HOG FARMING, PAST, PRESENT, AND FUTURE: AN ECONOMIST'S VIEW

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I. INTRODUCTION

This article is a brief overview of recent developments, current status and trends, and forecasts related to pig farming. Observations on the past, present, and future of hog farming are examined in the context of economic principles.

A core theme of this Note is the definition of economics: the study of the optimal allocation of resources to maximize the welfare of people. Markets are presented as a central focus of economics as are non-market goods and services and the development of policy and law to enable markets and address issues not well served by markets. An idea raised throughout this note is that economics and law are fundamentally linked.

Applications of economics range from individual behavior to decisions of the firm to market behavior to policy, and to the performance of regional, state, national, and global economies. The welfare of people is measured against their desires and preferences, and constrained by their resources, technology, and efficiency.

Economics can be applied to characterize people's decisions to purchase and consume pork products including which pork products and how much of each at various prices; in other words, the demand for pork. Economics also can be applied to characterize people's decisions to produce pigs and pork products including quantity, location, method, and quality of production; in aggregate constituting supply. Economics is applied to examine decisions that determine effects of pig and pork production and consumption on resource use, manure management and emissions, and other effects on the environment. Economics is applied to develop policy that determines community relationships with pig and pork production and local economic development.

Law establishes rules for interaction including the basis for property rights, resulting markets, and explicit and implicit contracts. Ronald Coase's work on property rights, transactions costs, and the efficiency of markets is fundamental to welfare economics and is a strong explicit link between law and economics.[1] Coase's work builds on the work of Vilfredo Pareto whose expression of Pareto Optimality defines the conditions for exchanges between people as being that at least one is made better off and none is made worse off by the exchange.[2] The limitations of markets and the role of policy, law, and regulation in addressing issues beyond the limits of markets are raised in this paper. The importance of property rights, markets, implicit contracts and policy is also examined in following sections of this paper, with particular attention to the growth and evolution of the hog farming industry domestically and internationally.

This Note touches on the inextricable links between rural economic development, pig and pork production, policy and law, external effects of pig production, and the economic importance of implicit contracts between communities and their pig producers and pork processors.

Finally, this note touches on the importance of innovation and technological change in addressing past and future challenges associated with pig and pork production, resource use, the environment, and human welfare.

II. CONSUMPTION AND DEMAND FOR PORK

Pigs produced on farms are an intermediate product with various pork products being the primary consumer goods derived from pig farming. Consumption of pork in the USA has been rising slightly faster than the population with per capita consumption ranging between fifty-eight and sixty-five pounds carcass weight per year over the past few decades.[3] Broiler chicken meat consumption was 106 pounds per capita and beef consumption was 81 pounds carcass weight per capita in 2017 in the USA[4].

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1. *See* THE LIBRARY OF ECONOMICS AND LIBERTY, *Ronald H. Coase (1910-2013)* https://www.econlib.org/library/Enc/bios/Coase.html.

2. THE LIBRARY OF ECONOMICS AND LIBERTY, *Vilfredo Pareto (1848-1923)* https://www.econlib.org/library/Enc/bios/Pareto.html.

3. *See Livestock and Meat Domestic Data (2018)*, ECON. RESEARCH SERV., U.S. DEP'T OF AGRIC., FEB. 27, 2019, PORK: NEW- RECENT AND HISTORICAL (PIVOT TABLES & MACHINE READABLE SHEET), https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/.

4. *See Livestock and Meat Domestic Data (2018)*, ECON. RESEARCH SERV., U.S. DEP'T OF AGRIC., FEB. 27, 2019, BROILERS: NEW- RECENT AND HISTORICAL (PIVOT TABLES & MACHINE READABLE SHEET), https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/

Globally, pork has been the meat most consumed by people although poultry meat consumption has been growing rapidly and is overtaking pork consumption.[5] Ritchie and Roser observe that global pork consumption has increased four to five fold since 1961 while global per capita meat consumption rose by 86% during that period.[6]

Roughly half of current global pork production and consumption occurs in China.[7] Ritchie and Roser observe that pork consumption in China rose thirty-five fold between 1961 and 2014.[8] Growth in consumption of pork in China supports the observation that consumers tend to increase food and meat consumption as their income rises, particularly when their income is initially very low.[9] Gao provides econometric evidence of consumers propensity to increase food consumption as their income rises.[10]

