Precision Agriculture and Food Production

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From Whence It Came and Where Is It Going?

By

Charles J. McMillan

Cambridge Scholars Publishing

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TABLE OF CONTENTS

Preface and Acknowledgements vii

List of Abbreviations xvii

Chapter 1 1
Food, Agriculture, Land – The Basis of Life

Food, Farms and the Value Chain – Engel's Law – Approaches to the Study of Agriculture and Food Production – Food and Precision Agriculture – New Collaborative Approaches to Food Production – Wicked Problems in Food Production

Chapter 2 27
Land, Food and Farming in Historic Perspective

The Agricultural Society – The Pastoral Farm – Land and Private Property – Rebellion Against Landowners – The French Revolution – Land in Abundance: The USA – Cultivating the Land – Soil and Human Health – Land Use and Ownership

Chapter 3 58
Farming and the Challenge of Mother Nature

Anthropocene Geological Epoch – Pandemics and Disease – Veterinary Medicine – Departments of Agriculture and the Politics of Food – Food and Nutrition – Weather Systems and Climate Change – The Farmer as Global Citizen

Chapter 4 89
Farm Tools: Cycles in the Mechanization of Farms and Agricultural Production

Farm Profitability – Agricultural Science – Early Mechanization – The Seed Business – Cyrus McCormick, the Mechanical Reaper, and the Reaper Wars – Tractors and Dominant Design: Harry Ferguson – Three Hitch Innovation – Mergers and Triumph of Corporate Scale and Scope – The Tractor as an Instrument of a Farm Platform

Chapter 5 122
The Ultimate Middlemen – Farm Commodity Traders

Agriculture and Trade – Food and the Price System – Farm Harvests as Commodities – The Rise of Commodity Exchanges – Commodity Trading: The Main Players – The Commodity Traders – Cocoa as a Case Study – Barriers to Commodity Trading

Chapter 6 158
The Food Processors – From Fresh Meat Carcasses to Frozen Pizza

Food and Disease – The US Beef Culture – Gustavus Swift and the Meat Processors – Refrigeration and the Railways – The Dairy and Milk Processors – The Big, Global, and Diverse Non-Perishable Food Processors – The Food and Drinks Sector – Processed Food and Nutrition – The Three Perils – Climate Change, Bacteria, Animal Welfare

Chapter 7 197
The Food Retailers – Big Box Stores, The Fast-Food Chains, The Convenience Outlets

The Shopping Experience and the Rise of Box Stores – The Fast-Food Revolution – Convenience Stores and The Seven Eleven Model – Covid and the Daily Delivery Model – Lessons in Retail Innovation

Chapter 8 230
The Protein Disrupters – The Plant-Based Food Segment

Plant-Based Food – Fad or Fashion – The Vegan Market – The Science of Plant-Based Foods – Food Meets Silicon Valley – Agtech 5.0 Disruption – Startups Become Establishment – Social Movement or Paradigm Shift?

Chapter 9 255
Haute Cuisine – The Chef's Delight

The Kitchen Meets TV – The Rise of TV Celebrity Chefs – The TV Chef as Celebrity Entrepreneurs – Haute Cuisine meets the Michelin Stars – The Disney Model of Creative Industries – The Global Food Culture

Afterword 281

Index 287

PREFACE AND ACKNOWLEDGEMENTS

"1 billion people in the world are chronically hungry.
1 billion people are overweight."
—Mark Bittman, American Author of *Food Matters: A Guide to Conscious Eating*

For centuries, food and agriculture have been necessities for subsistence and well-being. But both topics are a metaphor for life, happiness and a quixotic sense of mystery, the unknown, and the unexpected. E. B. White, an American humorist of some note, quotes a mother giving a dish to her child, "it's broccoli, dear," but getting a quick response – "I say it is spinach, and the hell with it". Oscar Wilde once mentioned to a waiter, "When I ask for a watercress sandwich, I do not mean a loaf with a field in the middle of it."

Most homeowners who take up gardening as a hobby – in Britain alone, the horticultural industry is a £24 billion sector – think little of spreading peat moss over the lawn and garden, not aware that peat-based compost sequesters more greenhouse gases than forests, so an average gardener can use more carbon emissions than heating a house for a week. The global food sector has evolved dramatically in the past decade. Once viewed as a stable, risk-averse, concentrated, and rather unexciting industrial sector, today the agricultural and food production system is one of the most vibrant, technologically transformative and innovative sectors on the planet.

The new drivers of change in this sector come from two sources – climate change and technological innovation. As in any industry, the stages of production from raw material sourcing to finished product and delivery – what management calls the value chain – face new challenges. And new opportunities! Globally, the food chain production system combines a paradox, namely unprecedented food abundance, as science allows new methods to increase food production yield, but also food shortages, even in a rich country like the United States. Even worse, various economic estimates by reputable think tanks and international agencies like the FAO show that annual food waste amounts to a trillion dollars per annum. In short, despite the widespread food choice for most citizens in rich countries, globally the food chain is riddled with waste, spoilage, and inefficiencies and lacking in ideas of regenerative food production from the soil.

Despite technical advances of improved agricultural yields, productivity, and recycling for farm produce, the pressures for a new paradigm shift are real. About 38% of the earth's surface is devoted to farmland, but this has a large carbon footprint, made worse by chemical additives and extractive exploitation of the soil. However, like other sectors such as auto production, healthcare, and beauty and fashion, there is a new convergence between natural science, engineering, medicine, and the digital revolution. There are also new techniques and applications for software, data storage and cloud computing, artificial intelligence, and data analytics.

While progress may appear to be slow, incremental, and narrow, the collective advances among different parts of the food value chain will accelerate rapid knowledge diffusion rates, from startups, food incumbents, and established firms diversifying into the food sector. Technological advances are pervasive in diverse areas such as the farm gate, the commodity traders, the food processors, and the food retailers and restaurants, and involve innovations in protein development, waste reduction, greenhouse gas emissions, retail ordering and payment systems, and customer needs and experience. The long-term impact of the green revolution in India and other developing countries is often unappreciated. Strategic investments over two generations have allowed many farmers to increase output from high-yielding crop varieties like rice and wheat, have better use of land and soil, and a better understanding of the implications for climate change. Agricultural productivity enhancement may improve internal capacities for industrialization itself, with employment growth, knowledge diffusion and improved standards of living. Further, the range of organizational, functional, and financial innovation shortens the production cycle and lessens food waste and spoilage. New opportunities for new business models, and healthier food choices become available, while improving the total system in a sustainable fashion for a population far more attuned to climate change and the waste in the global food system.

