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Environmental Economics

– Lecture Notes –

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to Huib Jansen and David Pearce

Preface

These lecture notes accompany the international second edition (2011) of the textbook *Intermediate Environmental Economics* by Charles D. Kolstad. Charlie's textbook is excellent, but some topics are not covered in sufficient depth and other issues are not discussed at all. These notes are meant to complement the textbook.

The audience are third year undergraduate students of economics in an English university. These students have seen calculus and two terms of micro- and macroeconomics.

Barcombe, June 2020 *Richard Tol*

Acknowledgements

These lecture notes are based on *Intermediate Environmental Economics* by Charles D. Kolstad. I have learned a lot from Charlie since we first met 25 years or so ago.

I used to teach environmental economics based on *Natural Resource and Environmental Economics* by Roger Perman, Yu Ma, Michael Common, David J. Maddison and James McGilvray. George MacKerron taught the same course using *Environmental and Natural Resource Economics—A Contemporary Approach* by Jonathan M. Harris and Brian Roach. Where I deviate most from Kolstad, I probably follow Perman or, less often, Harris.

George MacKerron helped in many ways, small and big. Sarah Jacobsen challenged me to look deeper into Malthus and the Romanticists. Michael Munger helped clarify what Robert Carlyle wrote, Marcel Severijnen pointed me to Tacitus. Paul Kelleher has a cameo in a footnote.

Contents

Part I
Foundations

Chapter 1
Origins

1 Proto-economics

Trigger warning: Many of the quotes in this section are rather racist.
Economics conventionally starts with the publication of *The Wealth of Nations* in 1776 by Adam Smith.[1] Before that, however, many anticipated what later became elements of economics.

In those early days, agriculture was the dominant sector in the economy. Production was production of food, trade was trade in food, consumption was consumption of food. Cato (*de Agri Cultura*, c160 BCE), Varro (*Res Rustica*, 37 BCE), Columella (*De Re Rustica*, 41-68) and Palladius (*Opus Agriculturae*, c400) all wrote handbooks on farm management. These proto-economists, like all farmers and land-owners, were keenly aware of the importance of climate and geography.

In those days, teleology was common: Things were as they should be. Marcus Tullius Cicero[2] (44 BCE, On Duties, I 42 151) argues that

> of all the occupations by which gain is secured, none is better than agriculture, none more profitable, none more delightful, none more becoming to a free man

Cicero was writing about large landowners, not about farmhands or peasants. He argued that the landowning elite, which dominated Rome politically and economically, was morally superior. Those on top deserved to be on top. In the words of John Kenneth Galbraith[3]

> what is called sound economics is very often what mirrors the needs of the respectably affluent.

[1] Smith (1723-1790) taught philosophy and law at the University of Glasgow.

[2] Cicero (106-43 BC) was a statesman, lawyer, and scholar.

[3] Galbraith (1908-2006) taught economics at Harvard University. His work was mostly qualitative and rather critical of stylized mathematical models.

1.1 Environmental determinism

Ancient scholars did not just think that the natural environment was important. They thought it was predominant. For instance, Hippocrates[4] (400 BCE, On Airs, Waters, Places, 23) wrote

> The other races in Europe differ from one another, both as to stature and shape, owing to the changes of the seasons, which are very great and frequent, and because the heat is strong, the winters severe, and there are frequent rains, and again protracted droughts, and winds, from which many and diversified changes are induced. These changes are likely to have an effect upon generation in the coagulation of the semen, as this process cannot be the same in summer as in winter, nor in rainy as in dry weather; wherefore, I think, that the figures of Europeans differ more than those of Asiatics; and they differ very much from one another as to stature in the same city; for vitiations of the semen occur in its coagulation more frequently during frequent changes of the seasons, than where they are alike and equable. And the same may be said of their dispositions, for the wild, and unsociable, and the passionate occur in such a constitution; for frequent excitement of the mind induces wildness, and extinguishes sociableness and mildness of disposition, and therefore I think the inhabitants of Europe more courageous than those of Asia; for a climate which is always the same induces indolence, but a changeable climate, laborious exertions both of body and mind; and from rest and indolence cowardice is engendered, and from laborious exertions and pains, courage. On this account the inhabitants of Europe are than the Asiatics, and also owing to their institutions, because they are not governed by kings like the latter, for where men are governed by kings there they must be very cowardly, as I have stated before; for their souls are enslaved, and they will not willingly, or readily undergo dangers in order to promote the power of another; but those that are free undertake dangers on their own account, and not for the sake of others; they court hazard and go out to meet it, for they themselves bear off the rewards of victory, and thus their institutions contribute not a little to their courage.

Hippocrates' prediction that Europeans can never have absolute monarchs is wrong in retrospect. Note that he argues that there are all sorts of things wrong with non-Greek Europeans and Asiatics—because of where they live—implying that the climate in Greece is responsible for the superiority of him and his countrymen.

Aristotle[5] (350 BCE, Politics, 7 VII) wrote

> Those who live in a cold climate and in Europe are full of spirit, but wanting in intelligence and skill; and therefore they retain comparative freedom, but have no political organization, and are incapable of ruling over others. Whereas the natives of Asia are intelligent and inventive, but they are wanting in spirit, and therefore they are always in a state of subjection and slavery. But the Hellenic race, which is situated between them, is likewise intermediate in character, being high-spirited and also intelligent. Hence it continues free, and is the best-governed of any nation, and, if it could be formed into one state, would be able to rule the world.

Aristotle predicted that Europeans could never rule over others. While he foresaw the empire of Alexander the Great, he missed the empires founded by Romans, Franks, Arabs, Mongols, Spaniards, Portuguese, Dutch, Mughals, English, French, Sikhs,

[4] Ἱπποκράτης ὁ Κῷος (c460-c370 BC) was a physician, often regarded the father of medicine.

[5] Ἀριστοτέλης (384-322 BC) made early contributions to physics, mathematics, biology, political science, psychology, and economics, among others.

and Russians. Like Hippocrates, he argued that his own people were superior by virtue of their climate.

The ancient Greeks were not alone. In an important, early Chinese text, Guan Zhong[6] (780 BCE, Guanzi, XIV 39) writes

> What is water? It is the root of all things and the ancestral hall of all life. It is that from which beauty and ugliness, worthiness and unworthiness, stupidity and giftedness are produced.
>
> How do we know this to be so? Now the water of Qi is forceful, swift and twisting. Therefore its people are greedy, uncouth and warlike. The water of Chu is gentle, yielding, and pure. Therefore its people are lighthearted, resolute, and sure of themselves. The water of Yue is turbid, sluggish, and soaks the land. Therefore its people are stupid, disease ridden, and filthy. The water of Qin is thick like gruel and stagnant. It is obstructed, choked with silt, and wanders in confusion free of its banks. Therefore its people are greedy, violent, and deceptive, and they like to meddle in affairs. The water of Jin is bitter, harsh, and polluted. Therefore its people are flattering and deceitful, cunning and profit seeking. The water of Yan collects in low places and is weak. It sinks into the ground, is clogged, and wanders in confusion free of its banks. Therefore its people are stupid, idiotic, and given to divination. They treat disease lightly and die readily. The water of Song is light, strong, and pure. Therefore its people are simple and at ease with themselves, and they like things to be done in the correct way. For this reason, the sages' transformation in the world lay in understanding water.
>
> Now, when the water is unadulterated, people's hearts will be correct, they have no desire to be corrupt. When people's hearts are at easy, their conduct will never be depraved. For this reason, the sages' bringing good order to the world did not lie in preaching to every person or persuading every household, but in taking water as their central concern.

The idea that you are what river shore you dwell on, seems odd to us. But note that Guan Zhong argues that you should not appeal to people's innate goodness. Instead, a wise ruler improves water courses. He so justifies the elite in a hydraulic society, whose main role was to provide public goods in water management.

The idea of environmental determinism lingered. Ibn Khaldun[7] (1377, Muqaddimah 1 4)

> We have seen that Negroes are in general characterized by levity, excitability, and great emotionalism. They are found eager to dance whenever they hear a melody. They are everywhere described as stupid. The real reason for these (opinions) is that, as has been shown by philosophers in the proper place, joy and gladness are due to expansion and diffusion of the animal spirit. Sadness is due to the opposite, namely, contraction and concentration of the animal spirit. It has been shown that heat expands and rarefies air and vapors and increases their quantity. [...]
>
> Now, Negroes live in the hot zone (of the earth). Heat dominates their temperament and formation. Therefore, they have in their spirits an amount of heat corresponding to that in their bodies and that of the zone in which they live. In comparison with the spirits of the inhabitants of the fourth zone,[8] theirs are hotter and, consequently, more expanded. As a

[6] 管仲(c720-645 BC) was a philosopher and politician.

[7] أبو زيد عبد الرحمن بن محمد بن خلدون الحضرمي (1332-1406) was a philosopher, social scientist and historian.

[8] Ibn Khaldun split the world into seven climate zones. The fourth zone, the middle one, had the optimal climate. Other zones were too hot or too cold. Ibn Khaldun lived in, where else, the optimal climate.

> result, they are more quickly moved to joy and gladness, and they are merrier. Excitability is the direct consequence.
>
> In the same way, the inhabitants of coastal regions are somewhat similar to the inhabitants of the south. The air in which they live is very much hotter because of the reflection of the light and the rays of (the sun from) the surface of the sea. Therefore, their share in the qualities resulting from heat, that is, joy and levity, is larger than that of the (inhabitants of) cold and hilly or mountainous countries. To a degree, this may be observed in the inhabitants of the Jarid in the third zone. The heat is abundant in it and in the air there, since it lies south of the coastal plains and hills. Another example is furnished by the Egyptians. Egypt lies at about the same latitude as the Jarid. The Egyptians are dominated by joyfulness, levity, and disregard for the future. They store no provisions of food, neither for a month nor a year ahead, but purchase most of it (daily) in the market. Fez in the Maghrib, on the other hand, lies inland (and is) surrounded by cold hills. Its inhabitants can be observed to look sad and gloomy and to be too much concerned for the future. Although a man in Fez might have provisions of wheat stored, sufficient to last him for years, he always goes to the market early to buy his food for the day, because he is afraid to consume any of his hoarded food.
>
> If one pays attention to this sort of thing in the various zones and countries, the influence of the varying quality of the air upon the character (of the inhabitants) will become apparent. God is the Creator, the Knowing One. Al-Masudi undertook to investigate the reason for the levity, excitability, and emotionalism in Negroes, and attempted to explain it. However, he did no better than to report, on the authority of Galen and Ya'qub b. Ishaq al Kind!, that the reason is a weakness of their brains which results in a weakness of their intellect. This is an inconclusive and unproven statement. God guides whomever He wants to guide.

Like Hippocrates and Aristotle, Ibn Khaldun argued that his climate was the best. He adds Cicero's teleology. Arabs were superior because Allah had bestowed them with the optimal climate. The dominant position of Arabs was not by happenstance, but God's will.

Ibn Khaldun's sentiment is reflected in the expression *God's own country*, which has been used to describe, amongst others, Kerala, Yorkshire, and Rhodesia. Robert Rankin[9] mockingly places the Garden of Eden in Brentford.

Montesquieu[10] (1748, The Spirit of Laws, 1 XIV) argues that the climate of France is best. He writes that

> [...] the temper of the mind and the passions of the heart are extremely different in different climates [...]
>
> People are therefore more vigorous in cold climates. [...] In cold countries they have very little sensibility for pleasure; in temperate countries they have more; in warm countries their sensibility is exquisite. [...]
>
> In northern climates, scarcely has the animal part of love a power of making itself felt. In temperate climates, love, attended by a thousand appendages, endeavours to please by things that have, at first, the appearance, though not the reality, of this passion. In warmer climates, it is liked for its own sake, it is the only cause of happiness, it is life itself.

In other words, only the French have the right mix of strength and purpose.

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[9] Rankin (1949-), Magus to the Hermetic Order of the Golden Sprout, 12th Dan Master of Dimac, is a writer of far-fetched fiction, tall tales and old toot.

[10] Charles-Louis de Secondat, Baron de La Brède et de Montesquieu (1689-1755) was a judge, man of letters, and political philosopher.

More than 200 years later, Ellsworth Huntington[11] (1915, Civilization and Climate) wrote

> Today a certain peculiar type of climate prevails wherever civilization is high. IN the past, the same type seems to have prevailed wherever a great civilization arose.

Huntington's main innovation on earlier environmental determinists was that he argued that climate is not static. Instead, climate changes. Huntington argued that climate changes people:

> In tropical countries weakness of will is unfortunately a quality displayed not only by the natives, but by a large proportion of the northerner sojourners. If manifests itself in many ways. Four of these, namely, lack of industry, an irascible temper, drunkenness, and sexual indulgence are particularly prominent, and may be taken as typical.

At the same time, he argued that

> the effect of a diverse inheritance would last indefinitely

in a thought experiment about "Teutons" and "negroes" moving to an empty country much like Egypt.

It was only in 1922 that Lucien Febvre[12] started the intellectual push back against environmental determinism. It is now an uncommon position in the social sciences. Indeed, the racist and self-serving reasoning of the early environmental determinists render it disreputable in the eyes of many of our contemporaries.

That said, environmental determinism has not disappeared. Jared Diamond[13] is probably the most prominent of current environmental determinists.

1.2 Early concerns about pollution

Early scholars wrote about the natural environment and its effect on society. Environmental pollution and resource degradation recognized too. Ancient Greece and Turkey, for instance, suffered from deforestation and soil erosion. Of his native Attica, Plato[14] (Critias, 360 BCE) wrote

> its mountains were high hills covered with soil, and the plains [...] were full of rich earth, and there was abundance of wood in the mountains.

but

> now losing the water which flows off the bare earth into the sea

[11] Huntington (1867-1947) taught geography at Yale University.

[12] Febvre (1878-1956) taught history at the University of Strassbourg.

[13] Diamond (1937-) is a physiologist, ornithologist and environmental historian, who teaches geography at the University of California, Los Angeles.

[14] Πλάτῶν (c425-c347 BC) was a philosopher.

That is, Plato understood the relationship between deforestation, soil erosion, and water run-off. Visitors to modern Greece may wonder how such a barren landscape could have supported such a rich civilisation. It did not. Greece was not barren then.

Rome and its empire suffered from lead poisoning in water and air, but they themselves were not aware of this. Air pollution was more easily detected. Seneca[15] Letters from a stoic, CIV, 61) wrote about

> the oppressive atmosphere of the city and that reek of smoking cookers which pour out, along with a cloud of ashes, all the poisonous fumes.

Environmental policy also goes way back. As the price of fuel wood rose in London, people switched to sea coal, bituminous coal mined on the northeast coast of England. King Edward I of England banned sea coal in 1307. Nonetheless, smog continued to plague London. In December 1952, some 4,000 people were killed by air pollution and maybe 8,000 more in the following months. The Clean Air Act of 1956 marks the beginning of the transition away from coal as the prime fuel for heating in the cities of the UK.

Condorcet[16] (Thoughts on the wheat trade, 1776) wrote of stubble burning that

> by corrupting the air, causes illnesses in neighboring homes.

This may be the first formulation of an externality, the unintended and uncompensated impact of an economic activity on a third party. Stubble burning is still a big problem, regularly causing major air pollution on the Indian subcontinent. Condorcet argued that externalities like these are the *only* legitimate legal restraint on property rights.

2 Classical economics

2.1 Adam Smith on public goods

Adam Smith's 1776 book *An Inquiry into the Nature and Causes of the Wealth of Nations* is often seen as the starting point of economics as a separate discipline.

Smith is seen as a proponent of laissez-faire, the idea that the government should not intervene much in the economy, particularly through the doctrine of the invisible hand, in which the market coordinates selfish interests to deliver the social good.[17] We now call this the First Fundamental Welfare Theorem. We recognize that it only holds under rather stringent conditions, and that Smith's social good is a Pareto optimum.

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[15] Lucius Annaeus Seneca the Younger (c4 BC-65 AD) was a philosopher, statesman, and dramatist.

[16] Marie Jean Antoine Nicolas de Caritat, Marquis of Condorcet (1743-1794) was a philosopher and mathematician, remembered in economics for his work on voting.

[17] You have one chance to make a first impression. Lay people typically think that Smith's views on economic policy are shared by all economists. This is peculiar, because Karl Marx was an eminent economist too. After World War II, many economists advocated some form of central planning, including Nobelists Tinbergen, Kantorovich, Koopmans and Klein.

Smith (Wealth of Nations, 1776 V 1) did argue, though, that

> The third and last duty of the sovereign or commonwealth is that of erecting and maintaining those public institutions and those public works, which, though they may be in the highest degree advantageous to a great society, are, however, of such a nature that the profit could never repay the expense to any individual or small number of individuals, and which it therefore cannot be expected that any individual or small number of individuals should erect or maintain. [...] The performance of this duty requires, too, very different degrees of expense in the different periods of society.
>
> After the public institutions and public works necessary for the defence of the society, and for the administration of justice, both of which have already been mentioned, the other works and institutions of this kind are chiefly those for facilitating the commerce of the society [such as good roads, bridges, navigable canals, harbours], and those for promoting the instruction of the people.

Smith realized that the market underprovides public goods, and called for government intervention—Smith's sole deviation from *laissez faire*.[18]

Recall that, in the same year, Condorcet called for government intervention on externalities. The intellectual foundation for environmental economics was laid in 1776.

2.2 Malthus, Ricardo and Mill on resource limits

Thomas Robert Malthus[19] (1798, An Essay on the Principle of Population) wrote

> Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio.

Figure 1 illustrates this. The supply of food increases linearly or arithmetically. The number of people, and so the demand for food increases exponentially or geometrically. Exponential growth is faster than linear growth. We will therefore run out of food at some point in the future, the *Malthusian Catastrophe*.[20]

Malthus had a solution too: Abstinence.[21] At that time, you could not have babies without sex.

Malthus' argument that food production grows only linearly hinges on decreasing returns to scale in agriculture. If you double the number of farmhands, on a piece of land, you will increase but not double the harvest.

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[18] Smith argued that the government should *not encourage* cartel formation, but take no action otherwise.

[19] Malthus (1766-1834) was an English cleric and scholar. He was the first professor of economics.

[20] Thomas Carlyle (1839, Chartism) referred to Malthus' work as "[d]reary, stolid, dismal, without hope for this world or the next". Carlyle (1849, The Negro Question) coined the term *the dismal science* in 1849, dismal in "find[ing] the secret of this Universe in 'supply and demand', and reducing the duty of human governors to that of letting men alone". Carlyle argued for slavery. Carlyle's suggestion was resisted by, among others, John Stuart Mill. Carlyle, an historian, philosopher and mathematician, lived from 1795 to 1881.

[21] Charles Trevelyan (1807-1886), one of Malthus' star students, contributed greatly to the *Great Famine* in Ireland and made smaller contributions to a series of famines in India.

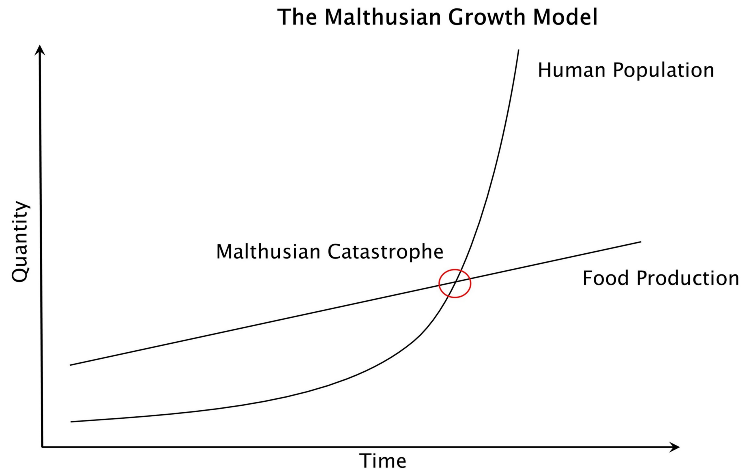

Fig. 1: Supply and demand for food over time.

David Ricardo[22] refined the argument. He distinguished between the *internal margin* and the *external margin*. You can increase food production at the internal margin by working crop lands harder. As Malthus noted, this is subject to decreasing returns to scale. At the external margin, you can take virgin lands into crop production. Malthus ignored this. Ricardo did not. Ricardo argued, however, that the external margin would not get around the Malthusian Catastrophe because our ancestors cultivated the best lands first. Expansion on the external margin is thus subject to decreasing quality.

John Stuart Mill[23] further refined the Malthusian argument, nothing that the Catastrophe can be postponed by input substitution. Fertilizers make up for a shortage of soil nutrients, irrigation for a shortfall of rain. However, like Malthus and Ricardo and indeed all Classical Economists, Mill was convinced that economic growth must come to a halt because of resource constraints.

2.3 Romanticism

The Classical economists were sons of the *Enlightenment*. A central part of the Enlightenment was that arguments should be based on observations rather than authority and that decisions should be rational. Economics at the time was typically

[22] Ricardo (1772-1823) was a banker and Member of Parliament of the Great Britain and Ireland. He is best known for his work on international trade.

[23] Mill (1806-1873) was a colonial administrator. Although his work was published under his name, Harriet Taylor (1807-1858) was a frequent co-author.

called *political economy*, a reference to rational, scientifically informed government of markets.

