990-1999	1.7	2.4	2.0	2.3	2.3
2000-2009	2.1	1.3	1.2	1.1	1.5
2010-2014	0.7	1.2	0.9	1.2	0.5

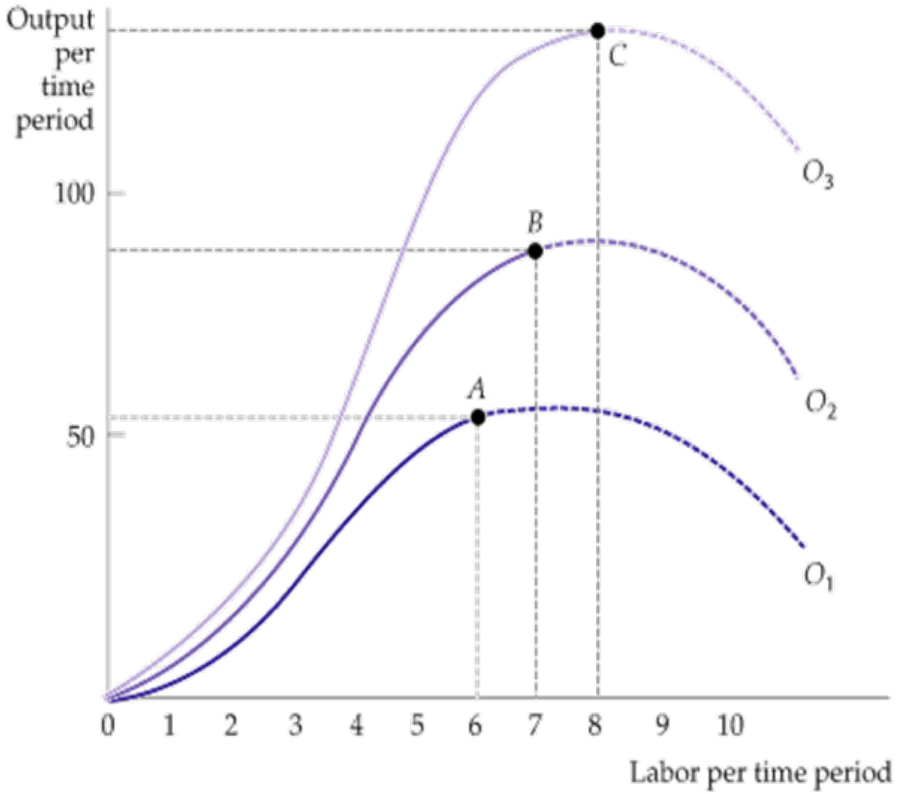
Will the standard of living in the United States, Europe, and Japan continue to improve, or will these economies barely keep future generations from being worse off than they are today? Because the real incomes of consumers in these countries increase only as fast as productivity does, the answer depends on the labor productivity of workers (MPL and APL).

Pindyck & Rubinfeld, CH6.2, Microeconomics, 9th E. Pearson.

The Law of Production: Extension

- Q=F(K, L): what would happen to MPL if K is not fixed?
- If K increases, MPL will rise; if K decreases, MPL will fall.
- What would happen to MPK if L is fixed?
- What would happen to MPK if L varies?
- If L increases, MPK will rise; if L declines, MPK will fall.
- What would happen to MPL/MPK if both K and L vary?
- This is a one million question!! (Hint: the ratio K/L matters.)
- Another rule: if AP of a factor falls, MP of other factors will rise.
- These extensions become incredibly powerful in analyzing the effects on the local economy of international immigration, technology transfer, foreign direct investment, and capital flows.

Technology Advance: Effects on MPL

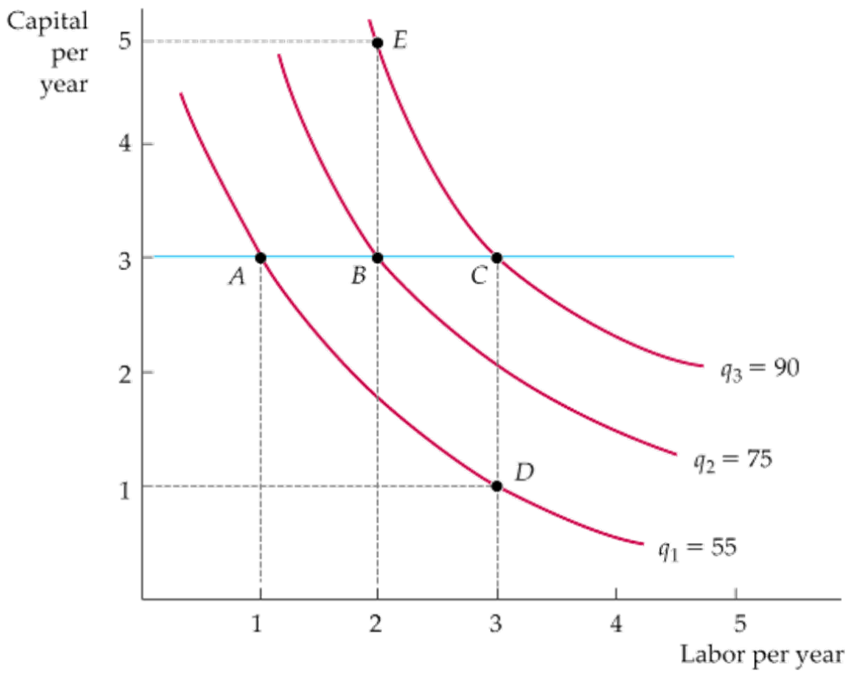


O1, O2, O3 represent outputs corresponding to different technologies with capital investment K1, K2, K3, respectively.

- Capital (technology) investment under O1<O2<O3.
- Labor productivity (MPL and APL) can increase if there are advancements in technology, even though any given production process exhibits diminishing returns to labor.
- As we move from point *A* on curve O_1 to *B* on curve O_2 to *C* on curve O_3 over time, labor productivity increases. Why?

Pindyck & Rubinfeld, CH6.2, Microeconomics, 9th E. Pearson.

Production Function: Isoquants



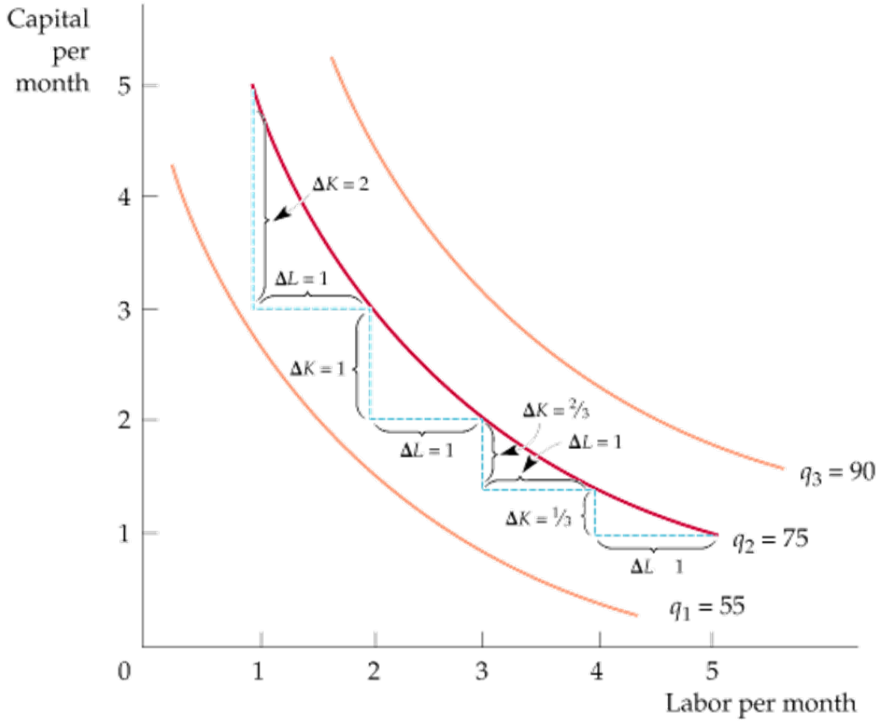
Isoquants show the flexibility that firms have when making production decisions: They can usually obtain a particular output by substituting one input for another. It is important for managers to understand the nature of this flexibility.