Global pork consumption is forecasted by some to increase by more than 50% by 2050.[11] Various analysts, including economists, predict meat consumption to rise by about 70% over 2005–2010 levels by 2050.[12] These forecasted increases in meat consumption are based on a 30% increase in global population from more than seven billion now to nine or ten billion by 2050 and, more importantly, based on a predicted 200% increase in global GDP (Gross Domestic Product; akin to income).[13] Most of the projected growth in GDP and in meat consumption is in developing countries where incomes are currently very low.[14]

III. PIG PRODUCTION AND SUPPLY

Basic economic theory suggests that producers will only produce goods and services that they find profitable given prices for inputs and outputs. This is conditional on available technology to convert

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5. *See Meat, pork: Crops and livestock products,* STATISTICS DIV., U.N. FOOD & AGRIC. ORG., FAOSTAT, http://www.fao.org/faostat/en/#search/pork%20consumption (last visited Mar. 10, 2019).

6. Hannah Ritchie & Max Roser, *Meat and Seafood Production & Consumption*, OUR WORLD IN DATA (Aug. 2017) https://ourworldindata.org/meat-and-seafood-production-consumption.

7. *Id.*

8. *Id.*

9. *Id.*

10. Grace Gao, *World Food Demand*, 94 Am. J. of Agric. Econ.25, 25 (2012).

11. *High Level Expert Forum - How to Feed the World in 2050: Global Agriculture Towards 2050*, FOOD AND AGRIC. ORG. OF THE U.N. (Oct. 12-13, 2009) http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf.

12. *Expert Forum, supra* note 11, at 2.

13. *See The Global Agricultural Imperative*, GLOBAL HARVEST INITIATIVE, 1 (2015) https://www.globalharvestinitiative.org/wp-content/uploads/2016/07/2015_Global-Agricultural-Imperative-1.pdf.

14. *Expert Forum, supra* note 11, at 2.

inputs to outputs, and conditional on risk, regulations and constraints on labor, management, land, capital, and other resources. Pig production has been a standard component of farming for centuries. Beginning around the Great Depression, in the 1930s, and based on technological change and employment opportunities off the farm, farms in the United States began to consolidate and specialize: growing fewer in number, larger in area, and producing fewer types of products.[15] Beginning around 1988, the United States saw a dramatic shift to indoor, large-scale, specialized pig production systems based on improved technology and management systems.[16] Much of the early adoption of the new pig production systems occurred in North Carolina where pig population grew from 2.7 million to nine million between 1987 and 1997.[17] These systems have since been adopted across the United States, Europe, China, and elsewhere.[18]

The rapid transition to new pig farming systems constitutes what economists call a supply shift: producers are willing to produce more at the same prices for product and inputs because they use a smaller quantity of inputs to produce each unit of product.[19] Transition to the new systems is associated with improvements in productivity measures such as pigs weaned per litter, feed consumed per pound of gain, average daily gain and market weight of hogs, and more generally, Total Factor Productivity.[20]

The transition to new pig farming technology occurred in concert with rapid changes in market coordination of pig production and marketing and in pork processing.[21] Production contracts were adopted to coordinate pig production across multiple farms engaged in distinct stages of pig production.[22] Marketing contracts were adopted to coordinate pig production with pork processing and

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15. Kelly Zering, *The Changing U.S. Pork Industry: An Overview, in* 205 THE INDUSTRIALIZATION OF AGRICULTURE: VERTICAL COORDINATION IN THE U.S. FOOD SYSTEM 205-216 (Jeffrey S. Royer et al. eds. 1998).

16. *Id.* This is the author's personal observation, as an extension economist studying the pigs and pork industry in North Carolina from 1984 to the present.

17. USDA National Agricultural Statistics Service, *Quick Stats* (2019) (unpublished dataset). https://quickstats.nass.usda.gov/.

18. Michael J. Boehlje, *Economics of Animal Agriculture Production, Processing and Marketing*, CHOICES (Mar. 8, 2006), http://www.choicesmagazine.org/2006-3/animal/2006-3-08.htm.

19. *See The Supply Curve*, NetMBA http://www.netmba.com/econ/micro/supply/curve/ (last visited March 10, 2019).

20. *See* Nigel Key & William McBride, *The Changing Economics of U.S. Hog Production*, USDA ECON. RES. SERV., (Dec. 2007) http://ageconsearch.umn.edu/bitstream/6389/2/er070052.pdf.

