Reflections on Technological Progress in the Agri-Food Industry: Then, Now & Tomorrow

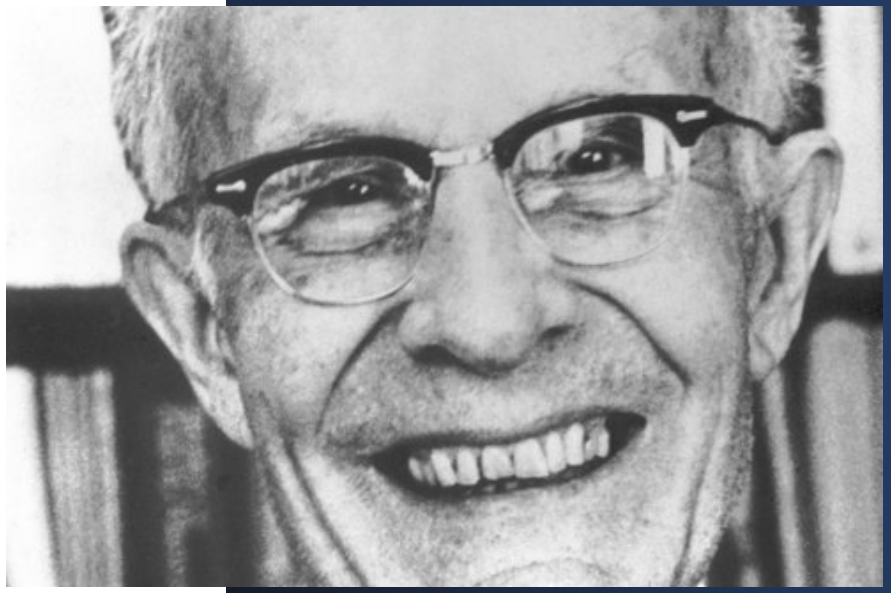
Getu Hailu,

Professor, Department of Food, Agricultural and Resource Economics

ECONOMIC DEVELOPMENT POLICY BRANCH, OMAFRA
SEPTEMBER 27, 2022

“Efficient but poor“ hypothesis

- Low-income levels in developing country agriculture are a result of the **low productivity** of the available factors of production, **not of inefficiencies in their allocation**.
- The implications of this thesis are:
    - A reallocation of the available factors of production could not help farmers improve productivity (through, for example, extension).
    - **Shift in the frontier:**
        - Importance of **investment in education** to facilitate the **diffusion of new factors** (innovation) that could enhance productivity.



Theodore Schultz (1964), Transforming Traditional Agriculture.

- **Getu Hailu**, Vera, B., Belay Kassa and Strock, H. (1998). Technical Efficiency of Smallholder Annual Crop Production in Moisture Stress Area of Eastern Oromiya of Ethiopia: a Stochastic Frontier Analysis, *Ethiopian Journal of Agricultural Economics,* 2(2):19–115.

CANADIAN JOURNAL OF *Agricultural Economics*
REVUE CANADIENNE *D'Agroéconomie*

Cost Efficiency for Alberta and Ontario Dairy Farms: An Interregional Comparison

Getu Hailu, Scott Jeffrey, James Unterschultz

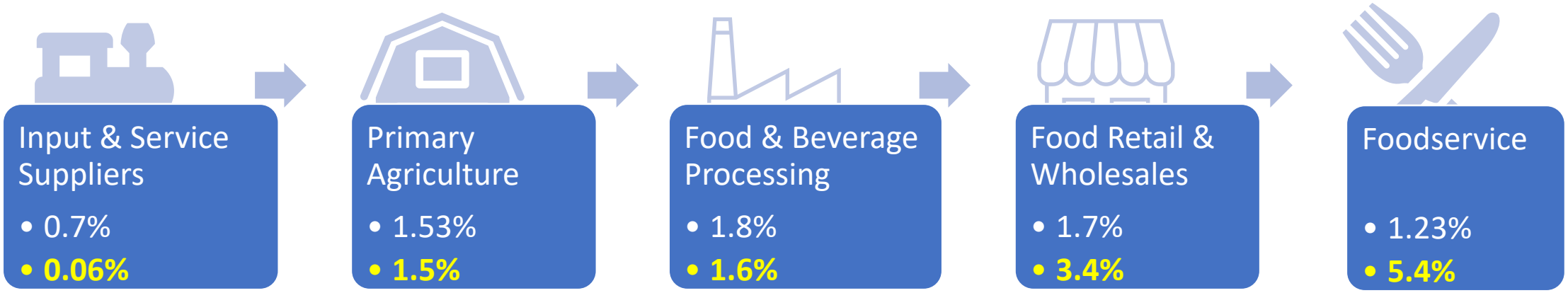
Abstract

EN ES

In this study, two non-homothetic translog stochastic meta-frontier cost functions—with and without local concavity imposed—are estimated using a nonlinear maximum likelihood estimation procedure to compare the cost efficiency of Alberta and Ontario dairy farms for the period 1984–96. The resulting cost efficiency estimates are not very sensitive to whether or not curvature is imposed. In contrast, the properties of the cost and input demand functions (e.g., elasticities) are sensitive to imposition of local concavity during estimation. The implication is that if an inappropriate model that does not satisfy the properties required by the economic theory is used, the estimated input demand functions may not be reliable. Average cost efficiency for the pooled sample, with local concavity imposed, is approximately 89%. This suggests some potential for improved performance in the sector. The results also suggest that Ontario dairy farms may be more cost efficient than Alberta dairy farms, but the statistical evidence is inconclusive.

First published: 29 July 2005 | https://doi.org/10.1111/j.1744-7976.2005.00314.x

Canada's Agri-Food Industry (2021)

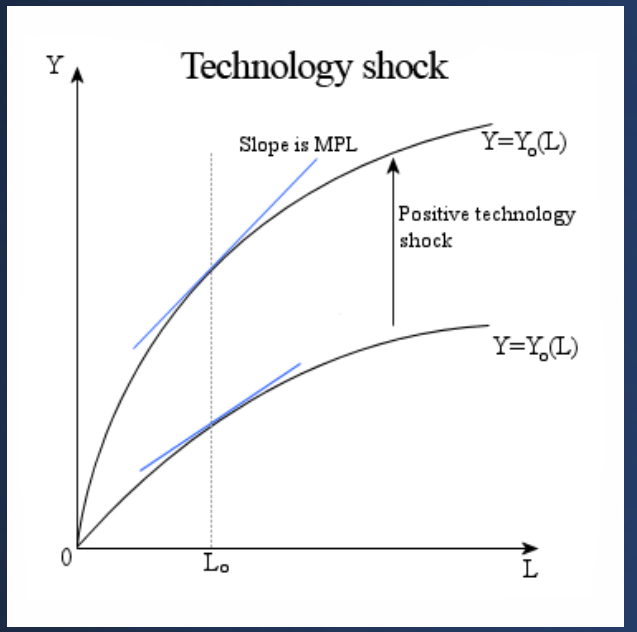


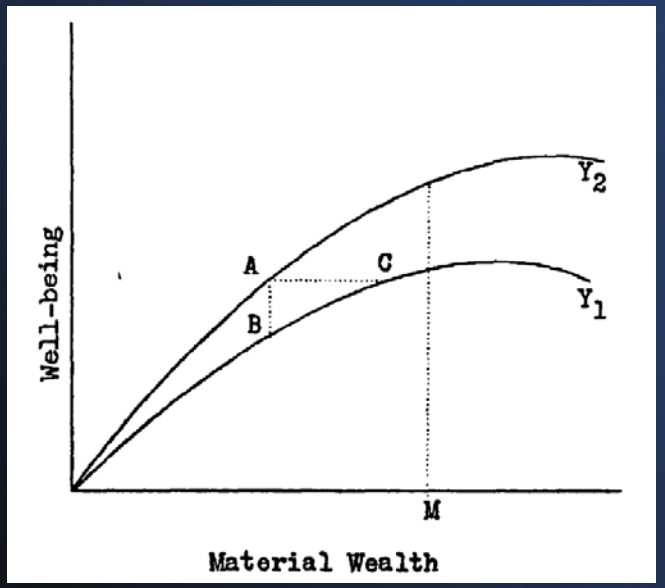
- GDP = $127.3 bn (6.3%)
- Jobs = 2,258,185 (11.9%)

Data Source: **Statistics Canada (2022)**

Technological Progress

- Our desire for more satisfaction (utility) gives rise to two **interdependent issues** that we must face:
  1) **how to increase the value of the scarce resource (efficiency),** and
  2) how to allocate the increment in wealth (**equity**).
- Innovation refers to doing something that has not been done before.
  - the development of a new method of production
  - the introduction of new goods/service
  - the opening of a new market
  - the discovery of a new source of supply
  - changes in the rules of the game (institutions, organizations)
- Innovation expands opportunity sets for society.
- Most innovations that affect the economy are **technological (scientific)** innovations.
- **Technology** embodies the **prevailing knowledge**.
- The growth of knowledge then creates new *technological possibilities* – **technological progress**.





Lok, 1959, CJAE

Pejovich, S. Property Rights and Technological Innovation, Social Philosophy and Policy, Volume 13, Issue 2, Summer 1996, pp. 168 – 180, DOI: https://doi.org/10.1017/S0265052500003502

Technological Progress, Productivity

- **Technological progress** = the discovery of new and improved methods of producing goods.
    - main driver of an increase in the **productivity** of factors of production (labour, capital).
- **Changes in TFP**= changes in output that can't be explained by changes in factors of production

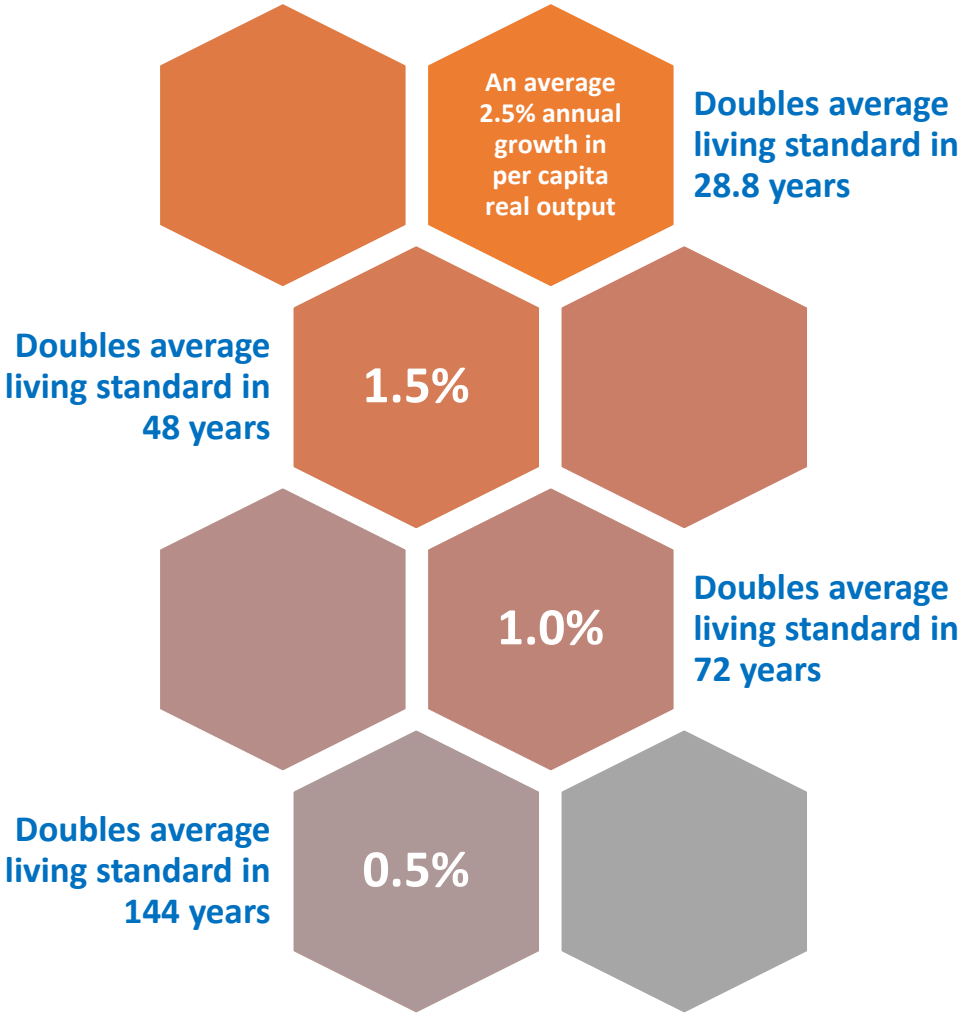
$$TFP = \frac{Y}{X}$$

$$\frac{dln(TFP)}{dt} = \frac{dln(Y)}{dt} - \frac{dln(X)}{dt}$$

Outline

1. **Why do productivity growth and productivity matter?**
2. **Some stylized facts and Technological Progress**
3. **Adoption of farm technologies**
4. **Reflections on Measurement, Agricultural Output and Productivity Growth**
5. **Policy**

Why does productivity growth matter?

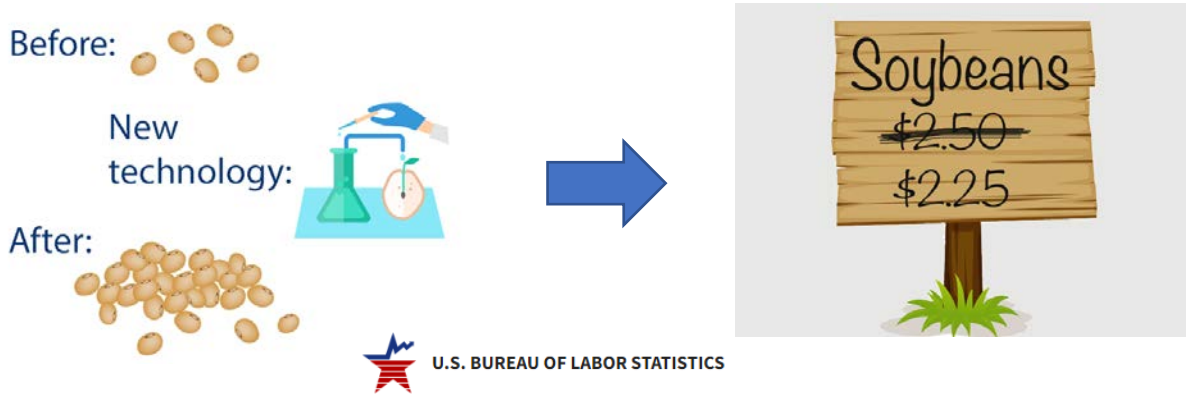


The Rule of 72:= 72/growth rate.