Romanticism was a countermovement to the Enlightenment. It was concentrated in the arts, mostly literature (Brontë sisters, François-René de Chateaubriand, Johann Wolfgang von Goethe, Friedrich Schilling, Hendry David Thoreau, William Wordsworth) and to a lesser extent painting (e.g., Caspar David Friedrich) and music (e.g., Johann Sebastian Bach). Romanticists shared three traits. They drew on the older school of *Sentimentalism*, arguing that emotions are a valid basis for decisions. They harked back to a simpler, better past, with comely maidens dancing at the crossroads. And they believed that nature was beautiful and to be enjoyed, rather than dangerous and to be subjugated. These conflicting portrayals of nature continue to today, from Bruno Latour's "how could I love nature? I'm from Burgundy" to Seamus Heaney's Death of a Naturalist.

Romanticism had three major offshoots: Communism, Nazism/Fascism, and Environmentalism.

Mao Zedong and Pol Pot took the harking for the past to the extreme, forcing city dwellers to move to the countryside and take up farming.[24] The longing for the past extended to the mighty kings of yore, and the fascists' desire for a strong leader—although other Romanticists misremember a past of direct democracy.[25] In that mythical past, everyone was blond with blue eyes. The racial purity of *Blut und Boden* is a key part of Nazism.

Environmentalists tend to argue that things used to be better, and often believe in the myth of the noble savage,[26] who represents the lost morality of the olden days. There is a famous quote

> Only when the last tree has been cut down, the last fish been caught, and the last stream poisoned, will we realize we cannot eat money.

This is often presented as a Cree Indian proverb, exemplifying the wisdom and environmental stewardship of pre-modern people.[27] In fact, whenever *homo sapiens* introduced itself to a new ecosystem, it wreaked great havoc, including mass extinctions. Some environmentalists embrace Wicca or some such. Respect for nature is a common trait in neo-paganism, the belief in magic is as anti-Enlightenment as it gets.

Environmentalism shares its roots with odious ideologies, but few environmentalists would support them.[28] That said, environmentalists tend to be to the political

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[24] In the Communist Manifesto, Marx and Engels wrote about the "idiocy of rural life".

[25] Direct democracy is probably more common among environmentalists than authoritarianism, even though people do not necessarily vote green in referendums.

[26] The noble savage was introduced into modern thought by Michel de Montaigne (1533-1592), a philosopher, in 1580. Earlier, in 98, Tacitus (56-120), a historian and politician, had described the Germans as noble savages.

[27] It is actually a modern quote of an Abenaki activist who left the reservation at age 7. The quote was popularized by Greenpeace.

[28] Many fascists love nature, Hitler prime amongst them, Communists less so. Guilt by association is a logical fallacy.

left, although the watermelon epithet—green on the outside, red on the inside—is an exaggeration. Some environmentalists argue that democracy is not suited for solving the crisis in the environment, calling for "scientific" oversight of policies or political candidates to be vetted by "experts".[29] The term *eco-fascist* is used with abandon in some circles. Although there are environmentalists who do not tolerate dissent and pursue their green goals through violent means, this is a small minority.

In older literature, danger lurked in the deep dark wood. Romanticists were the first to describe nature as something to enjoy rather than fear. This is a reflection of the times. Large predators had mostly disappeared from Western Europe, and you were never far from people. Nature had been tamed and could be enjoyed. People even started swimming in the sea. The oldest environmental organizations began as nature conservation,[30] and emphasized that nature made you a morally better person.

Many people care about the environment but not about Romanticism. The *Ecomodernist* movement explicitly embraces the Enlightenment and combines it with concern for the environment. It takes positions that are often controversial to environmentalists, arguing for instance that nuclear power is a valid strategy to reduce carbon dioxide emissions and that intensive agriculture is better for nature than the organic sort. Environmental economists are probably more comfortable with ecomodernism while ecological economists tend to associate more with environmentalism.

2.4 Mill on amenity values

John Stuart Mill (1848, Principles of Political Economy) brought some Romantic elements into economics,[31] writing

> There is room in world, no doubt, for a great increase in population, supposing the arts of life to go on improving, and capital to increase. [...] The density of population necessary to obtain all of the advantages both of cooperation and of social intercourse [...] has been attained. A population may be too crowded, though all be amply supplied with food and raiment. [...] Nor is there much satisfaction in contemplating the world with nothing left to the spontaneous activity of nature.

and adding, for good measure,

> it is only in backward countries of the world that increased production is still an important object[ive]

[29] The clergy in Iran has a similar position. Francis Bacon (1561-1622), a philosopher and statesman, put scientists in charge of his utopian Bensalem.

[30] The World Wide Fund for Nature was started to protect the African hunting grounds of nobility and royalty from the incursion by black people after the end of colonialism. One of its founders was a member of the *Hitlerjugend*, the other of the *Afrikaner Broederbond*. WWF has never quite lost that attitude, see its scandals with indigenous rights and beatings.

[31] Romanticists were fond of Malthus' work, but he was not a Romantic. Malthus was a numbers man, striving for a better future rather than pining for a misremembered past and, as all Classical economists, rather wary of a strong government.

That is, Mill argued against equating well-being with *material* well-being. This foreshadows Kuznets'[32] admonishment that Gross Domestic Product (GDP) is a measure of economic activity, not welfare. Mill noted the importance of social intercourse (which we would now rather call interaction) and emphasized the amenity value of nature.

3 Neo-classical economics

The neo-classical revolution, led by William Stanley Jevons[33], Carl Menger[34] and Léon Walras[35], radically changed economics. The now common tools of partial and general equilibrium and marginal analysis go back to this period.

Jevons (1865, The Coal Question) worried that

> I must point out the painful fact that such a rate of growth will before long render our consumption of coal comparable with the total supply. In the increasing depth and difficulty of coal mining we shall meet that vague, but inevitable boundary that will stop our progress.

a Malthusian position with coal replacing food. However, by and large, the neo-classical revolutionaries were not really interested in issues of environment and resources. This is partly because analysis had moved to the margin, and partly a reflection of the time: Technological progress and industrialization were rapid, and land seemed boundless, with the push into the American west, the Siberian east and the African interior.

Harold Hotelling[36] was one of the few others neo-classical economists to work on resource problems, developing the *Hotelling rule* that the price of an exhaustible resource should rise at the rate of interest. Earlier, but largely ignored until much later, Martin Faustmann[37] had developed a Hotelling rule for a renewable resource, forestry. Despite Hotelling's prominence, this work was largely ignored until the 1974 papers in the *Review of Economic Studies* by Robert Solow[38] and Dasgupta

[32] Simon Kuznets (1901-1985) taught economics of the University of Pennsylvania, Johns Hopkins University, and Harvard University. He won the 1971 Nobel Prize for his work on inequality. He invented the Gross Domestic Product.

[33] Jevons (1835-1882) taught economics at what is now the University of Manchester and at University College London. He was the first to graduate in economics.

[34] Menger (1840-1921) taught economics at the University of Vienna.

[35] Walras (1840-1905) taught economics at the University of Lausanne.

[36] Hotelling (1895-1973) taught at the University of North Carolina, Columbia University and Stanford University. He is one of the true greats of economics and statistics. Besides the Hotelling rule of resource depletion, he is responsible for Hotelling's law of minimum differentiation of products, for Hotelling's lemma that relates optimal production to marginal profits, for Hotelling's T^2 distribution which generalizes Student's t, for canonical correlation analysis, and for principal component analysis. He also helped prove the First and Second Fundamental Welfare Theorems, and trained Ken Arrow.

[37] Faustmann (1822-1876) was a German forester.

[38] Solow (1924-) taught economics at MIT. He won the 1987 Nobel Prize for his work on economic growth.

and Heal. Partha Dasgupta[39] and Geoffrey Heal[40] later gave this a book length treatment.

Although neo-classical economists paid little attention to the environment, they did lay the foundations for the economic analysis of environmental problems and environmental policy. In 1906, Vilfredo Pareto[41] formulated *Pareto superiority*—situation A is better than situation B if at least one person is better off and no one is worse off—*Pareto improvement*—moving from B to A—and *Pareto optimality*—a situation is Pareto optimal if there are no Pareto improvements. Abba Lerner[42] leaned on this and Adam Smith's invisible hand to state the *First Fundamental Welfare Theorem*—the equilibrium in a perfectly competitive market is a Pareto optimum—and the *Second Fundamental Welfare Theorem*—any Pareto optimum can be reached in a perfectly competitive market with the appropriate redistribution of initial endowments. Lerner showed this graphically, the first mathematical proof is due to Hotelling.

Although much of neo-classical analysis was centred on perfectly competitive markets, these economists were not blind to the limitations of this assumption. They just did not know what to do about it. Alfred Marshall[43] was aware of open-access resources, he called them "free goods", but did not know how to fit them into economic theory.

Marshall also noted that markets were imperfect because of externalities—an externality is an unintended and uncompensated effect of an economic activity on a third party. It was Pigou[44] who, in 1912, found the first solution to the problem that externalities pose to the efficiency of the market. Pigou (1928, Economics of Welfare (3rd edition), II.XI.11) wrote

> If the amount of investment in any industry was carried exactly to the point at which the value of the marginal social net product there is equal to the central value of marginal social net products, the national dividend, so far as that industry is concerned, would be maximised. Disregarding the possibility of multiple maximum positions, I propose, for convenience, to call the investment that would then be made in the industry the ideal investment and the output that would be obtained the ideal output.
>
> Under conditions of simple competition, if in any industry the value of the marginal social net product of investment is greater than the value of the marginal private net product, this

[39] Dasgupta (1942-) taught economics at the University of Cambridge. He is a student of Nobelist James Mirrlees and married to a daughter of Nobelist James Meade. He is best known for his work on bringing natural resources into economics.

[40] Heal (1944-) teaches corporate social responsibility at Columbia University. His research is in environmental and resource economics. He did his most influential work while at the University of Sussex.

[41] Pareto (1848-1923) taught political economy at the University of Lausanne, succeeding Léon Walras. Besides his work in welfare economics, he worked on the distribution of income, proposing the Pareto distribution in the process. He also made important contributions to sociology.

[42] Lerner (1903-1982) taught at more than 30 universities. His contributions to economics are just as prolific although he is remembered in the Lerner Curve, a measure of market power.

[43] Marshall (1842-1924) taught economics at the University of Cambridge. His 1890 textbook Principles of Economics dominated university education for many years

[44] Arthur Cecil Pigou (1877-1959) taught economics at the University of Cambridge.

> implies that the output obtained is less than the ideal output: if the value of the marginal social net product is less than the value of the marginal private net product, this implies that the output obtained is greater than the ideal output.
>
> It follows that, under conditions of simple competition, for every industry in which the value of the marginal social net product is greater than that of the marginal private net product, there will be certain rates of bounty, the granting of which by the State would modify output in such a way as to make the value of the marginal social net product there more nearly equal to the value of the marginal social net product of resources in general, thus—provided that the funds for the bounty can be raised by a mere transfer that does not inflict any indirect injury on production—increasing the size of the national dividend and the sum of economic welfare; and there will be one rate of bounty, the granting of which would have the optimum effect in this respect.
>
> In like manner, for every industry in which the value of the marginal social net product is less than that of the marginal private net product, there will be certain rates of tax, the imposition of which by the State would increase the size of the national dividend and increase economic welfare; and one rate of tax, which would have the optimum effect in this respect.
>
> These conclusions, taken in conjunction with what has been said in the preceding paragraphs, create a presumption in favour of State bounties to industries in which conditions of decreasing supply price *simpliciter* are operating, and of State taxes upon industries in which conditions of increasing supply price from the standpoint of the community are operating.

Pigou argues for the State to intervene to internalize externalities, by imposing taxes on negative ones and subsidies ("bounties") on positive ones.[45]

Pigou's contribution was verbal. A formal treatment of externalities had to wait till Meade (1952, *Economic Journal*)[46] and Bator 1958, *Quarterly Journal of Economics*.[47]

4 Keynes and the modern synthesis

For all the methodological advances in economics, the Great Depression caught the discipline empty-handed. The policy, if you can call it that, of *laissez faire* had failed. Economics was micro, but the problems of the economy were macro. John Maynard Keynes[48] single-handedly created macroeconomics, focusing on the business cycle and countercyclical government policy.

After World War II, the discipline of economics worked on the *Modern Synthesis* of the recent Keynesian macroeconomics with the older neo-classical microeco-

[45] Some students complain about the use of mathematics in undergraduate economics. Compare and contrast Pigou's definition of the Pigou tax to the one you find in any textbook, and the one below.

[46] James Meade (1907-1995) taught economics at the London School of Economics. He won the 1977 Nobel Prize for his work on international trade.

[47] Francis Bator (1925-2018) taught public policy at Harvard University.

[48] Keynes (1883-1946) taught economics at the University of Cambridge. He worked for the UK government in various roles, was instrumental in building international institutions after World War I and World War II.

nomics. One product were the growth models of Harrod[49] and Domar[50], of Solow, and of Ramsey[51], Cass[52] and Koopmans[53]. At the core of these models lies the Cobb-Douglas production function,[54] which has that economic output depends on three factors, labour, capital and technology. Natural resources are not there. A one-sector growth model can be interpret as a multi-sector dynamic general equilibrium model if markets are perfect, that is, if there are no public goods and no externalities.

Methodological progress was made. In 1952, *Resources for the Future* (RFF) was founded, the first think tank devoted to resource economics; environmental economics was added later. John Krutilla[55] discovered existence values and helped create the theory of resource conservation and cost-benefit analysis, his colleague Allen Kneese[56] was an architect of market instruments for environmental policy. In 1954, Scott Gordon[57] developed the theory of exploitation of common pool resources. In the same year, Paul Samuelson[58] formulated the conditions for providing public goods. Mancur Olson[59] coined the term free-rider in 1965. Francis Bator[60] laid the foundation for the modern understanding of externalities in 1958. Ronald

[49] Roy Harrod (1900-1978) taught economics at the University of Oxford.

[50] Evsey Domar (1914-1997) taught economics at the Massachusetts Institute of Technology.

[51] Frank Ramsey (1903-1927) taught mathematics at the University of Cambridge. He made noted contributions to mathematics, economics, and philosophy.

[52] David Cass (1937-2008) taught economics at the University of Pennsylvania.

[53] Tjalling Koopmans (1910-1985) taught economics at the University of Chicago and at Yale University. He led the Cowles Foundation. He won the 1975 Nobel Prize for his work on linear programming. His work on autocorrelation was seminal, and he made an important contribution to quantum chemistry.

[54] The Cobb-Douglas function was invented by Philip Wicksteed (1844-1927), who taught economics at the University of London. Charles Cobb (1875-1949), who lectured at Amherst College, and Paul Douglas (1892-1976), who taught at the University of Chicago, popularized the function named after them through their empirical work.

[55] Krutilla (1922-2003) was an independent scholar, associated with RFF.

[56] Kneese (1930-2001) was an economist at RFF.

[57] Gordon (1924-2019) taught economics at Carleton University, Indiana University, and Queen's University.

[58] Samuelson (1915-2009) taught economics at the Massachusetts Institute of Technology. He was awarded the 1970 Nobel Prize. Samuelson is a key architect of the Modern Synthesis, that merged neo-classical microeconomics with Keynesian macroeconomics. Samuelson contributed greatly to the mathematization of economics. His textbooks led the market for decades.

[59] Olson (1932-1998) taught economics at the University of Maryland.

[60] Bator (1925-2018) taught economics at Harvard University.

Coase[61] published his "theorem" in 1960. In 1966, Thomas Crocker[62] suggested tradable pollution permits,[63] an idea picked up by John Dales[64] two years later.[65]

Neo-classical and Keynesian economics largely ignored nature and the environment. This changed during the Modern Synthesis, but environmental and resources economics was not yet recognizable as a separate field of economics.

5 Environmental economics

Things changed in 1970s. As before, economics changed not because of internal pressures but because society changed. After World War II, economic growth was rapid. People could afford cars, and ended up in traffic jams. Those cars emitted gases and particles into the atmosphere. Electricity demand grew rapidly with the use of appliances, and coal-fired power plants added to the pollution of the air. New products were invented, new chemicals developed. What seemed like brilliant inventions at first—fertilizers, pesticides, coolants —turned out to be harmful later—causing eutrophication[66], cancer, and the hole in the ozone layer. The waste of the rapid industrialization was dumped. Rachel Carson[67] published *Silent Spring* in 1962, a book that noted that pesticides weaken egg shells, harming bird reproduction; she predicted a future without birdsong. In 1969, the Cuyahoga River was so polluted it caught fire. In 1972, the Club of Rome published its report on the *Limits to Growth*, a Malthusian tract that predicted society's collapse because of resource constraints well before the average reader of these lecture notes was born. (Hint: It did not happen.) In the same year, the crew of Apollo 17 took the first photo with Earth in full view. Although people had known *intellectually* that our planet is a globe, this was the first *sensory* perception that the Earth is round and finite and we're all in this together. The first oil crisis struck in 1973.

After all that, no one could plausibly deny that

- natural resources are scarce;
- environmental externalities are substantial; and
- environmental services are valuable.

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[61] Coase (1910-2013) taught economics at the University of Chicago. He won the 1991 Nobel Prize for this work on transaction costs and property rights, which helped to explain why firms exist.

[62] Crocker (c1945-) was a PhD student at the University of Wisconsin at the time. He taught economics at the University of Wyoming, working with Ralph d'Arge to lay the foundations of environmental economics.

[63] Crocker, Thomas D. 1966. "The Structure of Atmospheric Pollution Control Systems." In *The Economics of Air Pollution*, edited by H. Wolozin, 61-86. New York: W. W. Norton.

[64] Dales (1920-2007) taught economics at the University of Toronto.

[65] John Harkness Dales 1968. *Pollution, property and prices : an essay in policy-making and economics*. Toronto: University of Toronto Press.

[66] hypoxia in American English

[67] Carson (1907-1964) was a nature writer.

Environmental economics was born out of that realization. Its aim is to bring the tools of economic analysis, developed earlier as sketched above, to bear on environmental problems and environmental policy.

Kenneth E. Boulding[68] reportedly said

> anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist.

Boulding was a prominent economist, author of a well-read textbook and president of the American Economic Association. He set out his Malthusian views in a 1966 lecture The Economics of the Coming Spaceship Earth, in which he emphasized that the economy operates on a finite planet.[69]

Nicholas Georgescu-Roegen[70] (1971, The Entropy Law and the Economic Process) wrote

> economics gives no signs of acknowledging the role of natural resources in the economic process . . . the product of the economic process is waste, waste is an inevitable result of that process and ceteris paribus increases in greater proportion than the intensity of economic activity

Georgescu-Roegen argued that economies are bound by nature (like Boulding), and that models of the economy too should reflect the laws of nature.

Environmental economics took a different route, however. The *Limits to Growth* report had drawn fiery criticism from economists like Graciela Chichilnisky[71] and William Nordhaus[72]. In 1980, Julian Simon[73] challenged Paul Ehrlich[74] to a wager. Ehrlich predicted that resource scarcity would drive up the prices of copper, chromium, nickel, tin, and tungsten between 1980 and 1990. Simon predicted a price fall as new discoveries would increase supply and improved technology would reduce demand. Simon won.

A common interpretation of the Simon-Ehrlich wager is that human ingenuity is the ultimate resource. We are so clever that we can overcome any challenge that nature might throw of us. This has been true until now. Whether it will be true in the future remains to be seen.

Another interpretation is that Simon represents the Enlightenment and Ehrlich Romanticism, the former advocating for the development of new technologies to solve environmental problems, the latter arguing for a return to the old ways to prevent environmental problems.

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[68] Boulding (1910-1993) taught economics at the University of Wisconsin and other universities.

[69] His spaceship metaphor is meant to convey a closed system with scarce resources. Other people saw it as a piece of engineering under autocratic control.

[70] Georgescu-Roegen (1906-1994) taught economics at Vanderbilt University.

[71] Chichilnisky (1946-) teaches economics at Columbia University.

[72] Nordhaus (1941-) teaches economics at Yale University. He won the 2018 Nobel Prize for his work on the economics of climate change.

[73] Simon (1932-1998) taught business at the University of Illinois at Urbana-Champaign and the University of Maryland.

[74] Ehrlich (1932-) taught biology at Stanford University and is a prominent member of the Club of Rome.

Environmental economics has adopted the position that the tools of economic analysis—first developed during the Enlightenment but extended to the environment by Bator, Baumol, Gordon, Knees, Krutilla, Samuelson—can be used to analyze environmental problems and that these problems can be solved by changing incentives at the margin.

Ecological economics, on the other hand, takes the position that the tools of economics are inadequate and that environmental problems require a Utopian overhaul of society. These Romantic roots are best visible among the degrowth movement, who call for economic shrink to solve environmental problems and other social ills, and argue that life is better when all are poor.

I am an environmental economist, and these lecture notes are for a course in environmental economics.

Chapter 2
Social choice

1 Alternative views on ethics

Social science is about three questions: *what if*; *so what*; and *what to do*.[1] Here is an example of the three questions. What would happen to eutrophication if fertilizer is taxed based on its nitrogen content? Do the costs of restricting nitrogen application to farmers and consumers matter more than the impacts of eutrophication on nature and recreation? Is it better to tax fertilizer or to forbid certain applications?

The first question, what if, is a positive one. It requires an as-accurate-as-possible, as-objective-as-feasible description of the relevant parts of the world as it is, as well as predictions of how the world would be should some things change. The third question, what to do, is normative. You cannot rank options without a clear idea of what is better and worse. The second question is a mix of normative and positive—the measurement of costs and benefits is positive, but the decisions what and who to include and exclude are normative.

The idea of what is better and worse is key to answering normative questions. Normative questions are rife in public policy advice and evaluation, including all aspects of environmental policy. Indeed, the aim of public policy in general and environmental policy in particular is to make things better. You cannot do that without an understanding of better.

Environmental economics, when informing public policy, has a more profound normative problem than other branches of applied public economics. The economic analysis of education, health care or labour markets is invariably confronted with making trade-offs between people. In environmental economics, we often make trade-offs between people too, but we also make trade-offs between humans and non-humans.