Isoquants for Q=F(K,L): describes the firm's production function with two variable inputs, capital and labor.

Output increases as we move from isoquant q_1 (at which 55 units per year are produced at points such as *A* and *D*), to isoquant q_2 (75 units per year at points such as *B*), and to isoquant q_3 (90 units per year at points such as *C* and *E*).

By drawing a horizontal line at a particular level of capital—say 3, we can observe diminishing marginal returns. Reading the levels of output from each isoquant as labor is increased, we note that each additional unit of labor generates less and less additional output.

Marginal Rate of Technical Substitution



Isoquants are downward sloping and convex. The slope of the isoquant at any point measures the MRTS—the ability of the firm to replace capital with labor while maintaining the same level of output. On isoquant q_2, the MRTS falls from 2 to 1 to 2/3 to 1/3.

Marginal Rate of Technical Substitution (MRTS) is the amount by which the quantity of one input can be reduced when one extra unit of another input is used, holding output constant.

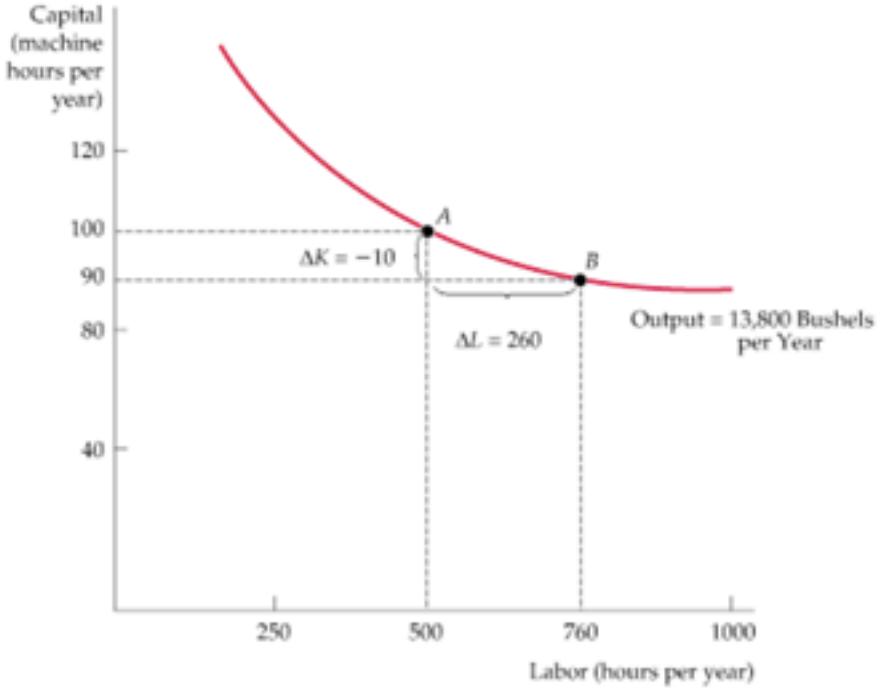
- MRTS = Change in capital input/change in labor input
- For a fixed level of Q, ΔQ=0
- ΔK*MPK+ ΔL*MPL= ΔQ=0
- **MRTS=(ΔK/ΔL)=MPL/MPK**

Pindyck & Rubinfeld, CH6.2, Microeconomics, 9th E. Pearson.

Example: Wheat Production MRTS

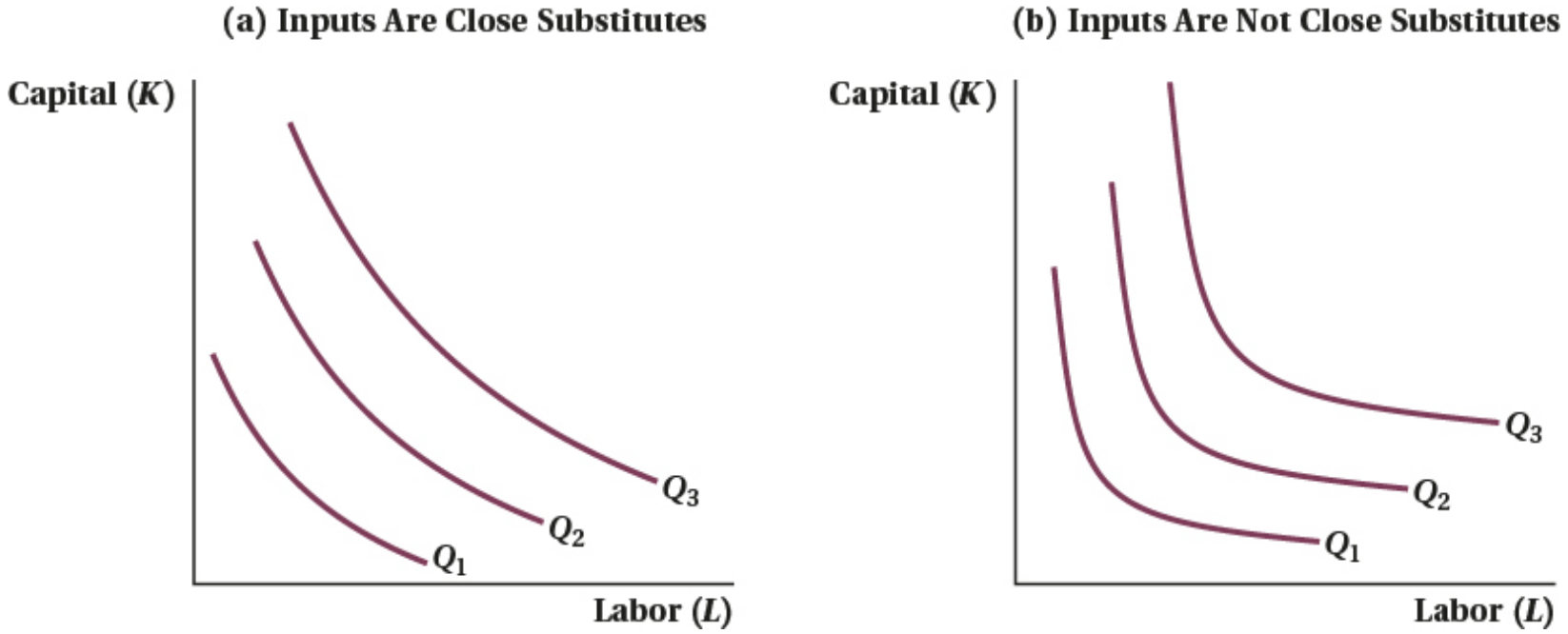
Food grown on large farms in the U.S. is usually produced with a capital-intensive technology.