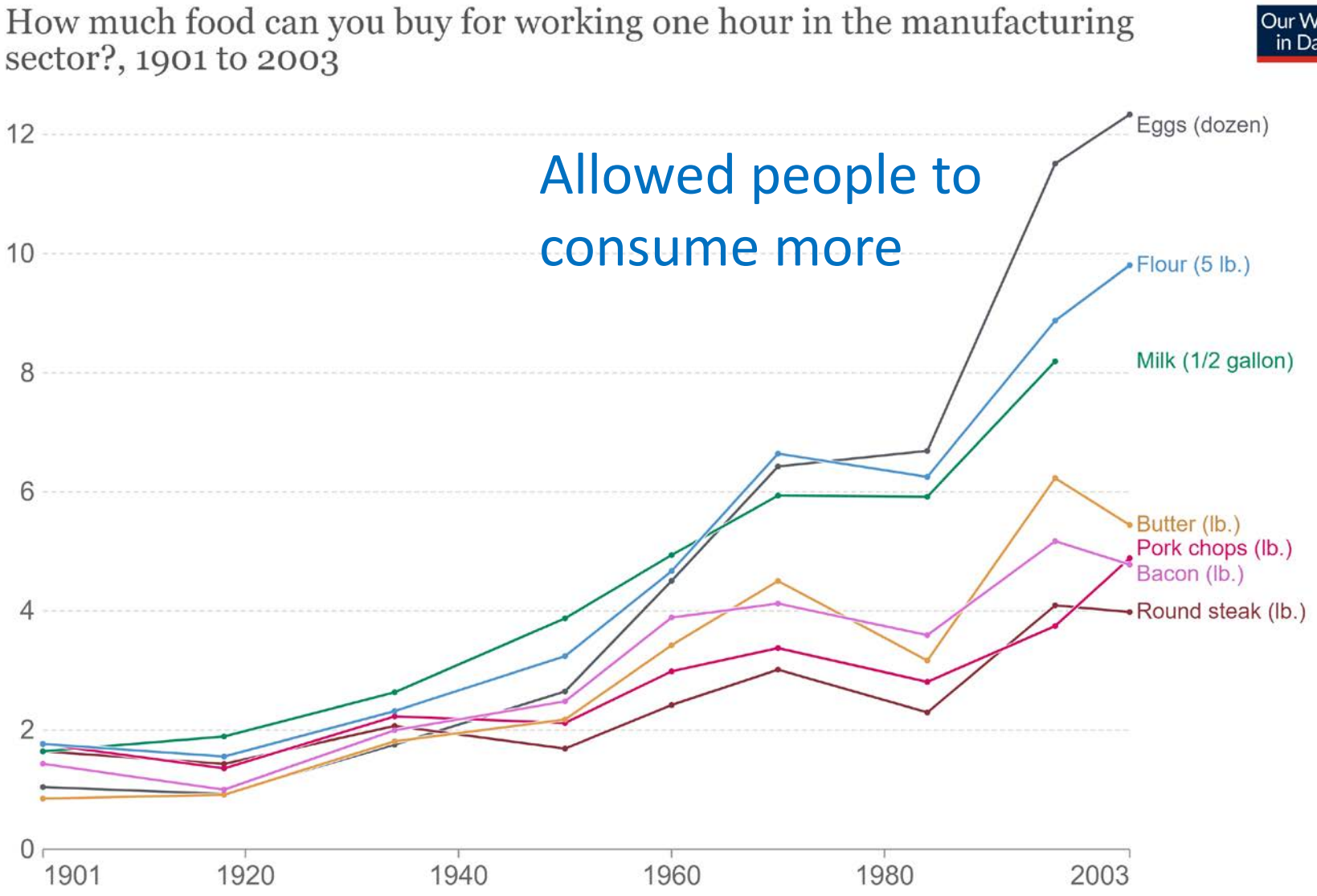
"Productivity isn't everything, but, in the long run, it is almost everything." — economist Paul Krugman

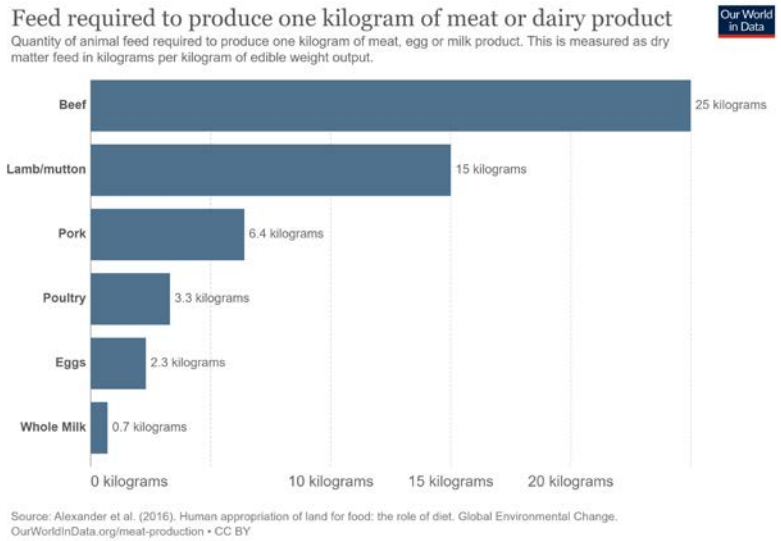
"Rising productivity is the key to making possible **permanent increases** in the standard of living."

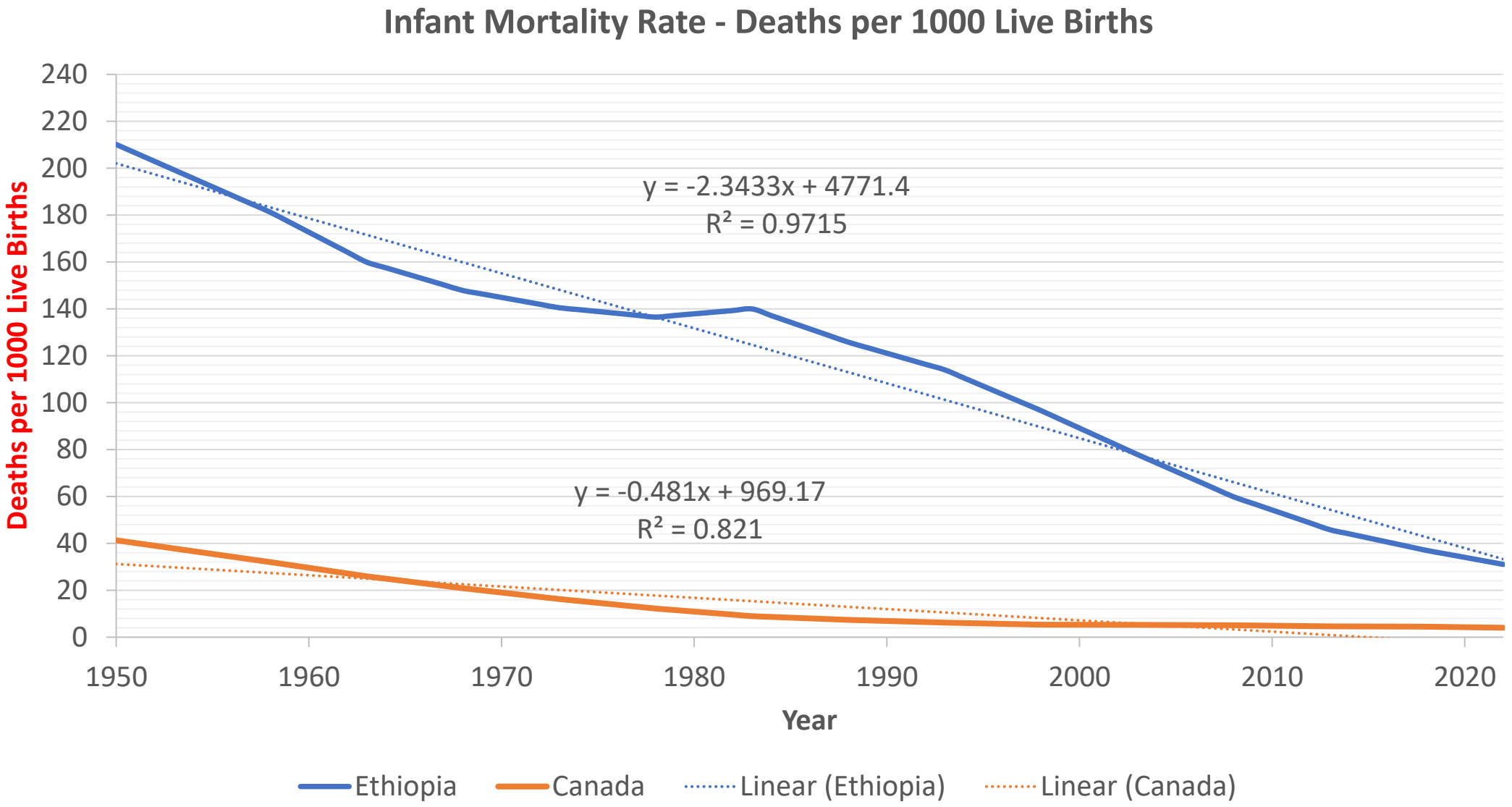
"Changes in technology are the only source of **permanent increases** in productivity."




Wages in the Manufacturing Sector vs. Several Food Prices USA, 1901 to 2003
Our World in Data
Hourly Wage in Manufacturing
Allowed people to earn more
$14
$12
$10
$8
$6
$4
$2
$0
1901
1920
1940
1960
1980
2003
Round steak (lb.)
Bacon (lb.)
Pork chops (lb.)
Butter (lb.)
Flour (5 lb.)
Milk (1/2 gallon)
Eggs (dozen)
Source: U.S. Bureau of Labor Statistics (2013)
OurWorldInData.org/food-prices/ • CC BY

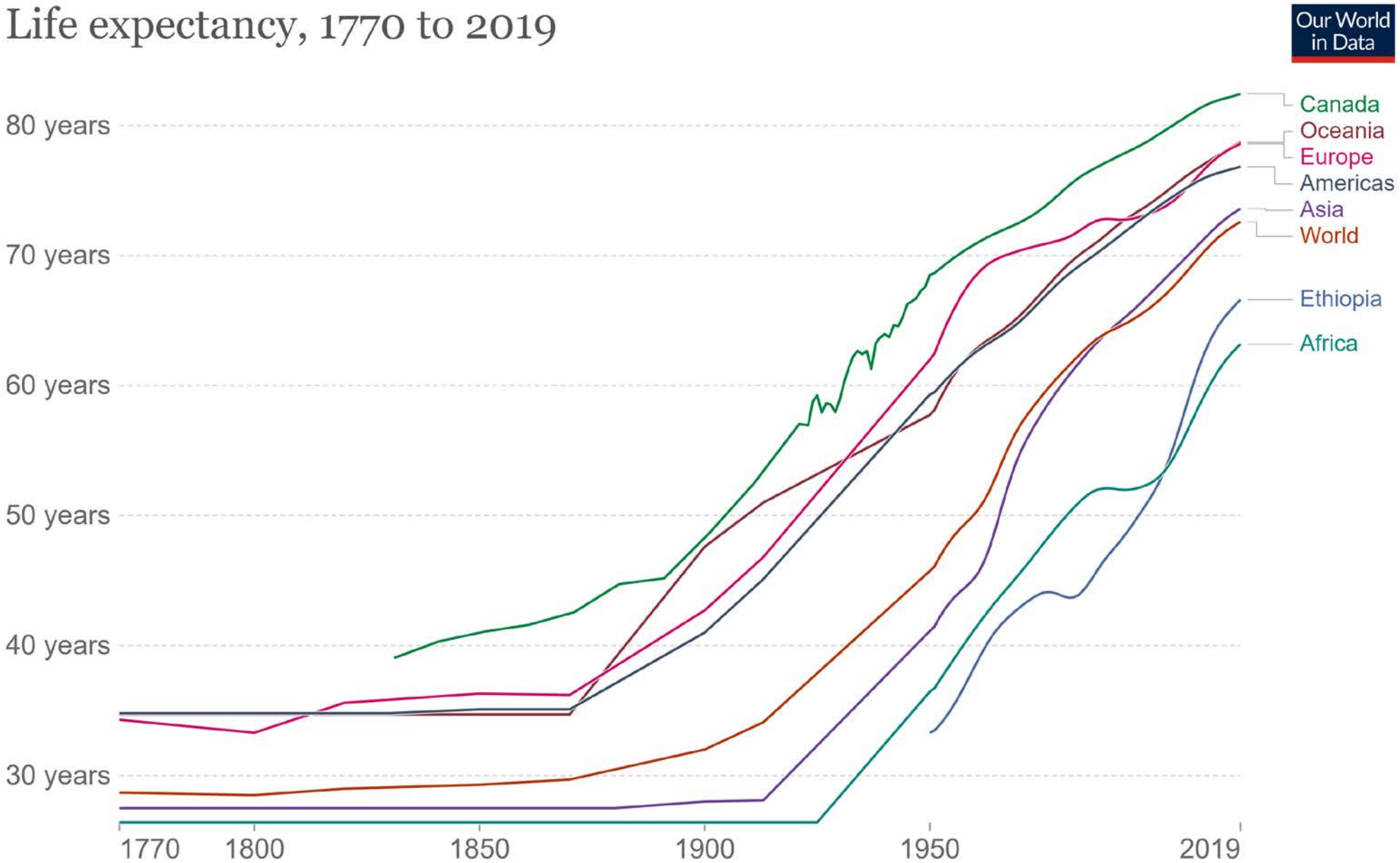

How much food can you buy for working one hour in the manufacturing sector?, 1901 to 2003
Our World in Data
Allowed people to consume more
12
10
8
6
4
2
0
1901
1920
1940
1960
1980
2003
Eggs (dozen)
Flour (5 lb.)
Milk (1/2 gallon)
Butter (lb.)
Pork chops (lb.)
Bacon (lb.)
Round steak (lb.)
Source: U.S. Bureau of Labor Statistics (2015)
OurWorldInData.org/food-prices/ • CC BY


Feed required to produce one kilogram of meat or dairy product
Quantity of animal feed required to produce one kilogram of meat, egg or milk product. This is measured as dry matter feed in kilograms per kilogram of edible weight output.
Our World in Data
Beef
25 kilograms
Lamb/mutton
15 kilograms
Pork
6.4 kilograms
Poultry
3.3 kilograms
Eggs
2.3 kilograms
Whole Milk
0.7 kilograms
0 kilograms
10 kilograms
15 kilograms
20 kilograms
Source: Alexander et al. (2016). Human appropriation of land for food: the role of diet. Global Environmental Change.
OurWorldInData.org/meat-production • CC BY



