Kenneth Arrow on Public Goods, Public Policy, and Environmental Economics

by

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Kenneth Arrow was an architect of modern welfare economics. But unlike his writings on social choice, risk and uncertainty, and general equilibrium theory, his publications on the theory of public policy are discursive, both in style and focus. Some are essays, with no mathematics to aid the exposition, and are written in an informal style that guide rather than direct readers toward ways in which the questions could be most fruitfully framed. Others are mathematical, have a sharper focus, and are enlivened by theorems. Arrow's style of discourse on the theory of public policy fitted his intentions. They have shaped the way the literature has developed and continue to develop.

Arrow took public policy to be society's reasoned response to failure of markets to allocate goods and services efficiently and equitably. But he almost always chose the setting to be the social management of externalities - most frequently the objects of study were public goods. That gives his writings on public policy a common flavour. Utilitarianism guided him, but by paying greater attention to individuals' expressed preferences than is welcomed by moral philosophers (Arrow, 1981), he avoided the authoritarian streak that has frequently marked Utilitarian writings. A deep meditation (Arrow, 1974) on the constraints on motivation and actions that asymmetrically dispersed information imposes on people reads as a tussle between the democrat and the Utilitarian in him. Arrow's democratic instincts curbed his Utilitarian leanings; his Utilitarian convictions in turn kept him far removed from Libertarianism. Although confident about the relevance of his models when establishing theorems, he was hesitant when lifting them to speak to the world we have come to know. This was a reflection of the value-pluralism he was wedded to (Sect. 3, below). Arrow opened his monograph of 1974 with the words of the great first century sage, Rabbi Hillel: "If I am not for myself, then who is for me? And if I am not for others, then who am I? And if not now, when?" That tension is present not only in the monograph, but also in his other writings on public policy.

The imprint of his work from the 1950s on general competitive equilibria is evident in the way Arrow studied market failure. His expositional strategy was to begin by rehearsing the two

fundamental theorems of welfare economics and then showing that they would not apply to the economy in hand. The questions he chose to study involve markets that cannot be improved upon by mere changes to property rights. Arrow did not advocate dispensing with markets, his work led him to characterise well-functioning mixed economies.

1 Informational Externalities

The paper that laid the foundations of the economics of health (Arrow, 1963) is paradigmatic of his approach. Someone in need of medical care in a market economy is the buyer, physicians are the sellers. Arrow first rehearses the conditions under which the two fundamental theorems of welfare economics would apply to the market for health care and then notes that if it were left unassisted, the market would fail because the buyer would not have the requisite information about sellers' abilities (doctors all look the same). To create a stark contrast between the two sides of the market for medical care, Arrow assumes that physicians know their own ability. He then shows that an unassisted market would unravel because physicians of high ability would be undercut by those of low quality. In the extreme, only quacks would remain. The paper (it is written without the aid of mathematical symbols) is now acknowledged to have introduced the problem of adverse selection to welfare economics. Arrow showed that the source of failure of an unassisted market for medical care lies in the externalities that are harboured when information is asymmetrically held by agents. What made the paper even more striking was the justification it offered for self-regulation in the medical profession. At a time when trade associations and guilds were viewed with suspicion of monopolistic practices, Arrow identified a broad class of cases where associations help to improve the performance of markets.

2 Knowledge as a Public Good

In a pair of enormously influential papers, Arrow (1962a, 1962b) studied the role technological change plays in economic growth. The papers are markedly different in style. Both begin with a recognition that knowledge is a public good, but then the two move in different directions. The 1962a essay contains a wide-ranging discussion of the problems inherent in the production, dispersal, assimilation, and use of knowledge. The institution of patents creates private incentives to innovate, but it comes at a cost: being monopolists, patent holders restrict their output of goods so as to earn super-normal profits. That much was already known to economists. But a brief set of remarks, containing a simple model of process innovation, laid the trail for the subsequent literature on market structure and innovation. Arrow asked whether a

monopolist (the patent holder) has as much incentive to innovate as society would ideally like to encourage. He showed that the gain to the monopolist from reducing his production costs is lower than is socially optimal. The model implied that patents on innovations retard the rate of technological change.