This transformation of the agriculture and food product system coincides with three inexorable forces: demographic trends, climate change, and the protein revolution. Global population increased, from about 3.5 billion at the end of WWII, to more than 7.5 billion at the start of the third decade of this century, showing a trend towards ten billion by 2050, with the African continent having a bigger population than China, or North America and Europe combined. At present, the food sector is not prepared or willing to service this population increase. Further, the land-intensive countries in Africa lack the appropriate tools, such as soil conditions, water and irrigation systems, and all aspects of food production, food processing, and

food delivery, especially to megacities like Lagos with populations the size of Tokyo, Shanghai, or Mumbai.

In many respects, based on demographic trends, population is destiny. Despite projections of population increases, both globally and by country or region, too often seen as a Malthusian bogeyman of over-population, a related challenge is the stunning drop in population by many countries, with 23 countries seeing their populations cut in half, led by Japan and Italy. Japan's population of 130 million may decline to 63.5 million by the end of the 21st century, and Italy from 61 million to 28.5 over the same time period, but this trend applies to many other advanced economies. Even the population of China, the largest country by population with 1.4 billion, may fall to 732 million, the same projected population of Nigeria. In most advanced countries, declining natural rates of population changes come not only from families and women having fewer children, from about 4.7 for a family to only 1.7 at the start of this century, but from a lower fertility rate, with a steady state measured at 2.1 to projections of a decline to 1.7 today.

These demographic trends greatly impact the agricultural and food production system, even more so with climate change impacts that affect land use, soil nutrition, water quality and availability, natural ecosystems and diversity, and sundry forms of biodiversity. The COVID-19 pandemic exposed many of these problems, but so has entrepreneurial innovation around the world. New startups, venture capital, private equity, and other pools of capital – in the simple dictum of follow the money – are financing this innovative approach and creating new business models for smart farming, sustainable agriculture, vertical farming, better land use, food processing, new plant-based meat substitutes, dairy, and processed food, and new tools for retailing and food delivery. The novel but appropriate term, "agritech," describes this innovative approach, combining traditional agricultural practices, the digital application of software and data management, and new interdisciplinary thinking to the food sector. More startups in food processing, retail and delivery outlets, universities and government agencies are designing new organizational ecosystems to encourage innovation at all stages, combining traditional disciplines in the natural sciences with the integration of health and dietary sciences, medicine, agricultural sciences and sub-disciplines, including veterinary medicine.

The protein revolution is the source of plant-based foods globally, including entry into classic Chinese cuisine, and illustrates novel production trends. Plant-based meat and dairy products, plus cell-based food, open new

consumer paths beyond the niche sector like vegan food, and introduce a new food mindset, with more awareness between food, diet, healthy living, and concerns about the natural environment and climate change. As in most things American, money talks, and the two plant-based meat firms, Impossible Meat and Beyond Meat, are part of a dramatic shift in consumer preferences in the estimated $450 billion protein revolution in plant-based or cell-based food products. The sudden emergence of plant-based meats – now including beef, chicken, pork, and fish – includes dairy products like milk, ice cream, and yogurt. Present trends show two directions. The first is the new forms of online distribution and delivery, as well as shopping beyond the traditional food retailers that also encompass restaurants, fast-food outlets, and convenience stores. This shift has an air of permanence, impacting the entire food value chain. A small but revealing insight confirming this consumer shift took place in the south of France where the Michelin Guide awarded a star to a vegan restaurant whose head chef, a woman of note, financed her firm by crowdfunding.

As in most sectors of the economy, public policy in the agricultural and food production system has played a major role for centuries. Despite political rhetoric for limited government intervention and a preference for market forces, policy challenges evoke tradeoffs within countries – income support for farmers funded from high food prices, with consequences for the high cost of food for non-farm consumers, knowing that a high output of farm products, i.e., more supply, leads to a lower price per unit and less demand. Among the advanced countries in the OECD, despite policies that seem to be especially egregious as market distortions, both the public and farm interest groups support government intervention in the input side, including land policy, and the output side, from trade policy to direct subsidies. Among the rich countries, the OECD estimates the annual costs exceed $620 billion per year, or an average share of roughly 15 per cent of farm receipts.

Around the world, but especially in the United States, there is a growing concentration on the food sector, with only a few firms dominating the input side of the complicated value chain where inter-dependencies flow through the supply chain. Economists have tracked the concentration of the national economy for over a century, measured by factors like the number of establishments in specific markets or the market share held by the top 4-5 firms per sector.

However, definitional issues remain, because in many industries, corporations centralize their informational technology and data management systems, but

decentralize their operations into specialized product brands for specific markets, often with the presence of local, smaller firms but without firm-level capacities to expand beyond their local customer base. The bigger, concentrated firms have high-fixed cost capabilities and competences – e.g., data analytics, product branding, supply chain logistics and warehousing – that provide declining overall costs with higher sales volumes.

Across the entire global food product value chain, the largest firms in commodity trading, food processing, and retailing have a presence in more than one sector, sometimes in alliance with other multinational firms. At the farm level, small farms of 50-250 acres face direct competition from vertically-integrated food processing firms – in the American state of Missouri, 23,000 independent hog farmers were reduced to 2,000 in a single generation, as a sign of high concentration rates in seeds (three dominant firms), and meatpacking (four firms, including ownership from Brazil and China). Big multi-plant, multi-product firms, like those in the beverage sector, have different economic size relations to smaller firms – a 100,000-hectare-liter craft beer operation has a very different engineering and economic cost calculation from a plant producing two million hector liters, or the largest, with ten million.

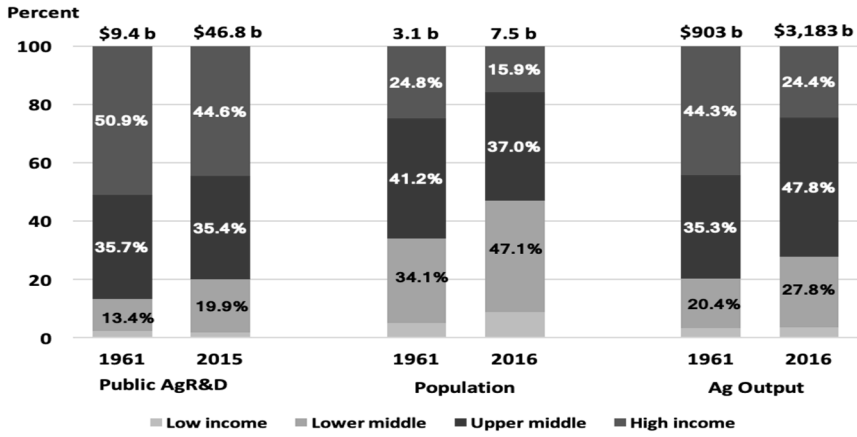
The economic and social impacts of the COVID-19 pandemic include the levels of deaths, the shortages of food, and starvation. Such issues illustrate what might be called the "hidden hunger" of protein deficiencies, lack of medicine for preventable diseases, and the untold deterioration of soil, deforestation, waterways, and ecosystems for biodiversity. The growing gap between rich and poor countries also encompasses access to farmland and food production, including the gap between population levels and agricultural output for food production.

