Energy Economics

ROUTLEDGE TEXTBOOKS IN ENVIRONMENTAL AND AGRICULTURAL ECONOMICS

Second Edition

Peter M. Schwarz

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ROUTLEDGE

Energy Economics

Energy Economics outlines the fundamental issues and possible solutions to the challenges of energy production and use, presenting a framework for decisions based upon sound economic analysis. This approach considers market forces and policy goals, including economic prosperity, environmental protection, and societal well-being.

The second edition has been thoroughly updated, addressing dramatic shifts in the use of fuel and electricity, accelerated plans for the use of renewable energy, and pathways towards a lower-carbon future. A new chapter on electric vehicles examines its impact on transportation, the electricity market, and carbon emissions. Global examples throughout the book reflect the universal application of energy economics. With this economic foundation, coupled with perspectives from real-world applications, and perspectives from related disciplines, this text sharpens the student's ability to understand, evaluate, and critique energy policy. A companion website provides reinforcement for students through multiple choice self-test quizzes and homework exercises, as well as additional materials for instructors.

This textbook should be essential reading for students of energy economics, environmental and natural resource economics, energy-related disciplines, and general readers seeking to expand their knowledge of energy economics and policy.

Peter M. Schwarz is Professor of Economics and Associate, Energy Production and Infrastructure (EPIC) at UNC Charlotte. He has published numerous articles on energy, environment, and electricity pricing that have appeared in such journals as the *American Economic Review*, the *RAND Journal of Economics*, and the *Energy Journal*. He has traveled internationally to present his work in these areas, including Israel, Turkey, Greece, Germany, and China (six times).

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Second Edition

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Preface to the second edition

The impetus for the second edition continues to be to expand the economic way of thinking in approaching our energy future. We can ill afford ignorance on the part of citizens as they are presented with ad hoc policies jumping from hydrogen to switchgrass to ethanol to clean coal, ad infinitum, and the associated costs to businesses and the economy of unpredictable and unstable energy directives. We will need a mix of energy sources in our portfolio, based upon cost, environmental considerations, and risks. The years since the first edition provide exciting applications, including dramatic global upheavals in energy markets, accelerated implementation of renewable energy and electric vehicles, and explicit pathways towards a lower-carbon energy future.

Society often makes its energy decisions in an *incoherent* fashion, as expressed by Michael Greenstone, an economist at the University of Chicago. We reset objectives with each election cycle, often devoid of economic analysis. I wrote the first edition of this book in the hope that economics will be a central part of energy decision-making. It is gratifying to see ever more attention to energy, but such a rapidly changing subject requires the second edition.

Economic thinking can sharpen the evaluation of the benefits and costs to the individual and to society of each energy source, whether used for transportation, electricity generation, or as an industrial feedstock for plastics and petrochemicals. In the absence of economic considerations, we run the risk of phasing out fossil fuels and nuclear energy prematurely, and rushing the adoption of renewables that present new issues. Wind and solar energy are intermittent sources of energy that can only provide electricity when the wind blows or when the sun shines. There are many energy issues in this book where economics will provide a new vantage point.

We have experienced energy crises: gasoline shortages and wars to protect oil supplies; nuclear energy disasters and no agreement on a permanent waste repository; fears of natural gas extraction using hydraulic fracturing, including water pollution, methane leaks, and even earthquakes; and deaths from coal mining and the pollution that comes from burning coal. We can learn from examining past energy events to illuminate our future. Economics provides guidance for the use of fossil fuels and nuclear energy, whether for continuing their use or for phasing them out. Economic tools can help evaluate the extent to which growth in renewable fuels should be left to the market, or if government can improve upon the market outcome to better achieve our societal goals in the use of energy.

A second impetus for the second edition is the revolution in online education necessitated by the COVID-19 epidemic. These changes are ongoing, and I intend for this book and its companion website to provide pedagogy that will support online education as well as enrich in-person teaching.

There is more material in this book than most instructors will be able to cover in a semester. Instructors can likely cover Chapters 1 through 9, beginning with energy economics foundational tools in Chapters 1 through 4, and conventional and alternative energy sources—oil, natural gas, coal, nuclear, and renewable fuels—in Chapters 5 through 9, although some instructors may choose to bypass coal or nuclear energy in favor of other topics such as next-generation alternatives (Chapter 10) or energy efficiency (Chapter 11). Many instructors will also want to include some or all of Chapters 12, 13, and 14, on electricity regulation, electricity restructuring, and (new to the second edition) electric vehicles. The remaining chapters relate energy to the environment, sustainability, security, and a capstone chapter that suggests what a coherent energy policy would look like.

The accompanying companion website for the text contains student and instructor materials. For the instructor, there are PowerPoint slides for each chapter, homework questions and answers as well as animated PowerPoints with answers to the questions, and quizzes for in-class testing. There are also web exercises and suggestions for online courses. For the students, there are homework questions and multiple-choice self-test quizzes. All website materials can be used according to the rule of a Creative Commons license that permits the user to make changes to the material as long as the original source is acknowledged, no commercial use is made of the materials, and other users are notified of the original conditions.

I hope students and instructors find energy economics an exciting subject, and a stimulating way to learn more broadly about applying economics. Some readers of the first edition contacted me regarding possible errors or with appreciation for the book. I welcome correspondence at pschwarz@uncc.edu.

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Acknowledgments

I wish to acknowledge the many people who have helped to make the second edition of this book a reality. I would be remiss if I did not first acknowledge those who assisted with the first edition: Michael Herron, Dr. Adedolapo Akinde, Chinedu Ifionu, Dr. Joseph Cochran, Brent Johnson, Gwendolyn Gill, Dr. Brian Jones, Dr. Melissa Duscha, and Dr. Carol Swartz.

Ercument Camadan has served in many capacities for the second edition, reading and commenting on the revised chapters, and performing myriad tasks related to finalizing the manuscript. Both in-class and online students taking my course in Energy Economics have read drafts of the revised materials and offered comments and corrections.

I wish to acknowledge the copyright permissions granted for select figures in the second edition. Figure 5.6 on the oil supply chain is reproduced courtesy of the Penn State University open source instructional materials for their course on energy markets, policy, and regulation. BP, plc granted copyright permission to use two figures from their 2021 Statistical Review, the first of which I reproduce in Chapter 5 on oil as Figure 5.2 on global production and consumption of oil, and the second in Chapter 9 on alternative fuels as Figure 9.1 on global renewable energy production and consumption. Evolved Energy Research granted permission to include a figure showing actions that could reduce CO_2 emissions, which I reproduce as Figure 11.1 in Chapter 11 on energy efficiency. The International Energy Agency (IEA) granted permission to use data from their annual energy balances 1990–2020 and also the chart on world large-scale carbon capture, use, and storage (CCUS) facilities operating and in development, 2010–2020, reproduced in Figure 10.2. PJM granted copyright permission for Figure 12.8 showing typical PJM electricity load curves and Figure 13.7 showing a sample of their locational marginal prices. I use figures from U.S. government agencies, particularly the U.S. Energy Information Administration, which require proper attribution, but do not require copyright.

The editorial staff at Routledge have been encouraging and patient. Andy Humphries gave the green light for the second edition, which then came under the guidance of Natalie Tomlinson. Chloe James provided administrative assistance, Helena Parkinson assisted in the latter stages, as did Chloe Herbert, and Michelle Gallagher offered her assistance as the new Senior Editor for Economics textbooks at Routledge just as I was delivering the manuscript.

I thank my wife Jennifer for her continuing belief in this project, her support and tolerance for the demands of writing, and most of all, for her love. I also thank my son, Jordan, daughter-in-law, Kristina, and granddaughter Julianne; daughter, Meredith, son-in-law, Zack, and granddaughter Caroline for sharing me with this project and encouraging me

to get it done sooner rather than later. In fact, my wife read chapters during the proofreading stage, my son, Jordan, a specialist in his chosen profession of mechanical engineering, enhanced my understanding of the critical interplay between the practical application of economic theory and engineering, and my daughter, Meredith, with a background in chemistry as applied to sustainable materials, contributed insight on sustainability from a business perspective. I hope my book can provide guidance on the energy mix that will allow economic growth as well as the health of the planet for the present generation as well as for granddaughters Caroline and Julianne, and all of the next generation.

Abbreviations

AC (1) Alternating current
AC (2) Air conditioning
AC (3) Average (total) cost (also ATC)
ACEEE American Council for an Energy-Efficient Economy
ACER European Union Agency for the Cooperation of Energy Regulators
AEC U.S. Atomic Energy Commission
AFC Average fixed cost
AJ Averch-Johnson
ANWR Alaskan National Wildlife Refuge
AP Average product
APOLLO Advance Projects Offering Low Levelized Cost of Energy Opportunities
ARR Auction reserve rights
ASHRAE American Society for Heating, Cooling, and Air Conditioning Engineers
ATC Average (total) cost (also AC)
AVC Average variable cost
BBL Billions of barrels
bbl Barrel of oil
BEV Battery electric vehicle
BLM Bureau of Land Management
Btu British thermal unit
BWR Boiling water reactor
CAA Clean Air Act
CAC Command-and-control
CAFÉ Corporate Average Fuel Economy Standards
CAISO California Independent System Operator
CANDU Canada Deuterium Uranium
CAPM Capital Asset Pricing Model
CARB California Air Resources Board
CAT Cap-and-trade
CBA Cost-benefit analysis
CCGT Combined-cycle gas turbine
CCS Carbon capture (use/utilization) and storage (also CCUS)
CEGB Central Electricity Generating Board
CERCLA Comprehensive Response, Compensation, and Liability Act