- A wheat output of 13,800 bushels per year can be produced with different combinations of labor and capital. The more capital-intensive production process is shown as point *A*, the more labor-intensive process as point *B*. The MRTS between *A* and *B* is 0.04.
- What determines the optimal K/L combination in practice?



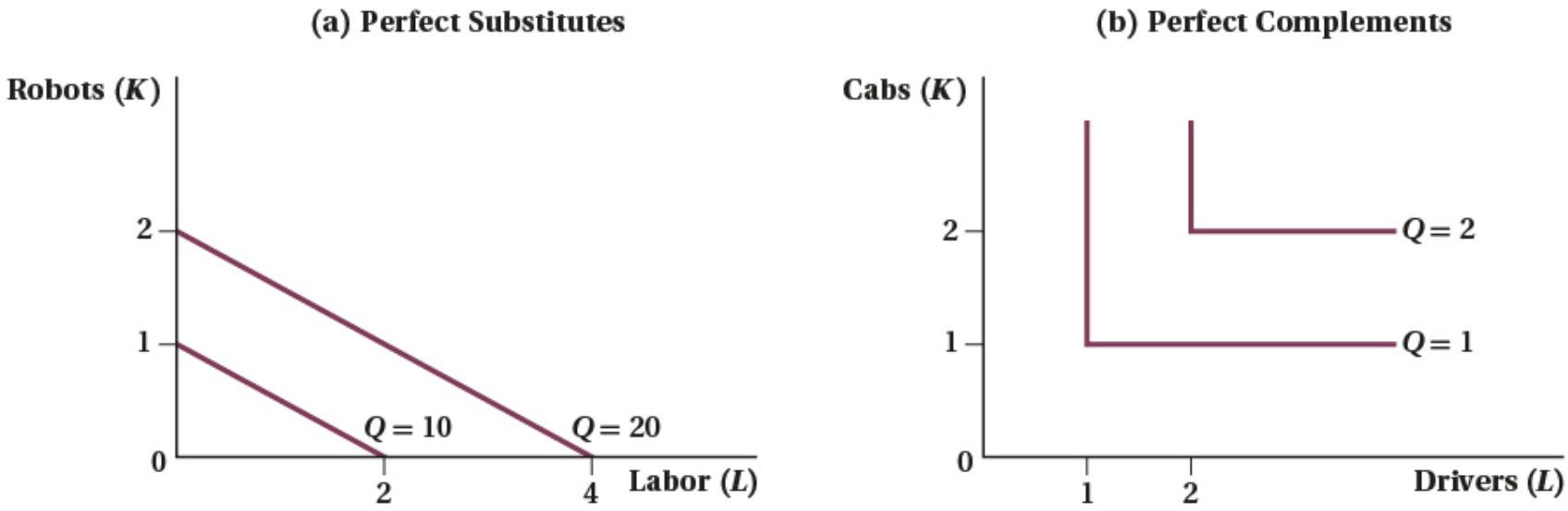
Pindyck & Rubinfeld, CH6.2, Microeconomics, 9th E. Pearson.

Isoquant and Technical Substitution



The shape of an isoquant reveals information about the relationship between inputs to production. Relatively straight isoquants imply that the inputs are relatively substitutable. MRTSLK does NOT vary much along the curve. Relatively curved isoquants imply the inputs are relatively complementary. MRTSLK varies greatly along the curve.

Isoquant and Technical Substitution

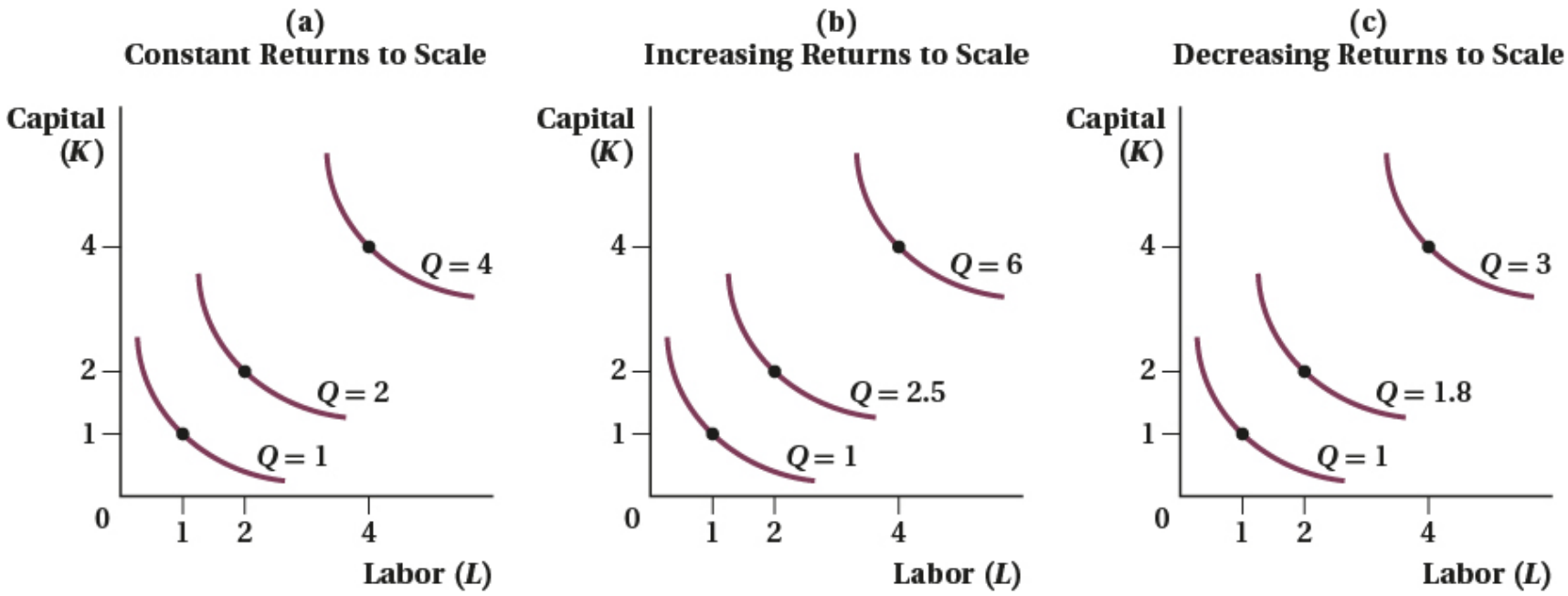


- When inputs are perfect substitutes, they can be traded off in a constant ratio in a production process. MRTS is constant.
- When inputs are perfect complements, they must be used in a fixed ratio as part of a production process.