Data Source: macrotrends

Life expectancy, 1770 to 2019

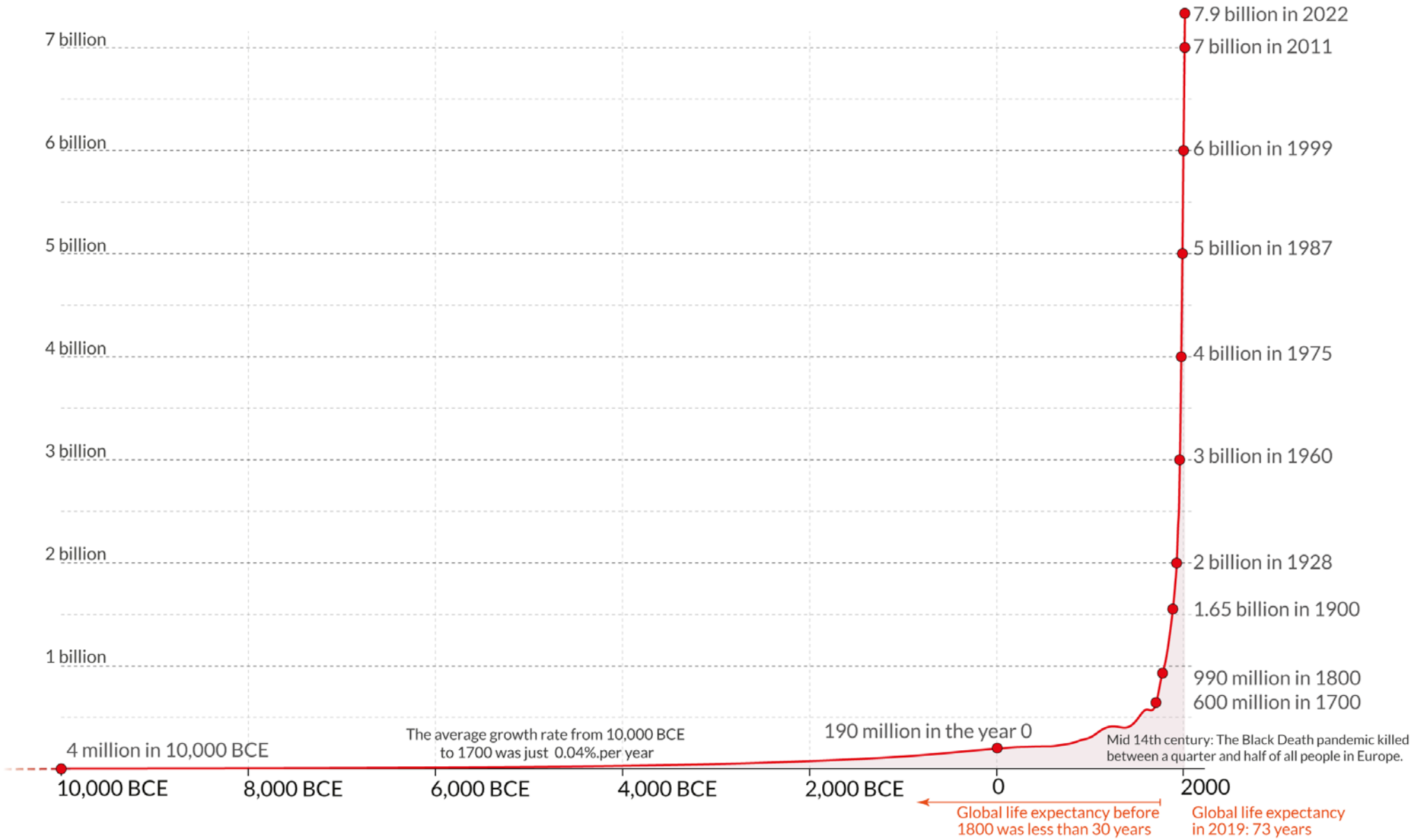


Source: Riley (2005), Clio Infra (2015), and UN Population Division (2019)
OurWorldInData.org/life-expectancy • CC BY
Note: Shown is period life expectancy at birth, the average number of years a newborn would live if the pattern of mortality in the given year were to stay the same throughout its life.

Our World in Data

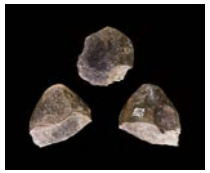
The size of the world population over the last 12.000 years

Demographers expect rapid population growth to end by the end of the 21st century. The UN demographers expect a population of about 11 billion in 2100.



Based on estimates by the History Database of the Global Environment (HYDE) and the United Nations. On OurWorldinData.org you can download the annual data.
This is a visualization from OurWorldinData.org.

Growth of World Population and the History of Technology



Source: Milken Institute, Robert Fogel/University of Chicago

CANADIAN JOURNAL
OF
AGRICULTURAL ECONOMICS

Volume I 1952 PROCEEDINGS Number 1

TRENDS IN FARM MANAGEMENT AND SCALE OF FARM OPERATION

Chairman: CLAUDE HUDSON, *Economics Division*

THE EFFECT OF TECHNOLOGICAL CHANGES ON FARM MANAGEMENT

LOWELL S. HARDIN[1]

Increasingly the job of the farm manager is to try to keep abreast of the technological parade — a parade which no longer moves on foot but at times launches forward as if jet propelled. It is the purpose of this discussion, therefore, to analyze the implications of selected technological changes in progress today.

A prime goal of management is to make full and profitable use of existing and available resources. Just as soil, labor and the management ability of farmers are resources, so also are the technological developments available. Slowly, at times, but surely, man is adopting and using technical developments to broaden management's control over other resources. The facets of modern farm technology are varied yet so interrelated as constantly to add complexity to the management problem. A simple, short run input-output analysis may be grossly inadequate in deciding "will the change pay"? The full impact of changes may not be felt for five or ten years. Complementary relationships, if involved, may require several years for full expression. Adding to this complicating factor is the ever present dynamics of physical input-output and price relationships in the changing weather, biological and economic scene.

Because of joint relationships which are involved and because the

Available technological developments are resources

1950s: "Increasingly the job of the farm manager is to try to keep abreast of the technological parade – a parade which no longer moves on foot but at times launches forward as if jet propelled."

A simple, short-run input-output analysis may be grossly inadequate in deciding "**will the change pay**"?

- Complementary relationship between technologies
  - Mechanization
  - Storage technology (including feed)
  - Breeding, fertilization and crop management
  - Animal nutrition and mechanization (vs. hand feeding)
- Dynamics of physical input-output and price relationships
- **The changing weather, biological** and economic scenes.
- Unpredictability of the outcomes of certain technological developments.
  - $E[Q] \uparrow, E[\pi] \uparrow or \downarrow$ and depends on the elasticity of demand
- Adoption of innovation and creative destruction

TRENDS IN SCALE OF FARM OPERATION — WESTERN CANADA

GORDON HAASE[1]

The more important changes in the farm business in Western Canada in recent years represent primarily changes in the relative proportions of the main factors used in agricultural production. The features of the farm business in Western Canada which have undergone significant alteration during the past twenty-five years or so may be summarized as follows:

1. Farms are becoming larger, and fewer in number while the farming area has grown only slowly;
2. Numbers of persons engaged in farming in the West are declining.
3. Amount of farm machinery in the region and the investment it represents, have increased markedly in recent years.

The nature and extent of these trends is illustrated by published

TABLE 1.— SIZE OF FARM, LABOR FORCE AND MECHANIZATION, PRAIRIE PROVINCES 1931-1951

Year	Av. Improved Acres per Farm	Farm Labor Force (b)	Investment in Machines (c)
	acres	thousand	thousand dollars
1931	208	426	$ 356,658
1936	202	456 (d)	261,193
1941	222	418	317,769
1946	241	394	481,166
1951	270 (e)	369	1,147,448

(a) Census of Canada and of Prairie Provinces.
(b) Dom. Bureau of Statistics Ref. Paper 23 and Quarterly Labor Force Surveys.
(c) Census of Canada and Prairie Provinces.
(d) Estimated as same proportion of Canada total as 1931 and 1941 i.e. 40 per cent.
(e) Estimated.

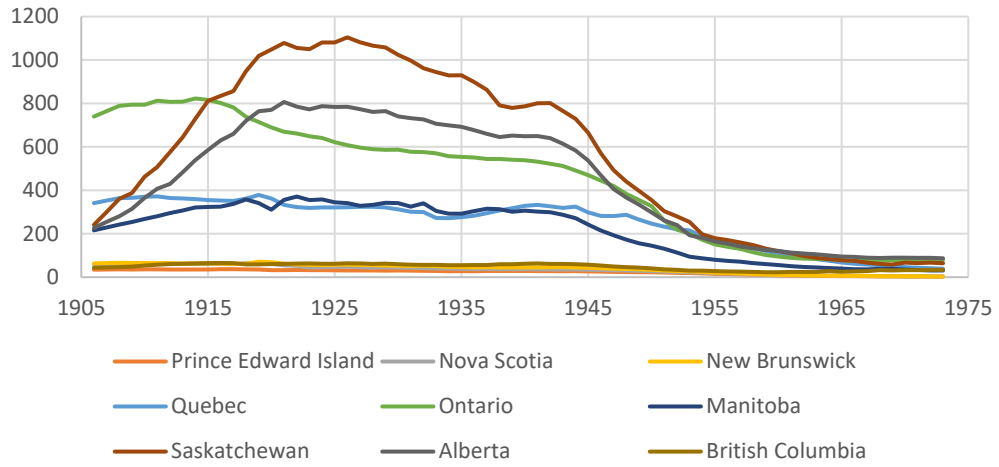
data relating to western Canadian agriculture. They indicate that farm size, labor supply and machinery complement are closely related in farming. An increase in the size of farm can ordinarily be achieved only by an increasing labor supply, or by using more and bigger machinery, or both these alternatives. Between 1931 and 1951, the average farm in the Prairie Provinces increased in size from 208 acres of improved land to about 270 acres per farm, (Table 1). However, the number of farm workers in prairie agriculture dropped by 57,000 in the same period, after increasing for a time during the back-to-the-land movement of the thirties. Increasing farm size and fewer farm

[1]Economics Division, Canada Department of Agriculture, Edmonton, Alberta.

Substituting Horsepower for Horses

- "... changes in the relative proportions of the main factors used in agricultural production."
- "Amount of farm machinery in the region and the investment it represents have increased markedly in recent years."
- **Implications for those beginning farming**
- $357 mil (1931) to 1,147 mil (1951)
- Each worker's departure was accompanied by the introduction of about $6,800 worth of machinery.

Technological progress and the number of horses on farms in Canada, x1000



TRENDS IN SCALE OF FARM OPERATIONS — EASTERN CANADA

G. P. Boucher[1]

The most significant developments in our Eastern agriculture in the war and post-war period are reflected in the increased productivity per worker. The number of agricultural workers has decreased but the volume of agricultural production has increased at a faster rate. Much of this success can be attributed to a high level of general economic development and prosperity and also to the use of new and better machinery, the adoption of better farming practices, more skilled workmanship and management, better financing facilities, the ability and willingness of the farmer to modify the structure of his farm business and his keen interest in the practical applications of experimental research. Technological developments have strengthened the farmer's command over resources and increased his ability to manage a larger business.

The farmer of Eastern Canada, however, does not usually find it easy to increase the size of his farm business by the acquisition of new land. Economies of scale are more easily realized by efforts to increase the capacity of the farm to make use of larger inputs of other factors of production or by the adoption of a more intensive type of production.

Intensification is likely to contribute to success but one must not overlook the fact that the diversified character of Eastern farming accentuates the co-ordination problem. Moreover, many of the smaller farms display little ability to take advantage of modern methods of farming and modern equipment, and to fully utilize all of their labour resources.

Increases in scale of operations, increases in machinery and various other sources of expenditures have all contributed to a pronounced increase in capital requirements. One can easily visualize the potential dangers of such a development in periods of economic instability. A particularly difficult situation is created for the young farmer with inadequate financial resources, planning the acquisition or establishment of an efficient farm.

Most of the foregoing observations are matters of common knowledge which can be supported by statistical evidence. Census figures, in fact, indicate that the total population of the five Eastern provinces has increased but that the farm population has decreased from 1931 to 1951. The decline in farm population was parallelled by a decline

[1]Economics Division, Canada Department of Agriculture, Ottawa.

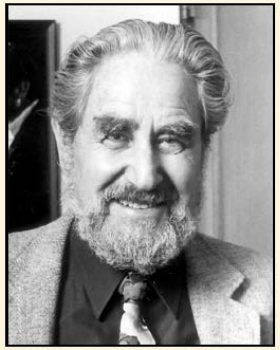
"Technological developments have strengthened the farmer's command over resources and increased his ability to manage a large business."

- High general economic development and prosperity
- More skilled workers and management
- **Adoption of more intensive types or production**
  - Fertilizer use: 239,062 tons (1941) – 595,292 tons (1951)
- Increases in farm mechanization
  - Tractors – 22,299(1931) -149,479 (1951)
  - Horse: 1,060,284 (1931)– 665,700 (1951)
- A pronounced increase in capital requirements.
- **Better financing facilities**
- **Farmers' willingness and ability to adopt better farming practices (acceptance)**
- Farmers' keen interest in the practical application of experimental research.
- **Smaller farms display little ability** to take advantage of modern methods

Takeaways …

- Growth in the agri-food sector has been spurred by **technological and institutional innovations.**
- Increase output and reduced inputs – process innovation
  - advances in plant and animal breeding,
  - mechanization,
  - agricultural chemicals,
  - irrigation and others
- Importance of institutions (finance, research, etc.)
- The results of sustained investment in agri-food
  - Enabled the delivery of safe, cheap and plentiful food.

Measure what you treasure


Zvi Griliches

In his presidential address to the American Economic Association (1994) Griliches wrote: "The major message that I will be trying to convey is that we often misinterpret the available data because of inadequate attention to how they are produced and that the same inattention by us to the sources of our data helps to explain why progress is so slow. **It is not just the measurement of productivity that is affected.** Other fields of empirical economics are also struggling against limitations imposed by the available data. Great advances have been made in theory and in econometric techniques, but these will be wasted unless they are applied to the right data."

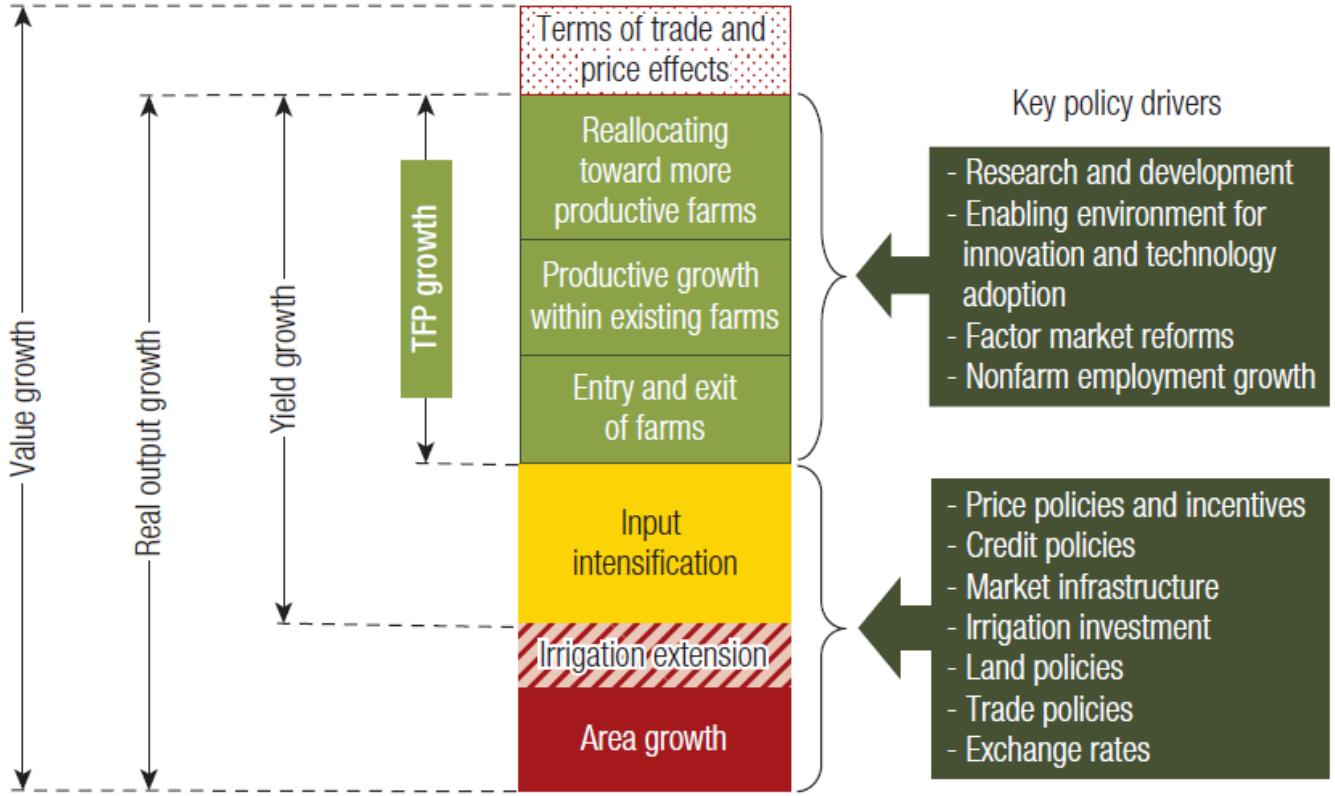
- **Issues**
  - Quality of inputs and outputs, aggregation
  - Introduction of new outputs over time
  - Bias in price indices
  - Measurement errors vary in importance over time

Sources Economic/Output Growth

What output growth drivers matter most?