CERN	Conseil Européen pour la Recherche Nucléaire, or the European Organization for Nuclear Research
CESER	Cybersecurity, Energy Security, and Emergence
CFCs	Chlorofluorocarbons
CFD	Contracts for differences
CFL	Compact fluorescent light
CHP	Combined heat and power
CIP	Critical infrastructure protection
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
cp or c.p.	Ceteris paribus
CPI	Consumer price index
CPP	Critical peak pricing
CR	Concentration ratio
CS	Consumer surplus
CSP	Concentrated solar power
CSR	Corporate social responsibility
cu m	Cubic meter (also m^3)
CV	Contingent valuation
CWA	Clean Water Act
CWIP	Construction work in progress
D	Industry demand
d	Firm demand
DC	Direct current
DCF	Discounted cash flow
DG	Distributed generation
DOE	U.S. Department of Energy (also USDOE)
DR	Demand response
DSO	Distribution system operator
DWL	Deadweight loss
EDF	Environmental Defense Fund
EE	Energy efficient
EI	Energy intensity
EIA	U.S. Energy Information Administration (also USEIA)
EMF	Electromagnetic field
EMR	Electricity Market Reform
EOS	Economies of scale
Ep or ε or η	(Own) price elasticity of demand
EPA	U.S. Environmental Protection Agency (also USEPA)
EPAct	Energy Policy Act
EPR	European pressurized water reactor
EPRI	U.S. Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ESG	Environmental, social, and governance
ESP	Electrostatic precipitator
EU	European Union

EU ETS	EU Environmental Trading Scheme
EV	Electric vehicle
E_x or E_{ij}	Cross-price elasticity of demand
F	Fuel costs
FC	Fixed cost
FCV	Fuel cell vehicle
FERC	Federal Energy Regulatory Commission
FGD	Flue gas desulfurization
FIT	Feed-in tariff
FPC	Federal Power Commission
FPL	Florida Power and Light
FTR	Financial transmission rights
FV	Future value
G	Generation
g	Growth rate
GDP	Gross domestic product
GGE	Gasoline-gallon equivalent
GHG	Greenhouse gas
GW	Gigawatt
HC	Hydrocarbons
HEV	Hybrid electric vehicle
HHI	Herfindahl-Hirschman Index
HVAC	Heating, ventilation, and air conditioning
I	Investment
IB	Incentive-based
ICE (1)	Intercontinental Exchange
ICE (2)	Internal combustion engine vehicle (also ICEV)
ICEV	Internal combustion engine vehicle (also ICE)
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
IOU	Investor-owned utility
IPCC	Intergovernmental Panel on Climate Change
IPE	International Petroleum Exchange
IPP	Independent power producer
ISO	Independent system operator
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
K	Capital
kg	Kilogram
kW	Kilowatt
kWe	Kilowatt equivalent
kWh	Kilowatt-hour
L	Labor
LCOE	Levelized cost of energy
LDC	Local distribution company
LED	Light-emitting diode
LEED	U.S. Leadership in Energy and Environmental Design

LMP	Locational marginal price
LNG	Liquid natural gas
LOLP	Loss of load probability
LPG	Liquefied petroleum gas
LR	Long run
LRAC	Long-run average (total) cost (also LRATC)
LRATC	Long-run average (total) cost (also LRAC)
LRMC	Long-run marginal cost
LSE	Load-serving entity
m^3	Cubic meter (also cu m)
MAC	Marginal abatement cost
MATS	Mercury and air toxics standards
MB	Marginal benefit
M/K/Tbbl	Thousand barrels of oil
MC	Marginal cost
MEC	Marginal external cost
MFC	Marginal factor cost
Mgal	Thousands of gallons
MISO	Midwest Independent System Operator
MIT	Massachusetts Institute of Technology
MMbbl	Million barrels of oil
MMBtu	Million British thermal units
MNB	Marginal net benefit
MOX	Mixed-oxide fuel
MP	Marginal product
MPC	Marginal private cost
mpg	Miles per gallon
MR	Marginal revenue
MRP	Marginal revenue product
MRS	Marginal rate of substitution
MRTS	Marginal rate of technical substitution
MSB	Marginal social benefit
MSC	Marginal social cost
MSR	Molten salt reactor
MUC	Marginal user cost
MVP	Mackenzie Valley Pipeline
MW	Megawatt
MWh	Megawatt-hour
NASA	National Aeronautics and Space Administration
NBER	National Bureau of Economic Research
NEPA	National Environmental Policy Act
NERC	North American Electric Reliability Corporation
NG	Natural gas
NGC	National Grid Company
NGL	Natural gas liquids
Ni-MH	Nickel-metal hydride
NOx	Nitrous oxide

NRC	Nuclear Regulatory Commission
NREL	The National Renewable Energy Lab
NSPS	New Source Performance Standards
NUG	Nonutility generator
NYMEX	New York Mercantile Exchange
OCC	Overnight construction cost
OFFER	Office of Electricity Regulation
Ofgem	Office of Gas and Electric Markets
O&M	Operating and maintenance
OPEC	Organization of Petroleum Exporting Countries
OTC	Over-the-counter
P	Price
PG&E	Pacific Gas & Electric
PHEV	Plug-in hybrid electric vehicle
PJM	Pennsylvania, New Jersey, Maryland; ISO now containing all or part of 13 northeast U.S. states + Washington, DC
PM	Particulate matter
PS	Producer surplus
PUC	Public utility commission
PUHCA	Public Utilities Holding Company Act
PURPA	Public Utilities Regulatory Policy Act
PV (1)	Present value
PV (2)	Photovoltaic
PWR	Pressurized water reactor
PX	Power exchange
PZEV	Partial zero emission vehicle
π	Profit
Q	Quantity or output (usually for industry or market) (also y)
q	Quantity or output (usually for individual firm) (also y)
QF	Qualifying facility
R	Discount rate
RCRA	Resource Conservation and Recovery Act
R&D	Research and development
REC	Regional electric company
REP	Retail energy provider
RfF	Resources for the Future
RGGI	Regional Greenhouse Gas Initiative
RoR	Rate-of-return
RPS	Renewable portfolio standard
RPT	Rate of product transformation
RTO	Regional transmission organization
S	Industry supply
s	Firm supply
SCR	Selective catalytic reduction
SEEM	Southeast Energy Exchange Market
SFR	Sodium-cooled fast reactor
SMCRA	Surface Mining Control and Reclamation Act

SMR	Small modular reactor
SO_2	Sulfur dioxide
SPARC	Soonest/Smallest Private-Funded Affordable Robust Compact
SPR	Security petroleum reserve
SR	Short run
SRAC	Short-run average total cost (also SRATC)
SRAVC	Short-run average variable cost
SRMC	Short-run marginal cost
SRTC	Short-run total cost
SUV	Sport utility vehicle
SW	Social welfare or social welfare analysis (also SWA)
σ	Elasticity of substitution
T	Transmission
TAP	Trans-Alaska Pipeline
TC	Total cost
Tcf	Trillion cubic feet
TMI	Three Mile Island
TNB	Total net benefit
TR	Total revenue
TVA	Tennessee Valley Authority
U	Uranium
U.K.	United Kingdom
UN	United Nations
UNFCCC	UN Framework to Combat Climate Change
U.S.	United States
USAEE	United States Association for Energy Economics
USDOE/DOE	U.S. Department of Energy
USEIA/EIA	U.S. Energy Information Administration
USEPA/EPA	U.S. Environmental Protection Agency
USSR	Union of Soviet Socialist Republics
VC	Variable cost
VOCs	Volatile organic compounds
VoLL	Value of lost load
WARM	Weather-adjusted-rate-mechanism
Wh	Watt-hour
WtE	Waste-to-energy
WTA	Willingness to accept
WTI	West Texas Intermediate
WTP	Willingness to pay
y	Output (also Q or q)
ZEB	Zero-emissions building
ZEV	Zero emissions vehicle

Part I

Fundamentals of energy economics

Chapter 1

Introduction

Why energy economics?

In 1973, the Organization of Petroleum Exporting Countries (OPEC) nationalized oil resources, expelled U.S. oil producers, and withheld oil supplies. As a result, the price of oil and gasoline increased by 50% within months. Almost overnight, the field of Energy Economics emerged. Economists began to apply supply and demand to energy concerns of national security and everyday well-being. Energy policy became an important issue as the U.S. set a goal of energy independence.

In 2020, as oil prices plummeted with the onset of the COVID-19 virus, that same organization proposed reducing oil supplies to reverse the oil price collapse. But over the decades, the U.S. and Russia joined OPEC leader Saudi Arabia as the top three oil producers, and Russia defied Saudi Arabia by increasing oil supplies in the hopes of increasing market share and harming U.S. producers. Oil prices continued to plummet, and in an unparalleled event, even turned negative! Producers were willing to pay to get rid of their oil as storage facilities filled to capacity, making storage costly if it could even be found. Ordinarily, prices are not negative. Yet here we have seen an example of negative oil prices, and elsewhere in the text, we will see that renewable energy has resulted in cases of negative electricity prices. In 2022, oil prices surged above $100 a barrel, with the Russia-Ukraine conflict at the heart of the oil price resurgence. Energy economics will help us understand these anomalies.

Energy economics uses the tools of economics to analyze the supply and demand of energy.[1] There are many basic principles involved such as the law of demand, consumer preferences, elasticity of demand, substitutes in consumption, economies of scale, elasticity of supply, market structures (perfect competition, monopoly, and oligopoly), inefficient outcomes due to market as well as government failures, substitutes in production, the impact of technology changes on costs, and the markets for inputs including energy, labor, and capital. In addition, there are some ideas that are unique to the energy markets such as the problem of allocating a nonrenewable resource between present and future periods. External costs and benefits play a big role in energy markets and in energy policy. Comparisons of marginal costs and marginal benefits are important for understanding policy options and for choosing among possible policies to meet a given objective.

This chapter introduces many of the themes and concepts that will be the focus of later chapters. We begin with an overview of the crude oil markets since 1970. After that, we consider the scope of energy economics, some applications, and economic principles of particular value to understanding energy markets. The chapter ends with an overview of the remainder of the book.

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Oil market performance from the 1970s to the present

While energy has always been a scarce resource, the dramatic events of the 1970s to the present time captured the attention of citizens, government officials, and scholars. Few commodities experience the kind of price rise that oil saw in the early 1970s or the price collapse in 2020 coinciding with the onset of COVID-19.