In international trade agreements, multilateral negotiations through both GATT or the WHO, agriculture was kept off the table. Bilateral and regional pacts often dealt with farm trade issues, so advanced countries dealt with the market-distorting issues of quotas, tariffs, subsidies, income support, and trade promotion, with some improved policy coordination and far fewer distortions from domestic policy action. However, in less developed economies, including India and China, the trends show more market distortions, from export subsidies to income support for farmers, as well as a range of support for inputs like fertilizer, water, and seeds. There are also vast differences between countries with high and low income with the broader ecosystem of agriculture and food production – the availability of veterinary medicine and vaccines, the quality of schools of veterinary

medicine and agricultural colleges, the understanding of biodiversity and climate mitigation, and the financial institutions that promote international trade and domestic food production.

Entering the third decade of this century, the advanced rich countries account for half the total global population but three-quarters of food production, meaning that poor countries with half the world's population account for only a quarter of total agricultural output. Even worse, the levels of investment in research and technology, total about $40 billion worldwide, or $5 per person, the price of a hamburger in Chicago. Much of this science investment has been diverted to high population countries like Brazil, India, and China, with trends for weaker domestic capacity among low-income nations on basic agricultural needs (soil conditions, water, and plant and animal husbandry), just as rich countries have cut back their support for R&D in agriculture, despite abundant evidence of very high payoffs, perhaps a ratio of 10:1 in the benefit-cost ratio.

Figure 1
People, Production, and Public R&D for Agriculture,
Population, and Agricultural Output – 1961–2016



SOURCE: Alston, Julian M. et al., "Rekindling the Slow Magic of Agricultural R&D." *Issues in Science and Technology* (May 3, 2021)

Despite innovative trends in the agricultural and food system – mainly as a result of converging applications of the biological, digital, financial, scientific and social forces at each stage of the value chain – rigidity and old perspectives remain. As more countries adopt national goals to reduce

carbon emissions, each industry sector faces scrutiny and comparisons of current methods and practices to further future sustainable goals. To cite a specific sector like agriculture, the potential political and social issues facing farmers, the livestock sector, and farm workers to address climate issues are real. International comparisons show that the international livestock industry, and especially the cattle sector, accounts for about 14.5 per cent of global greenhouse gases, with an indirect impact on deforestation, as well as the destruction of Brazil's Amazon forest. America, the largest consumer of beef, shows no sign of a shift in food choice. In fact, during the 2020 pandemic, meat consumption actually increased, with the average meat consumption reaching 224.3 pounds of beef, pork, and poultry.

Movements to mitigate the carbon footprint of the agricultural and food production system include vertical farming, regenerative agriculture, and sustainable farming, using tools to improve biodiversity, soil nutrition, plant and animal husbandry, and water waste. Satellite photos show the breakup of ice glaciers in cold parts of the earth's surface, endangering the great river systems of fertile lands around the world, forcing changes in traditional agricultural practices that account for 70 per cent of freshwater use, 30 per cent of carbon emissions, and a huge depletion of biodiversity and natural ecosystems. A better understanding of these environmental issues now impacts all aspects of the agricultural system and the value chain components, as well as related industrial sectors. New technologies like blockchain allow tracing across the value chain, as well as all aspects of the global supply chain, and potentially enlighten consumers. Further, as more companies implement ESG measures of corporate performance, transparency and accountability are enhanced in financial markets and equity sources for new investment.

The disruptive force of plant-based foods to traditional food processors and retailers coincides with new business opportunities across the entire food value chain, including for farmers. New technologies, new products, and new production systems pose threats to conventional thinking but present novel and innovative ways for food production. As in other sectors, technological and knowledge forces are real, but they mean growth opportunities as well as setbacks. In fact, against this apocalyptic backdrop, some of the most sophisticated plant-based proteins ever developed are changing the views of both consumers and the farm community, with novel ideas for smart farming, vertical farms, and a mixture of plant-based and animal-based food.

In the increasingly complex value chain of agriculture and food production, the two dominant players at each end, the farmer on the land, and the chef in the kitchen, face new challenges, competence building, and unpredictable events, from a global pandemic to the havoc of weather disasters. Jeremy Clarkson, the Yorkshire-born broadcaster and former star of the BBC series *Top Gear*, focusing on auto brands and car safety, while inviting celebrities to test their driving skills, took up farming at his 1000-acre farm near Chipping Norton in the Cotswold Hills in Oxfordshire. He soon discovered the complexities of farm life, which he quickly determined was "phenomenally difficult", needing multi-abled skills. In his view, a farmer must be a conservationist, scientist, shepherd, shopkeeper, midwife, engineer, accountant and tractor driver, often at the same time.

At the other end of the food value chain is the kitchen chef, who has learned many of the skills and used the tools cultivated for centuries, starting with *haute cuisine* developed in France but now catering to food tastes diffused from all over the world. The professional restaurant chef is the grandmaster of the kitchen, orchestrating a harmony of teamwork and camaraderie, cleanliness, and meticulous attention to detail, while allowing experimentation and embellishment of the virtues of patience and prodigal frugality of time, yet sharing customer laurels among diners and guests. Cooking is both art and science, incorporating food sciences, gastronomy, craftsmanship, and nutrition, while taking into account the dark side of restaurant economics, such as greedy suppliers, staff pilferage, the management of egos, and exploitive landlords. Great chefs take their love of food and drink to the staff, customers, and competitors, and become teachers, marketers, and brand managers, with identities for both tradition and novelty that provide the ultimate art, good food and restaurant ambiance. These global trends have introduced a new intellectual excitement to the entire food sector, introducing new ideas to young farmers around the world, the scientific community working closely with food groups, and the universities and community colleges that see the interdisciplinary nature of the global food sector.

The challenges and changes taking place in the agricultural and food production system are now getting much more attention around the world in high schools, community colleges, and academe. The parallel with the links between Silicon Valley, California's leading university graduate programs, and the digital revolution of computers, smart phones, and the Internet now applies to the food sector. Leading American universities like Harvard, Stanford, Tufts and Columbia now offer courses and programs on various aspects of food production, including Berkeley Alt Meat Lab.

Similar programs and courses now exist in places as diverse as France, Israel, Brazil, Canada, Singapore, and Holland, where a group of students initiated a course in protein transition at Wageningen University, and a new Wageningen Alternative Protein Project, working with the Good Food Institute. Like other programs, this approach has long-term objectives beyond raising the profile and public awareness. Reforms to the academic curriculum and the building of new academic alliances and consortia, include the Cultivated Meat Consortium at the Davis campus of the University of California, with an initial $3.5 million of funding from the National Science Foundation.