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[1] Natural science is only about *what if* questions. The incomplete education of natural scientists leads to endless confusion and discussion when they leave the ivory tower to partake in policy debates where *so what* and *what to do* questions are prominent. They even created a new paradigm for this called *post-normal science*, where *normal* is a reference to Thomas Kuhn (1922-1998), a philosopher of science, and *post* means *not* rather than *after*.

It is therefore important to discuss what we mean by better and worse. Economics is by and large based on a utilitarian ethics. Alternative views are rarely discussed. Yet, utilitarianism is a minority view among moral philosophers.

I discuss three major strands in moral philosophy, viz. *naturalist ethics* and two strands of humanist ethics, *libertarianism* and *utilitarianism*. I particularly focus on utilitarianism, because economics is based on that. There are other, less relevant strands of ethics, but these are not discussed here.

2 Universality

Immanuel Kant[2] is one of the most important philosophers in history. Although he died more than two centuries ago, young philosophers still study his work, only to discover what a singularly obscure writer he was. Among other innovations, Kant introduced the *moral agent* and the *Universal Law* or *Categorical Imperative*.

A moral agent is the unit of analysis in ethics. Rights and duties can be bestowed on moral agents and on moral agents only. Only the pain and pleasure of moral agents count in the felicific calculus.

Kant's universal law holds that, if a rule applies to one moral agent, it applies to all moral agents. For instance, assume that you and I are both moral agents. If I argue that you cannot chop off my arm, then I cannot chop off your arm either.[3]

3 Naturalism

Naturalist moral philosophy is centred on the question *who* is a moral agent. This is perhaps best illustrated with a review of political rights.

It used to be that only the views and interests of rich white male Protestants mattered. Rich white male Protestants argued that only they mattered because only they were worthy and capable. And because they were in power,[4] it was irrelevant that others might have disagreed.

Then along came Jeremy Bentham,[5] a rich white male Protestant, who wrote that government should strive for the greatest good for the greatest number. This was a

[2] Kant (1724-1804) taught anthropology at the University of Köningsberg, now Kaliningrad, the city where he was born and died. Besides his work on ethics, he is best known for his contributions to epistemology, aesthetics, and political science. He was also an early advocate of racism.

[3] If you want to wind up a philosopher, say that the Universal Law is the same as the Golden Rule—the Christian ”do unto others as you would have them do unto you", a sentiment found in most other religions too. The difference between the Categorical Imperative and the Golden Rule is subtle.

[4] This story is placed in Northwestern Europe and North America

[5] Bentham (1747-1832) was an independent scholar.

radical proposition.[6] Poor lives matter.[7] The government should serve not just the elite, but the less fortunate too. Bentham argued in favour of people who were not like him.

This intervention set off a cascade. If you cannot argue that someone else is worthy only if she is just like you, then you need a different criterion to delineate moral agents from other entities.

Catholics were emancipated first.[8] You cannot maintain that someone is less worthy because he reads a different translation of the same book. The poor followed. Women were next. The notion that women are too hysterical to own property or vote was shown to be a self-serving lie than men like to tell each other. Skin colour was last. A physiological adaptation to the limited sunlight of Northern Europe—a light skin promotes the creation of vitamin D, at the expense of sunburn and a higher risk of skin cancer—has nothing to do with other human capabilities.

However, if as a rich white male Protestant you cannot argue that only rich white male Protestants matter, then as a human you cannot argue that only humans matter. It is a self-serving argument.

Some people argue that the right delineation is a sense of self. If you put a parakeet in front of a mirror, it will sing to its mirror image—and will continue to do so even if the mirror does not answer back. A parakeet does not have a concept of self and no concept of other. A moral rule that constrains the self in how it treats others is therefore meaningless to a parakeet. That said, other primates, dolphins and elephants do recognize themselves in the mirror. These animals also have an understanding of cause and consequence, and seem to have a sense of right and wrong. Some human rights would therefore also apply to other higher animals. In 2015, a judge in Argentina ruled that, since Sandra had broken no laws, it was illegal to hold her captive. Sandra is an orangutan.

Utilitarianism is not about rights and duties. It is about minimizing pain and maximising pleasure. If that is the ethical starting point, then what sets a moral agent apart is not her ability to self-identify, but rather her ability to experience pain and pleasure. Cats may not recognize themselves in the mirror—there are countless videos on YouTube that prove this point[9]—but cats sure are able to experience pain and pleasure. Many people oppose torture of animals as they oppose torture of humans, and many countries have laws against cruelty to animals. That is, we recognize, to a certain extent, animals as moral agents.

The human ability to experience pain and pleasure derives from our central nervous system, with nerves throughout the body and a brain to coordinate it all. Worms do not have a central nervous system. If you chop a human in two, you have two halves of a dead human. If you chop a worm in two, you have two viable worms.

[6] When he lived, only some 3% of English men had the vote. In the year he died, voting rights were extended to some 16%.

[7] Bentham went much further. Although not fond of Catholics, non-whites, women or homosexuals, he argued that they had rights too and may even be allowed to vote. He also argued for animal rights.

[8] A Catholic still cannot be King or Queen of the United Kingdom.

[9] Here is an exception.

But if you cannot argue that someone is unworthy because they have a different skin tone—a physical characteristic—then you cannot argue that something is unworthy because it lacks a central nervous system. Octopuses have nine brains, a big one in the body plus smaller ones in each tentacle. Octopuses are smart and have complex personalities. They are like us in some ways, and unlike us in others—but who are we to deny them our rights just because they're different? Extending human rights to all animals may seem extreme to people who grew up in a society influenced by Christianity or Islam, but it is a common position in Hinduism. Vegetarians oppose killing animals for food.

Trees too signal distress in a way that is alien to humans but clearly recognizable nonetheless. Fruitarians extend the well-accepted rule against cannibalism to all living beings.

The cascade does not stop there. The occasional media flurry on the discovery of life on Mars or, more recently, Venus is rooted in our inability to distinguish organic material from dead material. At the macroscopic scale, it is easy to tell a bear from a tree from a rock. At the microscopic scale, such distinctions are blurred. Viruses, for instance, are somewhere between alive and not. Deep ecologists like Aldo Leopold[10] and Arne Naess[11] argue that non-living entities indeed have a right to integrity of body just like humans do. Certain religions recognize abiotic entities, such as rivers or mountains, as spiritual beings worthy of respect and protection. The Whanganui River in New Zealand is a legal person.

4 Libertarianism

Libertarianism is one of the schools of humanist moral philosophy. It grants rights and duties to humans only, although some of the reasoning can readily be extended to other species.

As the name suggests, libertarianism is about individual rights and liberties. John Locke[12] argued property is *just* if it is acquired through labour. That is, if someone goes into the forest, cuts down the trees and starts cultivating the land, then that land is theirs. When Locke wrote this, King James VII and II was trying to establish an absolute monarchy in England and Scotland, including the notion that all land belongs to the crown. Locke disagreed. This thinking is reflected in the US Homestead Act of 1862, and it reflects Germanic traditions of property law. It

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[10] Leopold (1887-1948) was the first professor of wildlife management, teaching at the University of Wisconsin. He is one of the early thinkers of deep ecology.

[11] Naess (1912-2009) taught philosophy at the University of Oslo. He coined the term *deep ecology*.

[12] Locke (1632-1704) was a philosopher and physician. He is noted for his work on the theory of mind and the social contract. His work on liberalism and republicanism is reflected in the US Declaration of Independence.

was also used to argue that hunter-gatherers do not own their lands *as they did not improve it*[13] and can therefore be removed.

Locke's idea of just property is impractical. Robert Nozick[14] added that property is just if obtained through free consent. Just property, acquired through labour, remains just after a voluntary exchange. Aristotle would agree.

Libertarianism is thus only concerned with *procedural* justice. What matters is how you get there, not where you end up. An unequal distribution of resources is of no concern to a libertarian provided that the rich got rich by moral means.

The role of the state is rather limited in libertarianism. The government should guard against unjust holdings, such as theft. The government should also guard against negative externalities, which are involuntary impositions on the liberties and properties of others. That is all.

Libertarians argue that taxation is wrong. It is, after all, an involuntary transfer of property. Governments can therefore not redistribute resources from the rich to the poor. Income inequality should be alleviated by charity. The government may provide public goods, but contributions to that should be strictly voluntary.

Classical economists would have agreed with libertarians on many points.

5 Utilitarianism

Utilitarianism is the polar opposite of libertarianism. Utilitarianism is *consequential* justice. What matters is where you end up, not how you got there.

At the individual level, utilitarianism is about pain and pleasure. At the social level, utilitarianism is about the greatest good for the greatest number. In narrow definitions of utilitarianism, this means the sum total of the utility of people.

In broad definitions of utilitarianism, the greatest good for the greatest number means some aggregate of the utility of people and perhaps animals.[15] The *Pigou-Dalton Principle*[16] is the dividing line between narrow and broad utilitarianism. According to the Pigou-Dalton Principle, social welfare should improve if income is transferred from rich to poor (without making the formerly rich poorer than the formerly poor). Narrow utilitarianism neither satisfies nor violates this principle. Broad utilitarianism either violates or, more typically, satisfies Pigou-Dalton.

According to utilitarians, the government should deliver the greatest good for the greatest number. It does not matter how. An autocratic government that brings

[13] Actually, hunter-gatherers do manage the landscape, just not in a way that an agriculturalist would recognize.

[14] Nozick (1938-2002) taught philosophy at Harvard University. He also worked on the theory of knowledge.

[15] Some philosophers argue that broad utilitarianism is not utilitarianism at all, but I have yet to see a cogent argument why not.

[16] Pigou is Alfred Cecil Pigou, also known for the Pigou tax. Hugh Dalton (1887-1962) taught economics at the University of London, where he worked on income inequality. He later become a Member of Parliament and Chancellor of the Exchequer.

material welfare to its citizens is better, according to utilitarians, than a democratic government of a poorer country.

Broad interpretations of utilitarianism can be captured with a Bergson-Samuelson-Atkinson welfare function

$$W = W(U_1, U_2, ..., U_n) = \frac{1}{1-\gamma}\sum_{i=1}^{n} U_i^{1-\gamma} \tag{2.1}$$

where W denotes social welfare and U_i the utility of individual $i = 1, 2, ..., n$. The right-hand side is due to Anthony Atkinson,[17] the middle part was independently suggested by Abram Bergson[18] and Paul Samuelson.[19] The parameter γ is relative inequity aversion.

At the margin, individuals i and j contribute to social welfare as follows

$$\frac{\frac{\partial W}{\partial U_i}}{\frac{\partial W}{\partial U_j}} = \left(\frac{U_j}{U_i}\right)^{\gamma} \tag{2.2}$$

If $\gamma = 0$, the social planner is inequity neutral. $W = \sum_{i=1}^{n} U_i$. It does not matter whether the utility of i or j goes up, because the ratio of their marginal contributions to welfare is always equal to one.

For $\gamma > 0$, the social planner is inequity averse. The social welfare function satisfies the Pigou-Dalton Principle. If i is happier than j, $U_i > U_j$, then $\left(\frac{U_j}{U_i}\right)^{\gamma} < 1$. That is, a utility gain for happy i is less important than a utility gain for miserable i.

There is another way to see the same thing:

$$W = \begin{cases} \min_i U_i & \text{if } \gamma \uparrow \text{inf (Rawls)} \\ \prod_i U_i & \text{if } \gamma = 1 \text{ (Bernoulli-Nash)} \\ \sum_i U_i & \text{if } \gamma = 0 \text{ (Bentham)} \\ \max_i U_i & \text{if } \gamma \downarrow -\text{inf (Nietzsche)} \end{cases} \tag{2.3}$$

As γ grows, more and more emphasis is placed on the plight of the worst-off in society.

Note that, for completeness, Equation (2.3) also includes the case $\gamma < 0$. The Pigou-Dalton Principle is violated. Social welfare increases when income is transferred from poor to rich. Few people would consider this to be desirable.

[17] Atkinson (1944-2017) taught economics at the University of Oxford and the London School of Economics. He worked on inequality and poverty.

[18] Bergson (1914-2003) taught economics at Columbia University and Harvard University. He worked on social welfare theory and the calculation of national output in Soviet economies.

[19] Samuelson (1915-2009) taught economics at the Massachusetts Institute of Technology. He won the 1970 Nobel Prize. He made many contributions, including the *modern synthesis*, the merger of Keynesian and neoclassical traditions. Through his work, his students, and his textbooks, Samuelson was responsible for the increased use of mathematics in economic analysis.

6 The Impossibility Theorem

In his 1951 PhD thesis, Kenneth Arrow[20] published his *Impossibility Theorem*. It shows that a welfare function cannot be an aggregate of individual preferences. That does not mean that you should not use social welfare functions. It does mean that you should be aware of their limitations.

More specifically, the Impossibility Theorem is about a society with two or more people and three or more goods.[21] Suppose that all agents in this society have a clearly defined preference order. Arrow showed that there cannot be social preference order that is non-dictatorial, universal, independent of irrelevant alternatives, and unanimous.

These are all desirable properties. Non-dictatorship means that no agent can impose his preferences on any other agent. Universality (or unrestricted domain) means that the social preference order applies to every conceivable outcome. Independence of irrelevant alternatives means that the ranking of two options does not change if a third option is added or removed. Unanimity means that if all prefer an option then so should society.[22]

In other words, any aggregate of individual preference orders has undesirable properties. As there is a one-to-one correspondence between preference orders and utility functions, any social welfare function that aggregates individual utility functions, is flawed too.

7 Critiques of utilitarianism

Utilitarianism is unpopular outside economics. Besides the alternative schools of moral philosophy, I highlight the work of two criticasters.

John Rawls[23] is seen as one of the key ethicists of the 20th centry. Rawls thought and wrote about what a just society would look like. He argued that a just society would be one that everyone in that society would agree on, if they were free to decide, rational, and impartial. For impartiality, Rawls introduced his *veil of ignorance*: You can be impartial only if you do not know what position you hold in society, if you

[20] Arrow (1921-2017) taught economics at Stanford University. He shared the 1972 Nobel Prize with John Hicks. Arrow's contributions to economics are many, but two stand out. His early work on social welfare theory demonstrated that a social planner cannot solve all problems. His later work with Gerard Debreu on general equilibrium theory showed that markets cannot be complete. The market cannot solve all problems either.

[21] It also works with two or more goods and three or more people. A society can be as small as a group of students sharing a flat.

[22] The original version of the Impossibility Theorem did not have unanimity. Instead, it had monotonicity and non-imposition. Monotonicity means that if some agent begins to like an option more, then society should not begin to like it less. Non-imposition has that society should not prefer things that no-one in society prefers.

[23] Rawls (1921-2002) taught philosophy at Harvard University. His work focused on justice and democracy.

do not know how skilled or talented you are, and if you do not know your attitudes towards risk, inequality and such things.

On that basis, Rawls argued that a just society would be as free as possible. Anyone should be who they like to be and do what they want to do, as long as it does not infringe on other people's liberties. Rawls also argued that a just society minimises resource difference. Incomes should only deviate if that income difference makes everyone better off, and if that income difference is attached to position. For example, doctors and firefighters have to be on standby for 24/7, so it stands to reason that they are compensated for their sacrifice lest no one wants to take that job. Doctors are trained for a longer period than nurses so it is reasonable to compensate them for that—but not for the fact they were born into a different class or have a greater aptitude for academic study. Rawls' just society is nothing like ours.

As shown in Equation (2.3, a Rawlsian income distribution can be captured in a social welfare function. Other aspects of Rawlsian justice, such as maximum freedom, cannot.

Amartya Sen[24] notes other problems. A utilitarian would applaud the government of Singapore which is fairly authoritarian but has made its people rich. The governments of South Korea and Taiwan were similarly down on freedom but up on economic growth, and were removed by its people. Not everyone agrees that material wealth is all that matters. Sen noted a deeper problem. An aggregate of individual utilities, cannot reflect properties of society, such as democratic freedoms: A Bergson-Samuelson function has that $W = W(U_1, U_2, ..., U_n)$. That is, $W \neq W(U_1, U_2, ..., U_n, F)$, where F stands for freedom. Nor is it easy to add freedom as an attribute to a utility function: Freedom is not consumed or produced in any conventional meaning of those words, and it is property of society rather than an individual.

Sen also highlighted altruism. At first sight, altruism is compatible with utilitarianism. If person i cares about person j, $U_i = U(C_i, U_j)$. That is, besides her own consumption C_i, utility is a function of the other person's happiness (or perhaps perceived happiness or consumption). There are two problems with this. First, the construction of the aggregate demand curve assumes that individual demand curves are independent of each other. The vertical aggregation of demand curves allows for the kind of altruism that affects our well-being but not our behaviour. You can work your way around this (not in an undergraduate class though) but then a different problem emerges. A social welfare function is supposed to be the foundation on which to give policy advice. A social welfare function that includes altruism has a fundamental inequity build-in. If your utility depends on your well-being and the well-being of the people you care about, then a social welfare function that reflects your utility double-counts the utility of those you care about. That would not be a problem if care were equally distributed. If not, such a social welfare function is biased towards popular people and biased against unpopular ones, biased towards people with large families and biased against people with small families.

[24] Sen (1933-) taught economics at a number of universities in India, the UK and the USA. He won the Nobel Prize in 1988. He is best known for his work on social welfare and on famine.

Sen further wrote about agency. People behave differently in different roles. You are different around your family then when you are with friends or colleagues. This is first and foremost a positive problem, an issue with describing and predicting what economic agents do. It is hard to construct a utility function and budget constraints, that together manifest themselves in first-order conditions that solve differently depending on who else is in the room.[25] But this also affects the social evaluation of individual behaviour, which is after all what a welfare function is about. A middle-aged man chatting up a young woman in a bar is met with pity, a middle-aged male professor chatting up a female student after class stands accused of harassment and abuse of power. A business man giving preferential treatment to an old friend is giving away his own money, whereas a politician gives away public funds. Different roles come with different expectations and responsibilities, so that a transaction can be legitimate and welfare-improving in one circumstance but not in another.

Utilitarianism is therefore an ethical system with many drawbacks. Applications of social welfare functions should always be treated with caution and inspected for flaws.

[25] Hard, but not impossible.

Chapter 3
Sustainability

Sustainability is a core concept in environmental policy. It is sometimes interpreted as a property of the social welfare function, but more commonly as a constraint we should impose on any decision we make.

1 Roots

John Stuart Mill[1] (1848, Principles of Political Economy) wrote

> If the earth must lose that great portion of its pleasantness which it owes to things that the unlimited increases of wealth and population would extirpate from it, for the mere purpose of enabling it to support a larger, but not a happier or better population, I sincerely hope, for the sake of posterity, that they will be content to be stationary long before necessity compels them to it.

Like his fellow Classical economists, see Section 2.2, Mill believed that economic growth must come to a halt. In the above passage, he argues that economic expansion should stop before economic output reaches its maximum because there is "pleasantness" apart from material wealth. He further argues that we should do this not for our own sake but for those who come after. Mill thus captured the essence of sustainability.

Gro Harlem Brundtland[2] and colleagues (1987, Our Common Future) give the following definition

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

This is intuitively appealing. We should develop but not hurt our children. The appeal of the Brundtland report led to a rapid and widespread support of sustainability. Every

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[1] Mill (1806-1873) worked for the British East India Company and was a Member of Parliament. He wrote about a wide range of economic, social and political issues and is often considered to be the most influential English-speaking philosopher of the 19th century. Late in life, he said that most of his work was co-written with Harriet Taylor Mill (1807-1858).

[2] Harlem Brundtland (1939-) was a physician, Prime Minister of Norway, and Director-General of the World Health Organization.

country and every organization wants to develop sustainably. Sustainability is the shared end goal, sustainabilizability the intermediate target.

The Brundtland definition is vague. What are needs? Food and water are beyond dispute, but I sometimes have a desperate urge to watch a silly show on TV. What is the ability to meet needs? Are we content if our descendants could have met their needs but did not? And what does compromising that ability mean? If their ability is reduced by 10% is it compromised, or is the threshold at 90%?

Brundtland's vagueness is her strength. The direction of travel is clear, but there is no precise prescription, which allows people from different convictions to subscribe to sustainable development.

Academics, however, do not like vagueness. There have therefore been many attempts to give a precise definition of sustainability. I review these below, in three major groups.

2 Weak sustainability

Jack Pezzey[3] argued that sustainability means that utility should not fall. We want to sustain human happiness. Utility is an elusive concept, though. John Hartwick therefore argued that sustainability means that consumption should not fall. In 1977, he formulated the Hartwick Rule: A constant level of consumption can be maintained perpetually from an environmental endowment if all the scarcity rents (net price, profit) from resource extraction are invested in other capital. That is, we should keep the principal intact, live off the service flow alone. Robert Solow argued that, with finite resources, non-declining consumption is indeed constant.

The Hartwick Rule appears sensible—do not run down your capital stock—and precise. But the Hartwick Rule does not specify whose consumption should be kept constant, however. Is it the median consumer's? Everyone's? Nor does it say at what time-scale should consumption be constant? Every year, every decade, every century? And it does not define the bundle of consumption, however. Is it the same bundle over time?

In order to overcome the last problem, Talbot Page and Robert Solow suggested that production possibilities should not fall. This avoids the problem of defining consumption for now and forever. As an analysis of sustainability is done by current scholars, assumptions about future consumption necessarily reflect current preferences. A focus on production is less paternalistic. Problems of time scale and representation remain, however.

A key aspect of all these definitions is that substitution is allowed. The Hartwick Rule explicitly says that it is fine to run down natural resources as long as the revenue is used to build up physical capital. According to these *weak* definitions of sustainability, what matters is that human welfare will not fall. A walk in the forest can be replaced with a walk in virtual reality.