In the United States, as the price of a barrel of oil rose from $3.60 per gallon in 1972 to $4.75 in 1973, and $9.35 by 1974, the government attempted to moderate the price increase by controlling energy prices at the gas pump. They imposed price controls, which led to shortages and gas rationing. Initially, the government limited how many gallons car owners could buy at one time. This scheme led to long queues, as drivers bought gas more often than if they had filled the tank. The government then restricted sales on a given day based on whether the last digit of the car's license plate was odd or even. Entrepreneurs seized upon the shortage to earn profits. Some gas station owners required drivers to buy a car wash along with gas, with the price of the car wash inflated to capture the buyer's willingness to pay more for gas than the legal limit.

The U.S. economy suffered through years of *stagflation*: simultaneous inflation and unemployment. In 1979, oil supply declined further as Iran took action against the U.S. for providing a haven for the deposed Shah of Iran. The second oil price shock sent the price of a barrel from $14.95 in 1978 to $25.10 in 1979, and $37.42 by 1980, and buyers turned to natural gas to heat their homes to avoid the high cost of electricity that relied on oil for its generation. However, there were also price controls on natural gas that had been in place due to a 1954 U.S. Supreme Court ruling regulating natural gas prices. The controls led to shortages of natural gas, and natural gas fell out of favor as it was viewed as unreliable to meet the winter demand for heating fuel. It wasn't until the advance in hydraulic fracturing, or "fracking" just before 2010, that natural gas took on its current importance, and in the United States, it now stands as the largest source of fuel for generating electricity.

By the 1980s, consumers and businesses reduced energy use in response to a decade of high prices, while countries outside OPEC began to increase oil production. OPEC had less power over price and energy prices declined throughout the 1980s and the 1990s. Consumers cheered. However, interest in energy economics waned as there was less incentive to search for energy alternatives or to seek energy independence. Gas prices remained low until September 11, 2001, when terrorists attacked the New York City World Trade Center and the Pentagon. The United States restricted imports from countries that were seen as sympathetic to the terrorists, initiating a new price spike. After a period of ups and downs, prices reached $140 in the summer of 2008, their highest level to date. However, energy prices again collapsed, this time in the aftermath of a global recession that was the deepest since the Great Depression. By the end of 2010, prices began to rise. Pundits cited inexorably rising demand in China and India and predicted higher prices for years to come. Yet by early 2016, oil prices were at $26 a barrel, their lowest level since 2003, with booming U.S. oil shale production and rising production by OPEC. While OPEC wanted to reign in supplies, it could not initially get the cooperation of non-OPEC suppliers, most notably Russia. By late in the year, OPEC took actions to restrict oil supplies, including Russia, giving birth to the term OPEC^{+}. While prices rebounded rapidly to $50 a barrel, the new normal no longer asserts that oil will inevitably return to its lofty peaks.[2] In fact, prices in 2020 ranged from $45 to $65 per

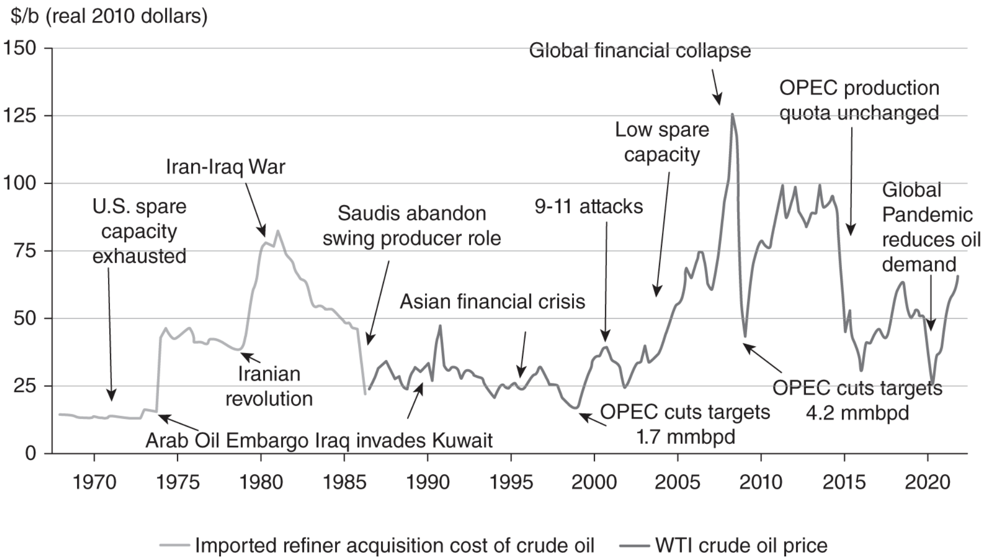

Figure 1.1 What drives crude oil prices?

Source: U.S. EIA (2022)

barrel before dropping precipitously with the onset of Covid, starting at $60, then below $40, then below $20, and then almost −$40 (you read that correctly!), before rapidly rocketing to over $100 in the first half of 2022. Box 1.1 gives the details on this unprecedented event.

The U.S. Energy Information Administration (USEIA or EIA) is a division of the U.S. Department of Energy (USDOE or DOE) that provides a wealth of energy data. Those statistics will be the primary source of data in this text. Figure 1.1, based on EIA data, provides prices for oil, in $/barrel, inflation-adjusted with 2010 as the base year from 1970 through mid-2021, identifying key events driving price swings. Where is the price as you read these words? Would you want to speculate on the price of oil one year from now? If you can be right a little more than half the time, you could be a millionaire.[3]

Box 1.1 The oil markets get a bad case of Covid before recovering

Oil prices started 2020 at $60 a barrel. We first heard about Covid from China in January 2020, with cases in Wuhan, a city of over 10 million people. China locked down the city to help prevent the spread, with further lockdowns in other parts of China, choking off demand for oil as the demand for gasoline plummeted. Covid spread globally, and countries worldwide began to lock down their economies by March.

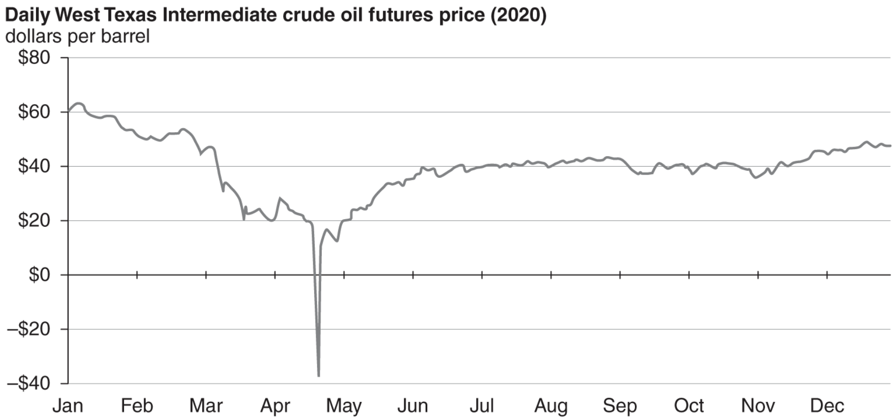

Figure 1.2 Oil prices briefly traded below $0 during the breakout of COVID-19

Source: U.S. EIA (2021)

Saudi Arabia, the largest oil producer in OPEC, attempted to reduce its supplies and to convince other OPEC countries to reduce their supplies. However, Russia and the United States each produce more oil than Saudi Arabia. U.S. oil producers operate independently of OPEC. Russia, while not an OPEC member, considers OPEC's actions in deciding how much oil to put on the market. The Saudis asked Russia to decrease production in line with OPEC's proposed cuts. Russia defied the request, hoping to drive the price of oil low enough to put U.S. shale oil producers out of business. In retaliation, Saudi Arabia turned on its oil spigots.

As global demand dropped and global supply increased, storage facilities filled to capacity. With nowhere to put the oil, producers were willing to pay someone to take their oil to avoid delivery. On April 20, crude oil prices for next month delivery—the futures price—traded below $0, briefly falling to almost −$40 a barrel.

Demand started to recover with a loosening of lockdowns. The OPEC countries and Russia were able to agree to reduce supplies. By June, the price had recovered to $40 per barrel and had risen to nearly $100 by early 2022 in both the U.S. and EU.

The content of energy economics

Energy economics, as well as the related fields of environmental, natural resource, and ecological economics, have established places in the news, in academia, and in government policy. Energy receives special attention because it is an essential input in everything we produce and consume. Environmental economics considers *externalities*—uncounted and unintentional spillover effects on other parties from the actions of producers or consumers—such as air and water pollution; these effects are ubiquitous with energy use. Natural resource economics considers how today's use of renewable and nonrenewable resources affects future availability; oil in particular raises concerns about whether today's use will leave enough for future generations. Ecological economics is a transdisciplinary field that places human activity within natural systems, incorporating scale of production and its limitations based on physical, chemical, and biological processes. The motivation for separate consideration of energy, as opposed to a topic within environmental, natural resource, or ecological economics courses, is to apply economics to energy questions to evaluate the merits of market outcomes and government policies in directing the use of energy resources.

Economists often take a different view of energy issues than the media, the average citizen, or government officials, or for that matter, environmentalists and ecologists. People often base their energy views on the latest soundbite, lambasting *fossil fuels*—sources of energy such as oil, coal, or natural gas composed of hydrocarbons formed from the decay of plants and animals—that emit carbon most scientists believe contributes to human-caused climate change. They endorse *renewable fuels*—replenishing sources of energy such as wind, solar, and biofuels—as well as energy efficiency and conservation, without considering that availability depends upon nature, and that their manufacture and disposal has environmental consequences. They condemn nuclear energy because there is no accepted solution to permanently store nuclear waste or because of the risk that its materials can be used to create bombs, without recognizing its role in reducing carbon emissions to slow climate change.