It wasn't until the mid-1970s that Arrow's analysis was reconsidered. Game theoretic arguments were deployed to study strategic behaviour in the race for patents. Building on Arrow's model, Dasgupta and Stiglitz (1980) showed that if the potential innovations are not overly large, a patent holder has the stronger incentive to make further innovations than rivals. That's because owning both patents enables the firm to earn more profits than a rival would if the market was subsequently to be shared. The authors' analysis suggested that the threat of entry can encourage the incumbent monopolist to spend more on R&D than is socially desirable. This was Schumpeterian competition in game theoretic settings. Subsequent work by Reinganum (1982, 1983) and Fudenberg and Tirole (1984), among others, showed that the relationship between market structure and technological change depends sensitively on the possibilities of strategic actions among agents.

Arrow (1962b) is the originator of endogenous growth theory. Appealing to what was then a sparse empirical literature within industrial economics, he assumed that a firm's productivity is a function of its cumulative output to date. Borrowing from Thomas Dewey's writings on education policy, Arrow called the phenomenon "learning by doing".[1] Economic growth in the macro model that he constructed on the basis of learning by doing was dependent on behaviour, it wasn't a function solely of exogenous factors. In economies where the learning spills over to other firms, growth is less than optimal. The paper introduced in a formal way the idea of "stock externalities", which are notable because they manifest themselves across time. Stock externalities were used in the 1980s by Robert Lucas and others to demonstrate the significance for long run economic growth of investment in human capital. They have also been found to be of the utmost significance in environmental and resourcee economics.

3 Optimal Accumulation in Second-Best Economies

Arrow's Utilitarianism isn't the one to be found in Henry Sidgwick's great work

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1 Dewey in turn had borrowed it from Aristotle: "Anything that we have to learn to do we learn by the actual doing of it: people become builders by building and instrumentalists by playing instruments." Aristotle, *The Nicomachean Ethics*, trans. J.A.K. Thomson (Harmondsworth: Penguin Books, 1976: p. 63). Rawls (1972: 424-432) subsequently christened "learning by doing" the Aristotelian Principle.

(Sidgwick, 1907). Arrow was an Intuitionist, at direct odds with Sidgwick, who had devoted an entire chapter criticizing Intuitionism. Arrow arrived at his Utilitarian thinking from such basic normative axioms as separability, monotonicity, and continuity of ethical preferences when the latter are taken to be functions of individual utilities. That is why Arrow's version of Intuitionism is also called Value Pluralism. In this he was influenced by Tjalling Koopmans, who had provided an axiomatic foundation for Utilitarianism in an intergenerational setting (Koopmans, 1960, 1972). Koopmans' axioms on ethical preferences were sharp enough to arrive at the Utilitarian form (a weighted sum of individual utilities), but were blunt enough to leave vital ethical parameters, such as the elasticity of marginal utility and rates of pure time preference, unspecified. Value Pluralism encourages one to iterate between the choice of ethical parameters and the consequences of those choices for public policy (Koopmans, 1965; Arrow, 1999). Without such experiments seemingly plausible expressions of ethical preferences can commend policies that are in deep conflict with other values the decision-maker may hold.

In a landmark monograph written under the auspices of *Resources for the Future*, Arrow in collaboration with Mordecai Kurz (Arrow and Kurz, 1970) identified discount rates that a government should use to evaluate public investment and then related those rates to the degree to which the government is able to control the future path of the economy (see also Arrow, 1971a).

To undertake their analysis, the authors considered an economy with an all-purpose commodity, the stock of which at date t can be converted with the help of inelastically supplied labour into output; which in turn can be allocated between consumption, investment in private capital, and investment in public capital. Generations are forecast to follow one another over an indefinite future.

Arrow and Kurz took the government's objective function (the social welfare function) to be the discounted sum of the flow of every generation's utility (Mirrlees, 1967). Whether the government can achieve the full optimum depends on the workings of private markets and upon the range of policy instruments open to it. The authors began by noting that governments cannot directly control either consumption or private investment in mixed economies, but that they can influence those choices through public instruments, such as income taxes and creation or retirement of public debt. They took that to mean that the social rate of discount (i.e. the consumption rate of interest – they chose consumption to be numeraire) depends on the mode of financing public investment. The authors took a given allocation policy to be *controllable* by a

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given set of instruments if there exist values of those instruments, varying over time outside a steady state, which cause the private and public sectors together to realize that policy.