- **Productivity-led:** Rate of growth of technological innovation (Uzawa 1965; Lucas 1988; Romer 1990; Grossman & Helpman 1992; Aghion & Howitt, 1992, 1998)

- **Resource-led:** Replication of existing technologies

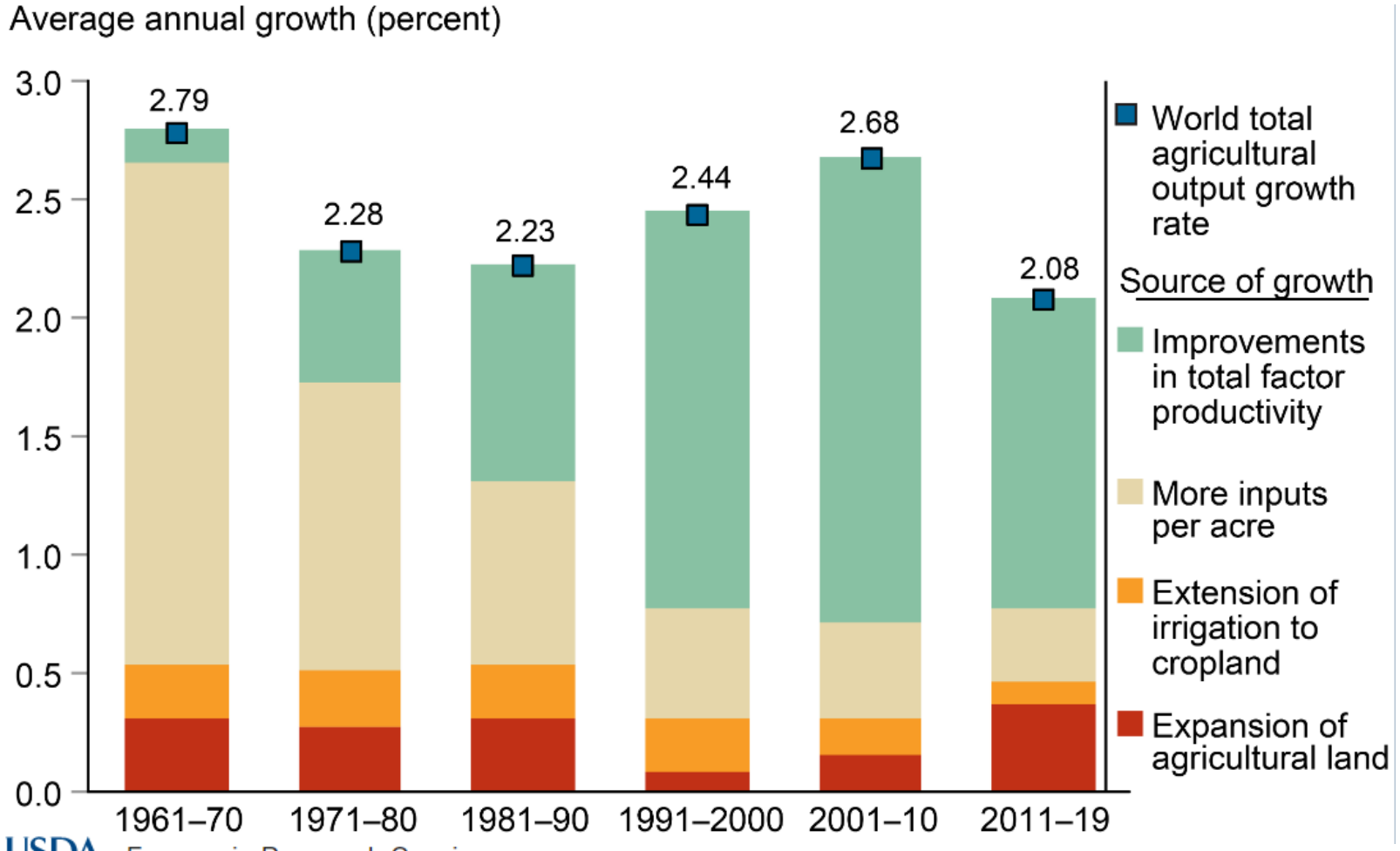


Source: World Bank.

Note: TFP = total factor productivity.

Source: Fuglie et al 2020, The World Bank Group

Sources of output growth in global agriculture, 1961-2019 (%)

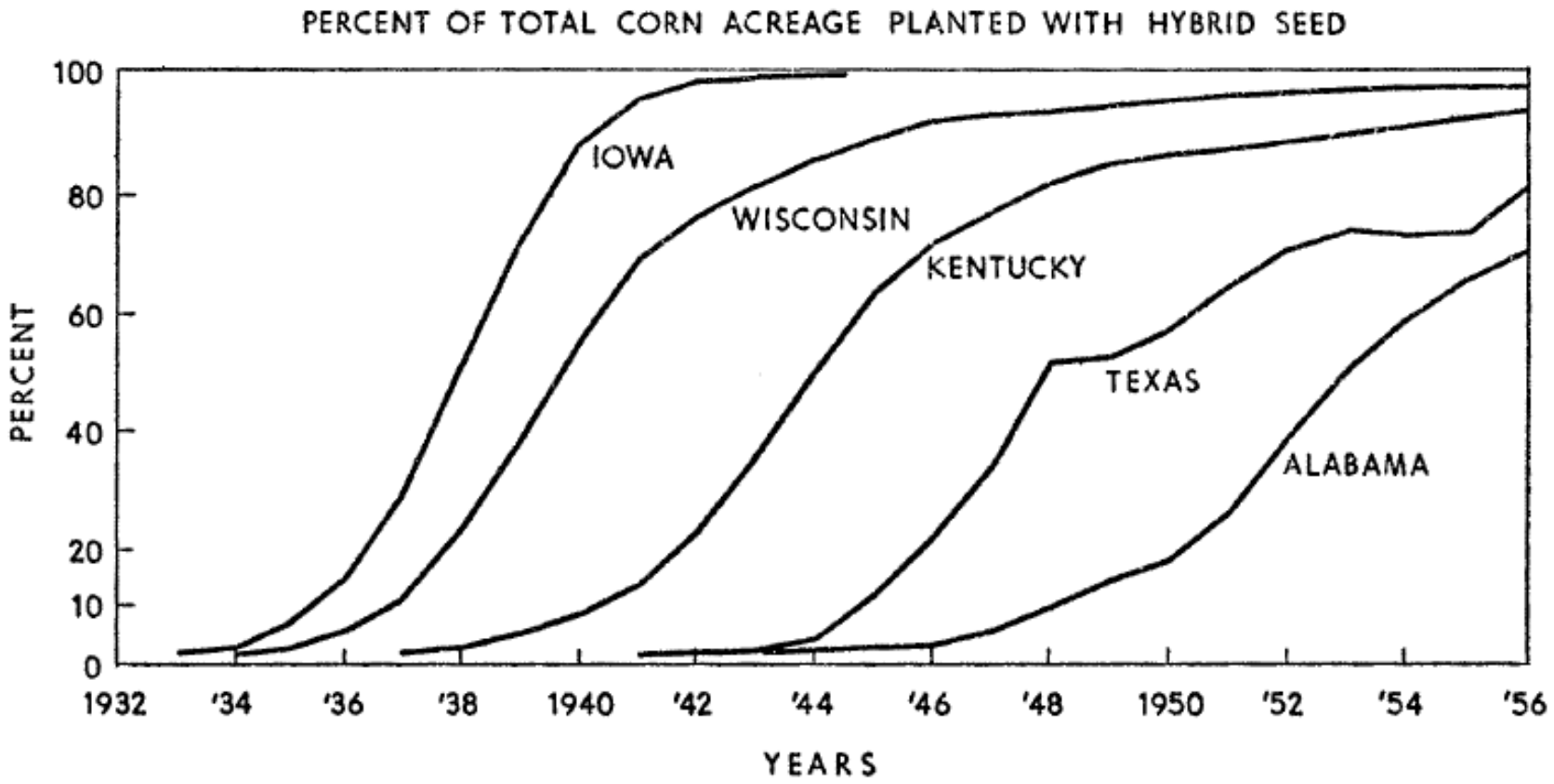


USDA Economic Research Service
U.S. DEPARTMENT OF AGRICULTURE

International Agricultural Productivity

2.3% (1961-2019) ~ 4X

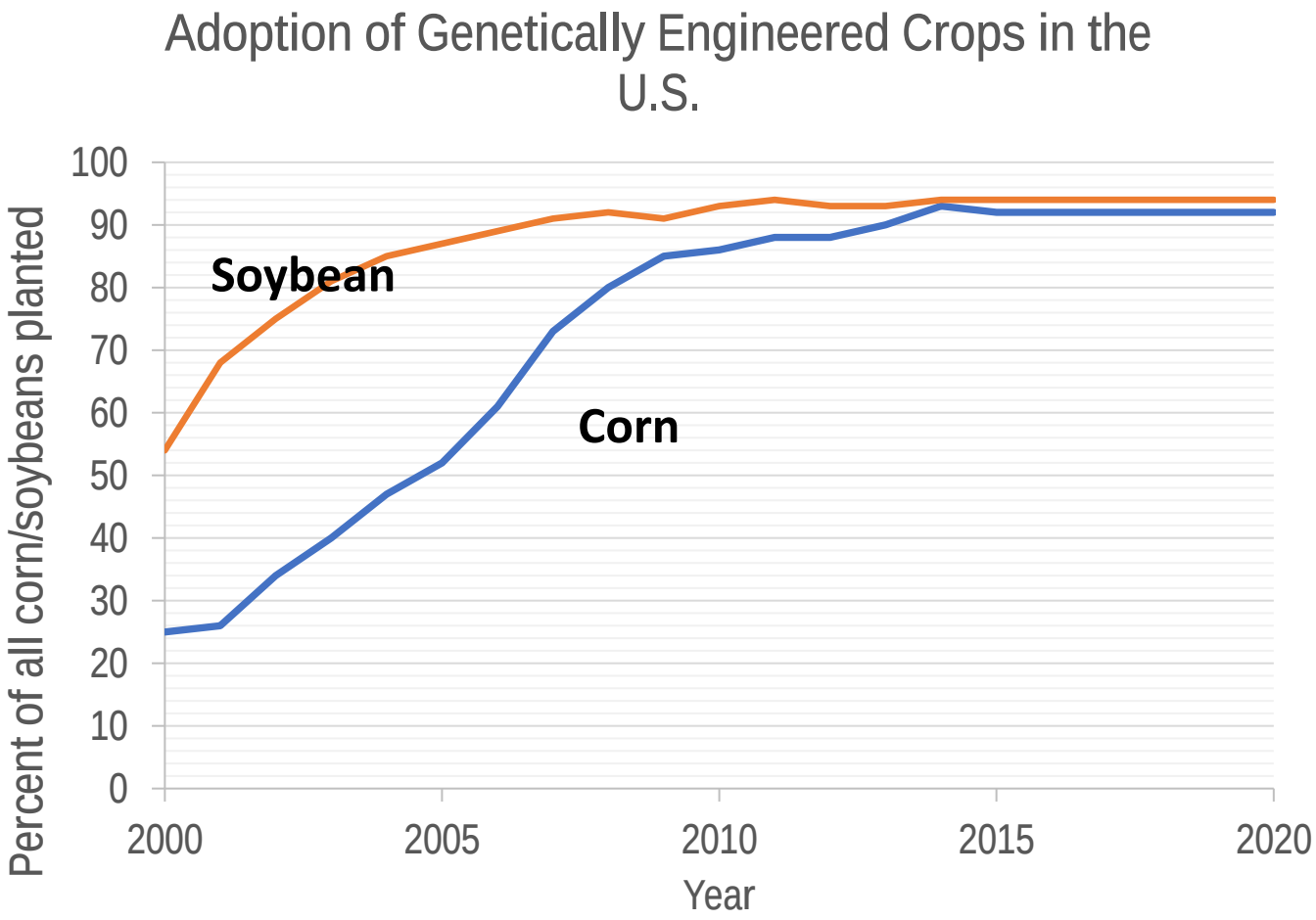
Adoption and Diffusion: Hybrid Corn: An Exploration in the Economics of Technological Change (Griliches, 1957)