Energy economics provides tools for positive and normative analysis. *Positive analysis* examines what is, while *normative analysis* evaluates what should be. Positive analysis evaluates the determinants of energy use, while normative analysis addresses the optimal use of energy. Economists first evaluate positive market outcomes, focusing on how markets determine price and quantity. They then evaluative the normative issue of whether markets produce the best outcome for society. Where markets do not produce the best outcome, there is a potential role for government. However, economics acknowledges that the government has its own objectives that will not necessarily improve the outcome.

Consider U.S. policies that mandate use of corn-based ethanol to reduce gasoline use in automobiles. Economics first examines market use of gasoline, and asks if there is a better outcome for society than the market outcome. We have already mentioned one such possibility, the desire to reduce carbon emissions. There is a potential role for government to reduce these emissions. Most economists favor *incentive-based policies* (IB) that work through markets to achieve society's goals. Cap-and-trade is an incentive-based policy where carbon emitters must purchase carbon permits. Economists argue against *command-and-control* (CAC)—policies that prescribe technology or mandate standards to achieve a goal—such as the ethanol requirement. If the goal is to reduce gasoline use to lessen carbon emissions, IB policies encourage a variety of approaches to achieving the goal, whereas CAC mandates one approach with no assurance that it is the least-cost approach.

Economics is commonly defined as the choices we make in a world of scarce resources. Price has the central role in consumer and producer choices. One key ingredient in improving energy use is to get the prices right. If society is using a scarce resource such as air quality for which there is no price, we have suggested one mechanism, a cap-and-trade system, as a way of improving upon the unfettered market outcome.

To consider another application, the American Council for an Energy-Efficient Economy (ACEEE) is a non-profit organization that promotes energy efficiency as a goal. An economic perspective leads to an insight that may surprise you: from a normative perspective, energy efficiency is not always desirable. If energy is cheap, it makes sense to use more of it, assuming the price includes all costs of its use. When gasoline prices are low, it may be economically efficient to enjoy a larger vehicle such as a sport utility vehicle (SUV) with greater comfort vs. a small, fuel-efficient car. However, if the SUV emits more carbon, the market alone will not lead to the socially optimal choice. As we have seen, we would need to price carbon if we seek to reduce emissions, which would increase the cost of driving a large car and lead to the socially optimal choice of car size. The EU has a carbon cap-and-trade market while the U.S. does not. The EU also has much higher taxes on gasoline. These factors help to explain why the EU drives more small, fuel-efficient cars than the U.S., which favors larger vehicles and pickup trucks.

Private cost is the direct cost to the market participants, such as buyers and sellers. *Social cost*, the full cost to society, includes both private costs and externalities. External costs such as pollution and climate change are pervasive in energy markets. If we are to get the prices right, they must reflect social costs including externalities. Markets will overuse and underprice goods such as gasoline in the absence of a price for externalities such as air pollution or carbon emissions that contribute to climate change.

While most externalities, such as pollution, are negative, there can be positive externalities, in which case the social cost is less than the private cost. Mass transit often receives government funding to reduce the use of private vehicles and unpriced pollution.[4] Toll roads sometimes exempt those who carpool from the toll. Hybrid and electric vehicles have received subsidies with the justification that they have lower carbon emissions than conventional vehicles.

Subsidies in the absence of external benefits lead to getting the prices wrong. There is little justification for an oil-depletion allowance that accelerates drilling for fossil fuels. However, we should not jump to the conclusion that there is a justification for subsidizing the production of ethanol. It received cash subsidies even though the production of this fuel is itself an energy-intensive process and so may not result in less pollution than conventional fuels. In addition, the CAC requirement that gasoline include a minimum percentage of ethanol is an implicit subsidy, increasing demand and consequently, price of ethanol. To add to the inefficiency, the U.S. only allows corn-based ethanol, and bans imports of sugar-based ethanol, which is cheaper to produce. Still another source of inefficiency is that the subsidy for corn-based ethanol pushes up the price of corn-based foods, not only food where corn is a basic ingredient, but almost all foods given the prevalence of corn syrup and corn oil in processed foods.[5]

Are subsidies to wind and solar producers justified? Certainly, they are cleaner than fossil fuels as a source of electricity production and have a zero fuel cost. However, the construction costs of solar and wind facilities are high, and their availability is at nature's whim. When the sun goes behind a cloud, electricity operators must quickly ramp up an alternative, such as natural gas. We must carefully examine whether these sources have a lower social cost than fossil fuels as well as carbon-free hydroelectric power, nuclear energy, or energy efficiency and conservation.

While competition ordinarily produces an efficient outcome, it can fail to do so in the presence of external costs such as pollution and climate change. Where external costs go unpriced, there is a missing market. Society is using valuable resources without paying for them. Where possible, one remedy may be to create a market where none currently exists, such as the European carbon trading market that determines the price of carbon dioxide emissions.

Some critics of the economic perspective define an economist as "someone who knows the price of everything and the value of nothing."[6] And indeed, energy has impacts on society that may challenge our ability to assign a price. Consider death from exposure to nuclear radiation, the loss of species due to the mining and burning of coal, supporting dictators to ensure oil supplies, leaving future generations worse off due to the depletion of energy resources, degrading the environment, and doing irreversible damage to ecosystems.[7] We can try to monetize these resources. But we may well have to develop alternative decision-making approaches when we are not satisfied with our ability to get the prices right.

Our approach in this text is to start with the market approach and the unfettered competitive price system. However, for energy economics, the competitive market is only a starting point. While competition achieves the lowest price, it may not be the lowest social cost once we allow for external costs, including damage to the environment. So the second step is to account for effects that fall outside the market exchange, and internalize those external costs into market transactions. If we cannot find a way to translate external effects into measurable costs, then we must take a third step and investigate alternative approaches that fall outside traditional economics, as is the case for ecological economics. We have to investigate other frameworks, such as *sustainability*—making decisions today in a way that does not compromise the ability of future generations to be as well off as we are—that reject economic orthodoxy.

Energy is essential at each moment of our lives, including now when I am writing this introductory chapter on my computer. A loss of electric power can lead to deaths of people who depend upon medical equipment for their survival, individuals unable to heat or cool their homes during extreme weather, or even drivers entering a busy intersection when traffic signals cease to operate.

Economic approach

We now consider some of the economic tools and theories that are particularly useful in understanding energy markets.

Efficiency and inefficiency

Economic efficiency means getting the most from our scarce resources. In this text, efficiency is closely aligned with *cost-benefit analysis* (CBA). The goal is to maximize net benefits, the difference between benefits and costs. At the margin, a change is economically efficient as long as marginal benefit (*MB*) is at least as great as marginal cost (*MC*). At the economically efficient point, *MB* equals *MC*.

When exchanges take place in a market, we have a measure of the benefits and costs. If the underlying market is competitive, we may be able to use that measure as an accurate value. But many of the evaluations that we must consider in energy economics are not always revealed in the market place, such as the willingness to pay more for carbon-free sources of energy.[8]

Where there is inefficiency, there is room for a deal. Someone who would gain from a rearrangement of resources could potentially compensate someone who currently owns the resource. One source of inefficiency is when a government regulation uses the CAC approach. At its extreme, the government not only dictates what a company must do, such as cut SO_2 emissions from the use of coal by 50%, but how to do it, requiring a specific technology, a "scrubber" to catch the sulfur emissions. The inefficiency is that the company might have a lower-cost solution, such as burning lower-sulfur coal or switching to natural gas. One company located close to low-sulfur coal supplies might choose that remedy, while a company far from low-sulfur coal might convert its plants to natural gas.

Incentive-based approaches can achieve socially efficient outcomes. The main IB approaches are emissions taxes and trading. A tax on carbon emissions increases its price and causes a firm to reduce use of carbon-emitting inputs. With carbon trading, a firm that emits carbon must own a permit. Taxes work through price, while permits work through quantity. Under simplifying assumptions, the two achieve equivalent outcomes that minimize the cost of reducing emissions.

Market failure and government failure

Energy markets may not produce socially efficient outcomes, especially given the ubiquity of externalities. The government may be able to improve upon these outcomes.[9] Government failure can also occur. The *public choice* perspective views government as pursuing its self-interest, not necessarily society's interest. In particular, government may seek votes and money, which can produce policies other than those that maximize society's best interests.

As referred to earlier, few economists think corn-based ethanol is an efficient source of energy. Yet U.S. oil policy mandates a percentage of ethanol in each gallon of gasoline and bans imports of sugar-based ethanol. Public choice economists would explain these policies as aiming to win farm votes. While Mexican citizens protested higher food costs, they don't vote in the United States and so have relatively little influence.

Some imperfections are not worth correcting even if government does pursue society's best interests. We contribute to climate change by exhaling CO_2 with each breath. However, there is little we could do to control our emissions, even if the government imposed a CO_2 breathing tax. And even if we could respond, the *transactions costs*—costs of monitoring and enforcement—would be prohibitive.

A roadmap

Part I of the text introduces energy fundamentals. Chapter 1 provides an overview of energy economics. The chapter introduces some of the major themes, topics, and tools in energy economics.

Chapter 2 focuses on economic efficiency, maximum social welfare, and sustainability as they relate to energy markets. The emphasis is on how energy markets work, market failures such as externalities when market outcomes don't align with societal objectives, and the potential for government intervention to improve upon market outcomes to achieve society's goals. External costs include pollution, climate change, and the costs of securing dependable energy supplies. Social welfare includes all costs—production costs as well as external costs—as well as considerations of *equity*, the distribution of costs and benefits. Sustainability requires us to use resources today in a way that does not diminish future opportunities. Economic efficiency, social welfare, and sustainability may coincide or they may conflict.

Chapter 3 addresses supply, demand, and static efficiency. *Static efficiency* is appropriate when today's use of resources has a negligible effect on the availability of resources in the future. Under certain conditions such as the absence of externalities, perfect competition achieves static efficiency. The chapter then provides a way to measure the social welfare loss from energy market failures such as restrictions on supply by OPEC or externalities from burning fossil fuels. Finally, we will consider why *public goods*—goods that are non-rival in use and from which no one can be excluded—cause problems for the market. We connect this market failure to the challenge of reaching an effective global climate change agreement.