[3] Pezzey (c1956-) has been a civil servant, researcher, consultant and lecturer in the UK, the USA and Australia.

3 Strong sustainability

The defining feature of weak sustainability is that human-made capital can substitute for natural capital. Advocates of strong sustainability disagree. Some go as far as arguing that sustainability means that natural capital stocks should be maintained.

This has far-reaching implications. Fossil fuels can no longer be used, or fossil water. Trees can only be cut for lumber if new trees are planted. Building materials would be scarce, a mining for sand and limestone comes to an end.

If all natural capital stocks are to stay at their current levels, human activity would be severely curtailed. A new road takes up space, necessarily taking away space from something else. Building a new house thus means taking down an old one. If strong sustainability is defined at the local level, the old house needs to be in the same county.

In practice, therefore, some substitution must be allowed. But at what spatial scale? If forest has to make way for a new road in England, should new trees be planted in England or is it fine to plant new trees in Hungary? To what extent do new trees substitute for old trees, which provide a much richer habitat for birds, plants and insects?

What natural capital stocks should be maintained? Ecosystems, species, or genes? The polar bear is a subspecies of the brown bear. Not much genetic diversity would be lost if the polar bear goes extinct. Or maybe we do want to preserve individual species from extinction, whether caused by humans or evolutionary dynamics. And what should we do with viruses and pests? Should we let malaria roam freely?

The desire to maintain natural capital stocks reflects a static view of the natural environment. Things should stay as they are or return to how they used to be. An alternative view on strong sustainability argues that, instead, services from natural capital stocks should not decline. What matters is that there are enough photosynthesizing plants to make sufficient oxygen; it does not really matter what species these plants are. What matters is that there are coastal forests to break storms and provide shelter and sustenance for fish larvae; it matters less whether there are more mangrove palms than buttonwoods.

A focus on nature's services begs the questions a service to whom or what? Plants can live without animals but animals cannot live without plants? And at what spatial or temporal scale should services be maintained?

A third group of definitions of strong sustainability centres on ecosystem stability and resilience. This does not solve the fundamental problem of lack of specificity, because stability has to be defined in terms of either stocks or services.

The key feature of strong sustainability is that it imposes stronger constraints on human behaviour than does weak sustainability. Weak sustainability argues that all is fine as long as humans are fine. This is a utilitarian perspective. Strong sustainability wants other species to be fine too, even if it comes at the expense of humans. This is a naturalist perspective.

4 A social construct

The academic quest for a more precise definition of sustainable development than Brundtland's has thus led to a variety of definitions that are not particularly precise either. There is a third group of definitions: Sustainability is what we decide it to be.

This is a truism. Sustainability is not some property of the real world that we try to uncover. Sustainability is an abstract human desire, a social construct. But the people who argue this have a deeper motive. Brundtland's recommendation that development should be sustainable was so popular that it crowded out other objectives of government. Advocates of other worthy goals can either resist the new kid on the block, or seek to co-opt the item newly at the top of the agenda. People who argue that sustainability is a social construct also argue that it matters how society construes sustainability, a libertarian focus on procedure over outcome, and typically advocate deliberative, participatory democracy.

Sustainable development was initially about environmental quality, but this was quickly replaced by the three pillars of sustainable development: Environmental quality, distributional justice, and economic efficiency. The United Nations now has no fewer than 17 *sustainable development goals*: a half one about economic growth, one about participatory democracy, three about the environment, and eleven and a half about development.[4] Sustainable development is now more development than sustainable.

Blurring concepts and re-purposing slogans is excellent politics but poor policy. Putting its three pillars under one heading masks the real trade-offs in sustainable development. Agriculture puts a lot of pressure on the environment. Cleaner forms of food production are more expensive. Greater environmental quality implies lower economic growth. Food is a necessary good. Poorer people spend a larger share of their income on food. Greater environmental quality implies a more unequal income distribution. Lumping everything under sustainable development hides these trade-offs. Vague words that appeal to every constituency is great politics. Ignoring the negative consequences of interventions is poor policy.

Jan Tinbergen showed that if you have N policy problems, you need N policy instruments. This is a corollary of Joseph-Louis LaGrange's work on constrained optimization. A simple example illustrate this. If you have two cars, you need two steering wheels. You can imagine a single car with two steering wheels, but negotiating a bend in the road requires a lot of coordination between the two drivers. Two cars that share a single steering wheel do fine as long as they go straight. Turning a corner is rather tricky. Killing two birds with one stone is so remarkable we made it a proverb.

Returning to example of food production, there are three objectives. A reduction in environmental pollution requires a change in farm practices. Economic efficiency demands that you do so for the lowest possible cost. As shown below, that is best done through a tax on emissions. Distributional justice dictates that part of the tax

[4] Sustainable development goal #12 says that production and consumption should be sustainable. This is a tautology.

revenue be used to raise the income of the poorest. Giving three problems the same name suggests there is only one problem, and that one intervention is enough to solve it.

Chapter 4
Externalities and public goods

1 Market efficiency

Let's recap the definition of *efficiency*. Efficiency is also known as *Pareto optimality*. Situation A is *Pareto superior* to situation B if no one is worse off and at least one person is better off in A than in B. We call A a *Pareto improvement* on B. A situation is Pareto optimal, or efficient, if no Pareto improvement is possible.

Aristotle noted that a voluntary exchange is mutually beneficial—in current jargon, Pareto improving. If the bargain were detrimental to either party, why would they agree to it? If we assume that economic agents are rational and all exchanges voluntary, the market improves welfare in Pareto's sense of that word—every market exchange is Pareto improving. If we assume that agents are insatiable and trade is costless, then they will continue trading until no Pareto improving deal can be struck. If we further assume that agents are perfectly informed about all offers on the market (and can accept these as trade is costless), then they will strike the best deals. This is the *First Welfare Theorem*, the Classical notion that the equilibrium of a free market is a Pareto optimum.[1]

A Pareto optimum is conditional on the initial distribution of endowments. If we rearrange the starting point, a perfect market would still be efficient, but the equilibrium reached would be a different one. This is the *Second Welfare Theorem*.[2] In order to choose between Pareto optima, we would need a social welfare function that reflects our collective preferences for the level and distribution of consumption.[3]

Let's now make this more precise.

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[1] Adam Smith argued this verbally, Abba Lerner showed it graphically, Harold Hotelling algebraically for a static economy, and Kenneth Arrow and Gerard Debreu for a dynamic economy.

[2] There is no Third Welfare Theorem, although the Coase Theorem may qualify.

[3] Arrow's Impossibility Theorem, another contender for the title Third Welfare Theorem, shows that is hard if not impossible to construct a social welfare function.

1.1 Exchange economy

Consider an economy with two agents, A and B, two goods, X and Y, and two inputs, L and K.

Utility U depends on consumption: $U^A = U(X^A, Y^A)$ and $U^B = U(X^B, Y^B)$ where the superscripts denote *whose* utility and whose consumption. Both goods are made with both inputs: $X = X(L^X, K^X)$ and $Y = Y(L^Y, K^Y)$. Subscripts denote first partial derivatives: $U_X^A := \frac{\partial U^A}{\partial X^A}$ is the marginal utility of agent A consuming good X and $MP_L^Y := \frac{\partial Y}{\partial L_X}$ is the marginal output MP of good X in input L.

Consumption efficiency requires that the ratio of marginal utilities, called the *marginal rate of substitution*, be equal for both agents:

$$\frac{U_X^A}{U_Y^A} = \frac{U_X^B}{U_Y^B} \tag{4.1}$$

Suppose that this is not the case. For instance, let the ratio be 5-to-1 for A and 1-to-5 for B. Then, A should give one unit of Y to B in exchange for one unit of X. A would lose one util and gain five, a profitable exchange. Similarly, B would lose one util and gain five. This deal is Pareto improving, and the original situation was neither optimal nor in equilibrium. Only when the marginal rates of substitution are equal is it impossible to strike a mutually advantageous bargain.

Production efficiency requires that the ratio of marginal production, called the *marginal rate of transformation*, be equal for both producers:

$$\frac{MP_L^X}{MP_K^X} = \frac{MP_L^Y}{MP_K^Y} \tag{4.2}$$

If this is not the case, then it would be possible to shift L from the production of X to the production of Y and K from Y to X (or vice versa) and make more of both X and Y.

Product-mix efficiency—also called x-efficiency or allocative efficiency—requires that the marginal rate of substitution equals the marginal production cost ratio:

$$\left(\frac{U_X^A}{U_Y^A} =\right) \frac{U_X^B}{U_Y^B} = \frac{MP_K^Y}{MP_K^X} \left(= \frac{MP_L^Y}{MP_L^X}\right) \tag{4.3}$$

At the margin, the relative gain should equal the marginal cost. To see why, suppose that the ratios on the left-hand-side is 5-to-1 and the ratios on the right-hand-side 1-to-5. That is, an additional unit of X is worth 5 utils while an additional unit of Y is worth 1 util. An additional unit of K or L makes one additional unit of Y and five additional units of X. If we shift 1 unit each of K and L from making Y to making X, we lose 1 Y at the cost of 1 util but win 5 X at a gain of 25 utils.

Together, consumption efficiency, production efficiency, and product-mix efficiency make efficiency. Production and product-mix efficiency are a precondition for optimality, whether Pareto optimality or some other kind. This is because production and product-mix *in*efficiency means that the pie is smaller than it can be. Regardless of your stance on the distribution of income, the total should always be as large as possible. (Recall that we have yet to introduce environmental concerns.) Optimality relates to consumption efficiency. If we want to maximize some social welfare function $W = W(U^A, U^B)$ then the first-order conditions require that

$$\frac{W_{U^A}}{W_{U^B}} = \frac{U_X^A}{U_X^B} = \left(\frac{U_Y^A}{U_Y^B} = \frac{U_Y^A}{U_X^B}\frac{MP_K^Y}{MP_K^X}\right) \tag{4.4}$$

As the ratio of marginal utilities of the two agents now need to be a particular number, we have introduced a new constraint on our economy. A new constraint can only be met if we also introduce a new instrument. A new requirement needs a new degree of freedom. That new instrument could be a transfer of endowments from one agent to the other.

1.2 Market economy

Let us now introduce prices. *Consumption efficiency* requires that the ratio of marginal utilities is equal to the price ratio:

$$\frac{U_X^A}{U_Y^A} = \frac{P_X^A}{P_Y^A} = \frac{P_X}{P_Y} = \frac{P_X^B}{P_Y^B} = \frac{U_X^B}{U_Y^B} \tag{4.5}$$

where the step in the middle assumes that both agents face the same relative prices—a sign of a well-developed market. If the price ratio is not equal to the marginal rate of substitution, an agent could readily improve her utility. Let the price ratio be 5-to-1 and the utility ratio 1-to-5. The agent could then sell one X, a utility loss of 1, and use the money to buy 5 Y, a utility gain of 25.

Production efficiency requires that the ratio of marginal productivities equals the input price ratio:

$$\frac{MP_L^X}{MP_K^X} = \frac{P_L^X}{P_K^X} = \frac{P_L}{P_K} = \frac{P_L^Y}{P_K^Y} = \frac{MP_L^Y}{MP_K^Y} \tag{4.6}$$

If not, a producer would buy less of one input and spend the savings on buying more of the other, raising production.

A rational producer sets marginal revenue equal to marginal cost. For input L in product X this is $P_X = MP_L^X P_L$. This implies that

$$\frac{P_X}{P_Y} = \frac{MP_L^X}{MP_L^Y}\frac{P_L}{P_L} = \frac{MP_L^X}{MP_L^Y} \tag{4.7}$$

This is the condition for *product-mix efficiency*.

We have so established that a market equilibrium is efficient.

There are a number of conditions, though. Agents need to be rational and perfectly informed. Rational agents maximise utility or profit. Without rationality, nothing of the above holds. Agents also need perfect information about prices. Trade needs to be costless. Markets need to be perfectly competitive, otherwise markups break the equality of marginal costs and revenues. From an environmental perspective, the key condition is that markets are complete. Every transaction has a market. There are no externalities, and no public goods.

We now turn to these two conditions, considering externalities first.

2 Externalities

An *externality* is the unintended and uncompensated effect of one economic agent on a third party.

Intent: We burn coal to make electricity, not to emit carbon dioxide and soot. We hold bees to make honey, not to pollinate flowers.

Compensation: If pollination is remunerated or emissions taxed, the market failure is less pronounced; or may disappear altogether if the price is right.

Third party: The victim of pollution or the beneficiary of pollination do not engage in an economic transaction with the polluter or pollinator.

You can also call an externality an external effect, an external cost or an external diseconomy. These words all mean the same thing. An externality may be beneficial or adverse. It may come about by consumption or production, and may affect consumption or production. If taxed, the externality is said to be internalised. The history of the concept is discussed here.

The effect of externalities on the efficiency of markets is readily established. Production efficiency demands that the marginal rate of transformation equals the relative price. The relevant prices are the prices, or opportunity costs, of society P^S, which are the sum of market prices P^M and externalities P^E:

$$\frac{MP_L^X}{MP_K^X} = \frac{P_L^S}{P_K^S} := \frac{P_L^M + P_L^E}{P_K^M + P_K^E} \tag{4.8}$$

Maximization of private profits, however, leads to

$$\frac{MP_L^X}{MP_K^X} = \frac{P_L^M}{P_K^M} \tag{4.9}$$

In other words, the market is efficient if externalities are zero $P^E = 0$.

In order to find a remedy for externalities, we simplify the model above. Good X is made with input K only and good Y with input L only. However, we also introduce an externality: Output X depends on the use of L in making Y. The model is simple so the example is contrived: The workers of company Y congest the roads so that the driverless cars of transport company X are slowed down.

Company X seeks to maximize its profits

$$\Pi^X = P^X X(K, M(L)) - P^K K \tag{4.10}$$

and company Y does the same for its profits

$$\Pi^Y = P^Y Y(L) - P^L L \tag{4.11}$$

The first-order conditions are

$$\frac{\partial \Pi^X}{\partial K} = P^X X_K - P^K = 0 \Rightarrow P^X = \frac{P^K}{X_K} \tag{4.12}$$

$$\frac{\partial \Pi^Y}{\partial Y} = P^Y Y_L - P^L = 0 \Rightarrow P^Y = \frac{P^L}{Y_L} \tag{4.13}$$

Now let us maximize the joint profits $\Pi^X + \Pi^Y$. The first-order conditions are

$$\frac{\partial \Pi^X + \Pi^Y}{\partial K} = P^X X_K - P^K = 0 \Rightarrow P^X = \frac{P^K}{X_K} \tag{4.14}$$

$$\frac{\partial \Pi^X + \Pi^Y}{\partial Y} = P^Y Y_L + P^X \frac{\partial X}{\partial M} \frac{\partial M}{\partial L} - P^L = 0 \Rightarrow P^Y = \frac{P^L - P^X X_M M_L}{Y_L} \tag{4.15}$$

Now return to the initial case, with a tax τ on the use of L. The profit function of company Y is then

$$\Pi^Y = P^Y Y(L) - P^L L - \tau L \tag{4.16}$$

and the first-order condition

$$\frac{\partial \Pi^Y}{\partial Y} = P^Y Y_L - P^L - \tau = 0 \Rightarrow P^Y = \frac{P^L + \tau}{Y_L} \tag{4.17}$$

Therefore, if $\tau = -P^X X_M M_L$, private optimization returns the social optimum. Note that $X_M < 0$ so that this is indeed a tax. Note also that if $X_M > 0$ the externality is positive and the tax is negative, that is, a subsidy.

The tax $\tau = -P^X X_M M_L$ is called the Pigou tax. It is not just any tax on a negative externality, but that tax that restores market efficiency.

3 Public goods

A *private good* has two key properties: It is *rival* and *excludable*. Rivalry in consumption[4] is best seen as something physical. If I eat my ice-cream, you *can*not have it because it is no longer there.[5] Excludability is a legal or moral concept. It is my ice-cream; you *may* not have it because that would be stealing.

A *public good* is non-rival and non-excludable.

A *commons good* is non-excludable but rival. The classic example is the commons, the land where all villagers could graze their sheep. It is rival because the grass that my sheep ate cannot be eaten by your sheep. It is non-excludable because every villager has the right to put her sheep on the commons. The key problem with commons good is overconsumption. It is in my interest to have many sheep. If they graze too much and damage the soil, the costs will be spread over everyone in the village. The other people in the village are similarly incentivized to have as many sheep as they can afford. The result is overgrazing. A public road is another example of a commons good. No car can be denied access, but too many cars on the road cause congestion.

A *club good* is non-rival but excludable. Only members and ticket-holders are allowed into the club, but those inside can enjoy the music and amenities, without affecting the enjoyment of other insiders. The main problem with club goods is that the club owner wants to admit as many people as possible. There is a fixed cost of providing the venue and hiring the band, but the variable cost is near zero. The result is, again, congestion as consumption becomes rival.[6]

Commons goods and club goods are sometimes called impure public goods. Examples of pure public goods are lighthouses and military defense. Anyone can see the light of a lighthouse and use it to their advantage, and this use does not prevent others from using it. No one is excluded from the national defense services provided by the military, and my use of this service does not affect your use.

Figure 1 shows individual and aggregate demand for rival and nonrival goods. If the good is rival, the market allocates it to *either* Ahmad or Barnali. If the good is nonrival, *both* Ahmad and Barnali get to enjoy it. Because of this, the aggregate demand curves are different. The efficient provision is different too, with a higher optimal supply for the nonrival good than for the rival good.

Figure 2 illustrates exclusion. The demand by Ahmad and Barnali is unchanged from Figure 1, but there is third consumer: Charlotte. Charlotte is not prepared to

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[4] Rivalry in consumption sets public goods apart from externalities. Externalities and public goods are often confused. Both are market imperfections. Both describe situations in which private and social interests diverge. The easiest way to tell them apart is that an externality is between an active agent and a passive one. A negative externality is imposed on an innocent bystander. A third party benefits from a positive externality. In contrast, all agents are active in public goods: They all want to consume the same good or service.

[5] You would need to pump my stomach, separate the ice-cream from its other contents, and refreeze it. It would be cheaper just to buy another one, and probably more appetizing.

[6] Club goods are sometimes called *congestible goods*, a practice that should be avoided for confusion with commons goods, which can be congested too.

pay much and her willingness to pay falls steeply, so she never cuts into the market. Charlotte is *de facto* excluded. For the public good, however, Charlotte's demand is included in the aggregate demand and she does affect the optimal provision.

There is another way to look at this, illustrated by 1. The total demand curve for a private good results from the *vertical* aggregation of individual demand curves. For a public good, however, total demand results from the *horizontal* aggregation of individual demand curves.

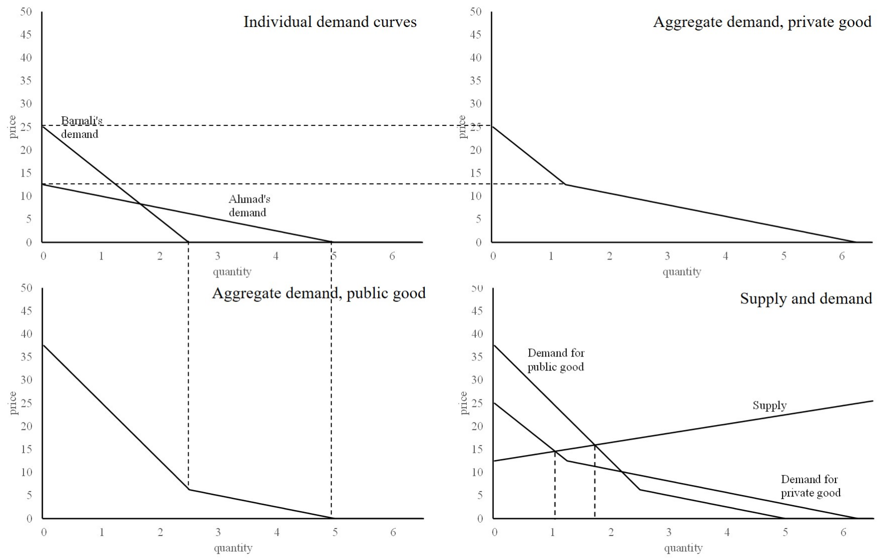

Fig. 1: Supply and demand, rival vs. nonrival goods. The top right panel shows the individual demand curves for the good. The top left panel shows aggregate demand if the good is rival. The bottom right panel shows aggregate demand if the good is nonrival. The bottom left panel shows the efficient provision of the good.

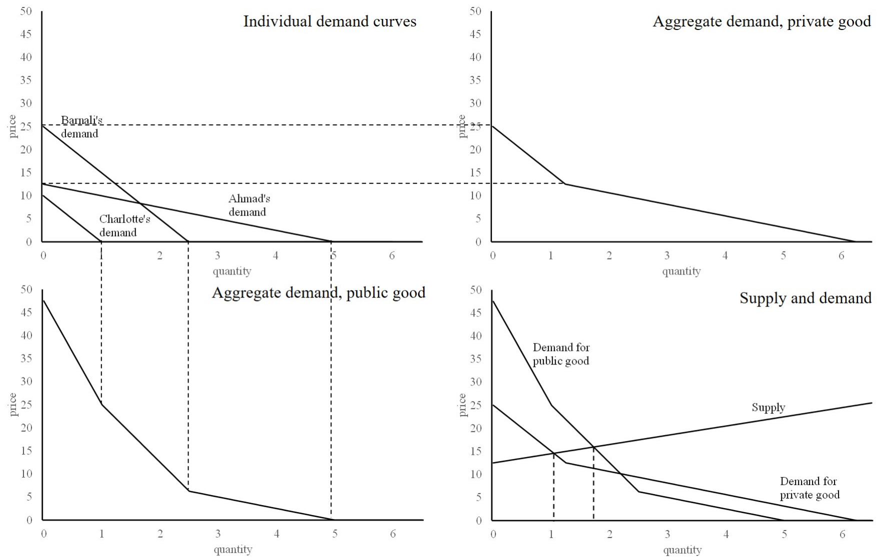

Fig. 2: Supply and demand, rival vs. nonrival goods, excludable vs. non-excludable goods. The top right panel shows the individual demand curves for the good. The top left panel shows aggregate demand if the good is rival and excludable. The bottom right panel shows aggregate demand if the good is nonrival and non. The bottom left panel shows the efficient provision of the good.