Production: Return to Scale

- Production functional forms Q=F(L): linear or nonlinear.
- **Constant Return to Scale** CRS: doubling inputs produces double amount of output. One-for-one response between inputs and output. aF(L)=F(aL)=aQ. AP=MP.
- **Decreasing Return to Scale** DRS: doubling inputs produces less than twice the output. F(aL)<aF(L)=aQ.
- **Increasing Return to Scale** IRS: doubling inputs produces more than twice the output. F(aL)>aF(L)=aQ.
- Examples: 1) $Q=L$; 2) $Q=L^{1/2}$; 3) $Q=L^{2}$.
- Questions: Which technology can describe reality better? Why can production function display various return to scale?

Isoquant and Return to Scale



- Constant Return to Scale (CRS): Q doubled as K and L doubled.
- Increasing Return to Scale (IRS): Q more than doubled as K and L doubled.
- Decreasing Return to Scale (DRS): Q less than doubled as K and L doubled.

Note: Labor and capital doubled between the isoquants.

Output and Technology: Summary

Apply the C-D production function $Q=(KL)^{0.5}$, we can summarize the laws of production with three examples.

- The first law of production: K fixed, L+ → MPL–

  $K=1, TP=L^{0.5}$, draw the graphs for TPL and MPL

- The second law of production: K+ → MPL+

  $K=4, TP=2L^{0.5}$, draw the graphs for TPL and MPL

- The third law: K– & L+ → MPK+ & MPL– & MRTS–

  Draw the isoquant for $Q=(KL)^{0.5}$ based on three different factor combinations: A(K=1, L=4), B (K=4, L=1), and C(K=2, L=2)

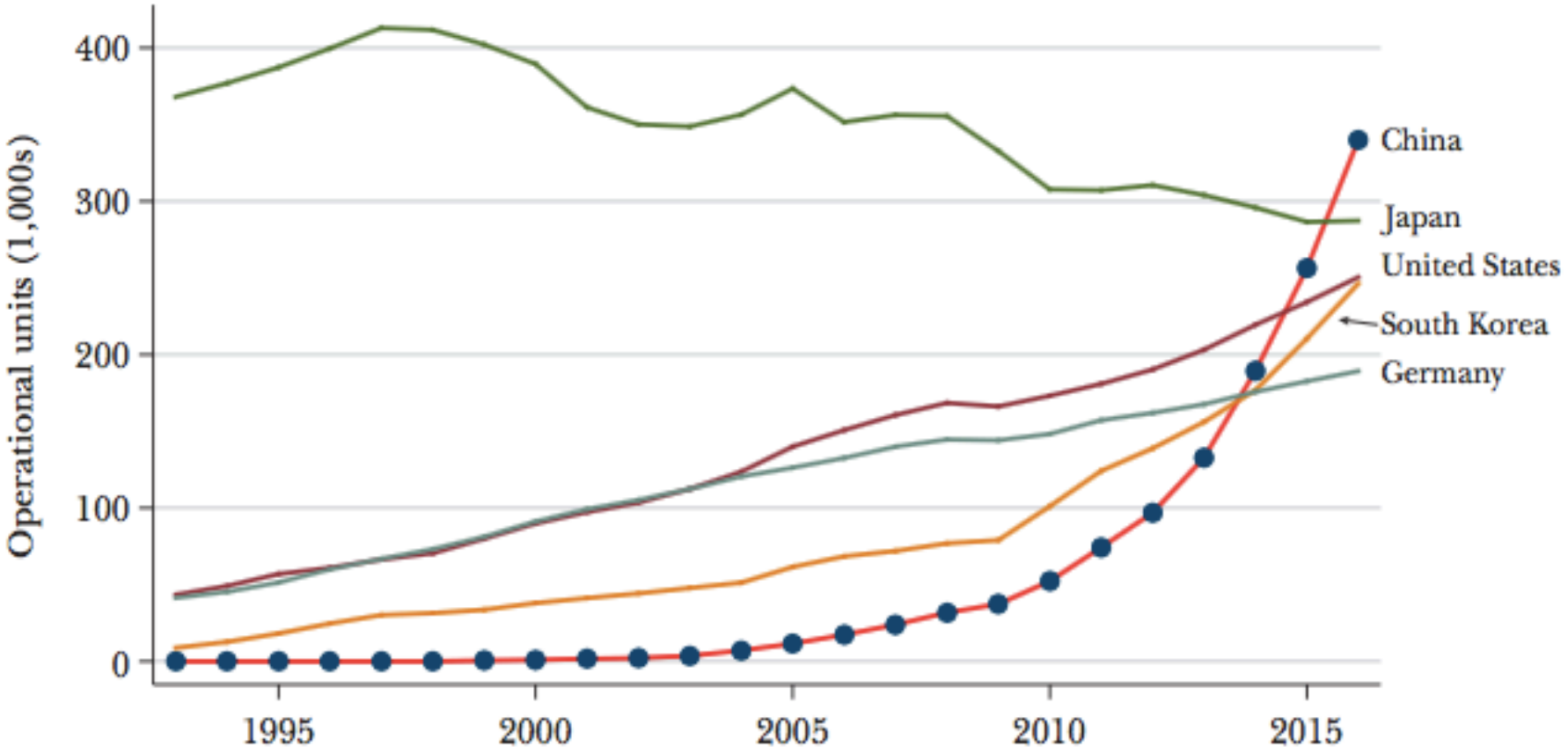
  Verify the third law of production with the isoquant.

The Rises of Robots in China

Cheng, Hong, Ruixue Jia, Dandan Li, and Hongbin Li. 2019. "The Rise of Robots in China." *Journal of Economic Perspectives*, 33 (2): 71-88.