Chapter 4 introduces dynamic efficiency. Dynamic efficiency considers efficient allocation over time, where today's resource use leaves less for the future. The Hotelling model is the foundation for using oil and other nonrenewable resources efficiently over time. While we consider the implications of the model in a variety of settings, we also consider its limitations and possible modifications to obtain more accurate predictions for the future price of finite resources such as oil. In a dynamic market, participants wish to reduce their risk from price uncertainty over time. Forward, futures, and options markets help manage risk. These markets are particularly active for oil, which displays high price volatility over time.

Part II of the text examines nonrenewable fuels, beginning with oil in Chapter 5. Oil is a global market, with oil suppliers throughout the world seeking the most profitable market. We examine the three largest oil producers—OPEC, Russia, and the U.S.—and their cooperative and competitive interactions. We apply dynamic efficiency to the production of oil. The Hotelling model predicts that oil producers will efficiently allocate their finite supplies between now and the future. In contrast, we consider the perspective of physical scientists who predict the exhaustion of oil supplies. Finally, we consider financial instruments used by buyers, sellers, and speculators to deal with oil price uncertainty.

In Chapter 6, we examine the natural gas market, from its start as a regulated public utility to its deregulation. Hydraulic fracturing has led to natural gas accounting for a greater portion of energy supplies, but has also raised concerns, including water use and contamination as well as emissions of methane in addition to carbon. There has also been increasing opposition to new pipeline construction that in some cases has led to the abandonment of pipeline plans or stopped the completion of pipelines under construction. Natural gas is a regional market because of high transportation costs, but is becoming more global with an increase in importing and exporting. There is rapid growth in *liquefied natural gas* (LNG)—converting natural gas to a liquid—leading to greater convergence in global natural gas prices. Japan is among the major buyers of LNG, which they purchase from many countries. We examine whether Japan can get a lower-than-competitive price through the power of *monopsony*—a single buyer of an input. Natural gas price can be highly volatile, so there is a growing use of financial instruments even extending to the LNG market.

Chapter 7 addresses coal, once the dominant source of fuel for electricity generation in the U.S., but still the largest source of fuel in China. In the U.S., there are no new plants under construction, and there have been numerous plant closures or conversions to natural gas. Coal has characteristics that fit a competitive market, although the largest firms may have exerted market power as suggested by high prices on occasion that do not seem attributable to a sudden increase in costs. We also examine the relevance of the *monopsony* model for the labor market for coal. Labor markets had characteristics of a *company town*, where one employer dominates hiring. While many countries have large reserves, coal faces ever-rising challenges to its use. In addition to a multitude of negative externalities—pollution from emissions, coal mine safety, degradation to the landscape, and coal ash spills—the major impediment to its future is its contribution to climate change. We review existing coal technologies, as well as proposals for cleaner technology such as carbon capture, utilization, and storage (CCUS) that may be necessary for coal's survival. We look at likely further developments in CCUS in Chapter 10 on next-generation alternatives.

Chapter 8 evaluates nuclear energy, still the largest source of carbon-free energy, but also under threat. The most recent plants begun in the U.S. experienced enormous cost overruns, with the VC Summer Station in South Carolina abandoned and the Vogtle Plant in Georgia under construction but with no guarantee that it will be completed. The primary environmental issue is radioactive waste. As of yet, no country has established a permanent depository for spent fuel or nuclear wastes. Reprocessing spent fuel is one way to reduce waste, and we consider this option. Costs of new plants threaten the technology's future. Safety is also a large concern, most recently reignited with the Fukushima disaster in Japan. Safety regulations that increase especially in the aftermath of nuclear accidents contribute to the expense of building and operating plants, and construction can easily take a decade. Nuclear energy has a history of substantial cost overruns, with each plant built to order depending on local conditions. China is building nuclear plants and is championing standardization and looking to build large numbers of plants both within China and in other countries to reduce costs, but has not found many takers outside China nor demonstrated convincingly that it can bring down construction costs.

Part III of the text examines alternatives to conventional fuels, with Chapter 9 focusing on renewable fuels, Chapter 10 on next-generation alternatives, and Chapter 11 on energy efficiency and conservation. Solar and wind energy have decreased in cost dramatically even as subsidies have diminished, and their share as a source of energy for electricity has grown rapidly.

The push for renewable energy stems from its environmental benefits, especially the absence of carbon emissions. Renewable energy also increases energy security since it is a domestic source of energy. While renewables are clean sources of energy, they present challenges for the electrical grid. They are only available when nature chooses and are not under the control of the grid operator. Their availability may not match times of high demand, although battery storage that can better balance availability with demand is seeing rapid cost reductions. Production may be far from population centers, requiring transmission lines to get the power to where it is needed. Wind, solar, and biomass require large amounts of land. There can be opposition to siting of wind and solar, even offshore wind as evidenced by the abandoned Cape Wind project off the coast of Massachusetts. Still, offshore wind is gaining attention despite having higher costs than onshore wind.

Chapter 10 introduces next-generation alternatives. Next-generation alternatives are feasible but not yet commercially viable. The private sector may underinvest in *research and development* (R&D) of energy alternatives, which has public goods characteristics. Developers may be unable to prevent other companies from copying successful innovations. Hence, government may have a role in subsidizing and protecting R&D. Government support may be directed to a particular technology more for political gain than society's gain, which is why economists argue for the use of IB solutions and against allowing government to "pick winners." The nuclear industry may lobby for support of small modular reactors or even smaller micro reactors, while coal and possibly natural gas will seek dollars for CCUS. Nuclear energy will also put forward alternatives to uranium to generate the nuclear reaction, such as thorium or molten salts, or the holy grail of nuclear fusion, reproducing the sun's energy process. Wave and tidal power are feasible sources of energy from water. Hydrogen is generating great excitement as a carbon-free source of energy if the process used to separate it from oxygen uses renewable fuels. Hyundai is among the car companies betting on hydrogen fuel cells, which could be refilled more quickly and have longer range than battery-powered cars.

Chapter 11 focuses on energy efficiency, which some view as the lowest-cost alternative. Economic analysis offers some surprising findings, akin to the Jevons Paradox introduced in this chapter that suggests caution in adopting energy efficiency to reduce energy use. Economists caution that the energy rebound effect can lessen savings from energy efficiency. We also consider the possibility of the energy efficiency gap, a market failure specific to energy efficiency where consumers forgo energy efficiency improvements despite apparent substantial cost savings. Yet government-mandated energy efficiency may lead to products consumers don't want, such as small cars that compromise safety or dishwashers that don't dry dishes. Most fundamentally, we distinguish between energy efficiency and economic efficiency. As this introductory chapter has suggested, we must compare the costs and benefits of energy efficiency just as for any other good or service.

Part IV of the text contains three chapters on electricity. Chapter 12 addresses traditional electricity regulation and Chapter 13 focuses on electric industry deregulation, more accurately called restructuring. Chapter 14 is on electric vehicles.

The U.S. is about evenly split between regulated and restructured states. Electricity regulation began in the 1930s on the basis that production exemplified a natural monopoly. Under regulation, the Public Utility Commission (PUC) uses average cost to determine a normal rate of return comparable to what is earned by firms in competitive industries. Economists have long proposed marginal cost rates rather than average cost pricing. With greater interconnections among utility networks, and smart grids that will allow utilities and their customers to better monitor use, the gains from prices based on real-time marginal costs will increase. However, there can still be government failures, such as regulatory capture where government regulators are too cozy with the industries they regulate, resulting in excessive rates that reflect inflated costs.

Deregulation came to a number of industries in the 1970s and 1980s, including natural gas. Advocates of the gains from markets and the limitations of regulation pushed for electricity deregulation, citing technological changes and government inefficiency. Increasingly, electricity generation can be done on a smaller scale, opening the door to competitive generation. There is also the potential for competition at the retail stage, with marketers offering to shop around for the utility with the lowest price or the greenest source of energy. In the 1990s, the U.K. privatized and restructured its electricity industry. California, motivated by having some of the highest electric prices in the country under regulation, was an early adopter in the U.S. California's model for deregulation contained incompatible elements such as deregulating the wholesale price while capping retail rates, which led to its abandonment. Other restructured electricity markets have been more successful. Texas has deregulated its market, and PJM, an expanding network of states that began with Pennsylvania, New Jersey, and Maryland, is a leader in operating a competitive wholesale electricity market. One concern of deregulation has been dramatic price volatility, at times making electricity the most volatile commodity. As a result, it is necessary to have accompanying financial markets to manage price risk.

Electric vehicles have gained the attention of drivers, investors, and governments. EVs will challenge the supremacy of oil as a transportation fuel. They will be both a demander and a supplier of electricity. They will be a factor in reducing CO_2 emissions. And they will face challenges from still newer technologies, such as hydrogen vehicles. The chapter evaluates prospects for this highly discussed mode of transportation. We examine market incentives for their adoption, possible market failures that inhibit their adoption, optimal government policies to achieve the socially efficient outcome, and actual government policies that may not achieve the optimal outcome.

Part V is on energy policy. Chapters 15 through 18 take up environment, sustainability, security, and a comprehensive view of energy policy.

Chapter 15 gathers issues that connect energy and environment by contrasting CAC with IB approaches. The discussion shows the inefficiency from government standards to protect the environment, and the efficiency gains from using market-based approaches. We relate the IB approaches of an emissions tax introduced by Pigou (1932) and the emissions trading approach inspired by Coase (1960). The chapter applies CAC and IB approaches to sulfur, NOx, and carbon emissions, with examples from the U.S., EU, and China, which is rolling out carbon emissions trading.