21. *See* Steve W. Martinez, *A Comparison of Vertical Coordination in the U.S. Poultry, Egg, and Pork Industries*, CURRENT ISSUES ECON. FOOD MKTS. (Econ. Res. Serv.), May 2002, at 1, 3, AgEcon SEARCH, File No. 33773.

22. *Id.*

marketing.[23] These changes in coordination are consistent with economics theory: they reduced the cost of processed pork, they alleviated constraints faced by individual farmers on capital, land, management, and risk, and they enabled greater control of pork quality.[24]

International trade in pork grew with the rapid evolution of the pork industry. The United States became a net exporter of pork around 1995.[25] In 2017, 21.8% of United States pork was exported and net exports of pork were 17.4% of production, with Japan, Canada, and Mexico being major markets for United States pork.[26] With about 12% of global agricultural land and about 5% of global population, the United States is a major exporter of grain, meat and other agricultural products.[27]

IV. RESOURCES AND THE ENVIRONMENT

Virtually all human and biological activity consumes resources, emits mass and energy, and affects the environment. Pig farming consumes feed (primarily corn, soybean meal, and minerals), water, housing, machinery and equipment, electricity and fuel, land, labor, management, and other inputs, and produces pigs, manure, mortality (pigs that die on the farm), dust, gases, odor and heat.

Management of manure, mortality, odor, the indoor environment for pig and worker health, and of emissions to the outdoor environment are important aspects of pig farming. Manure, mortality, and odor and other emissions pose potential concerns for the environment and for neighbors of pig farms and are the focus of policy, law, and regulation. The U.S. Clean Water Act and the associated National Pollutant Discharge Elimination System and Effluent Limitation Guidelines were adopted in the 1970s and include sections addressing livestock farms.[28] Rules addressing livestock farms were updated in the 1990s as larger pig farms and dairies became more common. States also adopted new rules

23. *Id.* at 3–4.

24. *Id.* at 4.

25. ECON. RESEARCH SERV., U.S. DEP'T OF AGRIC., LIVESTOCK AND MEAT DOMESTIC DATA (2018), https://www.ers.usda.gov/webdocs/DataFiles/51875/RedMeatPoultry_ProdFull.xls?v=4077.5 (last visited Mar. 10, 2019).

26. Econ. Research Serv., U.S. Dep't of Agric., Livestock and Meat Domestic Data (2018), https://www.ers.usda.gov/webdocs/DataFiles/81475/Pork_MonthlyFull.xls?v=3469.8

27. STATISTICS DIV., U.N. FOOD & AGRIC. ORG., FAOSTAT, http://www.fao.org/faostat/en/#home (last visited Feb. 5, 2019).

28. Theodore A. Feitshans & Kelly Zering, *Federal Regulation of Animal and Poultry Production Under the Clean Water Act: Opportunities for Employing Economic Analysis to Improve Societal Results*, 10 PENN ST. ENVTL. L. REV. 193, 193-94 (2002), http://nationalaglawcenter.org/wp-content/uploads/assets/bibarticles/feitshanszering_animal.pdf.

regulating pig farms and other livestock farms in the 1990s. Nuisance lawsuits and other legal processes were common in the 1990s (and again now in North Carolina) as the conversion to larger pig farms occurred. In 1997, the State Legislature in North Carolina imposed a moratorium on new and expanded pig farms that use conventional manure management systems.[29] No new or expanded pig farms have been permitted and built in North Carolina since 1997.[30]

A search for improved manure management systems is ongoing. Two conventional manure management systems are widely used in the United States; (1) storage and land application of untreated manure as a crop fertilizer, and (2) anaerobic treatment of manure in an open lagoon and land application of the wastewater and occasionally the sludge from the anaerobic lagoon as crop fertilizers.[31] The anaerobic lagoon and sprayfield system was adopted in North Carolina as a USDA NRCS and EPA supported conservation technology best suited to the small acreage farms there in the 1970s and 1980s.[32] In 2000, the Attorney General of North Carolina entered into a Consent Agreement with Smithfield Foods (and later Premium Standard Farms and Frontline Farmers) known as "the Smithfield Agreement".[33] Through the agreement, Smithfield Foods committed $15 million for the immediate evaluation of alternative manure management technologies and $50 million over twenty-five years to enhance the environment in North Carolina.[34] North Carolina State University was designated to manage the evaluation of alternative technologies.[35] About eighteen technologies were selected from proposals, then built, operated, and evaluated for operational performance, selected emissions, and costs

29. Clean Water Responsibility Act, § 1.1(a), 1997 N.C. Sess. Laws 458, 458, https://www.ncleg.gov/Sessions/1997/Bills/House/PDF/H515v6.pdf (replaced by G.S. 143-215-101).