In the body of their work Arrow and Kurz solved a succession of optimization problems that arise when the government has limited controls at its disposal. Their aim was to see how far the consumption rate of interest would diverge from the marginal productivity of private capital. Social rates of discount in second-best economies are related to optimum consumption rates there. The techniques invented by Arrow and Kurz allow one to estimate the intergenerational welfare losses that arise from partial controllability on the part of government. Theirs was a first; nothing existed previously that was as sharp and rigorous on second-best policies in fully dynamic economies. The authors had to reconstruct dynamical control theory in order to characterize the respective optima.

In later years Arrow returned to the study of dynamic second-best economies. Arrow and Dasgupta (2009) analysed consumption behaviour in a world where individual preferences are socially embedded. Although Veblen in his classic work on the Gilded Age had suggested that conspicuous leisure takes the form of elaborate and costly idleness (Veblen, 1889), it has been widely argued in recent years that if conspicuous consumption matters to people, the consequent economic distortion must take the form of a "rat race", where people work harder and consume more than they would if ideal public policies were in place. The implication of that line of argument is that well-chosen public policies that discourage consumption (e.g., a general consumption tax (Layard, 2011) or restrict working hours (Alvarez-Cuadrado, 2007)) would be welfare enhancing.

Although seemingly plausible, the intuition that conspicuous consumption leads to excessive consumption is unreliable. Consider a world where labour is supplied inelastically. If individuals are forward looking, they would know that consumption relative to others matters to them not only today but will matter to them also in the future. They would then realise that, although consuming more today would improve their relative standing now, it would worsen their relative standing in the future. Individuals will wish to strike a balance between their conflicting desires. Arrow and Dasgupta studied how the structure of utility functions mediates that inter-temporal conflict. Whether there is under- or over-consumption to day depends on the structure of individual utility functions.

4 Markets for Externalities

Arrow (1971b) is one of the two modern landmarks on the economics of externalities (although published in 1971, the paper was in wide circulation from 1968). He began the paper by noting that externalities are associated with absent property rights but kept his analysis general by not specifying the reasons for their absence. Once again he first rehearsed the two fundamental theorems of welfare economics, but then noted that the theorems cannot be resurrected by an expansion of the commodity space because each externality pertains to a unique pair of agents. If my smoking affects you because you are in my proximity, markets for externalities would involve "named goods": the smoke I exhale and the smoke you then inhale. Such markets, being thin in the extreme, cannot be competitive. The paper demonstrated that Lindahl's famous proposal (Lindahl, 1958), that creating markets for externalities is an alternative to Pigouvian taxes and subsidies, is faulty.

In the presence of negative externalities there is a further reason Lindhal markets cannot function, which is that they give rise to non-convexities in production and consumption possibility sets. That discovery was made in the other landmark paper on externalities, by Arrow's student and subsequent colleague, David Starrett. Starrett (1972) observed that there is a lower bound to the harm pollution can inflict on a site. That's because a site cannot be harmed further once it is destroyed completely. It was long recognised that in timeless economies non-convexities give rise to a multiplicity of local optima, and that identifying the global optimum requires global cost-benefit analysis. What hadn't been shown was how the argument carries over to dynamic economies. Arrow (2002) contains a demonstration. Assuming that the flow of utility is a declining function of the stock of pollution created by past production, Arrow also showed that the non-convexities arising from the stock externality imply that, other things equal, society should specialise in its production activities; it should not spread its choices thinly across the menu of production activities available to it. The argument can be applied quite naturally to a different context: the spatial arrangement of pollution sites. The Arrow-Starrett analysis affirms that pollution should be deposited in discrete sites, it should not be spead thinly across the landscape.