Chapter 16 addresses sustainability. Sustainability requires that we use today's resources in a way that does not leave the future worse off. The term is becoming ubiquitous in every aspect of the economy, from statements and practices of corporate social responsibility (CSR) to university curricula and specialized degrees. Energy sustainability is a prominent focus. Environmentalists advocate *strong sustainability*, leaving future generations with at least the level of resources as we enjoy today. We apply the economic approach to sustainability, best characterized by Robert Solow's definition that we use resources today in a way that does not compromise the *capacity* of the future to be at least as well off, known as *weak sustainability*. We contrast the economic perspective with the perspective outside the economics discipline that invokes ethics as well as the Porter hypothesis that businesses benefit from sustainability. Economists doubt that businesses "leave $20 bills lying on the sidewalk," and focus on the costs should society incorporate sustainability as a goal. We consider policies aimed at energy sustainability, such as LEED (U.S. Leadership in Energy and Environmental Design) standards.

Chapter 17 delineates energy security issues. The U.S. sought energy independence to lessen its reliance on unfriendly suppliers. Such reliance can conflict with domestic interests. In addition, there are military costs to maintaining access to oil supplies. There are also concerns about terrorism aimed at LNG terminals, nuclear plants, and electricity grids. Much as with sustainability, the term has become an umbrella for a broad range of issues, including the reliability and resilience of electricity. Reliability refers to the ability of the electric system to keep the lights on. Resiliency is the ability to withstand extreme events, be they cybersecurity attacks or the increasing threats of extreme weather associated with climate change.

Chapter 18, the final chapter, offers a comprehensive energy policy. While there is wide agreement among economists that we "need to get the prices right," there is a danger doing so in a piecemeal fashion. Considering the parts without the whole will result in inefficient substitution from one source to another, and inefficiency as businesses make decisions only to find that they would have done things differently if all the policy pieces were determined together. For example, opposition to nuclear energy without evaluating the alternatives for reducing carbon emissions is a piecemeal approach to policy, while a holistic policy would consider the benefits and costs of nuclear vs. alternative solutions. In this final chapter, we lay out a holistic energy picture. By incorporating the full social costs of energy, we will be able to make maximum use of the power of the market for determining our energy future. At the same time, we will illuminate areas where we may want government to assist in order to make the best use of energy resources.

Welcome to the study of energy economics. By taking this journey you will join those citizens who will help us to make the best use of scarce resources in meeting our future energy needs, as you challenge prescriptions that fail to take into account economic considerations.

Notes

1 We take a predominantly microeconomic approach in this text. Macroeconomics is also relevant to topics such as the relation between energy prices and business cycles. Energy price spikes contributed to U.S. recessions since 1973, as well as to inflation.
2 DiLallo (2016, December 17).
3 If this text helps you make a profit, all I ask is 10%. If the text does not help, you don't own me anything (a joke!).
4 Mass transit may also reduce congestion and the need for parking.
5 In 2007, Mexicans protested a huge increase in the price of tortillas that resulted from a surge in the demand for corn to produce ethanol.
6 The definition comes from Oscar Wilde's definition of a cynic (Wilde, 1892).
7 The U.S. Environmental Protection Agency (EPA) does put a value on statistical life, also known as the value of mortality risk. It is an estimate of what people are willing to pay to lessen the chance of death, such as paying more for a house farther away from a contaminated site, or taking a job with a lower risk of a fatal accident, and not the value of a particular human life. Even so, studies show we place a higher value on dying from nuclear radiation than from a fatal ski accident.
8 While the U.S. had not put a price on carbon emissions as of 2020, other countries had. The most prominent is the European Union Emissions Trading Scheme (EU ETS).
9 The government may also intervene when a market outcome is seen as inequitable. In this text, I will refer to inefficiency, but not inequity, as a market failure. Economists have no special provenance at dictating what is equitable. However, the concept of social welfare can allow for specific definitions of equity, bearing in mind that there will be disagreement on what is equitable.

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Chapter 2

Energy, markets, and society

Introduction

Economics focuses on making the best use of scarce resources, the concept of *economic efficiency*. The theory applies to energy resources as it does to any other scarce resource. Societies have a wide range of objectives and we want to attain each objective in a way that uses energy efficiently. Economic efficiency can be thought of as maximizing the size of the pie, where the pie encompasses well-being of consumers and producers.

We can make the distinction sharper by distinguishing between private and social efficiency. *Private efficiency* involves only the parties participating in the market exchange. *Social efficiency* also includes those who were not directly involved in the exchange. In this text, economic efficiency is synonymous with social efficiency. Under certain conditions, the privately efficient outcome will also be socially efficient, and we will want to clearly establish the conditions where that happy outcome holds. When it does, the market produces the socially efficient outcome without any government intervention.

In energy markets, private and social interests often diverge. If I sell you my used gasoline-powered Hummer automobile that gets 10 miles per gallon and weighs close to 10,000 pounds, you and I both gain from the exchange. If we account for the carbon emissions from driving the Hummer, society might be better off with the Hummer in a landfill.[1] In fact, the vehicle was discontinued in 2010, not because of societal considerations but because the gas guzzler fell out of favor due to record-high gas prices in 2009. For those who still want to drive the behemoth, there is an all-new electric Hummer priced at around $100,000. If you want one, get on the waiting list. For now, the model is fully subscribed.

Society may object to market outcomes for reasons other than inefficiency. We may object on *equity* grounds. Markets distribute income, but there is much consternation about outcomes that increase inequality. On efficiency grounds, EU countries tax gasoline heavily, one reason Europeans drive smaller cars than Americans. However, such a tax takes a larger percentage of income from the poor than from the wealthy.[2] For another example of inequity, production in one location can result in pollution in another location. North Carolina sued the Tennessee Valley Authority because emissions from eastern Tennessee's coal-burning power plants blew into western North Carolina. Another possible inequity is that impoverished areas often experience higher levels of pollution, the issue of *environmental justice*.

Social welfare is a broad measure that encompasses social efficiency and equity. If efficiency is the size of the pie, equity refers to how we slice the pie. A *social welfare function*

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encompasses both efficiency and equity. For any objective, there can be many efficient points, some of which favor the poor and some the rich. Of these efficient points, the Bliss Point is the one that achieves the highest level of social welfare. The social welfare function is a theoretical ideal, but difficult to operationalize.[3]

A practical alternative to the social welfare function is *cost-benefit analysis* (*CBA*). The explicit purpose of CBA is to identify socially efficient uses of resources; implicitly, it embeds an equity judgment that a dollar is a dollar, no matter who receives it.[4] In essence, CBA typically ignores who receives the dollars.[5]

One other criterion for decision-making is sustainability. *Sustainability* requires that we use today's resources in a way that does not compromise the ability of future generations to be at least as well off as we are. Sustainability incorporates an intergenerational equity perspective. It constrains today's generation to resource uses that leave future generations at least as well off. The most widely referenced definition is that of the Bruntland Commission established by the United Nations: *sustainable development* meets the needs of the present without compromising the ability of future generations to meet their own needs.[6]

Sustainability is a challenging concept for economists because it is ambiguous. How much weight should we give today relative to society in ten years? 50 years? 1,000 years? Furthermore, understanding the meaning of "Future generations to meet their own needs" creates issues about assumptions of technological change and resource substitutability.

Let us sharpen the distinction about what we mean by future generations meeting their needs. Those who adhere to the Bruntland definition are referring to specific resources, such as oil or ecological services. In contrast, economist Robert Solow (1991) defined sustainability as using resources today in a way that allows future generations to have the *capacity* to be as well off as we are. The difference between the two is the degree to which we can substitute one resource for another. *Strong sustainability* does not allow substitution. Economists allow substitution to a greater degree, referred to as *weak sustainability*.

While economic efficiency and maximum social welfare may achieve sustainability, the objectives can conflict. Economic efficiency may favor the use of fossil fuels over renewable fuels based on cost considerations, social efficiency may favor renewable fuels once we allow for fossil fuel emissions, while social welfare may reach a different preferred outcome after incorporating income distribution considerations. Sustainability might reject continued use of fossil fuels if it leaves future generations with a smaller oil supply (strong sustainability) or undesirable climate change (weak sustainability).

Efficiency and sustainability as goals have different underlying ethical assumptions. Ethics guide human actions to distinguish good and bad. Economics embeds the ethical viewpoint that we should maximize our well-being or *utility*, implicitly accepting the philosophy of utilitarianism developed in the eighteenth and nineteenth centuries. The corresponding social welfare function indicates we should choose the action that produces the greatest good for society, depending on the weights we assign to individual well-being. In utilitarianism it is consequences that matter, not the morality of the actions leading to the consequences.

Under the utilitarian ethic, sustainability has no special meaning. If society today views itself as better off leaving future generations with at least as much productive capacity as we have today, then sustainability is a candidate for the best choice. If on balance we judge ourselves better off using resources today in a way that leaves the planet less habitable for future generations, then utilitarianism does not lead to a sustainable outcome.

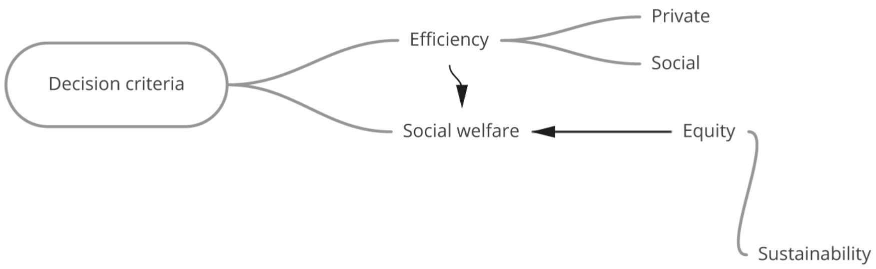

Figure 2.1 Criteria for decision-making

Sustainability has a different ethical underpinning. From perspectives such as to consider the seventh generation, or the Boy Scout dictum to "Leave no trace," the ethics of sustainability include the action, not just the consequence.[7] Furthermore, economics uses an *anthropocentric* perspective, where we only consider how our decisions affect human beings. Sustainability may use a broader biocentric perspective, where we consider all living things, whether or not they directly benefit us as human beings.[8] To the extent that today's decision damages ecosystems needed for life support, it may be that our traditional concept of efficiency is too narrow and tends to emphasize short-term benefits at the expense of long-term costs. Sustainability advocates might challenge the use of hydraulic fracturing (fracking) to release more oil and natural gas for many reasons, including the use of large quantities of water, damage to groundwater, and delaying the use of renewable fuels. Economists also consider these factors, but only within an efficiency framework. Strong sustainability advocates would call a halt to activities that make the future worse off regardless of the trade-off between short- and long-term gains.