These issues and trends force a new way of thinking about the food sector, and like the blind man viewing an elephant, the traditional perspective is too narrow, too confined. Today, science uses a new term – *consilience* – a useful framework that allows an all-embracing perspective including history, natural sciences, business, economics, medicine and the new world of digital approaches to describe the complex domains of knowledge. The term has a long history, dating back to a father of the philosophy of science, William Whewell, a Cambridge scientist, theological professor and Master of Trinity College, whose work, *History of the Inductive Sciences* (1837), attempted to bring a collective view of growing science specialization. The modern usage owes much to the writings of a Harvard University biologist, Edward O. Wilson, and his work, *Consilience: The Unity of Knowledge,* published in 1998. Like Whewell, Wilson wanted to use scientific ways of thinking, grounded in observations of reality, but with more unified ways of various academic disciplines without the silo constraints of disciplinary boundaries, loyalties, and assumptions.

This book covers detailed analysis by scholars, public policy experts, and key players in the agricultural and food sector. Each chapter will have its own audience, but the book is really intended for a wider audience, knowing how the world's food production system faces many wicked problems, especially climate change. During the course of researching and investigating the agricultural and food product system, I have exploited the ideas of my immediate family, who have diverse backgrounds and work experience in medicine, diets and nutritional sciences, pharmacy, law, fashion, nursing, politics, and sports. I also have direct work experience in a very large meat-processing plant, with a range of jobs extending from the kill floor to the smoking house and the shipping room, and a range of managerial tasks. This work included inventory control, production forecasts using linear programming techniques to combine imported plasma, lamb, fats and casings with local meats, trimmings, additives, and sugars for smoking and

processed food sold in sundry forms – frozen, packaged, refrigerated, and vacuum-packed.

My international travel and work experience have afforded me the luxury of studying agricultural and food culture in many countries, including states in the former Soviet Union, China and Viet Nam, and the haute cuisine of France, Italy and Japan, the fusion of dishes and cooking style which is now so widespread, especially among young people who have traveled, experimented, and copied dishes and recipes from all parts of the world. I have many people to thank and express my appreciation for their cooking talents, knowledge of food and the agricultural system, and the changes taking place worldwide. I wish to single out Guillaume Carton, now at the EMS Lyon Business School, by coincidence in the lively city where I once taught, thanks to the kindness of the then Dean, Jacques Lagarde, and the faculty and students. Guillaume knows the history of agriculture and food production in France, where only a generation ago, despite devoting about 20 per cent of the GDP of France to agriculture and food, the country had no French companies in the top 25 global firms. He first interested me in the complicated value chain of the global food production system, provided me with many sources and readings, and some of the changes taking place, the unanswered questions, and the challenges for the global food system. Guillaume read the manuscript, providing many sources and pointed out numerous errors of commission and omission, in both French and English.

I wish to thank many other colleagues, friends, and family for their advice and guidance but wish to single out Regis Duffy, Dr. Aodh Ó Dochartaigh, Lucy Waverman, Suhan Hannan, Clara Kan, Mark and Muireann Snow, Jeff Overall, Guillaume Carton, John Hull, Osamu Matsubara, Jon Hyuk Lee, Tom Hout, Heye Schefel, Aengus O'Dochartaigh, Barry Prentice, Dr. Colin McMillan, Ben West, Nick Christoffersen, Alan Middleton, Eduardo Jason, and Eleanor Westney and my daughters, Aya and Mari. I treasure the many sumptuous meals enjoyed in so many countries and thank friends and acquaintances on behalf of myself and my wife Kazuyo, to whom this book is dedicated.

Charles McMillan,
Toronto, Canada
December 28, 2021

List of Abbreviations

ADB – Asian Development Bank
AFCFTA – African Continental Free Trade Area
AI – Artificial Intelligence
APO – Asian Productivity Organization
ASEAN – Association of South-East Asia Nations
BMI – Body Mass Index
CA – Conservation agriculture
CO2 – Carbon dioxide
CPI – Consumer price index
CRED – Centre for Research on the Epidemiology of Disasters
CSA – Climate-smart agriculture
DIY – Do it yourself
ECMWF – European Centre for Medium-Range Weather Forecasts
ECOWAS – Economic Community of West African States
EDF – European Development Fund
ESG – Environment, Social, Governance
ETS – Emissions trading scheme
EU – European Union
FAO – Food and Agriculture Organization of the United Nations
FAPRI – Food and Agriculture Policy Research Institute
FBDGs – Food-based dietary guidelines
FBS – Food Balance Sheet
FIES – Food Insecurity Experience Scale
GATT – General Agreement on Tariffs and Trade
GCM – Global circulation model GDP Gross domestic product
GFSP – Global Food Safety Partnership
GDP – Gross domestic product
GHG – Greenhouse gas
GWP – Global warming potential
IFAD – International Fund for Agricultural Development
ILO – International Labor Organization
IMF – International Monetary Fund
IPC – Integrated Food Security Phase Classification
IPCC – Intergovernmental Panel on Climate Change
IPPC – International Plant Protection Convention
IQ – Intelligence quotient

ISO – International Organization for Standardization
JME – Joint Malnutrition Estimates
LIFDCs – Low-income food-deficit countries
LMICs – Low and middle-income countries
NGO – Non-governmental organization
NT – National treatment
NTBs – Non-tariff barriers
NTMs – Non-tariff measures
OIE – World Organization for Animal Health
OECD – Organization for Economic Cooperation and Development
R&D – Research and development
RCP – Representative Concentration Pathway
REDD – Reducing Emissions from Deforestation and Forest Degradation
SENASA – National Service of Agri-food Health & Quality
SDG – Sustainable Development Goal
SDT – Special and differential treatment
SDGs – Sustainable Development Goals
SIC – Standard Industrial Classification
SKU – stock keeping units
SMEs – Small and medium-sized enterprises
SOCO – The State of Agricultural Commodity Markets
SSG – Special Agricultural Safeguard
SSM – Special Safeguard Mechanism
SSP – Shared Socio-economic Pathway
STDF – Standards and Trade Development Facility
TBTs – Technical barriers to trade TFP Total factor productivity
TRIPS – Agreement on Trade-Related Aspects of Intellectual Property Rights
UNFCCC – United Nations Framework Convention on Climate Change
UCDP – Uppsala Conflict Data Program
UNDP – United Nations Development Programme
UNICEF – United Nations Children's Education Fund
UPS – ultra-processed food
USAID – United States Agency for International Development
USDA – United States Department of Agriculture
VCA – Value Chain Analysis
WB – World Bank
WDR – World Development Report
WFP – World Food Program
WHA – World Health Assembly
WHO – World Health Organization