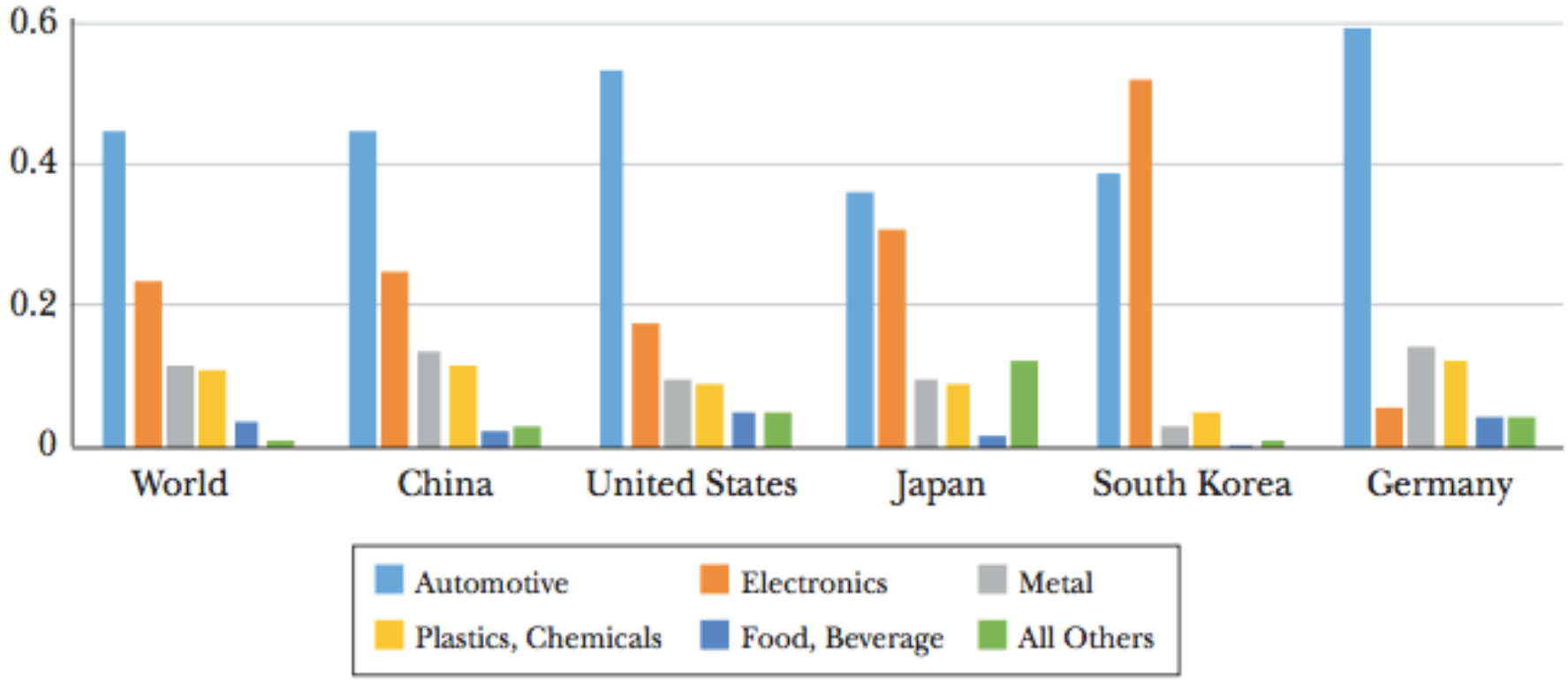
- China is the world's largest user of industrial robots. In 2016, sales of industrial robots in China reached 87,000 units, accounting for around 30 percent of the global market.
- To put this number in perspective, robot sales in all of Europe and the Americas in 2016 reached 97,300 units (according to data from the International Federation of Robotics).
- Between 2005 and 2016, the operational stock of industrial robots in China increased at an annual average rate of 38 percent.
- The Chinese government's industrial policies are likely to affect both robot adoption and production in the future.

Stock of Operational Robots in Major Countries 2016



Source: Data is from International Federation of Robotics (2017).
Notes: This figure plots the operational stock of robots in the five major markets. China exceeded Japan and became the country with the largest operational robot stock in 2016.

Industrial Composition of Operational Robot Stock in Major Countries 2016

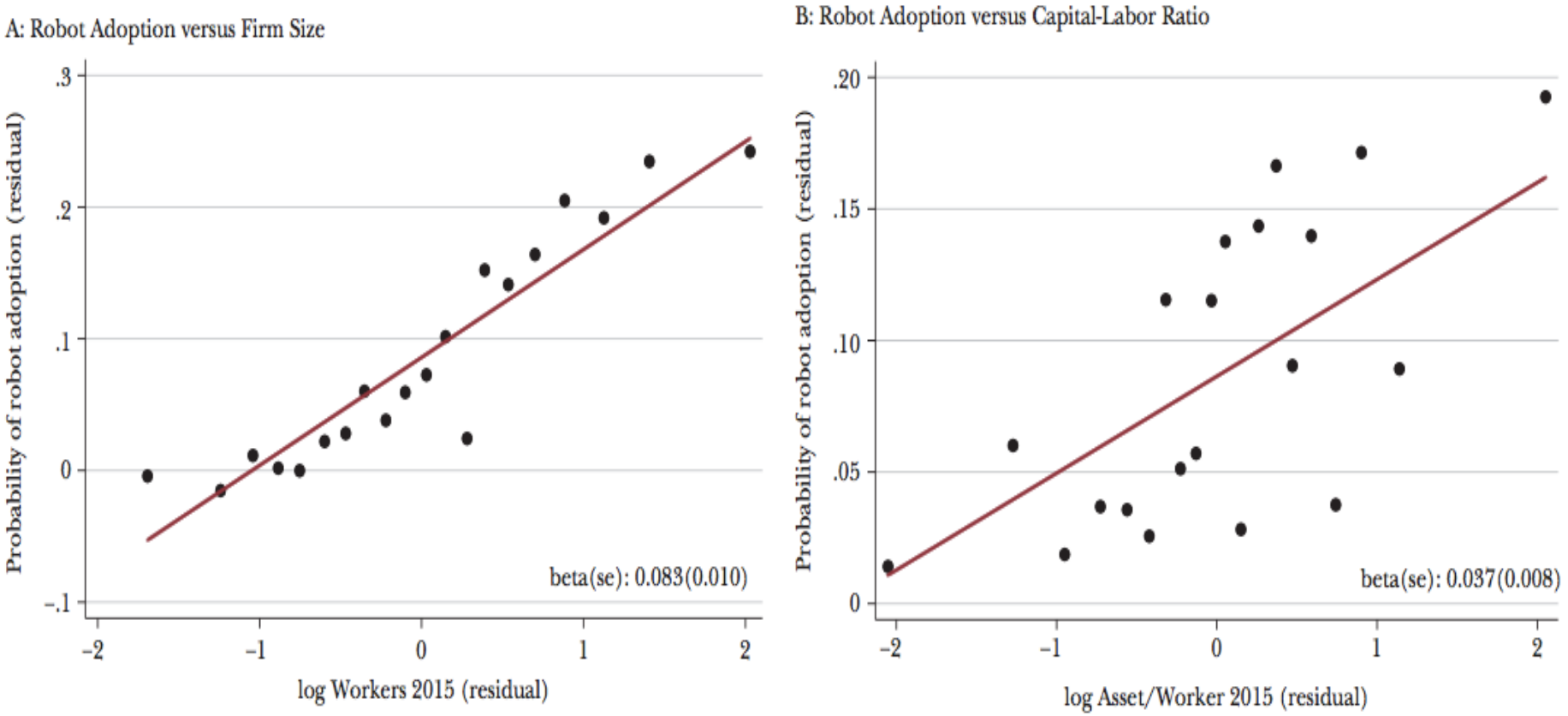


Source: Data is from International Federation of Robotics (2017).
Notes: This figure plots the share of robots across industries in the manufacturing sector by countries. China is not dramatically different from the other countries, suggesting that the supply of the technology matters in explaining which sectors use robots more.