- **Availability problem**
- **Acceptance problem**

Econometrica
Vol. 25, No. 4 (Oct., 1957), pp. 501-522 (22

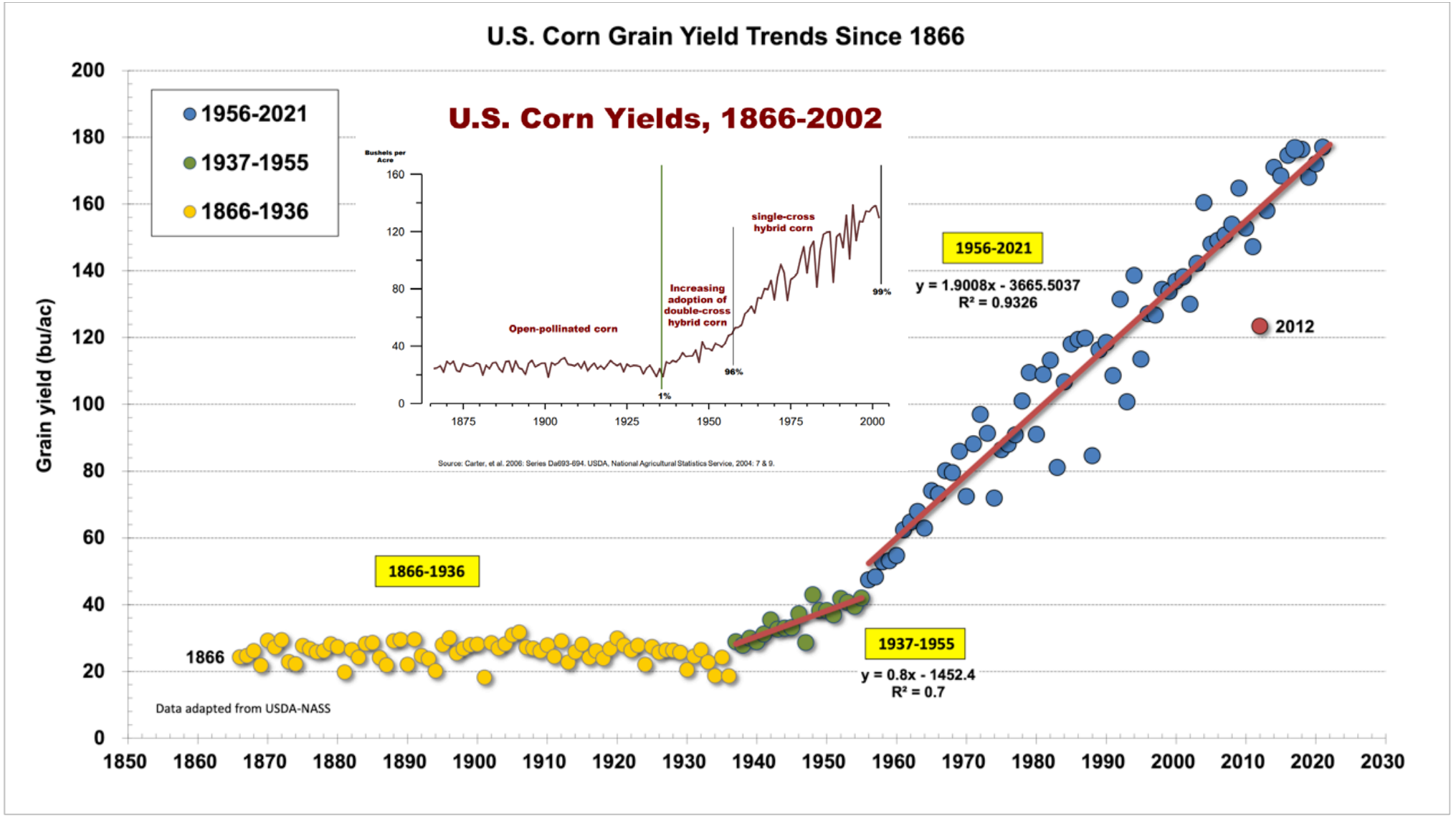
Cited by 4911

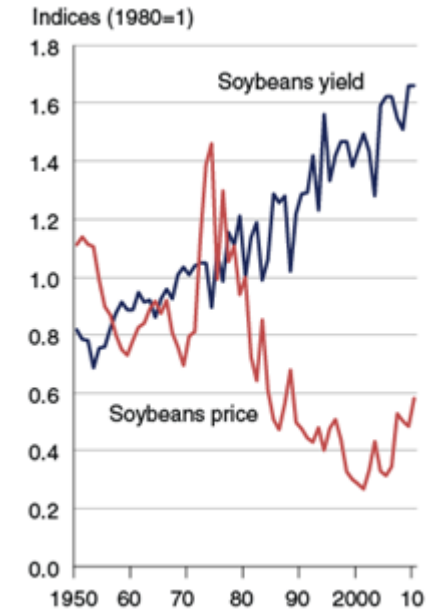


Adoption of genetically engineered crops in Canada

year	Canola	Soybeans	Corn	Sugar Beats
2015	95%	71%	83%	100%
2016	95%	75%	86%	100%
2017	95%	82%	88%	100%
2018	95%	81%	88%	100%
2019	95%	79%	90%	100%
2020	95%	78%	90%	100%
2021	95%	80%	91%	100%

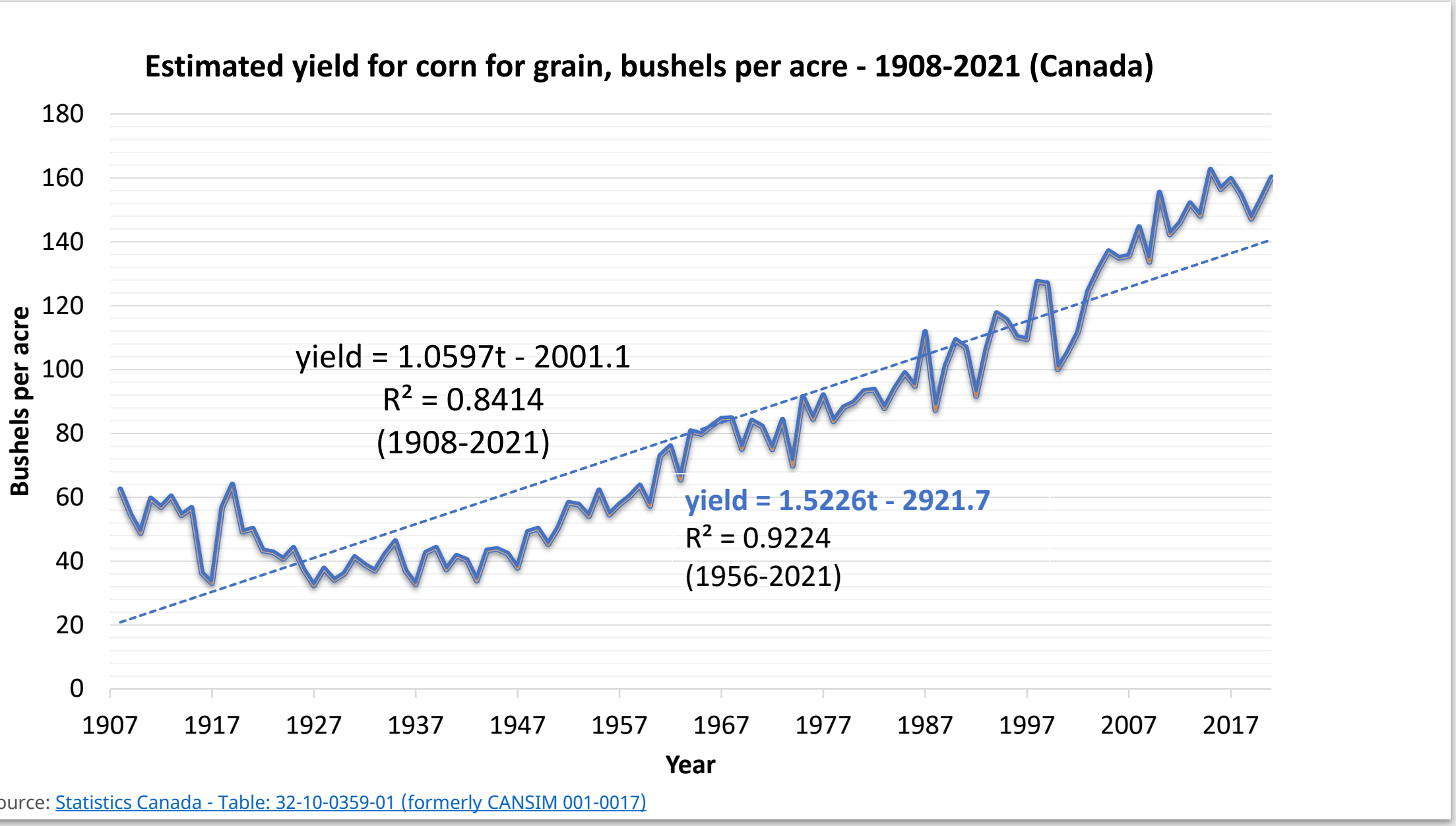
Data Source USDA Economic Research Service U.S. DEPARTMENT OF AGRICULTURE



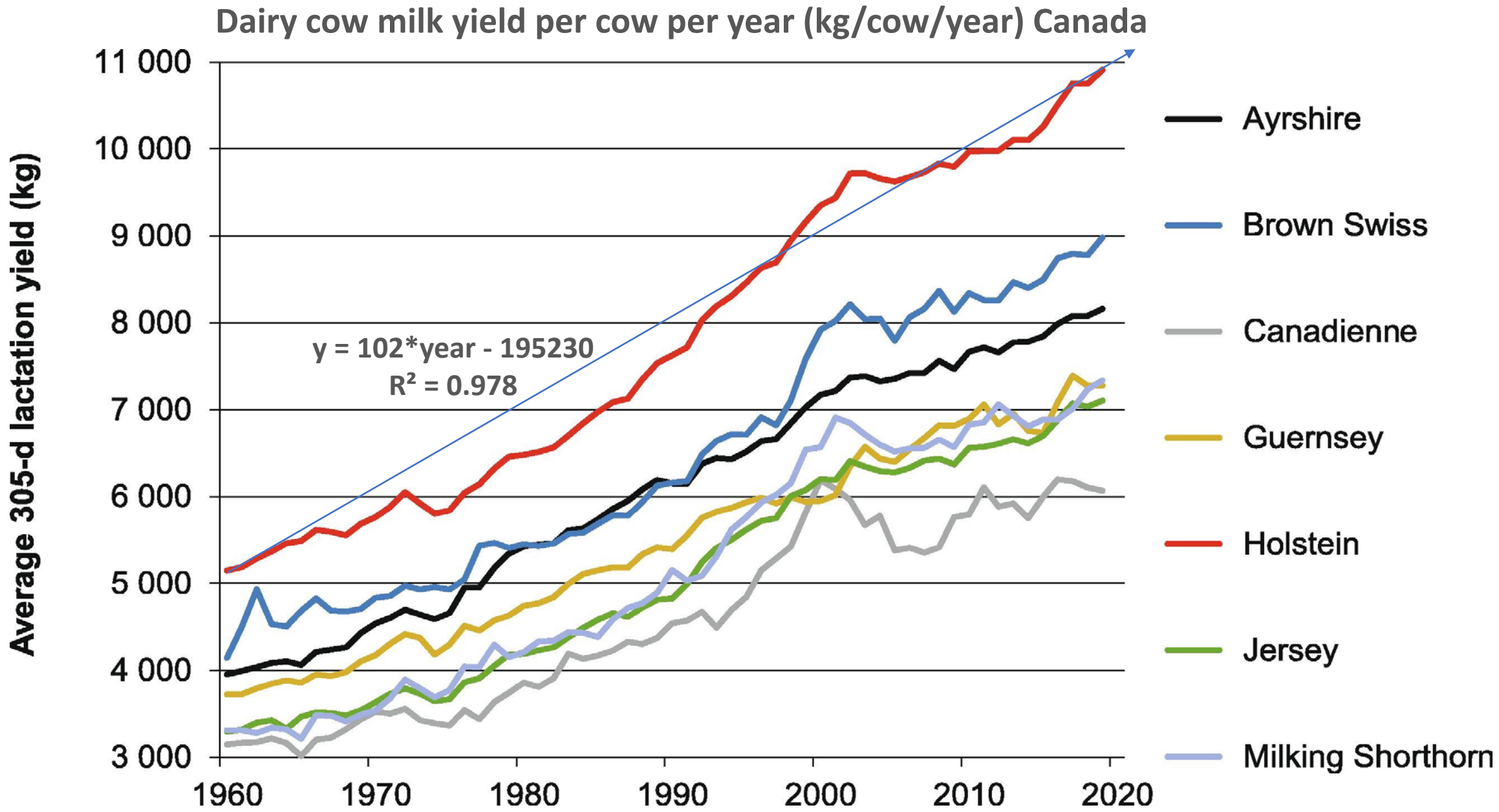


USDA Economic Research Service
U.S. DEPARTMENT OF AGRICULTURE

[Nielsen 2022]



Data Source: Statistics Canada - Table: 32-10-0359-01 (formerly CANSIM 001-0017)



Data source: Canadian Dairy Information Centre, 2022; Brito et al 2021

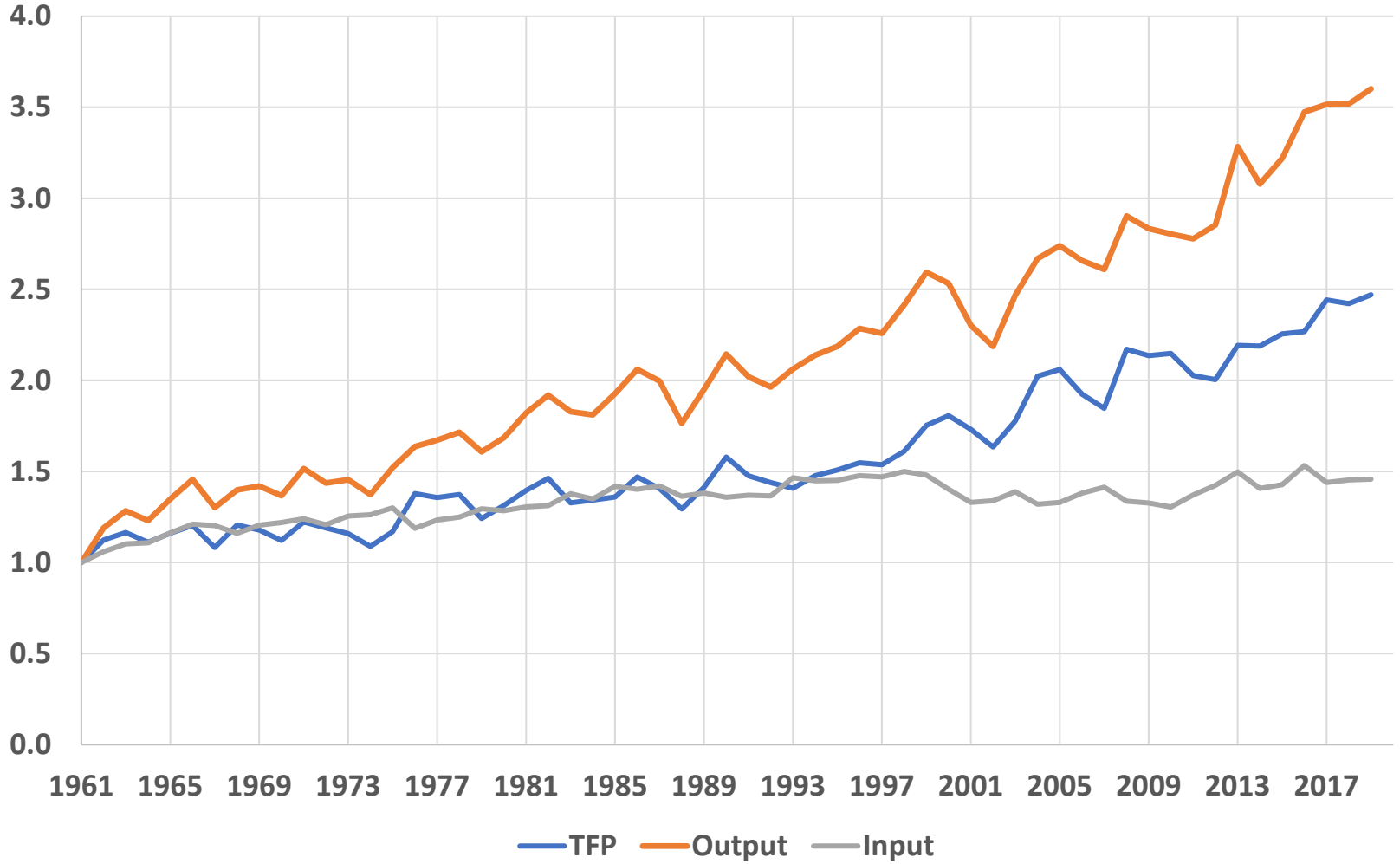
Production Accounts and Productivity Growth Measures for Canadian Agriculture