CHAPTER 1

FOOD, AGRICULTURE, LAND – THE BASIS OF LIFE

"The farmer is the only man in our economy who buys everything at retail, sells everything at wholesale, and pays the freight both ways."
—President John F. Kennedy

Food, Farms and the Value Chain – Engel's Law – Approaches to the Study of Agriculture and Food Production – Food and Precision Agriculture – New Collaborative Approaches to Food Production – Wicked Problems in Food Production

Introduction

Across the millennia, mankind has prioritized agriculture and food production for human survival. In ancient Rome, governments practiced a policy of *cura annonae* – care for the grain supply, and the provision of bread for the masses, mostly imported from Egypt. Food shortages and food abundance became linked to military and colonial conquest, and the source of wealth for landowners, such as the plantation system in the American confederacy, the nobility in Europe, and Tsarist regimes in Russia. As an economic sector, agriculture and the main capital input, land, were a source of political agitation. Farmers and farming were often restricted by small plots and arid soil, and subject to uncontrollable forces, including weather patterns (extreme cold, drought, and storms that cause flooding, soil erosion, deforestation and more recently, severe firestorms).

For most people in the rich, industrialized economies, the availability of food, where it comes from, and the variety are taken for granted. Even the choice of a loaf of bread, for instance, varies tremendously, not only in price alone, but simple questions of the time of baking, the combination of ingredients (butter, flour, wheat, salt, yeast, water) and sundry additives like barley, flax, raisins and oats – Italian bread, French bread, rye bread, whole wheat bread, white bread, sourdough bread, pita bread, or the staple in France and now many other countries, the French *baguette*. The variety of

breads illustrates the wide potpourri of fruits, vegetables, dairy, meat, fish and seafood, plus a new range of products, from the cell-based hamburger to plant-based eggs, meat or ice cream.

Food and freedom from want have a long association[1] for poets, philosophers, economists, and the political class. The insight that three political revolutions – the French in 1789, the Russian in 1917, and the Chinese and Mao's march – all stemmed from food shortages and bad harvests is telling for the political order. The Irish famine in the 1840s, for example, or the Chinese famine lasting three years in the 1930s, have left scars that haunt those countries to this day, and illustrate the fragility of today's global food system, and the coexistence of food abundance and food scarcity. Yet for most people, whose understanding of the food production system is limited to the idyllic family farm in a close-knit rural community, farmers are the source of a great meal in the company of family and friends.

Who can match the mouth-watering description of a yuletide dinner in *A Christmas Carol,* written by one of the most famous authors, Charles Dickens? Raised in an impoverished family household in 19th century England, Dickens offers an amazing depiction of a family dinner for the reader:

> *Mrs. Cratchit made the gravy (ready beforehand in a little saucepan) hissing hot; Master Peter mashed the potatoes with incredible vigour; Miss Belinda sweetened up the apple-sauce. … At last the dishes were set on, and grace was said. It was succeeded by a breathless pause, as Mrs. Cratchit, looking slowly all along the carving-knife, prepared to plunge it in the breast; but when she did, and when the long expected gush of stuffing issued forth, one murmur of delight arose all round the board. … The youngest Cratchits in particular, were steeped in sage and onion to the eyebrows!*

In this passage, Dickens captures more than a wholesome sketch of the meal, and the star fixings like the Christmas goose, potatoes, vegetables, apple sauce, and pudding. The rituals of a Christmas meal, the toasts and opening prayer, and the family roles of who does what and when enhance the conversation and the childish delights of the first cut of the Christmas

[1] For historical background and an analysis of the food system in recent history, see Harriett Friedmann, "The Political Economy of Food: The Rise and Fall of the Postwar Food Order", *American Journal of Sociology* Vol. 88 (1980), pp. S248-S286. As the author notes: "Almost 200 years ago, a similar specter appeared in England, accompanied by growing enthusiasm among the common people for the ideas of the French Revolution. In 1798 and 1803, Malthus published his two essays on population, offering what he claimed to be 'conclusive [proof] against the perfectibility of the mass of mankind.'"

bird. Around the world, a similar narrative takes place for special events like birthdays, weddings and New Year, often with the same altruism displayed by the obnoxious and embittered Ebenezer Scrooge before his conversion in Dicken's immortal writing.

What a contrast to a sausage meal foisted on guests by the Master of the House in the musical play, *Les Misérables*:

> Food beyond compare, Food beyond belief
> Mix it in a mincer. And pretend it's beef
> Kidney of a horse, Liver of a cat
> Filling up the sausages, With this and that.

Despite the staggering progress in the past two centuries, the agriculture and food production system combining an enormous increase in overall output, it remains a sector often tied to 19th century thinking and as a 20th century silo between the various components – the farm gate, commodity trading, food processors, and food retailers. Paradoxically, when food is a staple for basic subsistence and a necessary component for special occasions, such as Christmas, Easter, weddings, birthdays, and national holidays, even before the arrival of the COVID-19 pandemic in 2020, even in a rich country like America, there was a paradoxical situation with an abundance of food, and farmers destroying their crops or putting milk in the sewer, and food scarcities and millions living day to day with no assurance of a meal tomorrow.

The Traditional Agriculture and Food Value Chain

The evolution of agriculture and food production in the past two centuries illustrates the inexorable substitution of labor for capital, in the form of farm implements and machinery and the declining role of agriculture in the national output, 1 per cent of GNP in America or Japan and 2 per cent in Europe, but 18.4 per cent in China, 43.4 in India, 33.3 in Thailand, 36.3 in Nigeria, and 41.9 per cent in Vietnam. Historically, agriculture is subject to the same forces that impacted other primary sectors, sometimes called the natural resource sectors like fishing, mining, and pulp and paper. The collateral impact of the industrial revolution, based on machinery production, the division of labor into discrete tasks, and a seamless innovation cycle – machines and the machines that make machines[2] –

[2] Phyllis Deane, *The First Industrial Revolution*, 2nd Ed., London: Cambridge University Press, 1979. She elaborates: "the process of continuing, self-generating

impacted agriculture directly, bifurcating the sector by size (small firms vs. large corporate farms, local and regional processing plants vs. large global giants with plants in many countries, and small retailers and local markets against big-box food retailers).