Part II
Targets for environmental policy

The true rule in determining to embrace or reject anything is not whether it have any evil in it; but whether it have more of evil than of good.

Abraham Lincoln

[E]conomists have the reputation of being unimaginative bean-counters, doggedly claiming to quantify the unquantifiable [...] and personifying Oscar Wilde's definition of a cynic as someone who knows the price of everything and the value of nothing. [...] It is true that they would give a lot for a rough quantitative answer; but that only reflects the fact that any policy can be pushed harder or less hard, further or less far, and that a useful evaluation has to suggest how hard and how far. The beans have to be counted, if only approximately: those gentle souls who merely ooh and ah over them are arguably part of the problem, not part of the solution.

Robert M. Solow

Every upside has its downside.

Johan Cruyff

Chapter 5
Decision analysis

Pollution is a negative externality, the unintended and uncompensated damage done to a third party.

The impact of pollution depends on a number of things, including transport and transformation in the environment and background levels of pollution.

Consider acid rain. Coal is mostly a carbohydrate, but it typically contains traces of sulphur and nitrogen. When the coal is burned, carbon dioxide (CO_2), water (H_2O), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) is formed and released into the atmosphere. Sulphur dioxide and nitrogen dioxide are nothing to worry about, if concentrations are low. However, if there are hydroxyl radicals around, and there typically are, nitrogen dioxide forms nitric acid (HNO_3) and if there is water too, sulphur dioxide becomes sulphuric acid (H_2SO_4). When deposited, for example in rain drops, these acids damage plants, animals and limestone monuments. Transformation matters.

The transformation of harmless sulphur dioxide into damaging sulphuric acid is not instantaneous. Two weeks can pass between emission and deposition. In that period, the wind can push sulphur dioxide hundreds, sometimes thousands of kilometres from its source. Transport matters.

A pristine environment can handle a little bit of acid rain. The first bits of coal burned do little damage. If there is already a lot of acid deposition, then adding to that causes more damage at the margin. However, if acid rain has killed all plants and animals already, then adding more acid to the environment makes little difference. Background concentrations matter.

It is important to understand the (environmental) problem before you try and solve it. Although environmental economics is economics, useful analysis of the economic aspects of environmental pollution requires a basic understanding of the environmental mechanisms and possible countermeasures. This implies that, as economists, we need to read up on our physics, chemistry, biology, and engineering.

There is another key distinction in environmental problems: *flow* versus *stock* pollution. Flow pollution ends as soon as the economic activity ends. Noise is a good example. Your neighbour may wake you up when he starts his car early in the morning. But as soon as he out of the street, the noise is gone too. Stock pollution is the opposite: It lingers after the activity stops. Nuclear waste is a prime example. Nuclear fission to generate electric power creates materials that will remain radioactive—that is, dangerous to health—for thousands or tens of thousands of years.

The distinction between stock and flow pollution is important because the latter is a static problem while the former is a dynamic problem. This has major implications for the analysis of optimal emission control. We take each in turn, before turning to a discussion of applied cost-benefit analysis and its alternatives.

1 Optimal flow pollution

Let us denote pollution by M (for emissions) and the damage done by pollution as $D = D(M)$. There are also benefits from the polluting activity—if there were none, there would not be any pollution—which we denote by $B = B(M)$. The net benefits are thus $NB = B(M) - D(M)$. If we seek to maximize the net benefits, we need to solve

$$\frac{\partial NB}{\partial M} = \frac{\partial B}{\partial M} - \frac{\partial D}{\partial M} = 0 \Rightarrow \frac{\partial B}{\partial M} = \frac{\partial D}{\partial M} \tag{5.1}$$

That is, in the optimum, marginal costs equal marginal benefits. The standard equimarginal principle applies to the environment. We saw above that the marginal cost of producing something should equal its marginal benefit. The same principle applies here. The marginal benefit of pollution should equal its marginal cost.

2 Optimal stock pollution

3 Cost-benefit analysis

Social cost-benefit analysis, pioneered by Otto Ekstein in 1958 for the development of water resources and pushed to include nature conservation by John Krutilla a decade later, extends the methods of project appraisal, already common in business, to public expenditure and investment. The rules of cost-benefit analysis are simple. If the benefits of a project are greater than its costs—phrased differently, if its benefit-cost ratio is greater than one—then the project is a worthwhile investment.

If there are a number of discrete projects, then you should finance them in order of their benefit-cost ratio until your budget is exhausted—unless you can borrow money, in which case you should finance all projects with a benefit-cost ratio greater than one.

If instead there is a continuum of choices, as with the setting of a tax or target, then you should find the choice that maximizes the net benefit, that is, benefit minus cost—as explained in the first two sections of this chapter.

Cost-benefit analysis was originally designed for *ex ante* project appraisal but it can just as easily be used for *ex post* project evaluation: Did the project's promised benefits materialize? Were its actual costs as budgeted? And, in hindsight, was it still a good idea? If not, what lessons can be learned to avoid repetition?

Unsurprisingly, not every public investment turned out to be quite as beneficial and cheap as initially claimed by their political champions. Robert Hahn found that only half of US environmental regulations between 1990 and 1995 passed the cost-benefit test, and David Pearce found a worse record for EU directives. Although a certain cynicism about the motivations of politicians is not unwarranted, it may also be that the conducted cost-benefit analyses omitted some key concerns that overturned the bottom-line recommendation.

While cost-benefit analysis is conceptually simple, it is more difficult in practice and indeed controversial. Cost-benefit analysis may be done in ten steps:

1. Describe the rationale for intervention.
2. Identify the portfolio of candidate projects and define a baseline: What will happen with any of these projects?
3. Decide whose benefits and costs count (standing, or accounting stance).
4. Identify all potential impacts, physical and biological.
5. Predict scale of impacts over the life of the project.
6. Monetise (attach money values to) all impacts.
7. Aggregate all the benefits and costs, calculate net benefits.
8. Discount to find present values.
9. Perform sensitivity analysis.
10. Recommend the alternative with the largest net benefits.

Step 1 is simple. Describe the problem, make the case that something should be done. That something is in Step 10. Potential issues arise in the intermediate steps

Step 2 comes in two parts. The baseline is a prediction, a forecast of all the bad things that would happen without government action. Predictions are always uncertain. The advocates of intervention have an incentive to paint a bleaker future than is realistic. This matters because the benefits of intervention are measured against the projected doom and gloom.

The selection of the portfolio of candidate projects may be controversial too. The sponsors of the cost-benefit analysis may have their pet solution. They would have no objection to comparing that to obviously inferior alternatives, but may resist the inclusion of seemingly attraction options on spurious grounds. One example is the discussion about additional runways for Heathrow Airport. Accepting the rationale for airport expansion, one option is to put the new runways in the grounds of Windsor Castle, but this option has never been considered by Her Majesty's Government.

Step 3 is just as hard. Project appraisal draws a box around a project and any*one* inside the box counts. Limiting the number of people who have standing simplifies the analysis but may bias the results. For example, the initial cost-benefit analysis of the London Super Sewer counted only the impacts on the people of London, even though the sewage ends up in Surrey.

Similar issues arise in Step 4. Project appraisal draws a box around a project and any*thing* inside the box counts. Again, limiting the issues considered simplifies yet biases the analysis. Implicitly, things that are not considered are given zero weight in the decision. Returning to the London Super Sewer, the impact on the people of Surrey was initially given zero weight. They simply did not count. In the revised analysis, health risks to humans, visual impacts, and fish kills were considered. Impacts on other aquatic organisms were disregarded.

Step 5 again involves a forecast, now with the considered government interventions. The impacts of a project are the difference between the prediction with and the prediction without the project. These forecasts are only as good as the models making the forecasts. Returning to Step 4, some things are excluded not because they are not important, but because they are hard to predict.

Step 6 is monetization of the impacts. We return to this, at length, in Part 4. For now, suffice it to say that this introduces yet more uncertainties and yet more choices, degrees of freedom that could be used to massage the bottom-line into the desired direction.

Step 7 seems simple: Add it up. Aggregation is not without its problems either. Returning to our example, London is home to some of the richest and some of the most deprived people in England. If we simply add up all the impacts, we lose track of who is impacted. Do the costs fall primarily on the poor and the benefits primarily on the rich? In aggregate, there is no way to tell.

In Step 8, the net present value is calculated. Most projects have a life-time measured in years and decades. Cost and benefits are spread over a longer period. The net present value (NPV) is defined as

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \tag{5.2}$$

where T is the life time (in years) of the project, B_t is the benefit at time t, C_t is the cost at time t, $B_t - C_t$ is the *net* benefit at time t, r is the discount rate and $(1+r)^{-t}$ is the discount factor. The discount rate is a crucial parameter. Most projects involve an upfront investment that pays off later. That is, the costs are in the immediate future, the benefits at a more remote time. A higher discount rate emphasizes the earlier costs over the later benefits. There is much debate over the “right” discount rate to use in public projects.

Step 9 should alleviate some of the concerns raised above. A systematic sensitivity analysis reveals how the results vary with the assumptions made, and so what assumptions are key. If the net present benefits of a project are positive for a wide range of plausible parameter values, then it is probably a good project.

4 Alternatives to cost-benefit analysis

Part III
Valuation

This part is about the monetary valuation of goods and services that are not traded on markets. I first discuss why one would like to know the price of something that is not traded, and then review the history of the theory of price and value. This leads to a chapter on types of value. After that lengthy introduction, the final two chapters discusses methods for valuing environmental goods and services.

Chapter 6
Purpose of valuation

Monetary valuation has several purposes. The first is in cost-benefit analysis. In Chapter 3 I assumed, without further ado, that costs and benefits could be added and subtracted. That is, all costs and all benefits are expressed in the same unit. There is a reason for that. Suppose that we care about one thing only, say the number of squirrels in a acre of forest. The ranking of forest types is then straightforward. Squirrels do not much like conifers, and they prefer acorns to hazelnuts. An oak forest is best.

Now suppose that we care about both squirrels and timber. We want to jointly optimize our forest stand for wildlife and wood. Hazels are simple: Squirrels do not like their nuts and carpenters do not like their wood. The choice between pine and oak trees is not. Pines grow much faster than oaks and are therefore more valuable as timber. Squirrels prefer oak. You cannot say which forest is better without somehow making squirrels comparable to timber. There are two ways of doing so: Express squirrels in money (as that is the measure of profit in timber) or express timber in squirrels. Once that is done, you can add squirrels and timber and say whether pine is better than oak.

There is a general principle here. In a single dimension, larger and smaller and therefore better and worse are defined. If there are two or more dimensions, larger is undefined. Therefore, if you want to find a maximum or compare two or more projects, you need to project all dimensions onto one.

Expressing squirrels in money is strange but not as strange as expressing timber in squirrels. We are actually quite used to comparing things according to their price. Students on a tight budget can take their loved one for dinner or buy new jeans, but probably not do both. The two options give a completely different kind of satisfaction, yet they are comparable through their price tag.

Indeed, this is one of the defining aspects of money. Money is a **unit of account**. In a barter economy with N goods, there are $N(N-1)$ prices. In a money economy, there are N prices. Money makes trade easier, and trade-offs simpler.

This is the first reason to attribute a monetary value to environmental goods and services: Without it, cost-benefit analysis does not work. Or rather, without it, cost-benefit analysis puts a zero price on the environment. In other words, environmental impacts that are not valued are ignored.

The second, closely related reason is that you would want to impose the Pigou tax on environmental externalities. Taxes are typically paid in money. If you do not express the value of the externality in money, you cannot impose the Pigou tax.

The third reason to give a money value to the environment is again related. You may want to pay people to preserve the environment, entice them not to burn down the forest or dump chemicals in the water. If you want to assess whether such payments are worthwhile, you again need to assess the value of the damage avoided.

The fourth reason is compensation. Environmental damage is often not avoided, and interested parties may demand restitution—money, that is. For a court to decide how much compensation is appropriate, the damage to the environment again has to be expressed in money terms.

Fifth but not least, the national accounts can be extended with the monetary value of the environment. The growth rate of its Gross Domestic Product (GDP) is a key indicator for the health of an economy, and the league tables of GDP per capita are very popular. GDP is part of the national accounts, which cover all *market* transactions—that is, timber is included but squirrels are not. Attributing a monetary value to the environment allows us to adjust economic growth rates for environmental degradation.

Chapter 7
History of value

1 Proto-economics

Adam Smith (Wealth of Nations I-IV, 1776) formulated the paradox of value thus:

> The word VALUE, it is to be observed, has two different meanings, and sometimes expresses the utility of some particular object, and sometimes the power of purchasing other goods which the possession of that object conveys. The one may be called 'value in use', the other 'value in exchange'. The things which have the greatest value in use have frequently little or no value in exchange; and on the contrary, those which have the greatest value in exchange have frequently little or no value in use. Nothing is more useful than water: but it will purchase scarce any thing; scarce any thing can be had in exchange for it. A diamond, on the contrary, has scarce any value in use; but a very great quantity of other goods may frequently be had in exchange for it.

Smith's words echoed earlier writers. The oldest surviving account is by Plato (Euthydemus, 304BC), who, remarking on Crito's easily copied oratory style, wrote

> for only what is rare is valuable; and "water" which [...] is the "best of all things" is also the cheapest.

The Ancient Greek philosophers, led by Aristotle, had little interest in price formation and why prices *are* as they are. They gave little consideration to value in exchange. Instead, they focused on value in use, using ethics to reason what values *should* be. They worried about the deviation of the actual price from the right price. The market was deemed *immoral*.

Some 750 years later, St Augustine replaced Aristotelian ethics by Christian theology. Like Aristotle, Augustine was mainly interested in what values should be. Unlike Aristotle, he argued that the right price can only be found by examining the will of God. Working some 850 years after, Thomas Aquinas by and large adopted Augustine's position. Something is valuable because God values it, or rather because of the human interpretation of whatever God's intention may be.

In 1662, William Petty wrote

> Labour is the Father and active principle of Wealth, as Lands are the Mother.

Petty maintained the notion that there is an absolute yardstick for value, but he replaced an intangible God with tangible assets.

The 18th century Physiocrats, led by François Quesney, followed Petty to a limited extent. They put God at one remove from value. Quesnay argued that society should be based on the *ordre naturel*, the laws of nature as dictated by God. Agriculture was society's interface with nature, and therefore only agriculture can yield a net surplus. Other economic activities do not add value, take as much in inputs as they make in outputs. Note that, according to the Physiocrats, it is nature (as an expression of God) that creates value. Farmers merely reap that value. The source of value is the land.

The land theory of value thus replaced one absolute yardstick—God—with another—land. It is easy to see how the Physiocratic theory of value served the landed elite of France. Quesney was a land-owner himself, and served at the court of Louis XV.

2 Classical economics

Adam Smith disagreed with the Physiocrats and returned to the other half of Petty's theory, arguing that labour rather than land is the true source of value.[1] David Ricardo and Karl Marx further elaborated Smith's labour theory of value.

Smith, Ricardo and Marx maintained the notion, going back to Aristotle, that value is absolute: Value is proportional to the quantity of labour invested in a good of service.

Marxian economists also held up another part of the Aristotelian tradition: If the market price deviates from the labour value, that is because the market is *immoral*.

Smith and Ricardo instead argued that the market is *moral*. The invisible hand guaranteed the greatest good for the greatest number. A perfect market delivers a Pareto optimum.

3 Neo-classical economics

The neo-classical revolutionaries—William Jevons, Karl Menger and Leon Walras—argued that value is relative. They abandoned the labour theory of value of Smith and Marx and the earlier absolute value theories, whether anchored on land or religion or morality. They reconciled value in exchange with value in use through marginality: If water is abundant, then it does not matter much if you have a little bit more or a little bit less. You would happily sell a small amount of water for a low price, and you would not be prepared to pay a great deal to get a little extra water. Even though the total value water is high, its marginal value is low. It is the

[1] Ibn Khaldun had earlier developed a labour theory of value, but this was not known in Europe until much later.

marginal value in use that sets the price, the value in exchange. Vice versa, diamonds are expensive because they are rare. The price is high because there are few, and this high value in exchange creates a high marginal value in use because pricey things signal status.

The neo-classical revolution was consolidated by Alfred Marshall and John Bates Clark and put on a firm footing by John Hicks. Although economics has changed a lot since the neo-classical revolution since 1870—with Keynesianism, the modern synthesis of Samuelson, the new economics of Dixit and Stiglitz, and the current empirical economics—the value theory of economics has not: Price equals marginal value.

4 Heterodox economics

Economists are a diverse lot. There are some trained economists who do not accept the neo-classical theory of value, and many more who are not trained in economics. Two are relevant in environmental economics.

First, some (Georgescu-Roegen, Costanza, Odum) argue that the value of a good or service derives from the energy embodied in that good or service. This is a return to the earlier notion that value is absolute. Although energy is an excellent accounting framework for physical, chemical and biological processes, it is less useful for thinking about social processes.

Second, other (Rees, Wackernagel) argue that land is a good standard for accounting. This can be dismissed as a return to Physiocracy, although land is now not just a creator of positive value but also a destroyer of negative value. We return to this, rather prominent, view in Chapter 3.

Chapter 8
Types of value

In Chapter 4, we met two types of value: The value in use and the value in exchange. This was a matter of debate for well over two thousand years until the neo-classical revolution showed that the value in exchange (or price) equals the value in use *at the margin*.

1 Neo-classical measures of value

We usually think of marginal value as price and of a change in value as the change in the consumer surplus. The latter is only approximately correct. The precise measure is the Hicksian *equivalent variation*, or willingness to pay, which is defined as the maximum amount of income you are willing to give up in order to obtain something. Formally, suppose that we're after X_1

$$U(X_2, X_3, ...; Y) = U(X_1, X_2, X_3, ...; Y - HEC) \tag{8.1}$$

On the right-hand side, we have X_1 but are HEV poorer. On the left-hand side, we do not have X_1.

Hicks also introduced the *compensating variation*, or willingness to accept compensation, in which we lose something but receive money in return. Formally,

$$U(X_1, X_2, X_3, ...; Y) = U(X_2, X_3, ...; Y + HCV) \tag{8.2}$$

On the right-hand side, we lost X_1 but are HCV richer. On the left-hand side, we still have X_1.

Besides the willingness to pay to obtain something, we can also define the willingness to pay to forego a loss. And we can define the willingness to accept compensation to forego a gain. The equations are as above. Unless there is loss aversion, the willingness to pay to obtain a gain equals the willingness to pay to forego a loss; and the willingness to accept compensation for a loss equals the willingness to accept compensation to forego a gain.

However, the willingness to pay to obtain a gain does not equal the willingness to accept compensation for a loss. One reason is that the budget constraint is different:

It tightens for the equivalent variation and loosens for the compensating variation. Loss aversion, an attachment to the status quo, is another reason. Agency is a third reason: You are the buyer with willingness to pay, a voluntary position, but the seller with willingness to accept compensation. You may be reluctant to “sell” to the person who caused your loss.

The Hicksian equivalent variation is defined by the equation above, but that is not how you would calculate it. Recall that the value in exchange of a good equals its price and its *marginal* value in use. To find the use value for a non-marginal change in price, you will need to integrate. The Hicksian equivalent variation integrates under the *expenditure function*, which gives the demand for *all* goods and services as a function of all prices and income. We typically approximate this by integrating under the *demand function*, which gives the demand for the good in question and how it varies with its price. This is the *consumer surplus*.

2 Ecosystem services

Valuation of the environment is sometimes approached through the lens of *ecosystem services*. Ecosystem services come in four classes, provisioning services, regulatory services, cultural services, and supporting services.

Provisioning services include such things as oxygen, food, water, and timber. The stock of nature gives an annual yield that humans take for use and consumption.

Regulating services include such things as the pollination of crops by wild insects, watershed control by vegetation, purification of water in rivers and lakes, and coastal protection by mangroves and coral reefs. These services benefit humans, but we do not take or consume anything from nature.

Cultural services include recreation and tourism, education, aesthetic appeal, and spiritual or religious practice. Like regulating services, this benefits humans, but the benefits are immaterial.

Supporting services do not directly benefit humans, but instead make sure that nature continues to be able to benefit humanity. Examples include soil formation, nutrient cycling, and primary production.

While the ecosystem service approach provides a welcome list of all the great things that the environment does for us (without charge!), it does not have anything to say about why we value nature.

3 Types of value

The classification of values according to their type does tell us *why* we cherish the environment.

Total economic value consists of three main types of value: use values, option values, and non-use values.

Use value consists of two subtypes: direct use and indirect use value.

Direct use value is further divided into consumptive and non-consumptive direct use.

Consumptive direct use value are the provisioning services mentioned above: food, water, timber. The terminology is obvious. We like food, or at least use it to sustain ourselves; this benefits us directly, and after we have use it, it is gone.

This last point sets it apart from *non-consumptive direct use value*. The resource is used and its benefits direct, but the resource remains (largely) intact. These are the cultural services mentioned above: recreation, tourism, amenity.