5 The Option Value of Natural Capital

Arrow's most famous work on environmental policy is his joint paper with Anthony Fisher on the value of keeping options open (Arrow and Fisher, 1974). In the context of environmental resources, the paper provided an argument for conservation that goes beyond the

one that says resources will have a value in the future. The authors' immediate inspiration was Krutilla (1967), which was a plea for public protection of environmental amenities such as places of natural beauty, on grounds that markets provide no incentives for their provision. The authors showed that environmental amenities have a value over and above their value as durable public goods. The additional value arises from the conjunction of two factors: (i) destruction of the amenity is irreversible; (ii) the amenity's future value is uncertain and that over time society will learn more about the state of the world. The argument, which does not require that the decision maker is risk averse, extends more generally to the preservation of biodiversity.[2]

Imagine two instants of time: $t = 0, 1$. The resource, which for illustration we assume is a piece of forest land, is of size 1. At $t = 0$ the net benefit from developing a marginal unit of the forest for other purposes (mining, say) is B_0. There are two possible states of nature, x and y. The true state of nature will be revealed at $t = 1$. If x were to occur (the probability of that is p), net benefit from development of a unit of forest land will be B_x. If y were to occur (the probability of that is $1-p$), the net benefit from development of a unit of forest land will be B_y. At $t = 0$ a decision is made on the amount of land to be developed. At $t =1$, when the state of nature is revealed, a further decision will be due on how much land should be developed. The decision-maker (DM) is assumed to be risk neutral.

Let D_0 ($0 < D_0 < 1$) denote the area developed at $t = 0$ and let D_x the area developed at $t = 1$ should the state of nature be x, and D_y the area developed should the state of nature be y. If r is the social rate of discount, the expected present value of net benefit from the proposed development policy $\{D_0, D_x, D_y\}$ is

$$B_0D_0 + [pB_xD_x + (1-p)B_yD_y]/(1+r). \tag{1}$$

To have an interesting problem, we assume $B_x < 0$, $B_y > 0$, and $pB_x+(1-p)B_y > 0$.[3] If development is fully reversible, the decision problem can be decomposed into two separate ones. The optimal value of D_0 depends solely on the sign of B_0 (if $B_0 > 0$, the optimum value of $D_0 = 1$; if $B_0 < 0$, the optimum value of $D_0 = 0$). Moreover, optimum $D_x = 0$ and optimum $D_y = 1$. Suppose however that development is irreversible. Then the constraints on the DM's choices are $0 \le D_0 \le D_x$, $D_y \le 1$. Using the backward induction argument just used in expression (1) reduces

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2   There were precursers to the Arrow-Fisher analysis (Marschak and Nelson, 1962; Weisbrod, 1964) and a parallel contribution (Henry, 1974), but the Arrow-Fisher paper was marked by its simplicity.
3   In x the loss owing to a reduction in forest land is greater in magnitude than the benefits of development and in y it is less. But the expected benefit from further development at $t = 1$ is positive.

it to

$$(B_0 + pB_x/(1+r))D_0 + (1-p)B_y]/(1+\text{r}).$$

That means $D_0 = 1$ only if $(B_0 + pB_x/(1+r)) > 0$, which is a stiffer condition on B_0 than $B_0 > 0$. The additional weight required on the current benefit from development $(-pB_x/(1+r))D_0)$ is the option value of forest conservation.

In a subsequent paper, Arrow (1995) used the idea of option values to show that the desire for the freedom to choose, which is the hallmark of Capabilitarianism (Sen, 1985, 2009), can be deduced entirely from Utilitarianism.

6 Ecological Economics and the Idea of Sustainable Development

Arrow's involvement in the development of ecological economics dates back to 1990, when he joined a seminar initiated by a group of ecologists and economists at Stanford University. That involvement was reinforced by his subsequent association with the *Beijer Institute of Ecological Economics* in Stockholm. In 1993 the Institute' Director, Karl-Goran Maler, initiated an annual workshop that was to be held in the Summer at the marine field station on the island of Asko in the Trosa archipelago. Each year the designated group, comprising equal numbers of ecologists and economists (members of the Institute's Scientific Board and a few invited scholars), chooses a theme for discussion and prepares a brief report. The records show that Arrow attended all but six meetings in the years since then, until his last, in September 2016. By then he was bent and weak and needed to pause after every few steps. We all queued to carry his back pack and luggage while Paul Ehrlich, his neighbour and friend, locked arms with his to prevent him from stumbling over the uneven fields of the island. Despite his frail state, Arrow not only took part in the discussion, he was insistent that the policies we discuss for encouraging reductions in fertility rates in sub-Saharan Africa should be built on liberal values. He also took part in socializing, joining Carl Folke, the current Director, in singing drinking songs in his imperfect Swedish. Despite his failing health, Arrow had been insistent on returning to Asko, writing to Christina Leijonhufvud, Office Manager of the Beijer Institute, that he wanted to pay one last visit to the annual gathering if only to be with his friends.