In today's digital world, agriculture and food production face transformational change, whether viewed within a domestic economy or globally, as population pressures and the confluence of food abundance and food scarcity place unprecedented pressures on the industry. Further, despite technological improvements, agriculture and the food industry remain highly traditional, with an entrenched and segmented value chain, including farm input suppliers, growers, crop and protein processors, and downstream food producers. High entry barriers, increasing firm concentration, and semi-monopolistic pricing practices in the middle of the value chain – commodity traders, food processors, and food retailers – put a cost squeeze on farmers and a pricing advantage on consumers. In contrast to other resource sectors like mining or fisheries, which are capital-intensive and integrated between input stages, down-stream processing, and output of finished products, agriculture and farming didn't go through the Fordist-type capital-intensive phase. Unlike manufacturing, where machines replaced labor for routine task activities, this sector has by-passed this evolution, despite the limited mechanization on the farm, such as milking dairy herds, planting crops, or harvesting farm output.

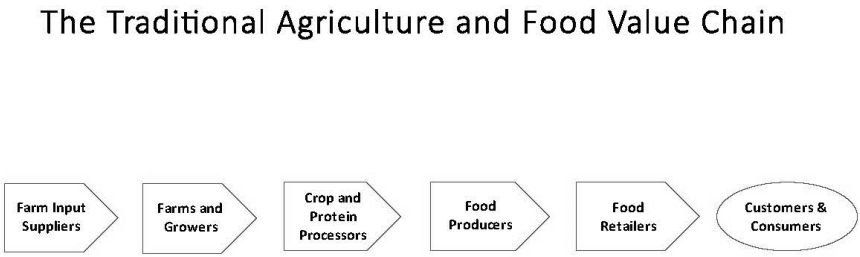
Farms and food production are resource-intensive, requiring cultivated land, clean water, and inputs like grass and animal feed that yield a high input/output ratio for end products coming from the food processors and retail food stores. At current levels, the industry requires about half the world's total vegetated ice-free land, and it is the most water-intensive of any sector, and releases about 25 per cent of all greenhouse gases.[3] In countries measured by disposable wealth, the geographic shift from rural areas to urban living imposes new cost demands, such as a shortage of farm labor, and the logistics of transporting output to processors and retailers. Infrastructure needs are a core investment for the farm ecosystem – electricity, high speed internet, and storage capacity. In rich and poor countries alike, farms and farming are often separated from the natural ecosystems where uncultivated land, small forestry, grasses and shrubs

technological change that is the ultimate cause of the sustained economic growth that we now take for granted" (p. 42).

[3] For background, see *The Future of Food and Agriculture – Trends and Challenges*, Rome: Food and Agricultural Organization of the United Nations.

provide a habitat for pollinators like bees and diverse wildlife, but are also a means to control pests, lessen soil erosion, and buffer water runoffs from croplands. The rural-urban divide exacerbates the problems of maintaining a rural ecosystem untrammeled by human traffic, including urban visitors looking for a weekend outing.

Figure 1.1



Countries vary widely by farmland values, with high population density countries like the UK, Denmark, Ireland and the Netherlands greatly exceeding, by a factor of four to five that of Australia, the US, Canada, or France. As a general rule, rural poverty exceeds urban poverty rates in most countries, often by more than 25 per cent, even in food-abundant America. In most advanced societies, agriculture is a seasonal business, lasting only a few months of the year, during late spring, summer, and early fall. In fact, the demographics of agriculture and the role of the family farm, left a lasting legacy. Farming has historically been a male-dominated occupation, and for the most part, technology innovation is confined to seeds, soil nutrition and animal health. Worldwide, most farms have a small acreage, less than 100 acres, and comparative studies of countries as diverse as Brazil, India, Columbia, and the Philippines confirm that the intensity of land use is higher on small farms, measured by indices of farm income per hectare and farm size and output per hectare[4], suggesting land reform and removing barriers to access land and farming lead to higher food output.

[4] R. Albert Berry and William R. Cline, *Agrarian Structures and Productivity in Developing Countries*, Baltimore: John Hopkins Press, 1979. For an American analysis, see V. Eldon Ball, Jean-Christophe Bureau, Richard Nehring, and Agapi Somwaru, "Agricultural Productivity Revisited," *American Journal of Agricultural Economics* Vol. 79 (October 1997), pp. 1045-1063. In a further international

The vast majority of farms produce cereal crops like soya, wheat, and rice, as well as dairy and meat (primarily pork, beef, and lamb). Environmental activists and lawsuits now jeopardize small farmers and inadvertently promote mergers and consolidation among smaller and less profitable units. In urban areas, farm output also faces environmental activism and political pressure for re-zoning, hence rising land costs. In the past century, agricultural output for commodity crops like wheat and rice and food production have become global, by input sourcing, by production, by marketing, and by the mindset of the consumer. The biggest national producers – China, India, the USA, the European Union, Indonesia and Brazil – are also huge importers across a swath of food categories. Agricultural production is multifaceted[5], by product (cereals, meat, vegetables, fruit, roots and tubers) and by the sourcing of inputs, such as fertilizer and water. Detailed value chain analysis shows how direct sales of farm products become inputs to value-added products of food manufacturers, whose strategies overlap industry boundaries like food, beverages and seafood.

Further, rising wealth and consumer expenditure on food are inversely related, a point first examined by a German-born statistician, Ernst Engels, whose "theorem", known as Engel's Law[6], suggests that "the proportion of expenditure devoted to food decreases as the standard of living of the household increases." In short, not only do poor people spend most of their

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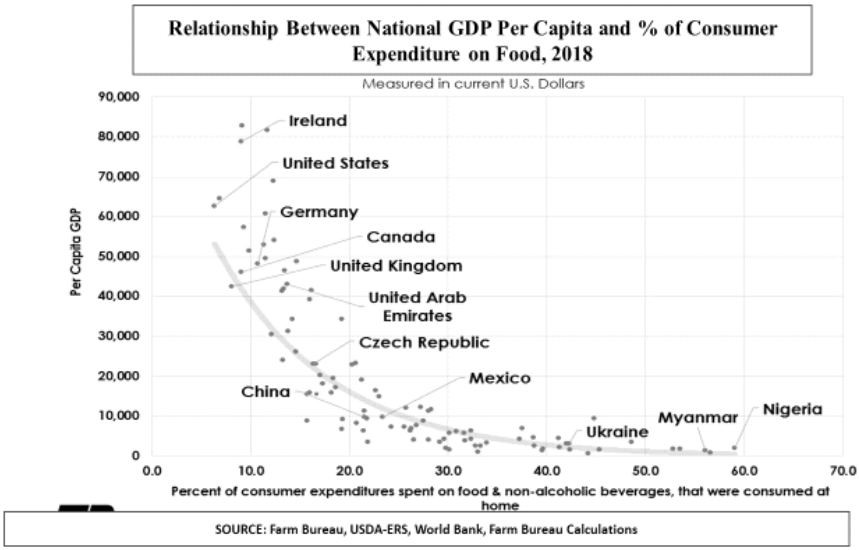
comparison, they found that there was a convergence by each country, depending on the capital intensity of farm investments.