- **Lok, S. (1961)** An enquiry into the relationships between changes in overall productivity and real net return per farm, and between changes in total output and real gross return, Canadian agriculture, 1926–1957. *Technical Publication* No. 61/13. Department of Agriculture, Ottawa, Canada. (**1926 – 1957, 2.0%).**
- **Furniss, I. (1964)** Productivity of Canadian agriculture, 1935–1960: A quarter of a century of change. *Canadian Journal of Agricultural Economics* 12, 41–53. **(1935–1960, 2.3%).**
- **Furniss, I. (1970)** Agricultural productivity in Canada: Two decades of gains. *Canadian Farm Economics* 5, 16–27. **(1950 -1969, 1.9%)**
- **Danielson, R. (1975)** Three Studies in Canadian Agriculture. Unpublished M.A. Thesis, Department of Economics, University of British Columbia, Canada. **(1946–1970, 2.0%).**

Production Accounts and Productivity Growth Measures for Canadian Agriculture

- **Islam, T. (1982)** Input Substitution and Productivity Change in Canadian Agriculture. Unpublished Ph.D. Thesis, Department of Economics, University of Alberta, Alberta, Canada. **(1961–1978, 1.8%).**
- **Brinkman, G. and Prentice, B. (1983)** Multifactor productivity in Canadian agriculture: An analysis of methodology and performance. Paper prepared under contract for Agriculture Canada, Regional Development Branch, Development Policy Directorate. **(1961–1980, 1.8%).**
- **Cahill, S. A. and Rich, T. (2012)** Measurement of Canadian agricultural productivity growth, CAB International 2012. Productivity Growth in Agriculture: An International Perspective (eds. Fuglie et al.) **(1961-2006, 1.6%)**
- **Statistics Canada. (2022).** Table 36-10-0217-01 Multifactor productivity, gross output, value-added, capital, labour and intermediate inputs at a detailed industry level DOI: https://doi.org/10.25318/3610021701-eng **(1961-2018, 0.61% gross output; 1.62%, value-added).**

Measured total output, input and TFP for Canadian agriculture (USDA data)



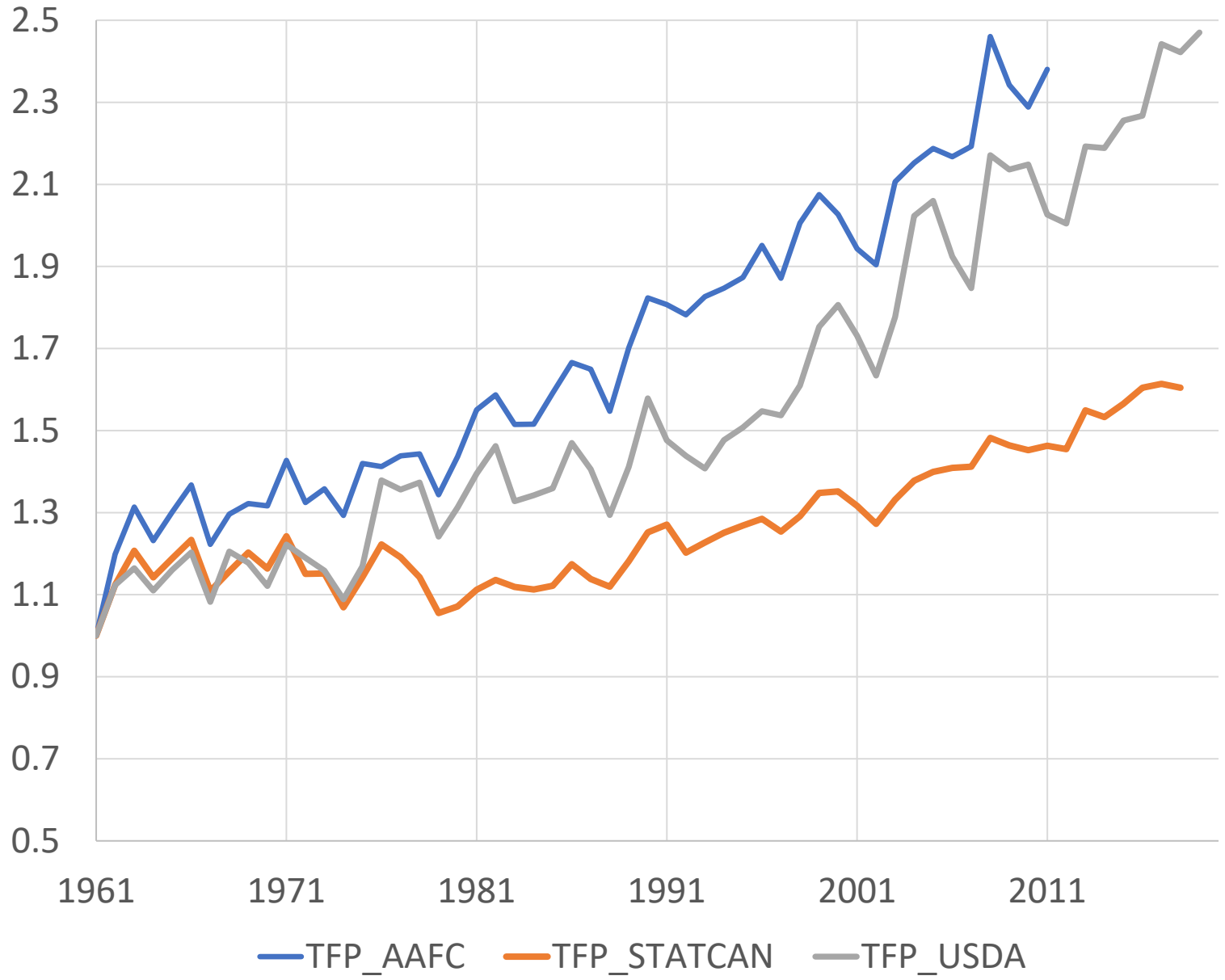
Data source: USDA

	1961-2018	Contribution to output growth
Output	1.83%	
Input	0.43%	23.5%
TFP	1.40%	76.5%

Productivity growth in Canadian agriculture, 1961-

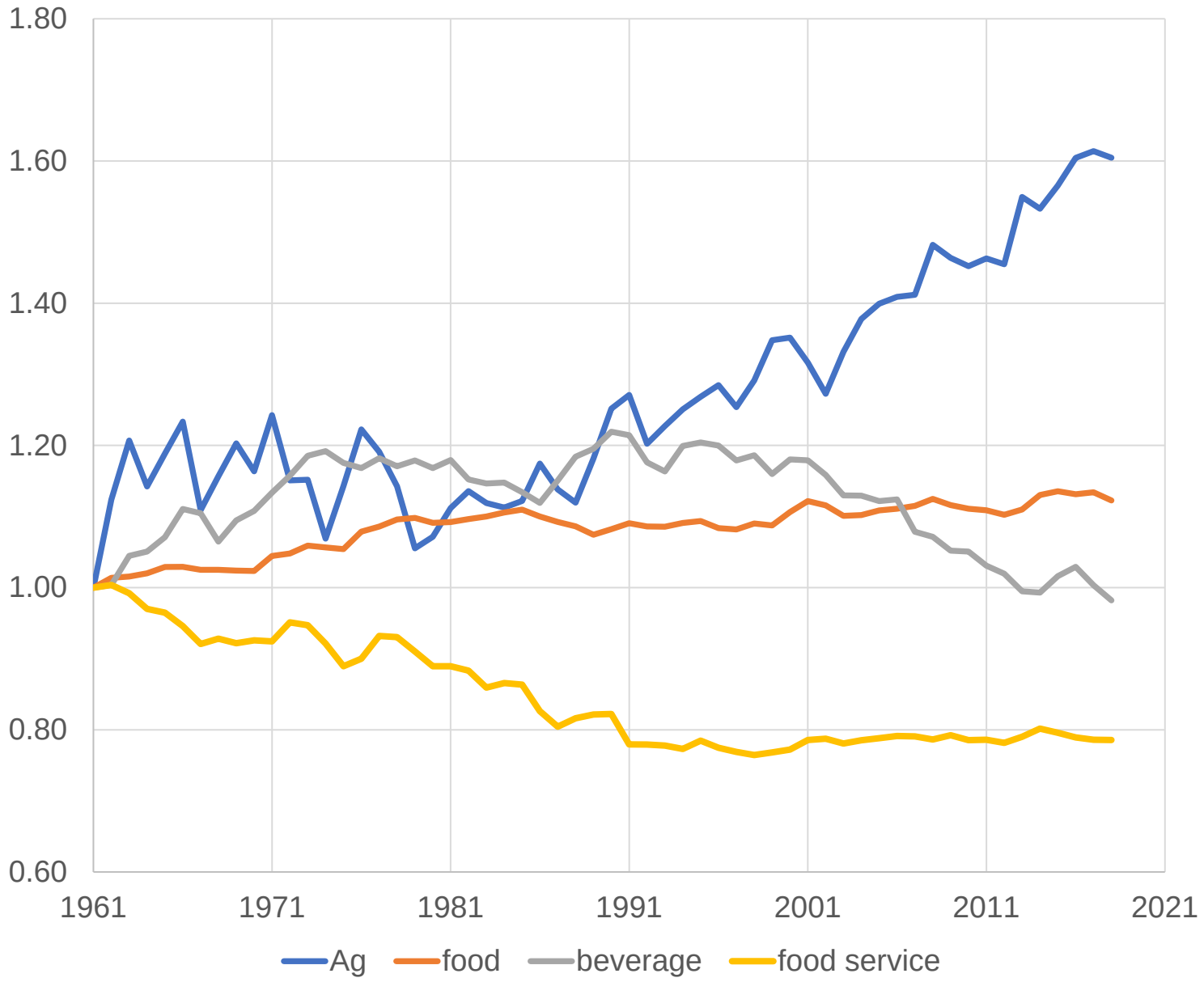
Correlation		
	AAFC	StatCan
StatCan	0.90	
USDA	0.97	0.91

TFP Average Growth Rate (1961-2011)	
AAFC	1.42
StatCan	0.51
USDA	1.31



Data source: Statistics Canada; AAFC; USDA

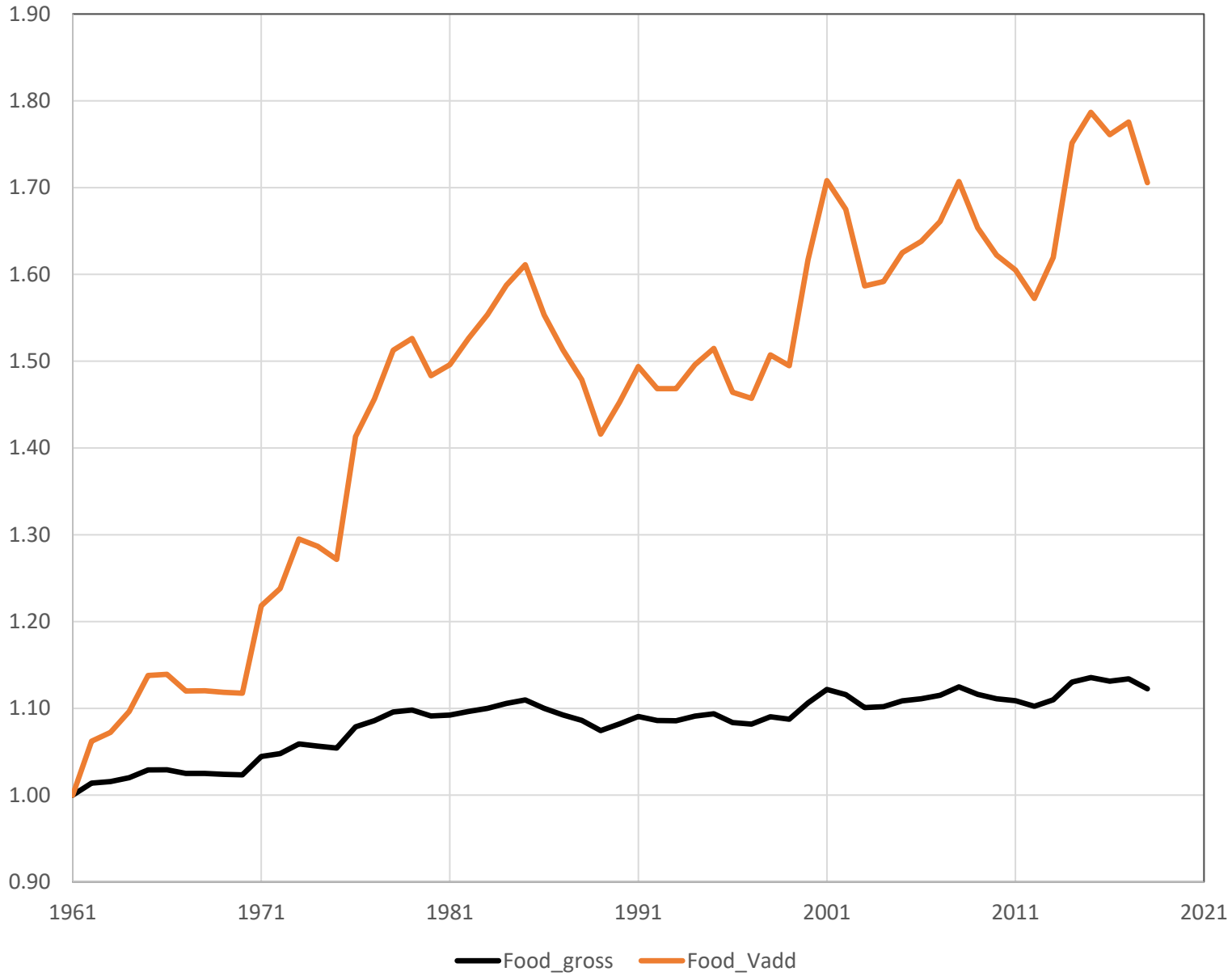
Multifactor productivity by sub-sector of the Canadian Agri-food industry



Data source: Statistics Canada

Multifactor productivity for the food manufacturing sector

– value added vs gross output



Data source: Statistics Canada

Considerable Inter-decile Productivity Dispersion for Food Manufacturing and its Sub-sectors

Year	311	3111	3112	3113	3114	3115	3116	3117	3118	3119
2000	3.16	4.83	5.65	4.03	4.83	6.00	4.05	2.11	2.40	3.34
2001	3.31	4.71	5.62	4.10	4.72	6.16	4.06	1.93	2.58	3.59
2002	3.20	4.51	6.31	3.64	4.84	5.61	3.54	1.65	2.30	3.18
2003	3.20	4.67	6.30	3.83	4.71	5.76	3.45	1.77	2.38	2.83
2004	3.41	4.89	5.75	4.13	4.56	5.87	3.33	2.34	2.88	3.37
2005	3.44	5.00	5.55	4.17	4.65	5.73	3.37	2.61	3.03	3.39
2006	3.51	4.96	5.38	4.66	4.75	5.86	3.34	2.39	3.13	3.18
2007	3.53	5.09	5.43	4.07	4.80	5.61	3.59	2.25	3.06	3.22
2008	3.42	4.45	6.03	4.00	4.86	5.74	3.66	2.23	3.01	2.98
2009	3.41	4.33	5.93	3.62	4.79	5.84	3.72	2.35	3.09	2.99
2010	3.50	4.68	5.52	3.65	4.88	5.56	4.05	2.24	3.19	2.79
2011	3.49	4.73	5.56	3.62	5.13	5.81	4.01	2.33	3.15	2.71
Average	3.46	4.76	5.83	4.09	4.94	5.87	5.81	2.15	2.92	3.13

Note: 3111= Animal food manufacturing; 3112= Grain and oilseed milling; 3113=Sugar and confectionery product manufacturing; 3114=Fruit and vegetable preserving and specialty food manufacturing; 3115=Dairy product manufacturing; 3116=Meat product manufacturing; 3117=Seafood product preparation and packaging; 3118=Bakeries and tortilla manufacturing; 3119=Other food manufacturing.