30. To support this assertion, the Authors draw from personal observations and experience as an extension economist studying the pigs and pork industry in North Carolina from 1984 to the present.

31. Animal & Poultry Waste Mgmt. Ctr., Coll. of Agric. & Life Scis., N.C. State Univ., *Development of Environmentally Superior Technologies for Swine Waste Management per Agreements Between the Attorney General of North Carolina, Smithfield Foods, Premium Standard Farms, and Frontline Farmers*, SMITHFIELD AGREEMENT, https://projects.ncsu.edu/cals/waste_mgt/smithfield_projects/smithfieldsite.htm (last visited Feb. 5, 2019).

32. Overcash, M.R., and F.J. Humenik, *State Of The Art: Swine Waste Production And Pretreatment Processes*, EPA 79-98 (Dec. 1976), https://nepis.epa.gov/Exe/ZyPDF.cgi/91016VHG.PDF?Dockey=91016VHG.PDF.

33. SMITHFIELD AGREEMENT, *supra* note 31.

34. The Agreement, https://projects.ncsu.edu/cals/waste_mgt/smithfield_projects/agreement.pdf (last visited Feb. 8, 2019).

35. SMITHFIELD AGREEMENT, *supra* note 31.

and returns.[36] Detailed reports are available at NCSU.[37] The "Smithfield Agreement" established five emissions criteria and an economic feasibility criterion that a manure management system has to meet to be designated as an "Environmentally Superior Technology" in North Carolina.[38] None of the technologies tested then or since met all the defined criteria.[39]

Technological and managerial improvements that improve Total Factor Productivity in pig farming have important effects on various "footprints" of pig farming and pork production. Notably, the amount of feed required to produce one pound of live market hog fell from around 4.5 in the 1960s to less than 2.8 pounds in 2015.[40] That gain results from genetic improvement (faster growing, more feed efficient pigs), more precise formulation of diets, better feed manufacturing and feeding systems, better pig health care and environment, and other factors.[41] The 1.3 pounds or greater than 30% reduction in feed required is equivalent to 44 billion pounds of feed saved in production of 34 billion pounds of market hogs in the USA in 2017.[42] Logically, reduction in inputs for a given quantity of outputs results in a greater proportional reduction in emissions. A recent study from the University of Arkansas provides footprint reduction estimates for the U.S. pork industry.[43]

The predicted 70% growth in global consumption of meat has raised concerns about resource use and environmental effects.[44] The need for continued improvements in Total Factor Productivity and associated reductions in footprints has been expressed.[45]

V. RURAL DEVELOPMENT

Economic development is a critical policy issue locally and globally. Where economics is the study of allocation of resources to

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36. *Development of Environmental Superior Technologies for Swine Waste Management*, NORTH CAROLINA STATE UNIVERSITY, https://projects.ncsu.edu/cals/waste_mgt/smithfield_projects/smithfieldsite.htm#technologies.

37. SMITHFIELD AGREEMENT, *supra* note 31.

38. *Id.*

39. *Id.*

40. Jim Eadie, *New Study From the University of Arkansas Shows U.S. Pork's Long-term Sustainability Progress*, SWINEWEB (Jan. 11, 2019), https://www.swineweb.com/new-study-from-the-university-of-arkansas-shows-u-s-porks-long-term-sustainability-progress/.

41. Ben Putman, et. al, *A Retrospective Assessment of U.S. Pork Production: 1960 to 2015*, University of Arkansas, (2018), https://cpb-us-e1.wpmucdn.com/wordpressua.uark.edu/dist/1/446/files/2019/01/Final_Report-1mgj3oo.pdf.

42. ECON. RESEARCH SERV., U.S. DEP'T OF AGRIC., LIVESTOCK AND MEAT DOMESTIC DATA (2018), https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/.

43. Putnam, *supra* note 41.

44. Kelly D. Zering et al., *Water and Land Issues Associated with Animal Agriculture: A U.S. Perspective*, COUNCIL FOR AGRIC. SCI. & TECH., Aug. 2012, at 1.