Figure 2.1 provides a snapshot of the normative criteria that guide what is best for society. Throughout this text, we first consider private efficiency for the parties directly affected and then whether it coincides with social efficiency for all members of society. We bring in social welfare to incorporate income distribution. We consider sustainability if we want to restrict outcomes to those that leave future generations at least as well off as the present generation.

What is different about energy?

There is broad dissatisfaction with leaving energy questions to the market, not always derived from sound economic reasoning. Concerns include running out of oil, energy security considerations, and environmental damage, especially climate change. In order to consider whether we share these concerns, we first determine the outcome of unfettered markets and their ability to achieve efficiency—private and social—and maximum social welfare. We can also consider sustainability, bearing in mind that the measure goes beyond traditional economic analysis.

Market failure results when markets produce an economically inefficient outcome. Some definitions include inequitable outcomes. We will take note of the income distribution consequences, but economists have no special provenance over what is equitable. Therefore, in this text, we typically restrict the failures to inefficiencies. Energy markets are often missing one or more of the necessary conditions that assure economic efficiency, such as an absence of externalities. When there is market failure, we consider whether government can improve the outcome. At the same time, we need to bear in mind that there can be *government failure*, where the government has an objective other than economic efficiency.

Consider the following policies concerning coal use, nuclear energy, and renewables. Sometimes the countries choose their policies using criteria other than economic considerations. Energy economics offers tools to make the best use of scarce energy resources to achieve maximum well-being.

Policies on coal range from rapid expansion to abandoning its use. China continues to build new coal plants at a feverish pace to supply the electricity needed to fuel its economic growth despite pledges to cut carbon emissions. The United States has virtually no new coal-fired electricity plants on the drawing board, and electric utilities are shutting down many existing coal plants before their planned retirement date, although the U.S. still exports coal to other countries, with India being the top destination. Coal reserves are plentiful in both countries, yet the use of coal differs. U.S. federal policy has yet to establish a federal policy to limit CO_2 emissions, but some states, companies, and consumers have taken voluntary action. China kicked off a national carbon trading market in 2021, after testing out the mechanism for several years with a number of pilot programs.

Nuclear energy also provides electricity generation and does not emit carbon. Yet since the late 1970s, the U.S. had a virtual moratorium on the construction of nuclear plants after an accident at Pennsylvania's Three Mile Island facility. As the twenty-first century began and climate concerns grew, some observers predicted a nuclear renaissance. However, those prospects faded when, in 2011, Japan was hit by an earthquake and tsunami that devastated the Fukushima-Daiichi nuclear plant. Germany called a halt to its nuclear plans, while the U.S. took a go-slow approach. China upgraded its nuclear technology and planned to press ahead with new nuclear construction.

Even before Fukushima, nuclear plant construction proved to be far more expensive than projected, and there is still no long-term solution for storing nuclear wastes in any country. Yet, the sudden rejection of nuclear energy in Germany after Fukushima was due more to a change in the political winds than to a change in its cost. Despite climate concerns, many who oppose fossil fuels also oppose nuclear energy, but do not necessarily base their position on careful consideration of costs and benefits. While Germany has increased its use of renewables as it reduces its dependence on nuclear energy, it continued to use lignite, a particularly polluting form of coal, although it has now announced that by 2030, it will phase out the use of coal.

Proponents of renewable fuels may base their case on finding continued use of carbon-based and nuclear fuels unacceptable, rather than making a case that the alternatives have a lower social cost. The costs of wind and solar have dropped dramatically, and some argue that by forcing more use of these technologies today, we will hasten the improvements that will bring down costs further and faster. However, renewables have their own shortcomings.

Wind impacts views, as well as the flight path of birds, bats, and possible aircraft.[9] Solar requires large amounts of land, and the mining and waste of silica that goes into solar panels. Wind and solar plants are projected to last 20 to 30 years, and will create waste when they reach the end of their lifetime. More fundamentally, wind and solar are intermittent sources that are only available when the sun shines or the wind blows, which does not necessarily coincide with when we need the power. Demand may be highest late on a hot summer day, just when the sun is setting. Wind may blow more at night, when electricity demand is low. Solar plus storage, where the solar system includes battery storage, can help to alleviate intermittency, and will take on a larger role as battery prices continue to fall. Alternatively, it may be possible to link wind and solar facilities so that renewable energy is available at more hours.

Two of the most widely used programs to accelerate the use of renewables are *feed-in tariffs* (FITs) and *renewable portfolio standards* (RPSs). FITs are a price-based mechanism, while RPSs are quantity-based. Feed-in tariffs are a contract, typically for at least ten years, that require utilities to buy renewables at a price above conventional alternatives, with the price declining over time. While FITs accelerate the use of renewables, the high initial payment drives up the cost of electricity. Germany and Denmark are among the countries using FITs, and have among the highest electricity prices in the EU. In 1978, the U.S. passed the Public Utilities Regulatory Policy Act (PURPA), which required electric utilities to purchase renewables from independent power producers even if the utilities could produce the power more cheaply using conventional fuels. With the cost of renewables having declined steeply since that time, U.S. utilities have been pushing to weaken or eliminate the PURPA requirement.

The United States favors the RPS over FITs. The RPS requires electric utilities to generate a given percentage of electricity using alternative fuels, including renewables and in some cases energy efficiency. The United States has not instituted RPS as a nationwide standard. Instead, it has left it to the states to decide whether or not to implement a renewables standard. A majority of U.S. states have implemented RPS policies, with each state tailoring its approach to its local conditions. Many states already exceed the renewables requirements, which were typically set a decade ago and did not anticipate the rapid drop in the cost of renewables. California is among the states that has added a Clean Energy Standard that allows carbon-free sources including nonrenewable sources such as nuclear energy. California's RPS specifies that one-third of the fuel used to generate electricity must come from renewables in 2020, and 60% by 2030.[10] The Clean Energy Standard calls for 100% clean energy by 2045. North Carolina has a lower RPS target of 12.5% by 2021, but recognizes hog and swine wastes as potential sources of fuel despite their high cost. It also counts energy efficiency and wood chips. Most economists would prefer that we simply price carbon, rather than FITs and RPSs that pursue carbon reductions in ways that do not minimize costs.

Efficiency

In 1776, Adam Smith wrote *The Wealth of Nations*. In the book, Smith explained the ability of markets to produce the best outcome for society. Individuals seeking their own self-interest will end up achieving society's best interest, as if guided by an *invisible hand*. Moreover, they will better accomplish society's interest by pursuing their own self-interest than if they had set out instead to achieve society's best interests.

Over the years, economists have identified a number of conditions necessary to assure this result. The most prominent conditions include these: (perfect) competition, (perfect) information, absence of externalities, absence of public goods characteristics, and macroeconomic stability. These conditions are necessary to ensure that markets will achieve efficient use of resources from a societal perspective.

Market failure

In this section, we focus on three sources of market failure that are prominent in energy markets: monopoly, externalities, and public goods characteristics. We also introduce economies of scale. We give briefer treatment to imperfect information, macroeconomic market failure—inflation and unemployment—and second-best considerations, where inefficiency in one market can alter the most efficient policy in a related market. In the next chapter, we will present formal models to show the social welfare loss due to market failures from monopoly, externalities, and public goods characteristics.

Finally, we revisit equity and sustainability. While these topics are not efficiency concerns, some would include them as market failures that merit attention in designing energy policy.

Monopoly

Market power exists when individual firms can influence the market price. At the *monopoly* extreme, there is only one producer in the market, and that producer determines the industry price. There must also be barriers that prevent new firms from entering the industry.[11] These conditions allow the monopolist to earn a positive economic profit.

Economists prefer competition to monopoly because the loss to consumers from higher prices exceeds the profit gain to the monopolist, so that on balance society is worse off. Implicit in this statement is the equity criterion that a dollar to consumers is worth the same as a dollar to producers. The objection to the Organization of Petroleum Exporting Countries (OPEC) is not that they earn more profit than they did in the years before the formation of OPEC, but rather that the world as a whole would be better off if energy were produced competitively. This loss in social welfare is a *deadweight loss* (DWL), the loss to society from forgoing output with larger benefits than costs. With the U.S. now the world's largest energy producer, the U.S. may actually gain from higher oil prices, with gains to energy producers and job creation outweighing higher costs to consumers. However, global social welfare is maximized by competitive markets even if major oil-producing countries are worse off.[12]

Unlike monopoly, economic profits in a perfectly competitive industry tend towards zero, as firms enter the industry when other firms are earning profits and exit the industry when firms are losing money. This long-run tendency of surviving firms to earn zero economic profits leads the survivors to produce at the lowest possible long-run average cost (LRAC). In a competitive market, long-run price equals minimum LRAC. In addition, at the output level that minimizes average cost, marginal cost equals average cost. Competitive markets are efficient because price equals marginal cost, and in the long run, price (P), marginal cost (MC), and minimum average cost are all equal.

The condition that price equals minimum LRAC indicates efficient resource use, insofar as there is no other combination of labor and capital that could produce a given level of output at a lower cost. In addition, $P = MC$ is the *hallmark of efficiency*. *Marginal cost*, the addition to total cost from producing an additional unit of output, can also be thought of as *opportunity cost*, the value of resources in terms of the best forgone alternative. When price equals marginal cost, there is an incentive to produce the efficient output. Monopolists charge a price above marginal cost. OPEC is not a monopoly, but resembles one insofar as it limits supply so as to charge a price above marginal cost ($P > MC$), and while OPEC gains, there is a loss to global social welfare as a whole.