Indirect use value are the regulation services from above. Mangrove forests provide consumptive direct use value in the form of game, nuts and timber; non-consumptive direct use value in the form of ecotourism such as tiger-watching and by breaking the energy of waves and storms. Mangrove forests also are also nurseries for fish. We do not eat fish larvae, but we do eat fish. The use value is thus indirect, one step removed from direct use.

Option values come in two flavours, option values and quasi-option values.

Option value is a potential use. I mentioned tiger-watching, but ecotourism is far less developed in the Sundarbans than it is in the Maasai Mara (where you would see lions). The option to expand ecotourism is a realistic one, here and now.

Quasi-option values are more elusive. There may be a potential use, but we do not know this for certain. Quinine, a great help against malaria and babesiosis, is made from the bark of the cinchona tree. Is there a mangrove tree species with a similarly useful medicinal purpose? Maybe. If we raze the mangrove forests we will never know, and definitely forego this possibility.

Non-use values are perhaps strange to an economist. There are two types, use by others and existence values.

Use by others come in two flavours. *Altruistic value* is the pleasure we derive from the direct use by someone else. Your friend may have gone tiger-watching in the Sundarbans and the thought of her pleasure lifts your heart. *Bequest value* is similar, but we know derive pleasure not from a contemporary, but from some future person. You may want to preserve the Sundarbans so that your children can one day visit.

Existence values are strangest. I derive utility from knowing that somewhere on this planet there is majestic forest, standing in the water on a tropical coast, a haven for myriad wildlife. I do not want to eat its products. I do not want to go there. I do not live in its hinterland. I will not profit from tourism development. I do not suffer an incurable diseases. No one who has been there has ever told me about it. My children may never visit. But I still appreciate that its there.

Chapter 9
Revealed preferences

1 Principles

Revealed preference methods for monetary valuation infer preferences for environmental goods and services by analysing actual behaviour in related, so-called *surrogate* markets.

There are three kinds of surrogate markets, and hence three types of revealed preference methods. In the first kind of surrogate, the observed market is a *substitute* for environmental quality. The associated method studies defensive consumption, defensive investment, and avertive behaviour. Examples include bottled water in lieu of contaminated tap water; double-glazed windows to keep the noise out; and early morning jogging to avoid the air pollution of rush hour.

In the second surrogate, the observed market is a *complement* to environmental quality. The corresponding method studies travel to desirable sites, such as beaches, nature reserves, monuments, and museums.

The third surrogate considers markets for goods and services with *bundled* attributes. The corresponding method is known as hedonic pricing. Examples including the housing market, where you buy or rent a house of a certain size, age and upkeep in a particular neighbourhood with its schools, crime, and air pollution, and the labour market, where you accept a job with a certain salary, task and colleagues but also a particular location with its night life, climate, and natural beauty.

The key strength of revealed preference methods is that values are inferred from actual choices made by people in real life. In hedonic pricing, for instance, we do not ask what people would have paid, or what their recollection says they have paid, but rely instead on the data from the transaction as recorded by the real estate agent, the mortgage lender, or the tax collector.

Another strength is that revealed preference studies are relatively cheap. For the travel cost method, data are often collected by survey but these questionnaires are fairly simple. But these studies typically rely on administrative data.

The main weakness of revealed preference methods is that we only reveal our preferences about direct use values. I travel to the beach to enjoy myself, not because my yet unborn grandchildren may one day do so. I am willing to pay more for a house because it has a good view of the forest, not because I care about biodiversity in the Amazon rainforest. I wear a seat belt because that reduces the chance of injury in an accident, not because it could lead to a breakthrough in material science.

Another weakness is that preferences are revealed indirectly. We observe human behaviour in the market. We infer preferences—making assumptions about the structure of the market, information held by agents, and their rationality. We may, for instance, estimate willingness to pay for improved health by studying diets. Regular consumption of vitamin C increases your expected life-time. However, the willingness to pay for vitamin supplements does not depend on the *actual* health benefits but on the *perceived* ones—and different people have very different, often badly informed ideas about what is good and bad for them.

2 Travel cost method

There are a number of methods, and many variants, to value environmental goods and services. The more reliable but narrower ones use the actual behaviour of people and households. The travel cost method is the oldest method, and perhaps the most intuitive one. It belongs to the broader class of household production methods.

Consider your local park. If you would ask its visitors where they are from, you would learn that most of them come from the neighbourhood. Many live a block away and are in the park with their dogs or children. Some cycled or drove 10–15 minutes. Few have travelled across the country, and none across the world to be in your local park. That makes perfect sense. Your park is nice, but nothing special. There are many similar parks elsewhere. Why would anyone travel just to visit your park?

Now consider the Great Barrier Reef. There are many visitors. There are locals, of course, but relatively few. People fly all the way across the world to visit the Great Barrier Reef. Why? Because it is unique and spectacular!

The food that you buy is worth at least as much to you as the money you spent on that food. The movie that you see in the cinema is worth at least as much as the ticket you need to get in, at least in expectation. You do not pay an entrance fee to get into your local park. However, you do spend time to get there, and you may spend money on a bus fare or something similar.

If you extend your visitor survey and ask people how long they needed to get to the park and how much money they spent getting there, you would find that many paid little, few paid more, and none paid a whole lot. You would find something that looks remarkably like a demand curve: Low price, high demand; high price, low demand. In fact, you have found a demand curve. If you integrate under the curve, you estimate the consumer surplus generated by your local park. If you then repeat the exercise for the Great Barrier Reef, you find that demand is still high at a high price—and its value is much greater than the value of your local park.

Although conceptually clear, the travel cost method is beset with practical difficulties. Travel time is valuable, but how valuable exactly? In a perfect labour market, the wage equals the marginal value of leisure—but labour markets are distorted in many ways. Trips often serve multiple purposes (e.g., going to the park and the shop; visiting Sydney and the Great Barrier Reef) and that means that the travel cost needs to be apportioned to these purposes. Sometimes the trip is a cost (e.g., travelling alone in a hot and crowded train), and sometimes the trip is part of fun (e.g., travelling in an open top car with friends). These problems can be overcome with a sufficiently detailed survey, plenty of data, and clever econometrics.

3 Hedonic pricing

The second class of revealed preference methods analyzes household consumption. Hedonic pricing is the best known example. A house that sits in a beautiful environment is worth more than the exact same house that sits in an ugly environment. The price difference is an indication of the value of environmental beauty.

Like the travel cost method, hedonic pricing is conceptually straightforward but difficult in practice. Builders are not stupid. They put the prettiest houses in the prettiest environments, and more ordinary houses elsewhere. Indeed, England's first public parks were financed from building villas nearby. Expensive houses attract more well-to-do home owners, who tend to be better educated and socially more attractive as neighbours. Such neighbourhoods tend to have better schools and other facilities. At the larger scale, wages compensate both for the local cost of living and for the attractiveness of the environment, and house prices in turn reflect wages. In sum, the housing market is influenced by many things, and you need a large amount of observations and clever econometric methods to isolate the effect of the environment—but it can be done.

4 Defensive expenditure

Defensive expenditure is a third class of revealed preference methods. You prefer clear air and clean water, but if it is not available you get an air filter or mask, you buy a water purifier or switch to bottled water. You prefer safe roads, but get a bike helmet because they are not. You pay extra for healthy food, or install double-glazed windows to keep the noise out. All these expenditures compensate for the lack of something in the environment that you like.

As above, defensive expenditure is conceptually easy but difficult in practice. Did you get double-glazed windows to keep the noise out or to save energy? Do you drink bottled water because other water is polluted or because you like its taste? Bottled water comes in a limited price range; the most expensive bottle in the shop may be well below your willingness to pay. There is another problem. A cursory glance at the media will tell you that experts often disagree about what food and drink is healthy and unhealthy. People do not purchase an objective reduction in the chance of premature death when switching to organic food. Even if the experts could agree on that change in probability, what matters is the subjective assessment of the buyer or others in the household. An empirical study would need data not only on purchases (which are easy to get if you find a cooperative retailer) but also on what good the purchasers think these things do. This introduces all sorts of potential biases. As one example, most people are not very good at probability calculus and they get progressively worse when handling very small probabilities.

Chapter 10
Stated preferences

Part IV
Environmental regulation

Angus Deaton said that the need to do something often trumps the need to understand what needs to be done. The chapters in this part discuss *how* the regulator can improve the quality of the environment. Before doing so, recall some the reasons for a benevolent social planner to intervene in the market. The first two are directly relevant for this book. *Public goods* are overconsumed and underprovided. *Externalities* impose unintended and uncompensated effects on third parties. Both imply that an *unregulated* market is not in a Pareto optimum and so justify government intervention.

There are other grounds for government intervention too. The accumulation of *market power* also requires the regulator to step in. Market power may occur because of cartel formation, or because of economies of scale, scope, or network. There are *natural monopolies* too, when the costs of facilitating competition are greater than its benefits, as is the case in the road network and the power grid. There are various ways to regulate market power, some good and some not so good, but these are not discussed below. Similarly, *asymmetric information*, when the buyer knows less than the seller, justifies regulation.

These are all good reasons for the government to step into the market. There are bad reasons too. Companies may lobby the government to create rents. Politicians may distort the market to favour their (prospective) voters. Civil servants may create rules to increase their budget. Although economists often and rightly consider what a benevolent social planner would or should do, actual policy makers are not social planners and some are not benevolent.

Chapter 11
Criteria for policy instruments

The next chapters discusses a large variety of things a regulator can do to improve the quality of the environment. This requires a systematic comparison. I do so based on the following criteria:

- Cost-effectiveness
- Administrative costs
- Environmental effectiveness
- Long-run effects
- Flexibility
- Equity

Before discussing these criteria in turn, it is important to note that the design of environmental regulation should reflect the environmental problem at hand. In Chapter 3, we look at the differences between a flow pollutant and a stock pollutant. That is important for target-setting. It is also important for instrument choice. Policies to reduce stock pollutants need to last a long time and so need to be robust to changes in public mood and political will. This is less important for flow pollutants.

The environmental medium is key too. Air pollutants get blown around by the wind and may cross borders between jurisdictions. Water pollutants move too but in one direction (downstream) only. Soil pollutants stay in place. Soil pollution can therefore be contained, either with a soil clean-up or a fence around the polluted area. This does not work for water and air pollutants.

Point sources of pollution should be approached differently than diffuse sources. There are 443 nuclear power plants in the world, using a handful of designs, and operated by two handfuls of companies. Numbers are, of course, much smaller in each jurisdiction: Only 8 plants and 2 companies in the UK. Regulation of nuclear waste is technically difficult but easy to organize: Just talk to EdF. There are about 1.5 billion cars on the planet, 33 million in the UK. Coordinating so many different users is a challenge.

Some environmental problems have a large impact in a small place, others a small impact in many places. Dioxins are an example of the former. Dioxins form if waste is burned at a low temperature. They causes cancer but do not travel far. This can be solved by moving incineration away from residential areas and grazing land. This does not help against sulphur which can travel hundreds, sometimes thousands of kilometres in the air.

Finally, it matters whether the environmental problem is local, regional, national, continental, or global. Authorities at different levels have different powers. A tax on emissions cannot be imposed by the United Nations and most cities lack that power too. Countries have border controls but counties do not.

The nature of the environmental problem thus matters for its regulation. You need to understand a problem before you can hope to solve it.

1 Cost-effectiveness

Let us consider a social planner, who seeks to reduce emissions at a minimum cost to society:

$$B = \sum_n B_n = \sum_n \beta_n R_n^2 \tag{11.1}$$

where B are the total costs of emission reduction, B_n are the costs of company n, R_n are the emission reduction efforts of company n, and β_n are parameters, the unit cost of emission reduction. Let R denote the desired total emission reduction effort. Then, the least-cost solution to the emission reduction programme follows from

$$\min_{R_n} \sum_n B_n \text{ s.t. } \sum R_n \geq R \tag{11.2}$$

Form the Lagrangian

$$\mathcal{L} = \sum_n \beta_n R_n^2 - \lambda(\sum_n R_n - R) \tag{11.3}$$

and take the first partial derivative to the policy instruments (i.e., the emission reduction effort) to derive the first-order conditions for optimality:

$$\frac{\partial \mathcal{L}}{\partial R_n} = 2\beta_n R_n - \lambda = 0\, \forall n \Rightarrow \frac{\partial C_n}{\partial R_n} = \lambda\, \forall n \tag{11.4}$$

That is, least-cost emission reduction requires that all emitters face the same abatement cost at the margin. Because there is a shared constraint R, the shadow price of the constraint λ is set at the societal level and is thus the same for all emitters.

The least-cost solution to meet a target is known as the *cost-effective* solution. Cost-efficacy is an optimum. A solution cannot be more cost-effective than another solution; it either is cost-effective or it is not. Some people use the words "more cost-effective" as an "erudite" alternative to the word "cheaper", but in fact they demonstrate their lack of understanding of the meaning of the concept cost-efficacy. Other people, particularly native speakers of French and German, use the word “cost-efficiency" as a synonym for cost-efficacy. In fact, cost-efficiency is the dual of productive efficiency, and if you do not understand what that means, then you should not use the word cost-efficiency.[1] Besides productive efficiency, we also care about allocative and cross-efficiency, which are captured by cost-efficacy if applied at the macro-scale.

2 Administrative costs

3 Environmental effectiveness

4 Long-run effects

5 Flexibility

6 Equity

[1] Reminder: In the primal formulation, a company maximizes output subject to a constraint on production costs. In the dual formulation, a company minimizes costs subject to an output constraint.

Chapter 12
Direct regulation

Equation 11.4 has that, in a cost-effective solution, the marginal costs of emission reduction are the same for all polluters:

$$\frac{\partial C_n}{\partial R_n} = 2\beta_n R_n = \lambda \, \forall n \Rightarrow R_n = \frac{\lambda}{2\beta_n} \tag{12.1}$$

A regulator can achieve this only if she knows β_n the marginal costs of every polluter and if she is allowed to discriminate between polluters on the basis of their marginal costs. Marginal costs are rarely observed. Regulation would also be cost-effective if every polluter works to the same target and marginal abatement costs are the same.

Chapter 13
Coasian bargaining

1 Coase in context

The Coase Theorem is a central result in economics.[1] It shows how, under certain conditions, economic actors can arrive at an efficient solution to an externality *without direct government involvement*. Prior to Coase's seminal paper, economists thought that externalities, which are at the heart of environmental economics, necessitate government regulation, particularly taxation. Since then, the Coase result has sometimes been used to argue that environmental externalities do not necessitate government regulation beyond the establishment and enforcement of property rights. Skepticism remains, however, regarding the applicability of Coase's theoretical result to real-world environmental problems.

The Coase Theorem was published in the *Journal of Law and Economics*. In its original form, it is not a theorem in the conventional sense of the word. Coase did not formalize his theorem, let alone prove it. There is not a single equation or rigorous definition in the paper. Instead, Coase offered a detailed discussion of common law on liability and nuisance. Coase agrees with Pigou that externalities are a problem, but disagrees with Pigou's solution.

Coase's critique of the Pigovian framing of environmental problems focuses on the nature of the transfer payment required to internalize an externality. He argues that, because of the symmetry of the problem, a tax on producers of a negative externality is not the only possible solution:

> "The traditional approach has tended to obscure the nature of the choice that has to be made. The question is commonly thought of as one in which A inflicts harm on B and what has to be decided is: how should we restrain A? But this is wrong. We are dealing with a problem of a reciprocal nature. To avoid the harm to B would inflict harm on A. The real question that has to be decided is: should A be allowed to harm B or should B be allowed to harm A?"

[1] Coase also made key contributions to the theory of the firm and the behaviour of a durable-goods monopolist.

That is, Coase takes issue with Pigou's premise that the one who causes the externality should be the one who is rewarded (if the externality is positive) or penalized (if the externality is negative). Judging from the textbooks reviewed above, Coase's criticism of Pigou's asymmetric treatment of pollutee and polluter is perhaps less well-known, but it was a key point in his seminal paper. To demonstrate the feasibility of alternative regimes, Coase discusses the different treatment under common law of escaped domesticated and wild animals. If a domesticated animal escapes and does damage, its owner is liable. If a wild animal escapes from captivity and does damage, the victim is liable rather than the former captor. Coase underlines the arbitrary nature of this distinction by discussing the rabbit, which many people would think of as *domesticated* (and tame), but is actually a *wild* animal under common law.

Coase' central example is cattle eating a neighbor's crops. Coase argues that, if the cattle-owner is liable for the damage done by her steers, she would limit the size of her herd to the point where the damage done by one additional steer equals the cattle's incremental profit. Coase then argues that, without such liability, the farmer would be willing to pay his neighbor to reduce the herd size, and that he would pay up to the point where the damage avoided by one fewer steer equals the marginal steer's value to the cattle-raiser. In other words, the final outcome is the same regardless of whether or not the cattle-owner has a duty to compensate for harm to her neighbor.

This example leads to the Coase Theorem: In the presence of externalities, clearly defined property rights, and the absence of transaction costs, agents can bargain their way to a Pareto optimum, and that Pareto optimum is the same regardless of who imposes an externality on whom.

Coase emphasizes that his conclusion only holds if there are no costs involved in the transaction and that it is easier to reach agreement if fewer parties are involved. He implicitly assumes that people are well-informed, act in their self-interest, that the money changing hands does not affect the demand or supply curves, and that the agreement reached by the bargaining parties will be enforced by courts if necessary. Another assumption is that the willingness to pay to avoid harm is equal to the willingness to accept compensation for harm. Coase himself did not seem to believe that these conditions were likely to be met in most situations, emphasizing the importance of considering the net value of alternative (imperfect) institutions that can be implemented in the presence of transaction costs. In his Nobel Prize lecture, he said that "the legal system will have a profound effect on the working of the economic system and may in certain respects be said to control it".

Coase's Nobel Prize lecture continues: "[s]ince standard economic theory assumes transaction costs to be zero, the Coase Theorem demonstrates that the Pigovian solutions are unnecessary in these circumstances. Of course, it does not imply, when transaction costs are positive, that government actions (such as government operation, regulation or taxation, including subsidies) could not produce a better result than relying on negotiations between individuals in the market. Whether this would be so could be discovered not by studying imaginary governments but what real governments actually do. My conclusion; let us study the world of positive transaction costs." That is, in his Nobel Lecture, Coase does not take issue with Pigou, but rather with the assumption of zero transaction costs.

2 Coase formalized

Stigler coined the term "Coase Theorem". Stigler did not, however, restate Coase' insight as a theorem. Let us do so. Consider two agents with an indirect utility function

$$v_i(p, w_i, h) = \max_{x_i \geq 0} u_i(x_i, h) \text{ s.t. } px_i \leq w_i \text{ for } i = 1, 2 \tag{13.1}$$

where p is the price vector for consumption bundle x_i of agent i, w_i is his budget constraint, u_i is utility, v_i is indirect utility and h is the externality. Assuming a quasilinear utility function with respect to a numeraire, we can write $v_i(p, w_i, h) = \phi_i(p, h) + w_i$. If both agents are price-takers, we can write $\phi_i(p, h)$ as simply $\phi_i(h)$.

Suppose that agent 1 chooses h to maximize ϕ_1. Then $\phi_1'(h^*) = 0$. The social optimum maximizes $\phi_1 + \phi_2$, so that $\phi_1'(h^\circ) = -\phi_2'(h^\circ)$. The equilibrium h^* is suboptimal unless $h^* = h^\circ = 0$. If $\phi_2'(.) < 0$, the externality is negative and $h^* > h^\circ$, that is, agent 1 chooses too much h. If $\phi_2'(.) > 0$, the externality is positive and $h^* < h^\circ$, that is, agent 1 chooses too little h.

Now suppose that agent 2 has the right to be free of externality h, but would be prepared to waive that right in return for compensation $T > 0$. Then agent 2 would solve

$$\max_h \phi_2(h) + T \text{ s.t. } \phi_1(h) - T \geq \phi_1(0) \tag{13.2}$$

where the constraint comes about because agent 1 needs to agree to the bargain. As the constraint binds, this is equivalent to

$$\max_h \phi_2(h) + \phi_1(h) - \phi_1(0) \tag{13.3}$$

The maximand is the social welfare function (shifted by a constant), and thus the equilibrium externality is the optimal one h°.

If instead there are no restrictions on agent 1, agent 2 would need to compensate her with an amount $T < 0$. Agent 1 would agree if $\phi_1(h) - T \geq \phi_1(h^*)$. Deciding on the offer made, agent 2 would solve

$$\max_h \phi_2(h) + \phi_1(h) - \phi_1(h^*) \tag{13.4}$$

The maximand is again the social welfare function (shifted by a different constant), and the equilibrium externality is the optimal one h°.

This simple proof of the Coase Theorem also reveals key underlying assumptions:

1. **No wealth effect** Quasi-linearity in the numeraire makes the externality h independent of budgets w_i and side-payment T.
2. **Perfect information** The agents know each other's indirect utility functions.
3. **Rationality** Agents maximize utility.
4. **No endowment effect** The utility functions are smooth in the status quo, and economic agents behave the same whether or not they have the right to be free of externalities.
5. **Zero transaction costs** The bargain can be struck without incurring costs.

The Coase Theorem can be split into three parts. The *efficiency thesis* states that, once property rights are assigned, a Pareto optimum is achieved. As the assignment of property rights completes the market, this result is equivalent to the First Fundamental Theorem of Welfare Economics. The *invariance thesis* states that the Pareto optimum is independent of the initial allocation, a result that is sharper than the Second Fundamental Theorem of Welfare Economics.

Zero transaction costs is the third—and most controversial—part. Large parts of economic theory assume that transaction costs are negligible. If so, the Coase theorem illustrates that there is no need for direct government intervention to internalize externalities.