45. *Id.*

maximize the welfare of people, allocation of resources in rural communities is an important application of economics. Rural economic development has proven particularly challenging as most jobs being created are in urban areas. U.S. Census data show that loss of population, employment, income, residential property value, tax base, and tax-supported infrastructure are real issues in rural counties in the United States.[46]

Globally, livestock production is critical to the income and welfare of 1.3 billion of the poorest people.[47] In the United States, livestock account for half of cash receipts from agriculture.[48] In North Carolina, animal agriculture accounts for about 67% of farm cash receipts.[49] North Carolina agricultural leaders, rural communities and their elected officials made conscious decisions to support growth of livestock production including pig and poultry farming. Public debate and frequent revision of laws and regulations accompanied pig farm development in North Carolina in the 1990s.[50]

Pig farming supports pork processing as well as feed grain production, equipment manufacturing, transportation, and other associated industries. A recent contribution analysis using IMPLAN found that 42% of employment and 54% of value added in Bladen County, North Carolina in 2016 was attributable to IMPLAN's industry sectors constituted primarily of pig farming and pork processing.[51]

Prior to, and following the adoption of "moratorium" laws affecting pig farms, North Carolina communities have supported expansion of poultry farming and processing.[52] Designing policy and law to support optimal allocation of resources to maximize the

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46. Stef W. Kight, *Why Rural Counties Are Dying in America*, AXIOS (June 20, 2018), https://www.axios.com/the-dying-rural-counties-of-america-0fbcaa2f-dae5-47e3-99f7-e14693397e2a.html. *See* U.S. CENSUS BUREAU, COUNTY POPULATION TOTALS AND COMPONENTS OF CHANGE: 2010-2017 (2018).

47. FOOD & AGRIC. ORG. OF THE UNITED NATIONS, LIVESTOCK'S LONG SHADOW: ENVIRONMENTAL ISSUES AND OPTIONS xx (2006), http://www.fao.org/docrep/010/a0701e/a0701e.pdf.

48. ECON. RESEARCH SERV., U.S. DEP'T OF AGRIC., ANNUAL CASH RECEIPTS BY COMMODITY (2018), https://data.ers.usda.gov/reports.aspx?ID=17832.

49. ECON. RESEARCH SERV., U.S. DEP'T OF AGRIC., ANNUAL CASH RECEIPTS BY COMMODITY (2018), https://data.ers.usda.gov/reports.aspx?ID=17832#P23cae7261fc84b5885dc0bd361577905_2_17iT0R0x33.

50. *See* N.C. Dep't of Envtl. Quality, *Animal Feeding Operations Rules and Statutes*, NC.GOV, https://deq.nc.gov/about/divisions/water-resources/water-resources-rules/animal-feeding-operations-rules-statutes (last visted Feb. 10, 2019).

51. Kelly Zering & Lei Pan (2018) (unpublished interim research report) (final report forthcoming).

52. *Id.*; *cf. Annual Cash Receipts by Selected Commodity, 2010-2019*, USDA ECONOMIC RESEARCH SERVICE (Nov. 30, 2018), https://data.ers.usda.gov/reports.aspx?ID=17832 (table showing cash receipts for poultry products in North Carolina).

welfare of people in rural areas continues to be an important focus in North Carolina and globally and an important nexus of law and economics.

VI. MARKETS, PROFIT, IMPLICIT CONTRACTS, INVESTMENT, AND POLICY

A central focus of economics is the study of markets. Global and local markets play an important role in determining where and how and in which quantities and qualities, pigs and pork are produced and consumed. Markets may be defined as institutions that process incomprehensible quantities of information from a myriad of interactions among individuals, including producers and consumers, to determine prices for various quantities and qualities of goods and services exchanged at various places and points in time.[53] Markets may be among the most democratic institutions known to people with almost everyone voting many times daily on the value of all kinds of traits of all kinds of goods and services. Markets are imperfect in that information about goods and services may be incomplete and not equally available, property rights may not be fully specified, and transactions costs may hamper price determination. The prices generated by markets directly affect the profit and risk faced by pig farmers and processors and affect the set of choices available to policy makers.

Pig farming and pork processing require substantial investments in buildings, equipment, and land improvements that may require decades of profitable operation to recover. Expected profit and risk are contingent on prevailing policy and law and their stability into the future. Prospective pig producers and processors, policy makers, and communities make decisions about economic development and long term investments based on current and forecasted prices in many markets.

Emissions to the environment and particularly impacts on the environment and on people are often difficult to price in markets. Reasons for this difficulty may include difficulty quantifying specific impacts of emissions and in some cases, very few "buyers" or "sellers" of specific impacts in a specific location. The incomplete specification and allocation of property rights may also limit potential market transactions.