Economies of scale

There is an exception where monopoly is potentially more efficient than competition. This is the case of *natural monopoly*, where the lowest-cost method of production is to have a single firm in the industry. *Economies of scale* exist as long as LRAC is declining in the relevant range of demand. To minimize LRAC, we only want one firm.

In electricity production, for example, we only want one set of electricity transmission and distribution lines. While *electricity generation*—the production of electricity using conventional and alternative fuels—was also characterized as a natural monopoly for many years, small-scale generation, such as from renewable energy, can now be cost-effective. *Microgrids* are small electricity networks that can operate independently of the utility grid. Nuclear and hydro energy are developing smaller-scale technologies.

Externalities

Externalities, also known as third party or spillover effects, occur when two parties make a decision that affects others, but the two parties do not internalize those third-party effects into their decision. Consider a steel firm choosing between coal and natural gas to heat a furnace to melt steel ore. In an unfettered market, the producer chooses the fuel that minimizes its private cost of heating but does not include the external cost to society for unpriced resources such as using the air as a pollution sink. We cannot assume that energy users or producers will voluntarily take into account emissions that reduce air quality or contribute to climate change.[13]

Gasland is a documentary about hydraulic fracturing that shows potentially alarming externalities. Among other effects, it depicts flames coming out of kitchen water faucets, purported consequences of chemicals used in the fracking process. Left unregulated, the producers disregard these spillover effects.[14]

You may argue that consumers would be willing to pay more for cleaner energy than for fracked fuels. However, even if some consumers would pay a premium for cleaner energy, we will still stop short of the socially efficient outcome. Some consumers will buy dirtier fracked fuel, while benefiting from less pollution if others are willing to pay more for cleaner alternatives. The benefits of cleaner fuel go to everyone, and no one can be excluded from them. Clean air has the characteristics of a public good, which brings us to the next source of market failure.

Public goods

Public goods are an extreme case of *positive externalities*, where the provision of a good has external benefits. In the case of a global public good such as less global warming, everyone benefits.[15]

A *pure public good* has two characteristics. It is nonrival and nonexcludable.[16] Nonrival means that my use of the good in no way diminishes the amount available to you. Nonexcludable means no one can be prevented from using the good. In contrast, pure private goods are both rival and excludable.

Range of goods between public and private

	Rival	Nonrival
Excludable	Pure private goods	Club goods
Nonexcludable	The commons	Pure public good

Figure 2.2 Range of goods between public and private

Viewing pure public and private goods as opposites in a taxonomy of goods, there are goods that are rival but nonexcludable (referred to as "the commons"), and nonrival but excludable (impure or quasi-public goods, also called club goods). Figure 2.2 classifies goods according to these two characteristics.

Markets will not provide nonrival goods efficiently, whether or not they are nonexcludable. Markets usually sell goods to individuals who in turn do not share with society in general. But where benefits are nonrival, the good should be freely available to all.[17] Where the good is also nonexcludable, markets will not only fail but fail miserably, as *free riders* will recognize that they can obtain the benefits of the good without paying. Where the good is excludable, it is technically feasible to sell the good in private markets, but it is generally not efficient to do so from a societal perspective.

Public goods characteristics are at the core of why it is so difficult to achieve a climate change agreement. All countries benefit from greenhouse gas (GHG) reductions, and no country can be excluded from those benefits. Hence, each country has the incentive to free-ride by advocating for a reduction in GHGs while finding a way to avoid participating. For example, China argued during initial rounds of climate-change talks that the United States polluted when it was an industrializing nation and China should now have the same opportunity until they fully achieve development.[18]

The efficient amount of research and development (R&D) into *nuclear fusion*—the process by which atoms fuse together and release energy, as on the sun's surface—is where the sum of the marginal benefits equals marginal cost. Suppose a company invents cold-fusion technology, a way to produce nuclear fusion without the need to achieve the sun's temperature. Efficiency calls for a zero usage fee to allow everyone to benefit. However, if no one can be excluded, the developer will have difficulty profiting from the discovery. Patents protect the developer by awarding monopoly rights for a specified number of years, but they inefficiently exclude other companies from using the new knowledge. In this case, there will be some R&D, but less than the efficient amount.

Other potential market failures

We complete the taxonomy of market failures by reviewing other potential challenges to market outcomes. Further sources of inefficiency include imperfect information, second-best considerations, and macroeconomic instability. Other challenges to market outcomes are due to inequitable income distribution or unsustainable outcomes.

There can be market failures in energy markets due to *imperfect information*. Consumers may be unaware of the connection between energy use and climate change. Or they may have little knowledge of energy prices, as seems to be the case in studies that show that consumers know the average price, but not the marginal price, of electricity. Average price includes fixed costs, which are irrelevant to efficient short-run decisions, whereas marginal price indicates the opportunity cost of using electricity. Where there is *asymmetric information*, one party has superior information. Manufacturers of compact fluorescent bulbs know the bulbs contain mercury and should be handled carefully. If you knew of that hazard, you might be less likely to purchase their product.

Competition achieves efficiency when the starting point is that all other markets are efficient. In a *second-best* world, our starting point is that there is an existing market failure in one or more other markets. If two markets are interrelated and it is not possible to correct the failure in the imperfect market, it may be beneficial to intervene in the perfect market. If the use of fossil fuels is contributing to global warming but carbon emissions go unpriced, there may be a justification to subsidize cleaner alternative fuels. Ordinarily, efficiency requires price to equal marginal cost. However, in the world of the second best where one market, such as fossil fuels, has a distortion, it may actually be more efficient to introduce a distortion in a second market for renewable fuels or energy-efficient appliances rather than to price them at marginal cost.

A macroeconomic market failure occurs when there is market instability due to inflation or unemployment. These failures cause inefficiency insofar as the economy performs below its potential gross domestic product (GDP). High fuel costs have triggered recessions beginning with the 1973 Middle East oil embargo. In the 2008 Great Recession, there were subsidies for green infrastructure projects as a way to create jobs. The justification for such subsidies depends on their opportunity cost. How many jobs are created per dollar spent? Would the overall gain in jobs be greater if the money were invested into R&D for traditional fuels? Or would society be still better off if the dollars were spent on mass transit, more roads, cleaner air, or nonenergy expenditure such as investment in public education (especially at the university where you are studying)?

Equity can be considered a market failure of a different type than market inefficiency. In 1991, economist Larry Summers, then Chief Economist at the World Bank, raised the ire of many when in a leaked memo, he wrote, "Just between you and me, shouldn't the World Bank be encouraging MORE migration of the dirty industries to the least developed countries?"[19] He was applying economic efficiency, whereby a low-income country would voluntarily accept dangerous products in return for compensation that could be used to address other problems such as providing food or improving medical services. Some would argue it is morally wrong to place developing countries in a position where they have to decide between profits and health. Advocates of environmental justice maintain that it is wrong for poor people, whether in lower-class neighborhoods in the United States or in developing countries, to suffer a disproportionate amount of environmental hazards. This exposure may be voluntary as in Summers' proposal, or involuntary, as in the case of Chester, Pennsylvania, an impoverished town that became an unwitting depository for toxic wastes.[20]

Sustainability might be categorized as a market failure to the extent that markets may not adequately protect future generations. There is even an economic efficiency argument made by Brock and Xepapadeas (2003) that we discuss later in the chapter that insofar as evolution is an efficient process that takes millions of years, economic efficiency evaluations are likely to undervalue such long-term changes. There could also be an equity argument that it is unfair for us to improve our well-being at the expense of the future, who are not here to represent their interests. Given the importance of this topic in public discourse, we return to it later in this chapter and it is the subject of Chapter 15 as well.

Social welfare

There are an infinite number of ways to allocate our scarce resources. The United States stockpiles oil in a strategic petroleum reserve (SPR), for use only in the event of adverse developments in the oil market. Is the SPR a sensible policy to smooth oil price fluctuations? If it is, has the U.S. stockpiled the right amount, or is it too large or too small? If there is another oil embargo, should we ration gasoline, or leave it to the market even if it means that the price could double overnight with the poor impacted disproportionately? Social Welfare Analysis (SWA) provides a framework for choosing the best outcome based on efficiency and equity considerations.

Pareto and Hicks-Kaldor efficiency

Efficiency provides a menu of all the outcomes that make the best use of societal resources. *Pareto improvements* restrict us to those outcomes that make at least one person better off, without making anyone else worse off. When we have reached the point where it is impossible to make someone better off without making someone else worse off, we have reached a *Pareto efficient* point.

The Pareto criterion has the advantage that we do not need to make interpersonal comparisons, as there are no losers. It gives us a measure of absolute efficiency. Something is either efficient or it is not. However, from a policy standpoint, Pareto efficiency is a very restrictive standard, as there may be few changes where there are only winners and no losers. A change that makes 1,000 people better off by $1 million each at the expense of making one person worse off by $1 would not meet the Pareto criterion.

Hicks-Kaldor efficiency is a relative efficiency measure. An outcome is Hicks-Kaldor efficient if the winners could compensate the losers for accepting a change, even if compensation does not take place. In that sense, it is a "potential Pareto improvement." If compensation does take place, it would then be a Pareto improvement.

On balance, countries that are not major oil producers likely benefit when gasoline prices fall. Consumers have more money to spend, and the economy benefits. Producers that use energy as an input also benefit. Losers include companies and workers in the oil and gasoline industries. Also, we all lose insofar as emissions increase. Lower gas prices may meet the Hicks-Kaldor definition of efficiency, but not the Pareto definition.

Efficiency vs. equity

Efficiency and equity can be conflicting goals. It may be efficient to allow the market to allocate oil, even if it means high prices during a time of tight supplies. The higher cost may fall disproportionately on lower-income households who use a larger proportion of their budget on gasoline purchases than do the wealthy. Alternatively, if we allow the poor to purchase gas at a below-market price, they will increase their purchases, resulting in still tighter supplies. If price does not cover opportunity cost, producers will lose money and production will decrease still further.[21]