[5] To give an example of the variation in farming output, consider the global flower sector pioneered in Holland, which includes bulbs for tulips, daffodils and other species, gathered from Dutch farms, sent to the auction houses in Amsterdam for sorting and auctioning to buyers from around the world and delivered by air cargo. Flowers illustrate the complexity of supply chains, the logistics of moving perishable products over long distances, and the need for time-based competitive strategies also seen in fashion, the seafood industry and hospitality. Other examples in the food sector include potatoes and special species to produce French fries by food processors who package frozen fries for retailers and global food franchise firms such as McDonald's, Chipotle Mexican Grill or Yum China Holdings. Special cases include illicit drugs like the cultivation of coca bush, opium poppy, and until recently, cannabis (now legal in Canada and many US states), where farmers in countries like Afghanistan, Mexico, Columbia, Cambodia, and Myanmar become captive to drug cartels and middlemen who provide the logistics for trafficking. For background, see UNODC, *World Drug Report*, New York: United Nations, 2013.

[6] Carle C. Zimmerman, "Ernst Engel's Law of Expenditures for Food", *The Quarterly Journal of Economics* Vol. 47 (November 1932), pp. 78-101.

income on basic necessities like food and shelter, but wealthier consumers also have more choices, from buying food and cooking at home, to eating out in restaurants or fast-food chains. Further, rising wealth allows novel food choices, as shown in China, where meat consumption has doubled in a single generation, and now increases three per cent a year.

Figure 1.2



According to the FAO in its 2018 report, global agricultural trade increased by five per cent annually from 2000 to 2016, to levels threefold higher in total value, or US$1.6 trillion, from only $70 billion in 2000, mainly by general economic advances and population growth. However, globalization impacts all stages of the value chain, with stunning advances in global logistics and corporate supply chains, leading to huge container ships like Maersk's *Emma Maersk*, which can transport 12,000 container boxes, linking the world's biggest ports to national railways and trucking firms in a just-in-time delivery system. Globally, the big-box food retailers led by Walmart reconfigured their logistical networks using bar codes, satellite imaging, and data analytics to track delivery from sourcing countries to

individual storefronts, providing fresh products of all descriptions to reach final destinations via ships and air cargo at lower unit costs[7].

The emergence of producers in the BRIC countries, and countries like Indonesia and South Korea in Asia, and some nations on the African continent, illustrates new trade arrangements in global supply chains. Size and scale provide new opportunities, as the global food manufacturers increasingly source inputs like food commodities, fish and meat, and fruit at harvest time in each producing country, but often opening an income gap between small farmers and the larger farm units with corporate financial support, investing strategically to serve large regional markets. In the postwar period, agricultural trade competition led to a spiral of agricultural subsidies, protectionist retaliation, and threats to the viability of the small farm sector, even in the so-called internationalist outlook of the United States.

Increasingly, farmers have little control over input costs (e.g., seed, electricity and fuel, fertilizer, machinery) and except for a few mega-farms, they are price-takers, often because of contracts from the big food processors. In rural areas, the output of agriculture – vegetable crops of all sorts, wheat, canola, soybeans and rice – requires infrastructure for gathering, sorting, storage, and transport, often to the nearest port for overseas shipments or to large metropolitan centers. Growing firm concentration and market power in the middle stages of the value chain have an inherent inflationary bias, starting with "fixed" costs at the farm gate where added costs flow through each input stage.

Academic Study of the Agricultural Sector

The study of agriculture and food production dates back to the ancient Greeks, the Scottish Enlightenment and the works of two French economists in the 19th century, Augustin Cournot, a college President and member of the academic elite in French education, and Jules Dupuit[8], a lesser known but widely cited young French engineer, and their analysis of monopoly. What is now called industrial economics is a branch of economics where

[7] McMillan, "Global Logistics and International Supply Chain Management", in Hossein Bidgoli (ed.), *Handbook of Technology Management,* New York: Wiley, 2008.

[8] For background on Dupuis, see Robert B. Ekelund Jr. and Robert F. Hebert, "Dupuit's Characteristics-Based Theory of Consumer Behaviour," *Kyklos* Vol. 44 (1919), pp. 1-21.

the performance output of an industry is not only a function of the strategies of the firms in the sector – more advertising, for example, or strategies to acquire rival firms, or an understanding of the price points to charge consumers – or the role governments play to regulate the sector. Governments, of course, serve many roles in a market economy, including one as the referee, i.e., setting rules for each sector, such as health standards, environmental risk, worker safety, and more recently, the carbon footprint of each sector. In general, governments want more open competition, such as new entrants, including foreign-owned firms. Governments can also enforce competition[9], by preventing certain mergers from happening, imposing severe penalties for misconduct, and in the extreme case, seen in US anti-trust cases, breaking up big monopolies, such as Standard Oil, or the telecommunications monopoly of ATT in 1984.

As a general rule, the advanced industrial countries have imposed strict rules, enforceable by penalties, fines, and even jailtime for health standards of the food sector, at each stage of the value chain, from the health of animals on the farm to government inspection of the food processing plants, including labeling of the products sold to the general public. Unfortunately, with the rapid advance of globalization, where international trade moves products around the world, there is now huge debate about the rules and regulations governing food products, including the component products (e.g., chemical additives) and the welfare of animals, including the methods of processing in corporate slaughterhouses. Industrial economics provides a

[9] There is a growing consensus that in most key industrial sectors, there is less direct competition, even with the rise of superstar firms and firms using their technology platforms to strengthen their competitive edge. For a non-technical analysis see David Wessel, "Is lack of Competition Strangling the US Economy?" *Harvard Business Review* Vol. 96 (March-April 2018). Consider this analysis of the US beer sector: "Despite the proliferation of craft breweries, two producers dominate the US market: Anheuser-Busch InBev (Beck's, Budweiser, Corona, Michelob, Stella Artois) and MillerCoors (Blue Moon, Coors, Miller, Molson). Recent research points to rising beer prices on greater concentration in the industry. When SABMiller and MolsonCoors (the number two and three brewers at the time) combined US operations, in 2008, prices abruptly rose — and not only for their beers but also for those of competitor Anheuser-Busch. Economists Nathan Miller of Georgetown and Matthew Weinberg of Drexel estimated that prices were at least 6% and 8% higher than they would have been without the joint venture and suggested that the competing brewers coordinated pricing. In 2015, the Justice Department, citing corporate documents in its initial objection to a subsequent Anheuser-Busch acquisition, said the brewer's strategic plan for pricing "reads like a how-to manual for successful price coordination."

theoretical framework to study these complex industry issues, around three broad topics, the so-called Structure-Conduct-Performance paradigm[10]. In an ideal theorical case, when industries vary around three pure forms, perfect competition (many players with no dominant firm), oligopoly (only a few firms, as in the energy sector, or even a duopoly like Pepsi vs. Coca Cola), and monopoly, structure determines conduct, which itself determines performance. Market structure is a term to describe the distribution of firms in an industry, their number and size (employees and sales) and the ease of entry and exit barriers, including by foreign firms entering the industry.