Policy, law, and regulation of emissions and operations that generate emissions of concern are common means of addressing issues where market solutions are viewed as insufficient or

53. Joan Violet Robinson, *Market*, ENCYCLOPÆDIA BRITANNICA (July 20, 1998), https://www.britannica.com/topic/market.

unavailable. For example, federal, state, and local policy, law, and regulation specified operating conditions for pig farms and pork processing plants in the 1980s and 1990s in North Carolina and elsewhere.[54] New permit requirements, record-keeping and inspection requirements, revised specifications for lagoon design and construction and operation, new conditions on land application of lagoon wastewater, new siting requirements and setback requirements, and other regulations were adopted for pig farms in North Carolina in the 1980s and 1990s.[55] These operating conditions effectively specified the emissions and impacts on the environment that would constitute a reasonable standard accepted by the community.[56] Rules such as required minimum setback from property lines and sprayfield requirements dictate which farms or tracts of land are too small to participate in commercial swine production.[57] The prevailing policies, law and regulations, established through vigorous public debate, constitute a critical part of an implicit contract between the community and their pig farmers and pork processors. That implicit contract resulted in billions of dollars of investment and all the economic, social, and environmental effects of the pig farming and pork processing sectors since then in North Carolina. Change in policy, law, and regulation is constant; and if badly managed, can impose substantial takings and large risk to future investment and economic development, particularly when substantial changes to implicit contracts devalue current assets and economic base.

Evolution of pig farming in North Carolina and elsewhere over the past three decades is a rich example of the interaction of economics, policy, law, regulation, and science and technology as people strive to improve their welfare.

VII. INNOVATION AND THE FUTURE

Economic theory recognizes technology, the capacity to derive welfare enhancing goods and services from resources, as a primary determinant of human welfare. US agriculture and food systems have generated tremendous returns to modest investments in

54. NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY, ANIMAL FEEDING OPERATIONS RULES AND STATUTES, https://deq.nc.gov/about/divisions/water-resources/water-resources-rules/animal-feeding-operations-rules-statutes (information regarding animal feeding laws promulgated by the U.S. EPA and North Carolina Legislature).

55. N.C. GEN. STAT. § 106.800-809 (2018).

56. *See, e.g.*, N.C. GEN. STAT. § 143-215.10I (2018) (performance standards for animal waste management systems).

57. *Id.; see also* 15A N.C. ADMIN. CODE 02T .0507 (2018) (minimum setback requirements).

education, research and development over the past century.[58] A measure of gain in human welfare attributable to research and development is the change in Total Factor Productivity (TFP).[59] Economists have estimated TFP for the US pig farming and pork processing sector as well as corresponding changes in "footprints".[60]

The prospect of a 70% increase in meat consumption by 2050 and related increases in consumption of most goods and services has intensified focus on innovation and the rate of TFP change in various sectors of the economy. Some have identified a gap between the lower rate of TFP change and the higher rate of TFP change needed to attain UN Sustainable Development Goals and are advocating for greater investment in public research and development to close that gap.[61]

Innovation is occurring and seemingly at an accelerating pace in some sectors of the economy. Several companies are developing and marketing plant based protein substitutes for meat. Some are developing laboratory meat cell culture processes to create meat without animal production. In some cases, meat processing companies are investing in the companies producing plant based substitutes. How people value meat substitutes and to what extent an increasing supply of meat substitutes will affect demand for pork are among various uncertainties regarding forecasts of the future. A series of grand challenges exist around needed innovation in agriculture and food systems, resource depletion and conservation, residuals management, environmental enhancement, and economic development; in other words, around how best to allocate resources to improve the welfare of people now and into the future.

58. *See generally* JULIAN M. ALSTON, ET AL., PERSISTENCE PAYS: U.S. AGRICULTURAL PRODUCTIVITY GROWTH AND THE BENEFITS FROM PUBLIC R&D SPENDING (2010).

59. Nigel Key & William McBride, *Production Contracts and Productivity in the U.S. Hog Sector*, 85 AM. J. OF AGRIC. ECON. 1, 121-33 (2003).

60. Eadie, *supra* note 40; Key & McBride, *supra* note 59.

61. *2018 GAP Report: Global Productivity Report,* GLOBAL HARVEST INITIATIVE (2018) https://www.globalharvestinitiative.org/GAP/2016_GAP_Report.pdf.