Hailu & Piedrahita, 2021

Internal Factors

1. Managerial practices/talent
2. Quality of labour and capital
3. IT and R&D
4. Learning-by-doing
5. Product innovation
6. Firm structure decisions

External Factors

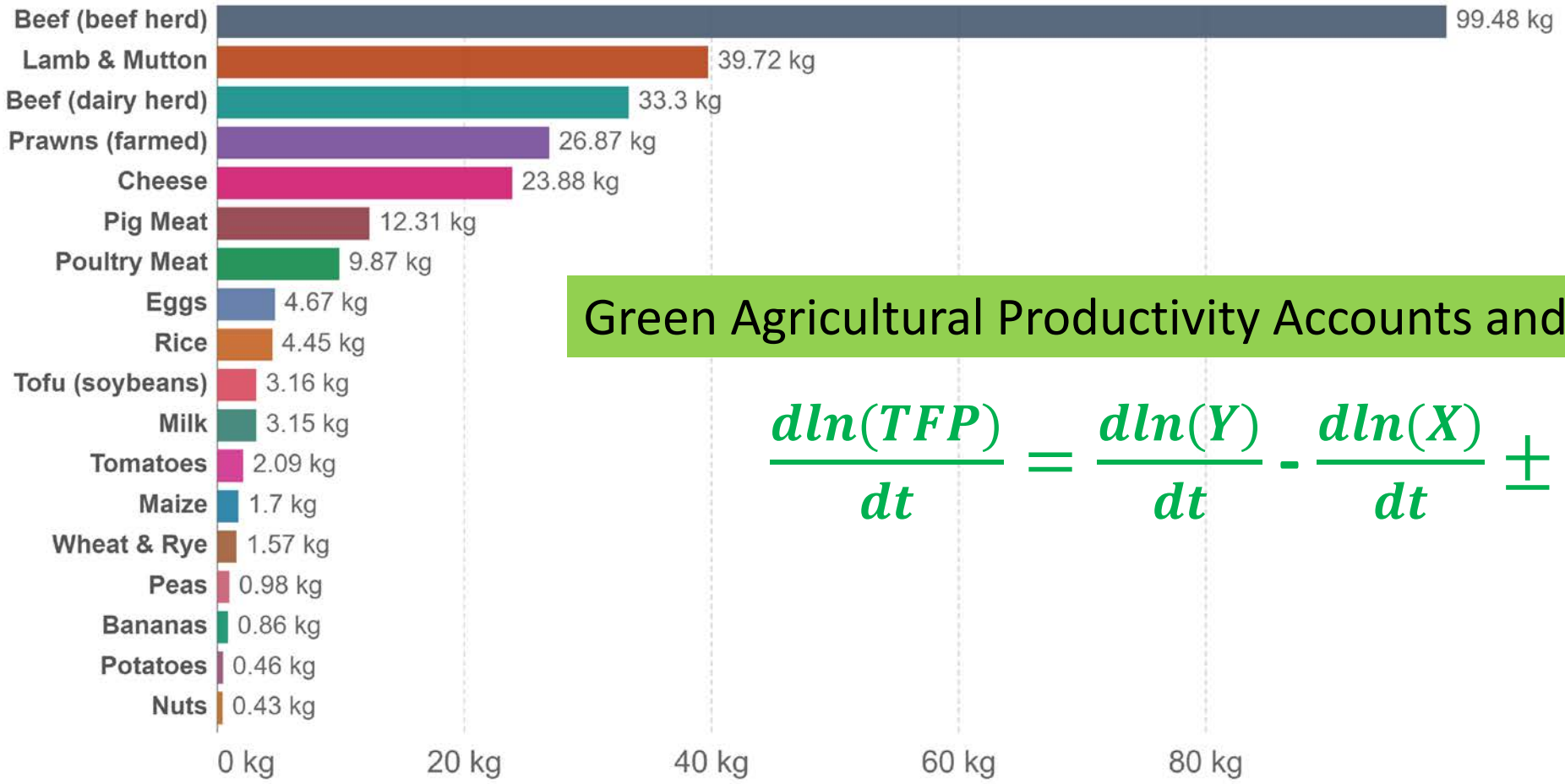
1. Productivity spillovers
2. Competition/Darwinian selection (both intra-market and through trade)
3. Regulatory environment
4. Input market flexibility

Syverson (2011, JEL)

Greenhouse gas emissions per kilogram of food product

Emissions are measured in carbon dioxide equivalents (CO2eq). This means non-CO2 gases are weighted by the amount of warming they cause over a 100-year timescale.

Our World in Data



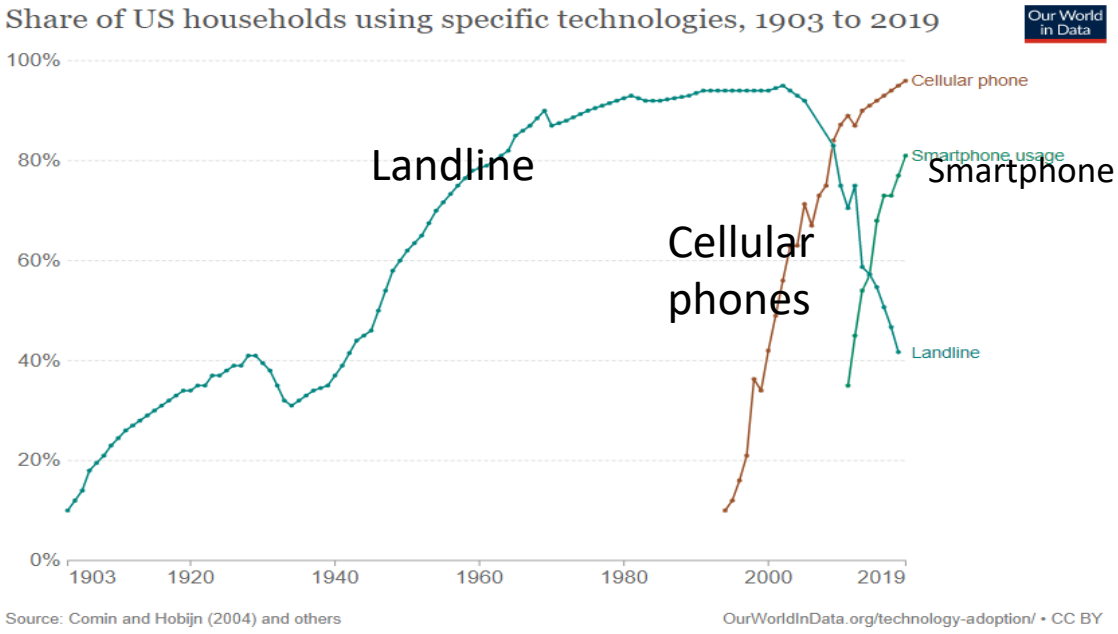
Green Agricultural Productivity Accounts and Growth Measure

$$\frac{dln(TFP)}{dt} = \frac{dln(Y)}{dt} - \frac{dln(X)}{dt} \pm \frac{dln(G)}{dt}$$

Source: Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers.
Note: Greenhouse gases are weighted by their global warming potential value (GWP100). GWP100 measures the relative warming impact of one molecule of a greenhouse gas, relative to carbon dioxide, over 100 years.
OurWorldInData.org/environmental-impacts-of-food • CC BY

Enabling Institutional Environment

- Developed financial market is crucial for the success of innovation (Schumpeter 1911; Hicks 1969; Hailu and Herath, 2022)
- Intellectual property rights
  - patent, trademarks, copyrights
- Human capital (Lucas 1988; Hailu & Herath, 2022)
- Openness to trade



Manitoba

No new equipment or land for a few years, say farmers hit by interest rate hike

Establishments reporting high impact of obstacles to innovation, (fiscal years 2016 to 2018)

Obstacles	*Innovating*	*non-innovating*
Shortages of skilled workers	43.5	23.3
Lack of internally generated cash flow	34.6	17.1
Long gestation period of innovation	26.5	5.1
Insufficient flexibility in regulations	21.9	11.9
Lack of external equity funding	21.1	9.6
Lack of debt financing	17.4	8.3
Lack of idea champions	12.1	6.9

Hailu & Herath, 2022

Challenges and Opportunities

Path Forward

PRESIDENT'S ADDRESS, AMERICAN FARM MANAGEMENT ASSOCIATION, BALTIMORE, MD., JANUARY 8, 1919.

JOURNAL OF FARM ECONOMICS
Vol. I. June, 1919. No. 1

G. A. Billings,
Office of Farm Management.

The unusual demand for food products and the scarcity of farm labor since the war began have given rise to conditions which demand greater concentration of effort on farm management problems. These problems affect the community, the state and the country as a whole and are in a measure sociological; nevertheless, since they bear a close relation to production and to the individual farm, the basic unit of production, they are of vital importance to the economic management of the farm.

There has been no period in the history of this country when economic conditions have changed so rapidly, requiring the most careful thought concerning the organization of farms of different types to meet present day needs, and the changes which may take place after the war; the policy of price fixing of farm products and its bearing on profitable production as compared with the fundamental law of supply and demand; the mobilization of farm labor to produce the supply of food needed; and many other important questions. The cost of producing milk in large dairy regions and the cost of producing wheat as the basis for fixing the minimum price of wheat to the farmers, illustrate the kind of information which has more recently been demanded. The requests for such information point out conclusively that the results from the investigation of farm management problems by state and federal departments should be tabulated, summarized and held in readiness for such requests. Moreover, this information should be put into such shape that it may be given to the farmer by extension workers as suggestions for adjusting his system of farming to meet these changing conditions.

In normal times the ratio between food production and the increase in population is quite constant. Statistics show that during the last three decades there has been a slight increase per capita in the production of wheat and corn, due in part to the cultivation of more land, but also to more intensive methods of farming. Under such

In 1919, in his presidential address to the American Farm Management Association, Billings note: "There has been no period in the history of this country when economic conditions have changed so rapidly, requiring the most *careful thoughts* concerning *the organization of farms of different types* to meet present-day needs..."

- Unusual demand for farm products
- Scarcity of farm labour
- Need for and importance of data

Challenges:

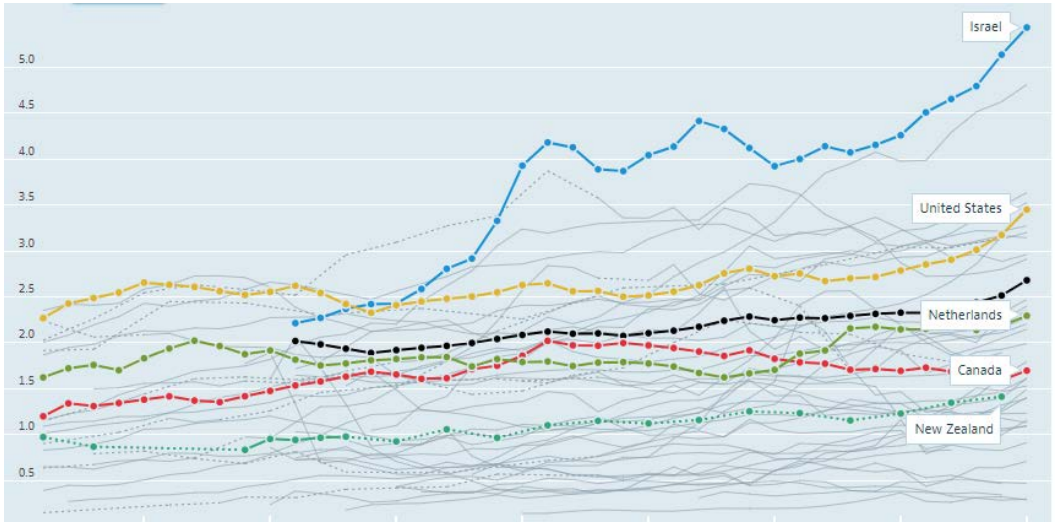
- Trade is the lifeline of Canada's agriculture.
  - Economic issues related to increasing competition at the international level
- Supplies healthy and nutritious food at reasonable prices.
- Climate change and volatile weather.
  - heat and drought can negatively impact crops and livestock.
- Farming produces greenhouse gases that contribute to climate change.
- COVID-19, conflicts and supply chain disruptions.
- Labour shortage, animal welfare/protection.
- New production techniques will be required to enhance productivity and the importance of innovation is even greater.

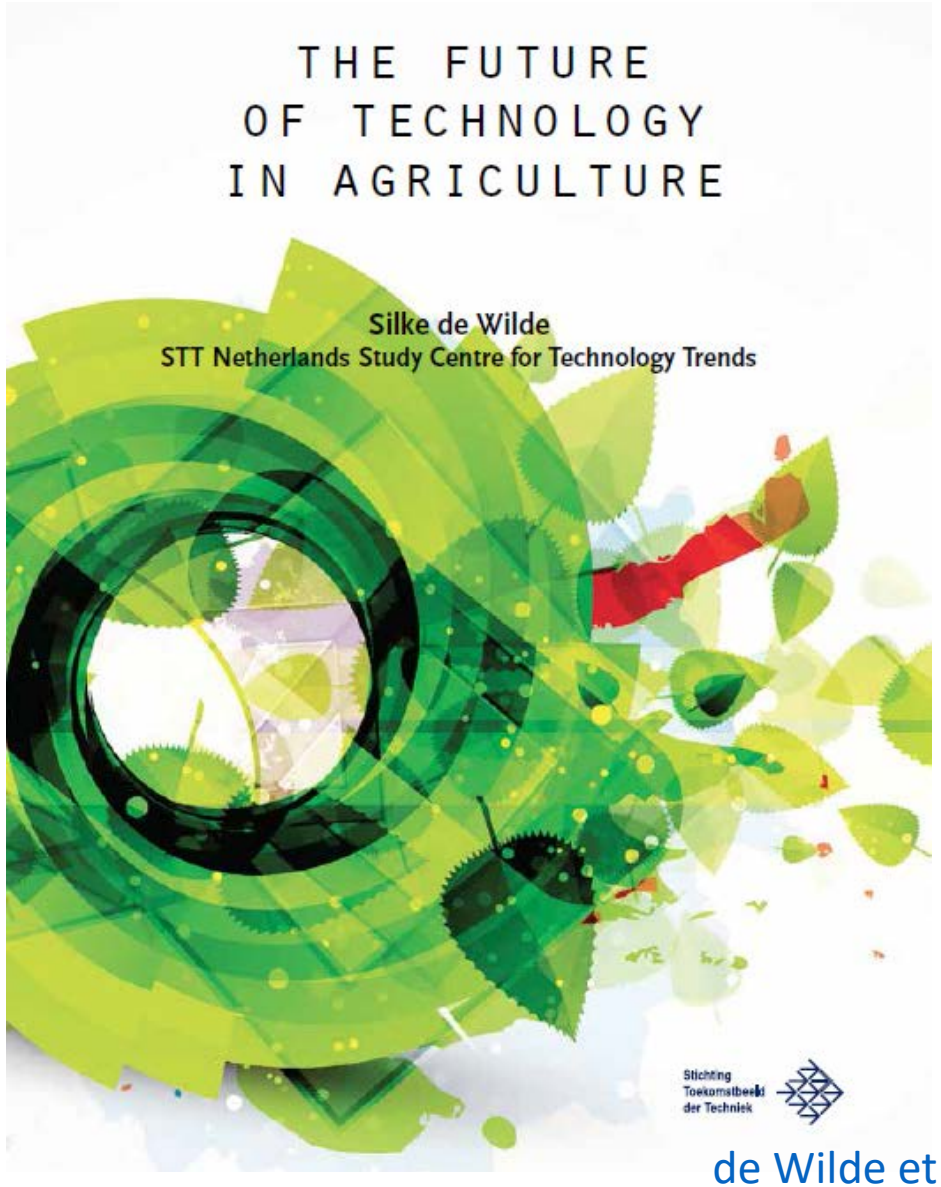
Opportunities:

- Growing global populations and rising income in developing and emerging economies
- Natural resources (water, ..)
- Continued application of advances in biotechnology.
- Invention
  - High level of education
  - Ranks among the top in public investment in R&D
  - Maintained significant investment in science
  - Many important technologies originate in Canada (agriculture, robotics, vaccination, etc.)