2.1 Coase generalized

The Coase Theorem only holds for two economic agents—one polluter and one pollutee, a 11 bargain. If there is more than one person involved on either side—$m1$, $1n$ or mn bargains—then coordination problems between polluters or pollutees prevent the attainment of an efficient solution.

As a corollary, if there is no coordination problem, the Coase Theorem does hold for more than two agents. For instance, a $1n$ bargain between 1 polluter and n pollutees is equivalent to n 11 bargains if there is no fixed cost of emission reduction, the variable costs are linear in emission reduction, the environmental damage is linear in emissions, and the polluter cannot exert market power over the polluttees. Under these (stringent and unrealistic) assumptions, each pollutee would strike a separate bargain with the polluter and those bargains would be efficient as the pollutees do not affect each other.

In more realistic settings, the action of one pollutee does affect the other pollutees—or polluters may affect each other. This would be the case if, for instance, the impact of pollution is non-linear in emissions. Then, coordination problems arise, and a pollutee may choose to free-ride on the efforts of her fellow pollutees to bargain with the polluter.

Coordination problems have been thoroughly studied and are hard to solve. That said, while mn bargains do not attain efficiency, they can still improve welfare. In the examples discussed below, we focus on coordination and improvements in welfare resulting from bargains between two or more actors, rather than on Pareto optimality. These can be thought of as impure forms of the Coase Theorem, or examples of Coase-like bargaining that do not necessarily result in a Pareto optimum.

3 Coase in the lab

Since the assumptions underlying the Coase Theorem were first made explicit, many laboratory experiments have been designed to understand which of these assumptions are mathematically convenient but can be relaxed without overturning the practical implications of the Coase Theorem and which assumptions are crucial.

In the first experiment, subjects were assigned to groups of two or three. One or two subjects were randomly assigned to be "controllers", who, analogously to being assigned initial property rights in the Coase Theorem, had the right to unilaterally choose the set of payoffs players would receive. The other participant(s) could attempt to influence the outcome via negotiations, including by offering to transfer some or all of her earnings to the controller.[2] In each case there was a unique scenario that maximized total cash payments, but whether or not payments were known to all participants varied. Any contract between the players was enforced by the experimenter, and payments were made publicly. Under conditions where payoffs were known and there was only one controller, 89.5% of the 114 experimental decisions resulted in Pareto optimal outcomes. In experiments with limited information and joint controllers, success rates were substantially lower.

In another early experiment finds that a contract negotiated over an externality comes, on average, within 3% of the Pareto optimum, and that there is no statistically significant difference between cases where the polluter or pollutee holds the initial property rights. This experiment ends with an ultimatum, and players appear to be motivated by fairness as well as efficiency.

Many experimental studies of the Coase Theorem and its limitations have been conducted, yielding much insight about when property rights are sufficient to yield Pareto optimal outcomes. An experimental design that makes cooperation individually rational—in the original set-up, it was impossible to distinguish between a fair allocation and a Pareto optimal one—find strong support for the Coase Theorem: The Pareto optimum is found in 97% of experiments. For zero transaction costs, complete information, and small incentives, subjects tend to opt for a fair allocation rather than a Pareto optimal one. Higher incentives lead to a shift to the Pareto optimum. The Pareto optimum becomes unattainable if transaction costs increase. Private (rather than public) information does not affect the ability of participants to attain the Pareto optimum. Asymmetric information does: Participants are less willing to trade in this case. Less secure property rights attenuate the effect of asymmetric information. Endowment effects would hamper Coasian bargaining. The Coase Theorem holds also when stress-tested with larger numbers of participants, asymmetric payoffs, uncertain payoffs, and more complicated bargaining. Transaction costs and time-limits have a negative effect on the probability of attaining a Pareto optimum, while face-to-face bargaining and information have a positive effect. The Coase Theorem also holds if either party can block the transaction and have the experimenter take away the good that they are bargaining over with mininal compensation.

At least in the lab, the Coase Theorem holds under its original assumptions—and that it sometimes holds under conditions that are less strict.

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[2] No physical threats were allowed.

4 Coase and the courts

To understand whether the experimental results discussed above have empirical counterparts, it is worth considering whether the world's legal institutions are conducive to Coasian bargaining.

Well-defined property rights (and, implicitly, enforceable contracts) are the key assumption underlying Coasian bargaining. In legal systems with strong protection of private property, such as the United States, clearly defining property rights may seem straightforward. However, specifying complete property rights requires attention to such details as mineral rights, wildlife harvesting rights, rights to make noise or emit noxious smells, and so on. As court cases demonstrate, there are many situations in which property rights are sufficiently vague to result in substantial disagreements between the affected parties about who holds a particular right. For simplicity, we will refer to the party producing an environmental externality as the "polluter" and the party experiencing the environmental externality as the "pollutee".

There are at least four reasons for the continued existence of ambiguous property rights. First, the common law theory of nuisance makes it very difficult to fully and clearly assign the right to create or assign the externality to the polluter, particularly for new types of harms where precedent has not been established. Second, it is difficult to define terms used in legislation and regulation in a way that leaves no room for an alternative interpretation. Third, the existence of multiple levels of government and of multiple, related, laws sometimes creates ambiguity about which law applies to a particular situation. Fourth, new laws and regulations change property rights, and shifting social norms and legal principles change what is deemed permissible.

The (very old) common law principle of nuisance is the basic legal principle determining the allocation of property rights around externalities from private property —who has the right to pollute and who has the right to be protected from pollution? In common law, the tort of nuisance goes back to the 13th century, in a case where King John of England (of *Robin Hood* and *Magna Carta* fame) ruled in favour of Simon of Merston after Jordan the Miller had flooded Simon's land in an attempt to expand the pond that powered Jordan's mill. Since the resolution of the Trail Smelter dispute, in which the smoke of a lead and zinc smelter in British Columbia affected farmers in Washington, the legal obligation to be a good neighbour also applies across country borders.

In modern legal theory, the nuisance principle allows for the "quiet enjoyment" of private property, while protecting other people from "unreasonable interference" as a result of that enjoyment. However, these are vague and general principles. In many situations, what constitutes "unreasonable inteference" is unclear, or at least contested, resulting in both polluters and pollutees asserting that they hold the right to inflict the nuisance or to be free from it, respectively. These cases sometimes lead to costly nuisance lawsuits, requiring a judge to weigh in to resolve the ambiguous allocation of rights.

Similar issues surface in other environmental settings. There have been lawsuits over the exact definitions of "discharge", "fill material", "navigable waterway", "flood or flood waters", and "acceptable noise." In other cases, there is ambiguity over which laws apply and over who decides. The considerations above result in imperfectly defined property rights and therefore inhibit Coasian bargaining, at least before precedent has been established through the courts.

Furthermore, property rights are not immutable. Rewilding is one example. Large grazers were introduced in many nature reserves in Western Europe to keep landscapes open. Large predators are now being introduced to prevent overgrazing. As these wolves also kill the occasional sheep, the European Union now recommends full compensation for lost livestock. A customary privilege of safety for farm animals has been replaced by an explicit right to compensation.

Environmental standards, in particular, are generally tightened over time. This trend implies that rights to pollute tend to disappear and rights to be free of pollution tend to appear. Loosened regulations have the opposite effect. When governments tighten environmental regulations, compensation may be offered to the companies newly deemed to be polluters. Recent examples include more stringent standards for nitrate emissions and odour from farms, as well as pesticide bans, with politicians promising to make farmers whole. This is not Coasian bargaining—which is bargaining *given* initial property rights—but rather bargaining over *the assignment* of initial property rights—meta-Coase bargaining, if you will.

Social norms can also play a role in defining the terms on which externalities are bargained over. Protests against and boycotts of large polluters have a long history. Like property rights, social norms can also shift over time with evolving standards of what constitutes a permissible nuisance as opposed to unacceptable behavior. Examples include shifting social norms around public littering or the disposal of dog waste. Decades ago, individuals had the "right" to dispose of waste in public spaces creating disamenities for others. But changing attitudes, sometimes driven by deliberate messaging campaigns and often codified in local laws and ordinances, shifted so that instead people now generally internalize at least some of the costs of responsible waste disposal while in public areas. As another example, the *Stop the Child Murder* movement in the Netherlands ensured that road safety standards were enforced. Similarly, China's Center for Legal Assistance to Pollution Victims focuses on the enforcement of existing environmental legislation. Lawsuits against emitters of carbon dioxide seek to establish a legal right to an unchanging climate.

5 Coase in the wild

Strictly, the Coase Theorem applies to a bargain between two players who have no other interactions and do not expect to meet again. Such conditions can be approximated in the lab, but are rarely if ever met in reality. Furthermore, with the exception of countries negotiating over transported emissions, there are few interesting environmental problems with only two agents. As illustrated by experimental evidence, however, the strict requirements of the Coase Theorem can in some cases be relaxed without jeopardizing its applicability. We therefore also include examples that involve more than two agents.

In the Coase Theorem, polluter and pollutee are symmetric in the sense that the Pareto optimum will be reached regardless of how property rights are initially endowed. From the point of view of the parties involved, however, the endowment of initial property rights is critical in the sense that it determines who is imposing the externality on whom, and therefore the direction of the transfers involved in the Coasian bargain. Ronald Coase was keenly aware of this, as evidenced by his detailed discussion of the differential treatment in common law of harm caused by escaped domesticated animals and wild animals in captivity. There are also long-established legal and moral principles about harm and nuisance to third parties. These legal doctrines of nuisance delineate the property rights relevant to the negotiation of externalities between parties, though are often open to different interpretations, as described in the previous section. As there is a difference between the polluter and the pollutee paying, we discuss them separately, starting with the polluter.

5.1 Polluter pays

We first discuss examples of Coasian bargaining where the polluter ended up paying. Frequently, even if courts were not involved, the prospect of legal recourse to enforce property rights via a lawsuit lurked in the background. For example, in 2002, American Electric Power bought all 90 houses in Cheshire, Ohio, and all 221 residents left after health concerns were raised about the release of fly ash from the nearby coal-fired Gavin Power Plant. Homeowners were compensated well above the market value. No lawsuit was filed, but the lawyers negotiating on behalf of the town did threaten to.

The American Electric Power company was certainly not the first to take this approach. Dow Chemicals, Georgia Gulf, Exxon, Shell, and Conoco have all bought properties near their chemical plants and refineries. Exxon and Shell appear to have started such purchases after explosions at their facilities caused damage to the people living nearby. Georgia Gulf's program began after a 1987 lawsuit, settled out of court, over contamination and health complaints. Reveilletown, Louisiana, no longer exists after Georgia Gulf bought it. Conoco's program is also in response to a lawsuit. Dow Chemicals' program was in response to *the threat of* a lawsuit after chemicals spilled into the drinking water of Morrisonville, Louisiana. The town was abandoned in 1993. These are all examples of the polluter agreeing to pay the pollutee, under the threat that property rights established under the nuisance doctrine would be enforced in court.

These are cases with one polluter and many pollutees. The coordination problem was solved by the polluter. The outcome need not be efficient, because the polluter had monopsony power.

Examples outside of the US include Severonickel, a copper-nickel smelter on the Kola Peninsula in Russia, which pays the nearby Lapland Biosphere Reserve

$300,000 annually, following a settlement in a court case Severonickel was likely to lose. Schiphol Airport in the Netherlands is planning to buy out homeowners troubled by the noise from an increase in the number of flights. The airport cannot grow without permission from the municipality of Aalsmeer, the local electorate is concerned about noise, and local politicians worry about re-election. Similarly, the Government of Berlin financially compensates homeowners for the noise it permitted Tegel Airport to make. The Royal Norwegian Air Force has bought houses near its Ørland base and paid for noise insulation for houses further afield. The US Air Force, by contrast, had to be ordered by the courts to pay compensation to the people living near the Yokota air base in the outskirt of Tokyo.

Chlorides in the Rhine river are another example of Coase-without-courts. After concerns were raised about local groundwater contamination, *Mines de Potasse d'Alsace* (MdPA) has, since 1931, dumped chlorides, a waste product of its potassium mining, in the Rhine instead, damaging farming and drinking water production downstream in the Netherlands. In the early 1970s, MdPA was the largest point source of chlorides, contributing 30-40% of the load. Companies in Germany and Switzerland also dumped chlorides in the Rhine. In 1972, an agreement was reached between the governments of France, the owner of MdPA, the Netherlands, Germany and Switzerland to jointly compensate MdPA for the profits lost to emission reduction. France, the polluter, covered 30% of the costs and the Netherlands, the pollutee, 34%. Germany and Switzerland covered the remainder. These countries would rather pay MdPA to clean up its act than compel companies in their own countries to do the same. The 1972 agreement was revised in 1991. Switzerland now contributes less (3% instead of 6%) because a soda factory, its main source of chlorides, had closed. A quarter of the available funds was diverted from reducing pollution at its source in France to water purification in the Netherlands, as this had become economical since the original agreement. While the 1972 agreement mixed payments by polluters and pollutee, after 1991 the polluters paid almost all (91%) of the costs of emission reduction. Transaction costs were high—at one point, the Netherlands recalled its ambassador to France—but not so high that it stopped negotiations. This example also highlights, as Coase did, that mitigation is as important as compensation.

The US Clean Water Act of 1972 empowered the Army Corps of Engineers to block development if that would damage wetlands. With the property rights firmly established, barter emerged. However, the Army Corps of Engineers cannot take money from developers. Instead, between 1993 and 2000, the Corps granted permits to damage some 24,000 acres of wetlands. In return, developers spent over $1 billion to create, restore, improve, or protect about 42,000 acres of wetlands. Similar barter is common under the US Endangered Species Act, where the Fish and Wildlife Service allows for habitat swaps via mitigation banking.

5.2 Pollutee pays

Next, we review examples of situations where the pollutee pays the polluter to reduce the harmful activity. With a few exceptions that we discuss first, these cases involve governments or non-governmental organizations making the payments. However, the government payments are distinct from Pigovian subsidies in that they are lump-sum rather than per-unit payments.

In 2016, apartment owners in a loft building in New York got together and paid \$11 million for the air rights next door, so that a developer could not build a building that would spoil the view; contributions were larger for owners of apartments on higher floors. Similarly, Mark Zuckerberg has bought out neighbors in Palo Alto, at a cost of \$43.8 million, to protect both his privacy and security.

Frequently cited as an example of *payments for ecological services*, the Vittel case can also be interpreted as a manifestation of the Coase Theorem. Vittel, now part of Nestlé, sells mineral water. Run-off from farms near its spring meant that there was too much nitrate in the water. This risked Vittel's brand and its legal designation as "mineral". As farm run-off was below the legal limit and land-zoning prevented the conversion of agricultural land to other purposes, Vittel bought out some farms and negotiated individual long-term contracts with 26 farmers; some farmers did not contract. Vittel made an upfront payment to the farmers, pays them an annual fee, and subsidizes labor and technical advice; contracted farmers can graze their animals on Vittel lands. In return, the farmers minimize the application of nitrogenous fertilizers. Nestlé has used a similar approach to protect its other brands. Transaction costs are small relative to the value of branded water, and fell as Nestlé gained experience in bargaining. This is an example in which a single pollutee pays multiple polluters. The coordination problem between polluters was solved by the pollutee, not necessarily efficiently as the pollutee may have exercised monopoly power. An effort to unionize the farmers failed, because some farmers preferred acting independently. The bargaining power of farmers fell as other farmers contracted.

New York City followed an approach similar to Vittel's to protect the watershed supplying the City's drinking water. By 2010, its Watershed Land Acquisition Program had purchased or obtained conservation easements on 100,000 acres (10%) in the Catskill-Delaware watershed from which New York City draws 90% of its drinking water. The program continues. The problem had arisen because Delaware County could meet new federal standards on drinking water and New York City could not. Purchasing land and changing its management to preserve drinking water quality, while expensive, was cheaper than building new water treatment plants.

Japan's Green Aid Plan is another example of the pollutee paying to reduce emissions. Japan invested over \$500 million in energy efficiency and clean coal projects in seven other countries in Asia, which China receiving more than two-thirds of the total. Concerned about winds blowing sulphur emitted in China to Japan, the Cleaner Coal Program stimulates the adoption of desulphurization technologies in coal-fired power plants. The program covers training and technical assistance as well as the donation of equipment. The projects in the program met their objectives. Desulphurization techniques were not taken up by power plants outside the program, suggesting it was Japanese funding rather than Chinese concerns about air pollution that caused the installation of scrubbers.

The Baltic Sea Action Plan is similar, but smaller. Funded by Sweden (€9 million) and Finland (€2 million), the program provides financial and technical support, particularly to reduce the discharge of nutrients into the Baltic Sea by Estonia, Russia, and several other countries. Earlier, Sweden funded similar projects, not just for water but also for air pollution.

Not all attempts to pay for pollution reduction are successful. A decade-long attempt by Finland, supported by Norway and Sweden, to clean up sulphur emissions from iron mining and smelting in Karelia and nickel smelters on the Kola Peninsula, came to nothing, partly because of the chaotic situation in post-Soviet Russia and partly because of the difficulty in writing and enforcing contracts in Putin's Russia. This example goes to the heart of Coase Theorem: Well-defined property rights and the enforcement of any resulting agreements are key to success.

It is often argued that the Coase Theorem only works with a small number of players: Coase used two agents. If there are many pollutees, they would free-ride on buying out the polluter. The City Council of Santa Maria, California, circumvented this problem by imposing a tax on residents near a feedlot causing pungent smells, and using the revenue to pay the owner to cease operations. The coordination problem between pollutees was solved by the local government.

In another example, the Nature Conservancy and Environmental Defense Fund, both non-governmental organizations, acted on behalf of many people worried about destructive bottom trawling for fish and shellfish and bought up fishing permits and harmful fishing equipment. An NGO in the Netherlands has been doing similar things since 1905, using donations to buy land to turn it into a nature reserve; the NGO now maintains almost 2.5% of the country's area. The Nature Conservancy used a reverse auction to pay 33 rice farmers in California's Central Valley to flood 10,000 acres during February and March, a time crucial for migrating birds. The program cost less than $100 per acre, a fraction of the costs of permanent wetland creation . In all of these cases, there are multiple polluters and multiple pollutees. An NGO put itself in between, a visible hand coordinating the Coase-like bargain. This is not likely to be efficient—the NGO has both monopoly and monopsony power and may well have motives other than the efficient coordination of bargaining. Nonetheless, all parties engaged voluntarily so the transaction are Pareto improving.

Chapter 14
Market-based instruments

1 Taxes

Now let us consider a company faced with an emissions tax τ. It seeks to minimize its costs

$$\min_{R_n} \beta_n R_n^2 - \tau R_n \forall n \tag{14.1}$$

The cost function is as in Equation (11.1), but for every unit of emission reduction effort R, it pays τ less in tax.

Equation (14.1) is an unconstrained optimization problem, so the first-order condition has that the first partial derivative equals zero:

$$2\beta_n R_n - \tau = 0 \forall n \Leftrightarrow \frac{\partial B_n}{\partial R_n} = \tau \forall n \tag{14.2}$$

Equation (14.2) is identical to Equation (11.4) if τ=λ.

2 Subsidies

If the regulator uses subsidies, Equation (14.1) becomes

$$\min_{R_n} \beta_n R_n^2 - \varsigma R_n \forall n \tag{14.3}$$

where ς is the subsidy. This is the same as Equation (14.1) but with ς instead of τ.

3 Tradable permits

If the regulator uses tradable permits, Equation (14.1) becomes

$$\min_{R_n} \beta_n R_n^2 - \pi R_n \forall n \tag{14.4}$$

where π is the permit price. This is the same as Equation (14.1) but with π instead of τ.

That is, a uniform emission tax, a uniform emission avoidance subsidy, and an emission permit market with a uniform price all lead to uniform marginal abatement costs—and to the same emissions if $\tau = \pi = \varsigma$. Put differently, taxes, subsidies, and emission permits guarantee cost-effectiveness.

There is no such guarantee for direct regulation. In fact, the regulator would need to know the marginal abatement cost function of each of the regulated households and companies in order to achieve cost-efficacy. That is unrealistic unless there are few agents or all agents use the same technology in the same way.

Part V
Topics

Chapter 15
Environmental Kuznets Curve

The late Alan Krueger used to joke that, although he was a labour economist, his most-cited paper was in environmental economics. I could return the favour. Although Alan's reputation is in causal analysis, his most famous paper is an association.

The Kuznets Curve is named after Simon Kuznets, the 1971 Nobel Laureate who defined Gross Domestic Product. Kuznets argued that poor societies are egalitarian, that societies first grow more unequal as they grow richer but that societies become more egalitarian again as they grow richer still.

Alan Krueger and Gene Grossman argued that poor societies are clean, that societies first grow dirtier unequal as they grow richer but that societies become cleaner again as they grow richer still. They called this the *Environmental Kuznets Curve*, often abbreviated to EKC.

Economic growth has a number of effects on environmental pollution and natural resource use:

1. *Scale* More economic activity means more pollution and more resource use.
2. *Composition* Industry typically imposes a greater environmental burden than agriculture and services.
3. *Technology* New technologies are often less resource-intensive, but may introduce new environmental issues.
4. *Demand* Richer people are willing to pay more for environmental care.
5. *Governance* Richer countries tend to have governments that are better able to deliver on policy priorities.

Some of these effects imply that richer means cleaner, some imply that richer means dirtier, and some can go either way.

International trade further complicates the relationship between growth and the environment. International trade stimulates economic growth and changes the structure of trading partners. It encourages the spread of technologies. Products are often made to the highest standards of all the markets in which they are sold—but production can be shifted to the country with the laxest regulation.