The Rise of Robots in China

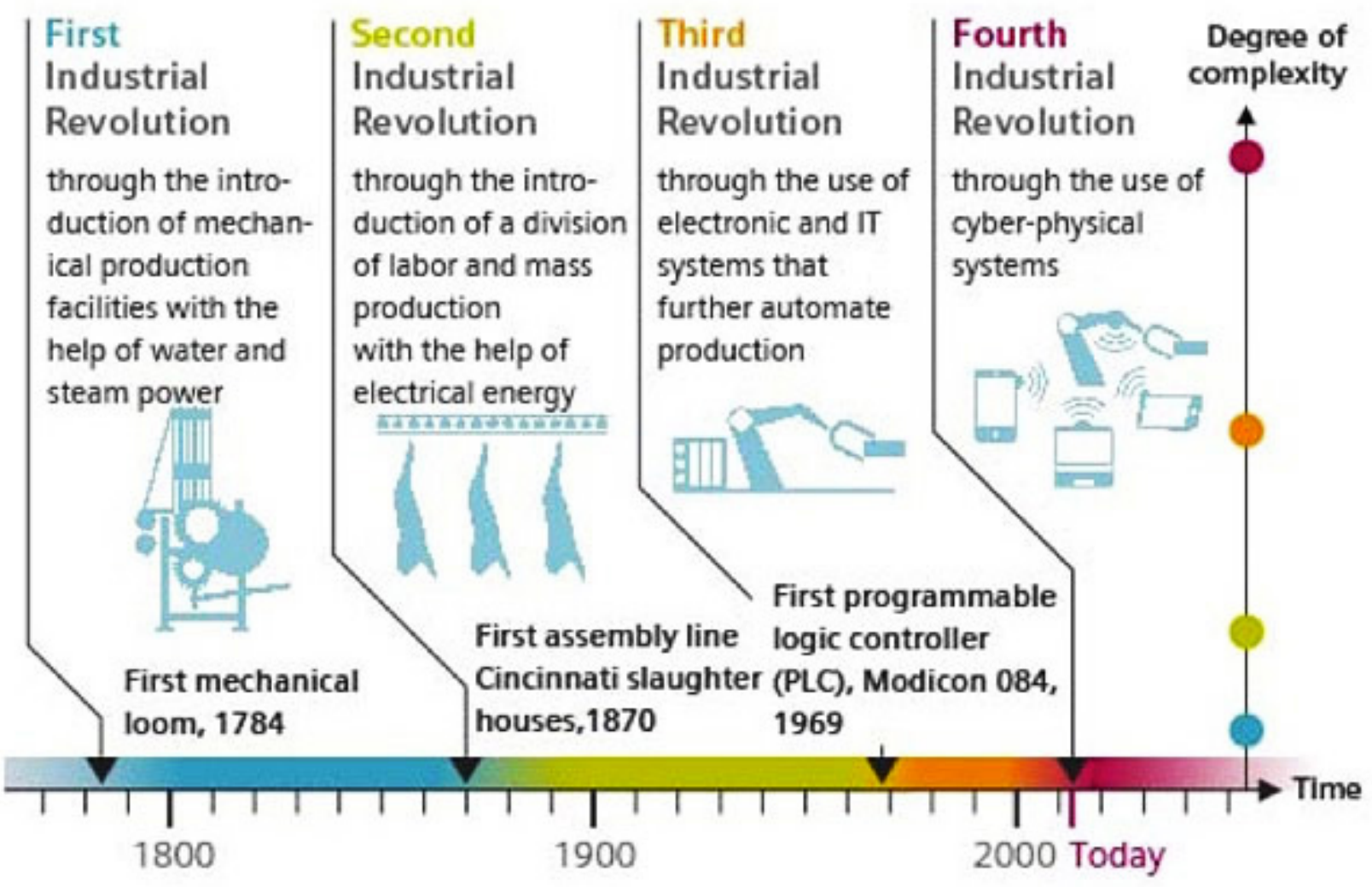
- At this stage, the threat of job replacement is not a high-priority concern in the mind of China's government or its citizens.
- Government policies are motivated by the challenges of labor costs and labor shortage, as well as the imperative to lead a new wave of Industrial Revolution.
- At the aggregate level, the rise of robots has accompanied a decline in the growth of the working-age population and an increase in wages, suggesting that the rising cost of labor is one underlying driver of robot usage in China.
- Because China is a global leader in the production and consumption of automotive and electronics, the two leading industries in robot adoption, China probably will play an even more important role in the robot market in the future.

Robot Adoption: Firm Size & K/L Ratio



Notes: This figure plots the correlations between firm size, capital-labor ratio and robot adoption, after controlling for province fixed effects and industry fixed effects. Log workers and log capital-labor ratio are standardized so that 1 (and –1) means one standard deviation above (and below) average. Each dot indicates a bin of firm observations. These correlations also hold when we run a horse race between these two factors.

A Timeline for Industrial Revolutions



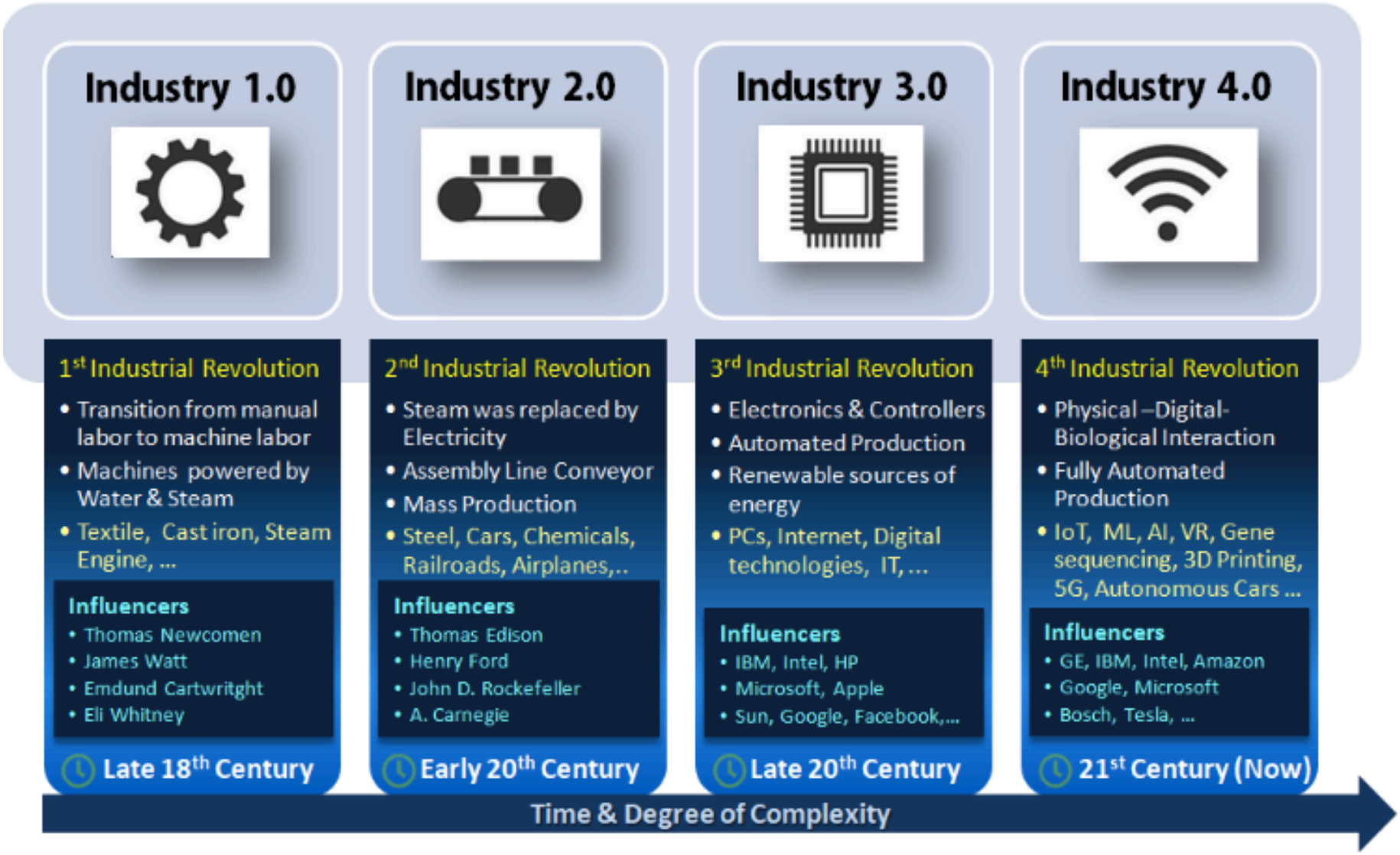
https://www.manufacturing-operations-management.com/.a/6a00e551030252883401b8d138b7c7970c-popup