As a conceptual part of the S-C-P paradigm, conduct refers to certain stable attributes of the industry that influence the firm's conduct, such as capital intensity, pricing, the firm's structure and governance, advertising efforts, and the complexity of the firm's goals and expectations and their links to internal coherence to implement these strategies. Such behavioral issues forced a traditional economist like Joe Bain to admit that structural issues influence the actual behavior of boards and senior managers, thus providing a feedback mechanism where organizational conduct impacts structural issues by creating barriers to entry. In the past, economists focused on durable notions of industry boundaries based on Standard Industrial Classification (SIC) codes. However, the strategic issues at the firm level get much more complicated – is a firm in the frozen food business or more generally in the consumer-packaged goods business? Further, the assumptions of the S-C-P paradigm often lead to questionable public policy recommendations, such as the constrained actions of managers given the external demands of the industry, or that all firms have equal access to resources, and similar managerial capabilities to pursue similar, rational, and competitive approaches, compared to collusion, or other forms of joint strategies, including pricing[11].

The complicated goals and strategies of the food retailers illustrate this complexity, but now include models of financial engineering to meet profitability targets and share price growth. The widely published merger in

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[10] For standard references in economics, and industry studies, see J. S. Bain, *Industrial Organization*, 2nd Ed., New York: John Wiley & Sons, Inc., 1967; F. M. Scherer and D. Ross, *Industrial Market Structure and Economic Performance*, 3rd Ed., Boston: Houghton-Mifflin Co., 1990; Jean Tirole, *The Theory of Industrial Organization,* Cambridge: MIT Press, 1988.

[11] For a study on the US breakfast cereal sector, with high markups well beyond competitive pricing, see Jeffrey J. Reimer, "Market Conduct in the US Ready-to-Eat Cereal Industry," *Journal of Agricultural & Food Industrial Organization* Vol. 2 (2007), pp. 1075-1075.

2015 in the financial media of Kraft with Heinz, largely financed by the Brazilian investment fund, 3G, and Warren Buffett's Berkshire Hathaway, provided a portfolio of consumer brands like Maxwell House Coffee and Oscar Mayer Meats, but left the merged firm with very high debt, almost $23 billion, while losing almost $1.6 billion per quarter. With its stock price in junk bond territory, Kraft Heinz sold its cheese division to France's oldest dairy firm, Lactalis, family owned and founded in 1930. For Lactalis, this acquisition strengthens their hold in the US market, gaining brands like Cracker Barrel and Breakstone & Knudsen, and dairy factories in New York, California, and Wisconsin. Similar issues are on public display in the private equity bids for William Morrison, the iconic British food retailer, with its freehold stores across the country, its own food processing factories, and an extensive property portfolio. Bidders could unlock value by the disposal of certain assets, increasing financial borrowings to leverage certain assets, or introduce new units like convenience stores.

Clearly, the definition of industry boundaries is increasingly difficult, in part because the entry and exit barriers and internal organizational activities and competences of firms are fluid, as are the product and technology life cycles, and corporate rules of the game[12]. Further, because industries can vary by their intangible knowledge component, such as the bundle of core assets, such as specialized machinery, work processes and protocols, there are also differences in their core activities encompassing distinctive competences and capabilities. Underlying variations imply that not all industries are profitable or have the high margins found in some technology firms, fashion houses or investment banks. Whether industries operate as monopolies or oligopolies, or in intensely competitive environments can depend on the regulatory framework, access to capital, and trade barriers. Other factors are also in play, such as the weather, internal capacities to reallocate executive attention to innovate, and guardrails to avoid the perils and penalties of strategic drift[13]. Industries and companies also have different time horizons, speed and tempo, risk vulnerabilities, and agility capabilities. As Seymour Tilles[14] suggested decades ago, "because industries' boundaries shift so rapidly, industry definitions cannot be a one-time decision. As with other

[12] C. Baden-Fuller and John Stopford, *Rejuvenating the Mature Business,* London: Routledge, 1996.
[13] X. Li and C. McMillan, "Corporate Strategy and the Weather: Towards a Corporate Sustainability Platform", *Journal of Problems and Perspectives in Management* Vol. 12 (2) (2014), pp. 1-22.
[14] S. Telles, "Making Strategy Explicit" in H. Igor Ansoff (Ed.), *Business Strategy*, Middlesex, UK: Penguin, 1966., p. 196.

strategic variables, its continued redefinition is a significant element in maintaining competitive position" (p. 196).

In economic terms, there is a relatively inelastic demand for farm output, and as a group of products, a small drop in price, say 10-15 per cent, doesn't lead to an increase in consumption. Equally, the supply side of agricultural output is very immobile, and within time period constraints, the input costs are relatively fixed, even if the output prices are low or high. Few sectors face constant uncertainty, from weather conditions to animal disease and farm pestilence. Further, the expectation of farm output prices for crops (e.g., wheat, corn, soya beans) and animals is a function of consumer demands for taste and quality, yet constant uncertainties persist, impacting freshness, perishability, and delivery timing. In this sense, farm outputs and food have the quality of an "experience good," with many intangibles illustrated in a high-class restaurant of *haute cuisine*.

Precision Agriculture

For centuries, entrepreneurs and mechanical engineers worked to shift agriculture and food production away from the back-breaking use of manual labor to capital-intensive production, not only on the farm by mechanized tools and equipment like today's ubiquitous tractor, but mechanical, mass assembly line processes in the slaughterhouses and the processed food companies like Kellogg, Heinz Kraft, or Nestlé. Thanks to superstores and big-box retailers like Walmart, Costco, or Tesco and Carrefour in Europe, automation, computerization, and new machines like drones have transformed the food production value chain, a $750 billion industry in the US alone. Even for distribution and delivery, now a $160 billion sector, food stores, restaurants, and specialty outlets like liquor stores, bakers, fishmongers, or butchers can align customers and services with established delivery firms like Grubhub and Uber Eats in North America or Just Eat and Takeaway in Europe, plus new startups like Delivery Hero, Doordash, or Deliveroo. In today's COVID-19 world, this is just-in-time with a vengeance. However, the new century is bringing an accelerating disruption, led in part by young farmers now schooled and educated in the venture capital sector, and new forms of university collaboration.[15]

[15] For one assessment of agtech startup funding, see Finistere Ventures, *2019 Agrifood Tech Investment Review*, San Diego, Cal., 2019. The new initiative for sixteen British universities to collaborate on priorities for research and innovation for agriculture is a welcome change when existing research capacities are unknown.