The Asko meetings were initially prompted by a puzzle raised by the global growth experience over the past hundred years and more. On the one hand, if we look at specific examples of natural resources (fresh water, ocean fisheries, the atmosphere as a carbon sink - more generally, ecosystems), there is strong evidence that the rates at which we are currently

utilizing them are unsustainable. On the other hand, one can argue that just as earlier generations (at least in the West) invested in science and technology, education, and machines and equipment so as to bequeath to the present generation the ability to achieve high income levels, the current generation is now in turn making investments that will assure still higher living standards in the future. The first of the Asko publications (Arrow et al., 1995), which is now much cited, asked whether contemporary growth models, neglecting to include as they do natural capital, offer the right framework for coming to terms with those conflicting intuitions.

Today we study the intuitions via the notion of "sustainable development". The term, coined in the famous Brundtland Report (World Commission, 1987), was taken to mean "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Put differently, the idea is that relative to their respective demographic bases, each generation should bequeath to its successor at least as large a productive base as it had inherited from its predecessor. If it were to do so, the economic possibilities facing the generation that follows would be no worse than those it faced when inheriting productive assets from its predecessor.

The problem with the way the notion was framed by the Brundtland Commission is that it left open the question of how the productive base is to be measured. Discussions at the Asko meetings led Dasgupta and Maler (2000) to start at a different end and define sustainable development in terms of economic welfare. Let $V(t)$ be the present value of the flow of utilities from date t onward. Assuming that by sustainable development we mean that $V(t)$ should not decline over time, the authors showed that the requirement is equivalent to the demand that the economy's *wealth* should not decline, where wealth is the shadow value of the entire stock of capital, including natural capital.

Wealth is the dynamic counterpart of income. In a stationary economy they amount to the same thing, but they differ in a non-stationary world. It can be that income increase over a period while wealth declines. If we were to relate this finding to the Brundtland Report, we would say that an economy's productive base is its wealth, and that movements in wealth over time reflect whether the corresponding development path is sustainable. Sustainability is a different notion from optimality. The former asks, "How are (were, or are likely to be) things?", while the latter asks, "How should things be?" Nevertheless, the same object – wealth - is the coin with which answers to both questions are obtained. That's because the well-known criterion for social cost-

benefit analysis - the present value of net social benefits - measures the changes in wealth occasioned by the projects being evaluated.

Dasgupta and Maler had assumed constant population. In Arrow, Dasgupta, and Maler (2003), the equivalence result was extended to economies where population not only changes, but is endogenous. They also identified a way to reformulate the notion of intergenerational welfare in such a way that wealth per capita serves as the index of sustainability. The reformulation amounted to the intergenerational average of Utilitarianism. In three publications, Arrow et al., (2004, 2012, 2013), the theoretical framework was put to work on contemporary growth experiences in a sample of countries and regions. Sub-Saharan Africa was found not have enjoyed sustainable development in recent history despite having experienced a small growth in GDP per capita, while a number of others in the sample had enjoyed an increase in wealth per capita, but some at very small rates. In each of the latter set of countries, GDP growth had been reached at the expense of a diminished stock of natural capital. The publications were the first to attempt at the quantitative study of the wealth of nations and their movements over time. They were also, to the best of my knowledge, the only times Arrow was engaged in studying national accounts.[4]

Above all else, it is his tireless espousal of ecological economics that will be remembered by those many scholars who have engaged with him at the Asko meetings and the teaching and training workshops on environment and development that the Beijer Institute organised over the years in the developing world (South Asia, Latin America, sub-Saharan Africa). Networks of mainly young economists in those countries that were established with the help of the Institute found Arrow in their midst, listening to their presentations, reading their works, and commenting on them on the margins of their manuscripts.

Kenneth Arrow is renowned in the West and Far East as a teacher and mentor, not simply as that greatest of social scientists. What may not be known there is that his death is being mourned by scholars in the developing world, who not only heard him lecture, but were also helped by him to formulate problems they had found on their own ground.

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4   Subsequent work initiated by the United Nations Environment Programme (UNEP/UNU-IHDP, 2012, 2014) has extended and refined the wealth estimates of the earlier publications.

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