Innovation:

- One of the lowest performers in terms of private-business R&D expenditures.
- Confusion between invention & innovation (**Breznitz, 2021**).





de Wilde et al 2016

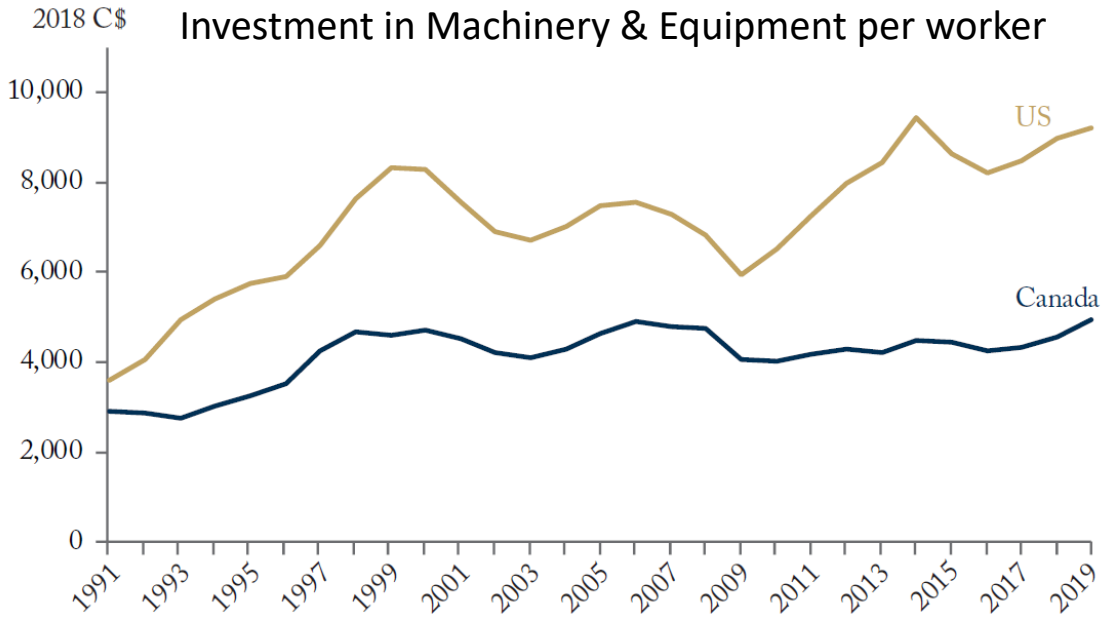
TECHNOLOGICAL DEVELOPMENTS

2.1 3D printing
2.2 4D printing
2.3 Smart materials
2.4 Robotics
2.5 Autonomous microrobots
2.6 Sensor technology
2.7 Information technology and IT infrastructures
2.8 Bioinformatics
2.9 Smart farming
2.10 Renewable energy
2.11 Biorefinery and biofuels
2.12 Genetics
2.13 Synthetic biology
2.14 Protein transition
2.15 Food design
2.16 Aquaculture
2.17 Vertical agriculture
2.18 Conservation technology
2.19 Transport technology
2.20 Weather modification

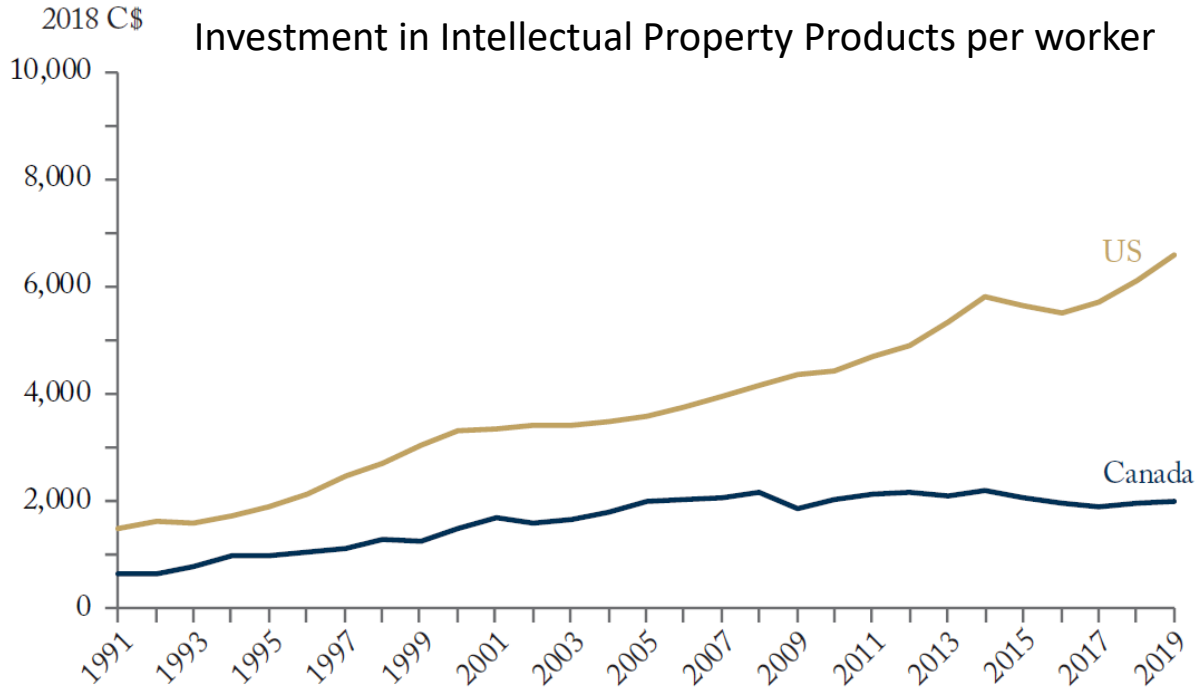
Canada has a productivity growth issue

- "Our third pillar for growth is a plan to tackle the Achilles heel of the Canadian economy: productivity and innovation." (Chrystia Freeland).
  - Lagging productivity and innovation are the Achilles heel of the Canadian economy
  - Canada's SME sector is lagging behind

Investment in Machinery & Equipment per worker



Investment in Intellectual Property Products per worker



Source: Robinson 2019

Innovation is key in the policy frameworks

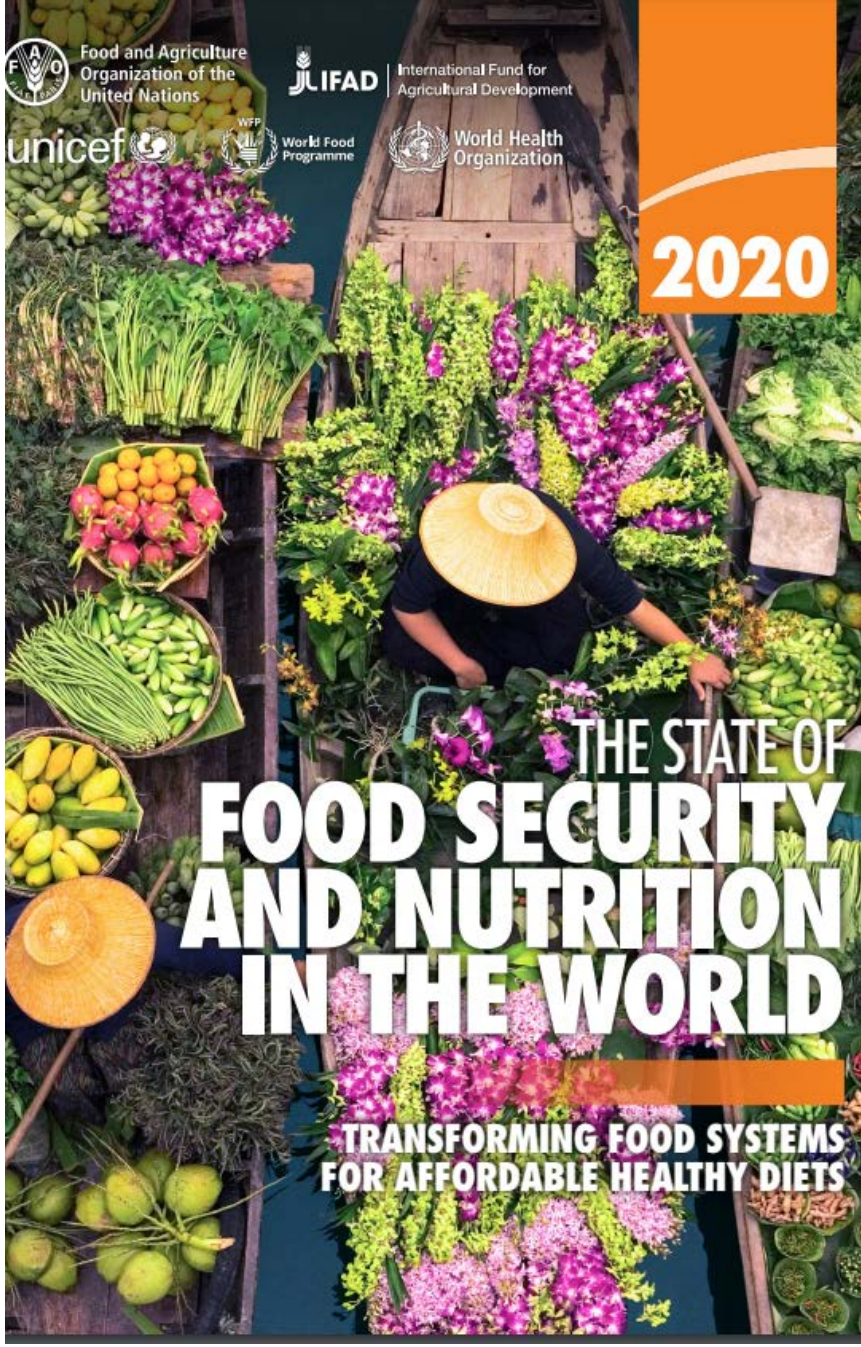
- Agricultural Policy Framework (2003-2008)
  - Focus: science and innovation
  - Outcome: improve competitiveness and profitability
- Growing Forward: (2008-2013)
  - Focus: innovation
  - Outcome: ensure productivity, profitability, competitiveness
- Growing Forward 2: (2013-2018)
  - Focus: innovation
  - Outcome: long-term profitability and competitiveness
- Canadian Agricultural Partnership (2018-2023)
  - Focus: science, research and innovation
  - Outcome: increase competitiveness, productivity, profitability

Importance of government support to innovation by source, (fiscal years 2016 to 2018) (%)

Sources of support	High	Low	NA
R&D tax incentives	53.1	29.1	17.8
Government R&D grants	46.4	28.8	24.8
Government financing support	42.7	28.7	28.6
Training and hiring programs	35.4	34.4	30.2
Government research facilities	27.3	38.7	33.9
Other government programs	27.3	32.6	40.1
Export development assistance	26.3	32.9	40.8
Government procurement	12.3	39.8	47.9
Incubator & accelerator programs	12.1	38.5	49.4

Canada can play a major role in fighting global poverty and hunger

- **Slowdown productivity and the rise in inequalities are of major concern**
- Two-thirds of the world's extreme poor earn their livelihood from agriculture.
- Globally, between 720 and 811 million people faced hunger (UN 2020).
- Nearly one in three people do not have access to adequate & healthy food.
- Civil conflicts, climate change, climate variability and extremes, economic slowdowns and downturns, COVID-19, and the Russian-Ukraine war are the major drivers slowing down progress, particularly where inequality is high.
- Hence, an increase in agricultural productivity is key.



Canada's animal genetic exports (for breeding purpose)

Animal genetic exports in Canadian dollars

	2017	2018	2019	2020	2021
Cattle embryos	8,461,298	7,525,307	5,643,074	5,970,007	5,211,121
Dairy semen	126,677,022	119,144,908	108,782,087	109,639,454	103,380,070
Dairy cattle	13,801,880	11,498,035	14,805,437	12,230,237	13,064,418
Beef cattle semen	6,746,062	4,867,394	6,456,247	4,662,768	9,189,835
Beef cattle	9,039,177	8,455,064	7,680,724	7,927,214	7,191,563
Swine	45,053,279	41,224,383	44,803,423	61,852,366	50,851,624
Purebred horses	8,933,527	9,820,798	15,217,517	6,877,026	6,358,354
Fowls, live domestic weighing not more than 185 g	23,304,091	20,685,784	19,808,639	14,374,587	15,567,165
Turkeys, live, weighing not more than 185 g	32,724,700	36,043,627	29,744,191	25,993,030	28,840,141
Ducks, geese and guinea fowls, domestic, live, weighing not more than 185 g	5,330,858	3,782,536	4,041,082	2,221,691	2,375,197
Hatching eggs	68,848,918	65,022,266	71,502,560	66,026,944	74,395,392
Total exports	**349,284,029**	**328,464,858**	**328,607,264**	**319,444,336**	

Sources: Statistics Canada; Small ruminant embryo and semen data sourced from the Canadian Livestock Genetics Association

Summary

- **Technological change** key to the agri-food sector.
- The challenges posed by the global food supply will continue to push the agri-food sector towards technological innovation.
- Much to be gained from data availability and accessibility:
  - Importance of collaboration in the production of data for research and access.
  - Efforts to measure business-level production practices.
- What is the effect of demand on measured productivity at the firm level?
- The role of intangible capital?
- What/Which productivity drivers matter most and in what agri-food sub-sector?
- What is the role of public policies that boost productivity growth (e.g., market regulation design)?
- Delighted to see what the next decades bring in technological progress and productivity research given the speed of technological advances.

Thank you!