It is therefore no surprise that the —large and growing—empirical literature on the Environmental Kuznets Curve is inconclusive. Results are different, depending on the indicator of environmental quality, the time period, the countries or economic sectors included, the model specification, the estimator used, and whether the analysis is done over time or between countries.

If anything, an Environmental Kuznets Curve can be seen in the data for local environmental problems that are directly harmful to human health. Environmental problems that are global, or affect nature rather than humans do not seem to follow the Environmental Kuznets Curve.

Even if the data reveal an Environmental Kuznets Curve, the results should be interpreted with care. The analysis shows an association rather than a causal relationship. Beyond the turning point, the environment does not get cleaner because we grow richer. The policy implication is not that we should get rich quick and the environment will be fine. Rather, the environment is cleaned-up because people no longer tolerate a dirty environment, take action themselves and demand that politicians do the same. Economic growth creates a demand and opportunities for environmental policy.

This is best illustrated with an example. The Netherlands are often seen as a great country for cyclists. Many people think it was always so. That is a mistake. Old photographs of Amsterdam in the 1950s show a city where the traffic was dominated by cyclists, much like it is today. But photos of Amsterdam in the 1960s and 1970s show a city full of cars, much like other cities across the world. There is an Environmental Kuznets Curve for car traffic in Amsterdam—low when poor, high when richer, low when richer still.

But that is not what happened in cities in other countries. In the 1950s and 1960s, car ownership and use rose rapidly, as did traffic accidents and deaths. The Dutch campaign for road safety gained momentum after the teenage son of an influential journalist was killed while riding his bike. That campaign included road blockades, die-ins, and Rutger Hauer, the biggest movie star in the country, seen being cool on a bike. That put so much pressure on the local authorities that measures were taken to make cycling safer, and which over time led to the Netherlands as we know it now. Countries like Belgium, Denmark and Germany have followed a similar path as the Netherlands did as has, belatedly, Paris.

Elsewhere, cycling is seen as sport rather than transport, as a niche activity rather than something for the masses. England is a prime example. Cycling is a popular sport. The cycling association has always resisted dedicated cycle lanes because that would restrict the freedom of cyclists to go where ever they want. Dedicated cycle lanes are being build, but mostly in places that are popular with tourists—rather than to connect residential areas with places of work and study.

Chapter 16
Environmental justice

Chapter 3 on the Environmental Kuznets Curve discusses how pressures on the environment differ *between* countries or over time and how some of these differences can be explained by differences in wealth, differences in priorities, and differences in access to technologies.

It stems to reason, therefore, that there are also differences in environmental pressures *within* countries, that is, between people. It is important to distinguish between direct emissions, the emissions that originate in the household, and indirect emissions, which arise from the things bought by the household. Richer people affect the environment differently than poorer people. Richer people consume more, live in bigger houses,own more appliances and gadgets, and take more and farther holidays. They also own newer and better equipment, and live and work in different places. Besides income, households also differ in other respects. Larger households consume more, but less per head because of economies of scale in heating and cooking. Households with infant, disabled, or elderly members tend to spend more time at home—and therefore need more heating fuel but less transport fuel. Ethnic minorities and recent immigrants are more likely to live in inner cities, in older, poorly insulated houses but with good public transport. Like with the Environmental Kuznets Curve between countries, it is therefore not possible to draw general, universally applicable conclusions. But while the empirical literature shows mixed results, some stylized facts emerge.

First, environmental pollution is often associated with essential goods and services: agriculture, energy, transport, water, waste. By definition, poorer people tend to spend a greater share of their income on essentials than to richer people. Richer people may well spend more in an absolute sense[1] but less relative to their budget. Environmental policy makes these essential goods more expensive, be it directly with taxes or indirectly by telling households and companies to switch to cleaner but

[1] Recall, though, that it is expensive to be poor. If you do not have access to transport, you cannot shop around for a better deal. If you live from hand to mouth, you cannot buy products cheaply in bulk and you may not have space to store them anyway. If you have a poor credit record, you pay as you go for communication and electricity.

more expensive technologies. The costs of environmental policy thus tends to fall disproportionally on the poor.

Second, environmental pollution also tends to fall disproportionally on the poor, and environmental policy thus tends to disproportionally benefit the poor. The relationship between income and pollution is complicated, as sketched above, but the broad pattern is that the rich tend to be less exposed to pollution. This is partly because they are better able to protect themselves. Chapter 3 discusses defensive expenditure—double glazing, air filters, bottled water. All these things cost money—that is key in valuing environmental services—so that those who can *afford* better protection are better protected. Chapter 3 also discusses hedonic pricing: Houses are more expensive in cleaner environments. The rich congregate in the nice parts of town and country, the poor are left with areas that are polluted, flood-prone, noisy.

Third, siting decisions disadvantage the disenfranchised. Hazardous and polluting facilities are not located randomly. Decisions to clean-up or protect some places before other places are not random either. Instead, decisions to site a plant or create a nature reserve are made after long deliberation, often following intense debate with local and sometimes national politicians and pressure groups. This means that people with political or media connections, people who can organize a local protest, people who can formulate a threat of legal action, are more likely to come out well. Such people tend to be richer and, importantly, part of the politically dominant group. Political dominance is different in different countries. It is organized partly along race in the USA, along class in the UK, along caste in India, along religion in Israel, and along tribe in Ethiopia. But however a polity may be structured, the disenfranchised are disadvantaged, also when it comes to environmental hazards.

Fourth, while many environmentalists lean to the political left and identify as progressive, the environmental movement has a more chequered history, as touched upon in Chapter , a history that environmentalists tend to disregard. So it came to be that the Green Party of Germany in their election campaign of 2021 sang to the tune of *Kein schöner Land*. The original lyrics are outright nationalistic. The song was the anthem of the *Wandervogel*, one of the precursor organizations of the Nationalist Socialist German Workers' Party, better known by its acronym *Nazi*. Some in the early environmental movement argued that nature would wash the great unwashed while others sought to protect the environment from the barbarous crowds. In practice, a day in the woods was reserved for the leisured class as it still often is. The World Wide Fund for Nature was founded to keep the natives of the African hunting grounds of the European elites. When neo-Maltusians warn about population growth, they refer to the high birth rates in Africa and Asia. When people worry about climate migrants, they are not concerned about Americans retiring in Florida or Europeans in Portugal. They worry about darker-skinned people coming to our shores.

Chapter 17
Green national accounting

1 GDP and its discontents

Gross Domestic Product (GDP) is a measure of economic activity. It was defined in 1925 by Simon Kuznets, the Nobel laureate who is also behind the Kuznets curve. In 1932, Kuznets wrote

> the welfare of a nation can scarcely be inferred from a measurement of national income

Kuznets' warning notwithstanding, many non-economists and even some economists use GDP as a welfare indicator. It is not. This follows immediately from the three alternative ways to measures GDP. GDP can be measured as

- **Total effective demand** Gross Domestic Product equals private consumption plus public expenditure plus gross investment plus exports minus imports.
- **Total value added** Gross Domestic Product equals value added in all economics sectors (e.g. agriculture, manufacturing and services), plus Value Added Tax.
- **Total income** Gross Domestic Product equals labour income plus capital income plus state revenue plus amortization of debt.

Although GDP was designed to be an indicator of economic activity, it is incomplete. Anything that is not traded on legal markets is outside the scope of GDP. Marijuana is outside GDP of most countries, even though there is a market with consumers, retailers, wholesalers, importers, exporters, and producers. Homework and growing food for own consumption—and so all subsistence farming—are therefore excluded from GDP.

GDP was never intended to measure economic welfare. Buying medicine is included, but feeling sick is excluded. Air pollution is not in GDP, and neither is a stroll in the park. GDP counts total income, but it is silent on the distribution of income. Free speech and the rule of law are omitted.

There is another problem with GDP: It counts gross investment. Additions to the capital stock are included, but subtractions are not. Breaking and fixing a window thus grows GDP. This is known as *Bastiat's broken window fallacy*.[1] The solution is the *Net Domestic Product*, which equal GDP minus depreciation. Unlike GDP, NDP counts the broken window, not just its repair.

Attempts to come up with complements to GDP, measures of economic welfare rather than economic activity, are often *ad hoc*, but there is some theory to guide that effort.

2 The welfare significance of national product

Let us assume that we want to maximise the net present utility of consumption:

$$\max_{C(t)} \int_{t=0}^{\infty} U(C(t)) e^{-\rho t} \mathrm{d}t \tag{17.1}$$

where $C(t)$ is consumption at time t, U is the utility function and rho is the pure rate of time preference. This maximization is subject to the constraints

$$Q(t) = Q(K(t)) \tag{17.2}$$

where production Q is a function of capital stock K, which follows the equation of motion

$$\frac{\partial K}{\partial t} := \dot{K}(t) = -\delta K(t) + I(t) = -\delta K(t) + Q(K(t)) - C(t) \tag{17.3}$$

where I is investment. Note that the right-hand side of Equation (17.3) incorporates Equation (17.2) so that there is only one constraint on optimization.

In order to find the optimum, form the current value Hamiltonion

$$\mathcal{H}(t) = U(C(t)) + \lambda(t)\dot{K}(t) \tag{17.4}$$

Note that the Hamiltonian is measured in utils.

The first-order condition for dynamic efficiency is

$$\dot{\lambda}(t) - \rho\lambda(t) = \frac{\partial \mathcal{H}}{\partial K} \tag{17.5}$$

We will ignore this condition. The first-order condition for static efficiency is

$$\frac{\partial \mathcal{H}(t)}{\partial C(t)} = U_C(t) - \lambda(t) = 0 \Rightarrow U_C(t) = \lambda(t) \tag{17.6}$$

Therefore

$$\mathcal{H}(t) = U(C(t)) + U_C(t)\dot{K}(t) \approx U_C(t)C(t) + U_C(t)\dot{K}(t) \tag{17.7}$$

[1] Claude-Frédéric Bastiat (1801-1850) was a Classical economist from the south of France, a staunch critic of protectionism and government intervention. He developed the concept of *opportunity cost*.

This implies

$$\frac{\mathcal{H}(t)}{U_C(t)} \approx C(t) + \dot{K}(t) \tag{17.8}$$

On the left-hand side, we divide the Hamiltonion by marginal utility. This transforms the left-hand side from utils to money. The right-hand side equals consumption plus the change in the capital stock, or consumption plus investment minus depreciation. This is the Net Domestic Product. It has a welfare interpretation: NDP equals the monetized, linearized Hamiltonian. The NDP is what we seek to optimize in the short run, while taking the long-term implications into account.

This insight is due to a young Martin Weitzman.[2]

3 The welfare significance of environmental product

An older Weitzman[3] extended the analysis to the environment.

Let us assume that utility depends on material consumption C and the state of nature N. We so want to maximize

$$\max_{C(t),P(t)} \int_{t=0}^{\infty} U(C(t), N(t))e^{-\rho t}\,\mathrm{d}t \tag{17.9}$$

subject to the constraints

$$\dot{K}(t) = -\delta K(t) + Q(K(t)) - C(t) - P(t) \tag{17.10}$$

and

$$\dot{N}(t) = \vartheta N(t) + P(t) \tag{17.11}$$

where ϑ is the natural regeneration rate of nature and P is the expenditure on nature conservation. This expenditure cannot be used for consumption or investment and therefore also appears in the equation of motion of capital. As we have two constraints, there are two co-state variables. The Hamiltonian is

$$\mathcal{H}(t) = U(C(t)) + \lambda(t)\dot{K}(t) + \mu(t)\dot{N}(t) \tag{17.12}$$

Nature conservation is a choice variable. We therefore have two first-order conditions for static efficiency (one for each choice variable) and two first-order conditions for dynamic efficiency (one for each stock variable). The dynamic ones are Equation (17.5) and

$$\dot{\mu}(t) - \rho\mu(t) = \frac{\partial \mathcal{H}}{\partial N} \tag{17.13}$$

[2] We met Weitzman when discussing the choice between environmental and tradable emission permits. He also made seminal contributions to setting priorities for nature conservation, to long-term discounting, and to decision-making under large uncertainty.

[3] Martin Weitzman published his first paper in 1965. Although he had an early interest in public goods and energy, he did not publish his first paper on environmental issues until 1992.

These do not interest us here.

The first-order conditions for static efficiency are Equation (17.6) and

$$\frac{\partial \mathcal{H}(t)}{\partial P(t)} = (U_N(t) - \mu(t))\frac{\partial N(t)}{\partial P(t)} = U_N(t) - \mu(t) = 0 \Rightarrow U_N(t) = \mu(t) \quad (17.14)$$

Following the same logic as above, we have

$$\mathcal{H}(t) = U(C(t), N(t)) + U_C(t)\dot{K}(t) + U_N(t)\dot{N}(t) \quad (17.15)$$

Therefore

$$\mathcal{H}(t) \approx U_C(t)C(t) + U_N(t)N(t)\frac{U_C(t)}{U_C(t)} + U_C(t)\dot{K}(t) + U_N(t)\dot{N}(t)\frac{U_C(t)}{U_C(t)} \quad (17.16)$$

so that

$$\frac{\mathcal{H}(t)}{U_C(t)} \approx C(t) + N(t)\frac{U_N(t)}{U_C(t)} + \dot{K}(t) + \dot{N}(t)\frac{U_N(t)}{U_C(t)} \quad (17.17)$$

The term U_N/U_C, the marginal utility of nature over the marginal utility of consumption, is the price of nature. So, if we care about both material consumption and nature, then the welfare equivalent to the Net Domestic Product equals consumption plus *the amenity value for nature* plus net investment in capital plus *net growth of natural capital*. This is known as the *Environmental Domestic Product*.

In sum, if we only care about material consumption, then the Net Domestic Product is an appropriate welfare indicator, one that accounts for current welfare (measured by consumption) and future welfare (measured by the change in the capital stock). However, if we care about both material consumption and the natural environment, then the appropriate welfare indicators adds the monetised value of the environment and the change in the natural capital stock.

Of course, we can redo the analysis with any number of attributes to the utility function—we could add knowledge and the company of friends, and human and social capital. That would complicate the notation without adding insight: There would be more terms in Equation (17.17) to reflect the things we value and net investment in corresponding stocks.

Note that the Environmental Domestic Product adds changes in the physical capital stock to changes in the natural capital stock. It assumes that the two are perfectly substitutable. The Environmental Domestic Product is a measure of weak sustainability.

4 Environmental products in practice

Well before Weitzman provided the theoretical underpinning of the Environmental Domestic Product, William Nordhaus[4] and James Tobin[5] proposed an *ad hoc* measure that is very similar: The Measure of Economic Welfare. The Measure of Economic Welfare equals Net Domestic Product minus economic bads (pollution control, repairs) and regrettable necessities (police, defense) plus household production, illegal production, and leisure. Although the authors described their proposal as primitive and experimental, it was very influential and was reincarnated under such names as the index of sustainable economic welfare, the genuine progress indicator, the sustainable net benefit index, and the measure of domestic progress.

The indicator that is now most widely used is Adjusted Net Savings, formerly known as Genuine Savings. This measure is adopted by the World Bank, who collect data that is consistent over time and between countries. Genuine Savings is, in theory, defined as net investment in manufactured capital, plus net investment in human capital, minus net depreciation of natural capital. That is, Adjusted Net Savings expands on the Environmental Domestic Product by including education.

Adjusted Net Savings omits consumption. It does not account for current welfare but only for the potential to generate future welfare. It therefore has an immediate interpretation for sustainability. Positive Adjusted Net Savings are weakly sustainable, negative Adjusted Net Savings are unsustainable.

5 Alternative indicators

[4] William D. Nordhaus (1941-) is professor of economics at Yale University. He won the 2018 Nobel Prize for his work on the economics of climate change.

[5] James Tobin (1918-2002) taught economics at Yale University, winning the Nobel Prize in 1981. He is known for his work on the demand for liquidity, the Tobit for regression analysis of censored data, Tobin's Q as a company's value, and the Tobin tax on the market in foreign exchange.

Chapter 18
Green corporate accounting

Appendix A
Optimization in continuous time

1 Discrete time

You are familiar with constrained optimization. If we want to find the optimal consumption path in a production economy, you could

$$\max_{C_0, C_1, \ldots} \sum_t U(C_t)(1+\rho)^{-t} \text{ s.t. } \Delta K_t = -\delta K_t + (Q(K_t) - C_t) \tag{A.1}$$

where U denotes utility, C_t consumption in year t, ρ the utility discount rate, K_t the capital stock at time t, δ the depreciation rate, and Q the production function.

In order to solve this, form the Lagrangian:

$$\mathcal{L} = \sum_t U(C_t)(1+\rho)^{-t} - \lambda_t \left(-\delta K_t + Q(K_t) - C_t - \Delta K_t\right) \tag{A.2}$$

The Lagrangian is the objective function minus the Lagrange multiplier times the constraint-rearranged-to-equal-zero.

The first-order conditions are

$$\frac{\partial \mathcal{L}}{\partial C_t} = U_{C_t} + \lambda_t = 0 \forall t \tag{A.3}$$

and

$$\frac{\partial \mathcal{L}}{\partial \lambda_t} = 0 \Leftrightarrow \Delta K_t = I_t - \delta K_t \forall t \tag{A.4}$$

where I_t is investment in year t.

The problem with these first-order conditions is that they are not particularly informative. For instance, we find that the shadow price of capital, λ_t, should be equal to the marginal utility of consumption, U_{C_t}, at every point in time—this follows from Equation (A.3)—but we discern nothing about the evolution of the shadow price over time. Equation (A.4) reproduces the equation of motion of capital, rather than its price.

2 Continuous time

You could also write the maximisation problem in continuous time

$$\max_{C(t)} \int_t U(C(t))\mathrm{e}^{-\rho t}\mathrm{d}t \text{ s.t. } \dot{K}(t) = -\delta K(t) + (Q(K(t)) - C(t)) \tag{A.5}$$

There are a few differences between Equations (A.1) and (A.5). Instead of a summation over time, we have an integral. Recall that a Riemann integral is summation in infinitisimally small steps. Instead of subscripts to denote time, variables are now functions of time. This is just a convention. Instead of the discount factor $(1+\rho)^{-t}$ we have $\mathrm{e}^{-\rho t}$. In the former, ρ is the annual discount rate. Measuring time in annual time steps is arbitrary. Instead of solar years, you could measure time in lunar months, or in days, hours, minutes, or seconds. If the time step goes to zero, $(1+\rho)^{-t}$ approaches $\mathrm{e}^{-\rho t}$. Finally, $\dot{K}(t)$ replaces ΔK_t. The latter is the difference between two periods, $\Delta K_t = K_{t+1} - K_t$. The former is the change at time t, $\dot{K}(t) = \frac{\partial K(t)}{\partial t}$. Although the notation has changed to account for the fact that we are working in continuous rather than in discrete time, our representation of the system has not changed.

You cannot use the methods developed by Joseph-Louis Lagrange to find an optimum in continuous time. Instead, you have to use the methods of William Rowan Hamilton and Lev Pontryagin. So, in order to solve this, we form the Hamiltonian, or more specifically, the current-value Hamiltonian[1]:

$$\mathcal{H} = U(C(t)) + \eta(t)\dot{K}(t) \tag{A.6}$$

The Hamiltonian consists of three elements. The first element is the current value of the objective function. That is, get rid of the integral. Only take the bit that you integrate, in this case $U(C(t))$. The second bit is known as the co-state variable, $\eta(t)$, which is a shadow price just like the Lagrange multiplier. The third part is the left-hand-side of the constraint, $\dot{K}(t)$. Compared to the Lagrangian, the Hamiltonian is considerably simpler.

This simplicity helps greatly with the first-order conditions. There are two. The first is

$$\frac{\partial \mathcal{H}}{\partial C(t)} = U_{C(t)} - \eta(t) = 0 \tag{A.7}$$

The first first-order condition has that the first partial derivative of the Hamiltonian to the control variable be equal to zero, just like in Lagrange's constrained optimization. As with the Lagrangian, this says that the shadow price of capital should equal the marginal utility of consumption. This is because we sacrifice consumption to invest so as to accumulate capital used to produce consumption goods.

The second first-order condition has no analogue with Lagrange. It is

[1] Mathematicians and physicists are better used to the present-value Hamiltonian. The results are the same. The current-value Hamiltonian is more readily interpreted for economic problems.

$$\dot{\eta}(t) - \rho\eta(t) = \frac{\partial \mathcal{H}}{\partial K(t)} = \eta(t)\left(Q_{K(t)} - \delta\right) \tag{A.8}$$

That is, the first partial derivative of the Hamiltonian to the constrained stock variable equals the change in its co-state variable minus the discount rate times the co-state variable.

This can be rewritten as

$$\frac{\dot{\eta}(t)}{\eta(t)} = Q_{K(t)} - \delta + \rho \tag{A.9}$$

The left-hand side is the proportional rate of change of the shadow price of capital. This is a variable with an economic interpretation. It is the equation of motion of the *price* of capital.

The elements on the right-hand side are intuitive too: the marginal productivity of capital $Q_K(t)$, the depreciation rate δ, and the utility discount rate ρ. Equation (A.9) thus says that the value of capital should increase with its productivity, and fall with depreciation, and rise with discount rate. The last result may not be intuitive. If the discount rate is higher, you care less about the future, therefore invest less, and thus have less but more valuable capital as a result.

3 Conclusion

Optimization in continuous time is daunting at first sight. However, it is just a trick. Constrained optimization is a trick. Form the Lagrangian. Write down the first-order conditions. Continuous time optimization is a trick too, albeit a different one. Form the Hamiltonian. Write down the first-order conditions. The good thing about the Hamiltonian is that its first-order conditions immediately lead to economic insight.