The Fourth Industrial Revolution

- The fourth industrial revolution, according to Yoval Harari (2020), is driven by AI technology (info-tech & bio-tech).
- Artificial intelligence is based on three key technologies
  - Big data analytics
  - Machine learning
  - Supercomputing
- What is the fourth industrial revolution? Watch a video.

  https://www.youtube.com/watch?v=v9rZOa3CUC8&t=29s
- Global challenges now and ahead
  - Pandemics
  - Nuclear wars
  - Ecological collapse
  - **Technology disruption**

Key Features and Influencers of the Industrial Revolutions



http://13.126.251.30/2019/01/02/timeline-of-industrial-revolution/

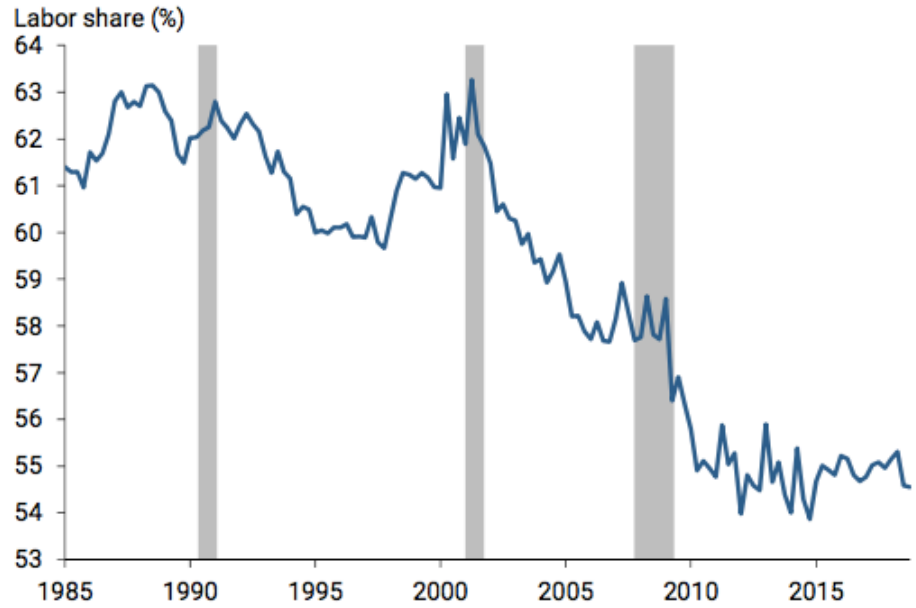
Automation and the Future of Work

- Will automation take away all our jobs? Why hasn't human labor become redundant and our skills obsolete?
- Here's a paradox you don't hear much about: despite a century of creating machines to do our work for us, the proportion of adults in the US with a job has consistently gone up for the past 125 years.
- How would you apply the theory of production to understand the evolution of our workplace?
- Are workers losing to robots?

https://www.ted.com/talks/david_autor_why_are_there_still_so_many_jobs

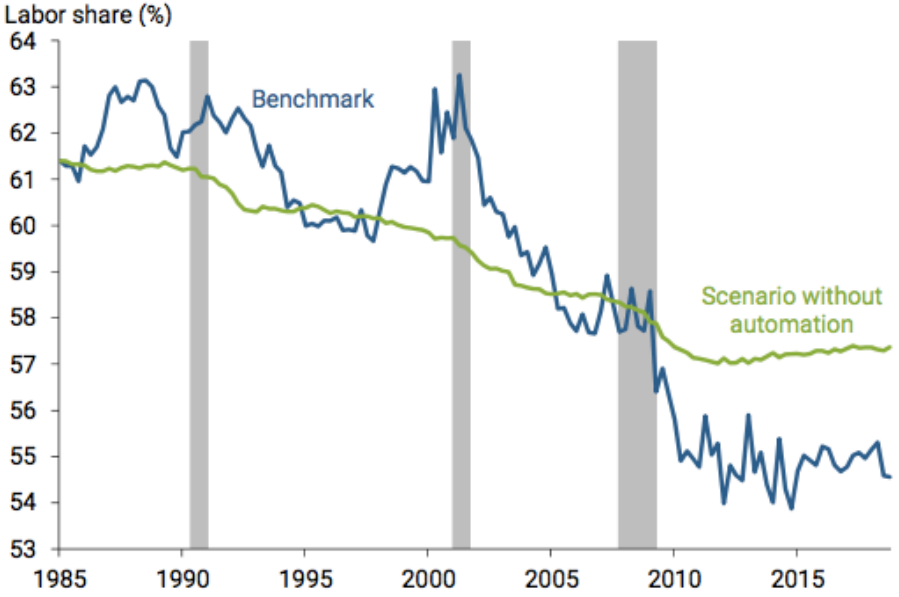
Are Workers Losing to Robots?

Figure 1
Labor share in U.S. nonfarm business sector



Source: Bureau of Labor Statistics. Gray bars indicate NBER recession dates.

Figure 2
U.S. labor share: Actual versus scenario without automation



Source: Bureau of Labor Statistics and authors' calculations. Gray bars indicate NBER recession dates.

The portion of national income that goes to workers, known as the labor share, has fallen substantially over the past 20 years. Even with strong employment growth in recent years, the labor share has remained at historically low levels. Automation has been an important driving factor. While it has increased labor productivity, the threat of automation has also weakened workers' bargaining power in wage negotiations and led to stagnant wage growth.

https://www.frbsf.org/economic-research/publications/economic-letter/2019/september/are-workers-losing-to-robots/

Will A.I. Replace Your Jobs?

10 jobs most likely

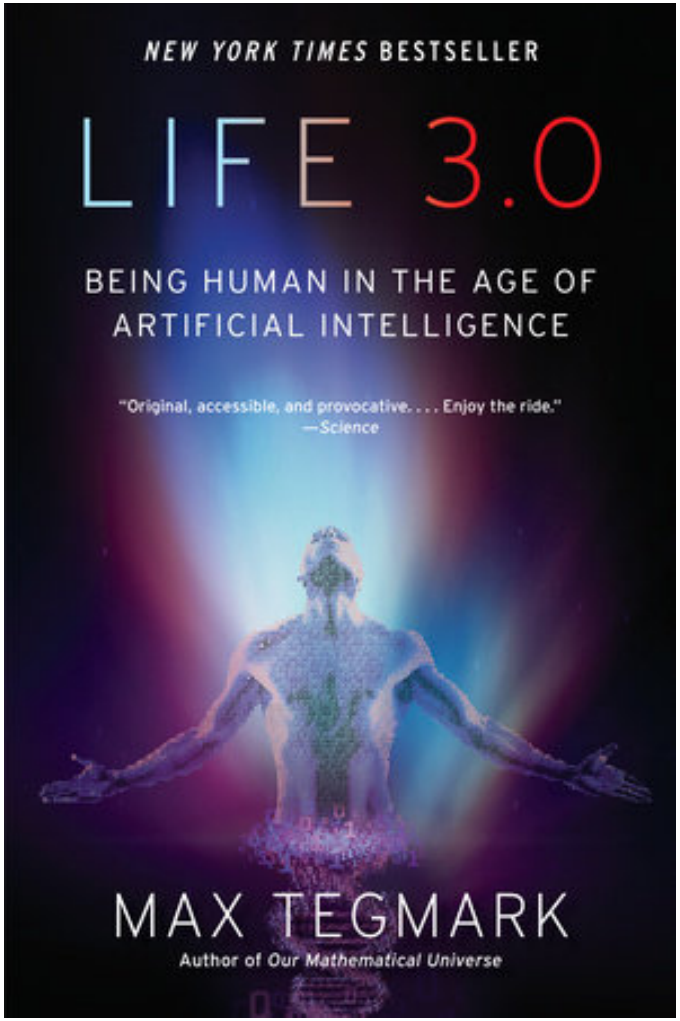
- Receptionists
- Factory workers
- Couriers
- Drivers
- Soldiers
- Doctors
- Security guards
- Sales manager
- Accountant
- Farmers

10 jobs most unlikely

- Software developers
- Writers
- Human resource managers
- Graphic designers
- Event planners
- Lawyers
- Clergymen
- Choreographers
- Social workers
- Psychiatrists

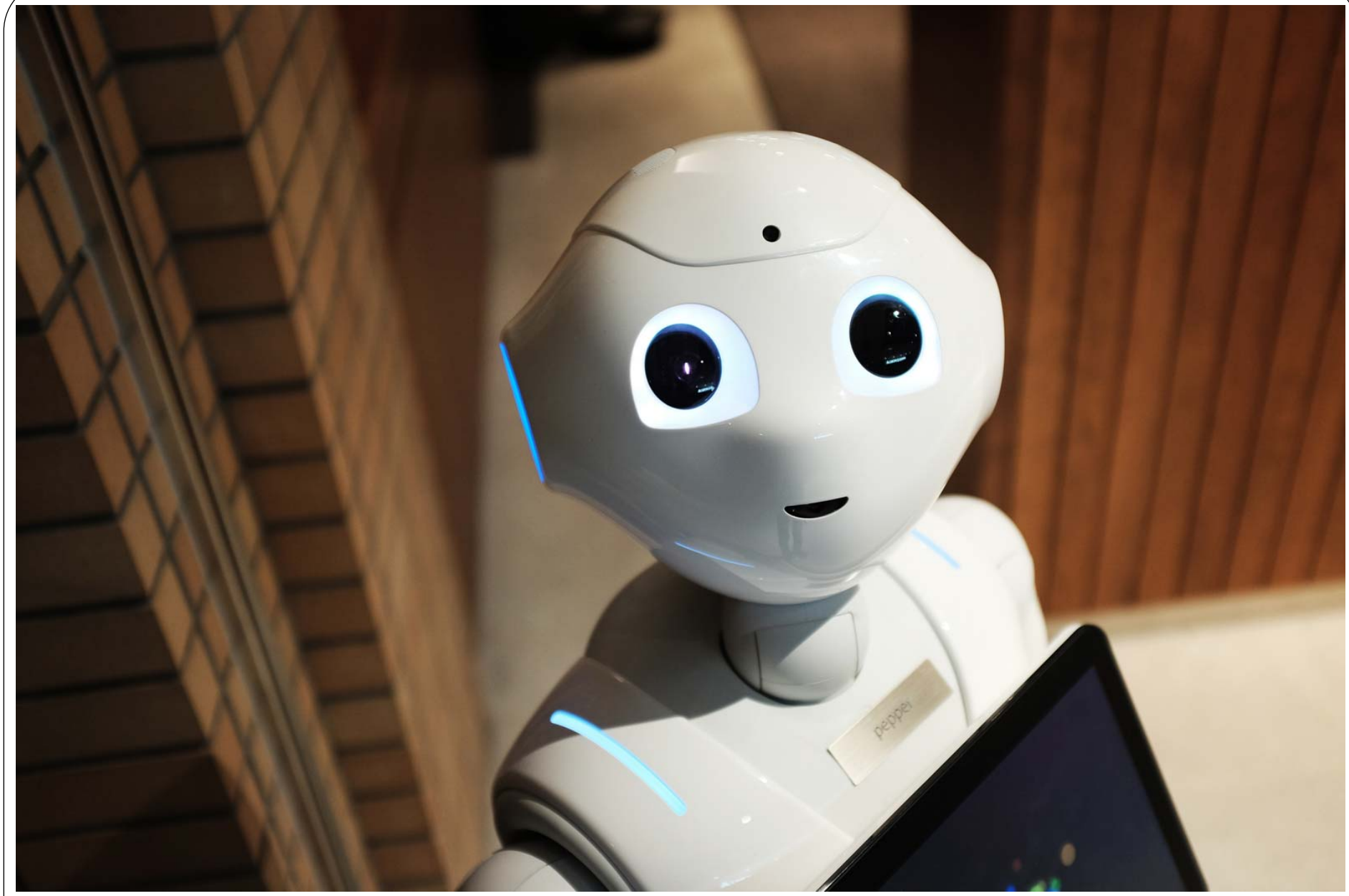
https://vanna.com/articles/read/10-jobs-that-will-and-wont-be-replaced-by-AI?hl=en

Being Human in the Age of A.I.



How will AI affect crime, war, justice, jobs, society and our very sense of being human? How can we grow our prosperity through automation without leaving people lacking income or purpose? What career advice should we give today's kids? How can we make future AI systems more robust, so that they do what we want without crashing, malfunctioning or getting hacked? Should we fear an arms race in lethal autonomous weapons? Will machines eventually outsmart us at all tasks, replacing humans on the job market and perhaps altogether? Will AI help life flourish like never before or give us more power than we can handle?

https://www.penguinrandomhouse.com/books/530584/life-30-by-max-tegmark/



https://vanna.com/articles/read/10-jobs-that-will-and-wont-be-replaced-by-AI?hl=en

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Videos: Industrial Revolution

20180511 Four Industrial Revolutions 4:50
https://www.youtube.com/watch?v=yMBE_EBDnKE

201607 What is the Fourth Industrial Revolution? | WEF 11:31
https://www.youtube.com/watch?v=kpW9JcWxKq0

201901 What is the Fourth Industrial Revolution? | CNBC 4:17
https://www.youtube.com/watch?v=v9rZOa3CUC8

201906 The best explanation of the Fourth Industrial Revolution ever 10:39
https://www.youtube.com/watch?v=okXk4Bnz2Lc

https://www.britannica.com/event/Industrial-Revolution

Videos: Technology Disruption

Will robots take our jobs? | CNBC Explains 3:25
https://www.youtube.com/watch?v=a-7Azih0D98

The Future of Work: Is Your Job Safe? | 19:02
https://www.youtube.com/watch?v=gUc5oN_ffRo

201709 Will robots steal our jobs? - The future of work (1/2)
https://www.youtube.com/watch?v=6IOH7b68byk

201709 Will robots steal our jobs? - The future of work (2/2)
https://www.youtube.com/watch?v=NGUbboTjT18