Chapter 6A

Estimating Shadow Prices

We have identified a variety of factors that determine shadow prices. But how should the prices be estimated? In this Appendix we study some of the methods that have been devised for estimating the shadow prices of goods and services. Among the commodities to which we will pay particular attention are natural resources and human health.

There is a Utopian scenario where market prices equal shadow prices. Economists call that state of affairs a "full optimum". Elsewhere, depending on the circumstances, market prices are reasonable approximations for some goods and services, while for others they are not. The theoretically valid procedure for estimating shadow prices is to put their definition directly to use. We now sketch a number of methods that have been devised.[1]

6A.1 Shadow Prices of Natural Capital

Using Definition 1 offered in Chapter 6 directly is problematic because of the enormous quantity of information demanded by requirements (i)-(iii). So environmental and resource economists have devised two indirect methods (Freeman, 1992; Smith, 1997 are fine expositions of the methods). In one, investigators ask people to place a value on ecological resources. In the other, they study behaviour and the consequences of that behaviour to infer the value individuals place on those assets (contingent valuation). In the latter method, market prices of those goods and services for which there are markets are often taken to be their shadow prices. As an example of the latter, consider an asset that has multiple characteristics (e.g., land). The hedonic method

[1] Freeman (1993) is an excellent treatise on the subject.

uses the market price of a piece of land to uncover the shadow price of one of its characteristic (e.g., the price of its aesthetic qualities). The hedonic method has been much used to value real estate. In their work on inland wetlands in eastern North Carolina (USA), Bin and Polasky (2004) found that, other things being equal, proximity to wetlands reduced property values, presumably because of a greater infestation of insects and possibly bad odor.

Behaviour and Preferences

The valuation methods that have become most popular were devised for environmental amenities, such as places of scenic beauty or cultural significance. The cost of travel to a site takes revealed preference to be the basis for valuing the site. Englin and Mendelsohn (1991), for example, is a well-known application of the method for estimating the recreation value of forests. In contrast, in those cases where there is no observed behaviour, the contingent valuation method (CVM) has proved to be extremely popular (see Carson, 2004, for an extensive bibliography and Smith, 2004, for an excellent history of the method). The idea is to ask people how much they would be willing to pay for the preservation of an environmental amenity (e.g., flood control) or a resource of intrinsic worth (e.g., an animal or bird species).

Each of the above methods is of limited use for valuing the local natural resource base in the poor world. Moreover, one can question whether requirements (i)-(iii) can be met adequately by studying people's behaviour or analysing their responses even to well-designed questions. One reason for being circumspect about those methods (there are many other reasons) is that people often aren't aware of environmental risks. Jalan and Somanathan (2008) conducted an experiment among residents of a suburb of New Delhi. The aim was to determine the value of information on the health risks that arise from drinking water that contained bacteria of faecal origin. Without purification the piped water in 60% of the households were found to be contaminated. Among households in the sample that had not been purifying their piped water, some were informed by the investigators that their water was possibly contaminated, while the rest were not informed. The authors report that the former group of households was 11% more likely to invest in purification within the following 8 weeks than the latter group. An additional year of schooling of the most educated male in the household was associated with a 3% increase in the probability that its piped water was being treated. The finding is noteworthy because the wealth and education levels of households in the sample were above the national average. If ignorance of environmental risks is pervasive, estimates of the demand for environmental quality that assume full information must be misleading.[2]

Using Nature's Production Functions

So we return to requirements (i)-(iii). In their work on the economics of climate change, Cline (1992) and Stern (2006) met (i) and (iii) directly (Section 12.3). Several recent valuation studies have met requirement (i) by estimating the production function for nature's service (e.g., pollination as a function of the distance to a forest; primary productivity as a function of biodiversity; net reproduction rate of a species), but have otherwise assumed that market data are more or less sufficient to meet the other requirements.[3] Pattanayak and Kramer (2001) and Pattanayak and Butri (2005), for example, constructed a hydrological model to measure the contribution of upland forests to farm productivity downstream. Hassan (2002) used quantitative models of woody land resources in South Africa to estimate the value to rural inhabitants of (among other resources) the Fynbois Biome, which dominates sandy soils there. Barbier (1994) and Gren at al. (1994) used formal ecological models to compile a catalogue of the various

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[2] Determining the "willingness to pay" for changes in risk involves additional problems. See Smith and Desvouges (1987).

[3] See Dobson et al. (1997), Barbier (2000), Turner et al. (2000), and Tilman et al. (2005) for illustrations of ecosystem production functions and the corresponding dynamics of the socio-ecological systems.

services that are provided by wetlands. In their study of wetlands in northern Nigeria, Acharya (2000) and Acharya and Barbier (2000) applied models of ground water recharge to show that the contribution wetlands make to recharging the basins is some 6% of farm incomes. That's a large figure.

The welfare economics of climate change requires that carbon in the atmosphere is priced. The early literature on the subject didn't have a spatial component to that price. A figure of 20 US dollars per ton for carbon's global shadow price was suggested by Fankhauser (1995) and Pearce et al. (1996). That figure has been used in the World Bank's work on sustainable development (Section 10.2). But there are likely to be enormous regional variations in the impact of global climate change on economic activity (Rosenzweig and Hillel, 1998; Mendelsohn et al., 2006; Dinar et al., 2008). Agriculture in semi-arid tropical countries is expected to suffer from warming, while in temperate regions it will probably benefit. If we apply distributional weights to the losses and gains, the disparity is bigger than the nominal figures that have been suggested, because the former group of countries are almost all poor while the latter are middle-income to rich. Using a range of climate models, Mendelsohn et al. (2006) have published estimates of losses and gains in year 2100. The authors aggregated five sectors: agriculture, water, energy, timber, and coasts. Depending on the scenario, they found that the poorest countries (almost all in Africa) are likely to suffer damages from 12% to 23% of their GDP, while the range of impacts on the richest countries (North America and northern Europe) is from damages of 0.1% to a <u>gain</u> of 0.9% of their GDP. Dinar et al. (2008) fear that with warming, the agricultural income in the semi-arid tropics could be more than halved in 2100 from its projected value in the case where there is no warming. But these estimates are based on market prices. If distributional weights are applied to obtain a global shadow price of carbon, it would be a lot higher than if we were merely to add the regional gains and losses. It should also be noted that the effects of climate change on health and the environment (e.g. loss of species) were not included in those estimates.

Option Values

Natural resources often possess yet another kind of value, one that is more amenable to quantification than their intrinsic value. It arises from a combination of two things: uncertainty in their future use-values (a subject that was discussed in the Appendix to Chapter 5), and irreversibility in their use. Genetic material in tropical forests provides a prime example. The twin presence of uncertainty and irreversibility implies that preservation of its stock has an additional value: the value of extending society's set of future options. Future options have an additional worth because, with the passage of time, more information should be forthcoming about the resource's use-value. This additional worth is often called an option value. The accounting price of a resource is, at the very least, the sum of its use-value and its option value.[4]

Biases in Estimates

What is the point of basing shadow prices solely on one particular use-value when we know that natural capital often possesses other values too? The answer is that the method provides us with biased estimates of shadow prices. That can be useful information. For example, in a beautiful paper on the optimal rate of harvest of blue whales, Spence (1974) took the shadow price of whales to be the market value of their flesh, a seemingly absurd and repugnant move. But on estimating the population growth functions of blue whales and the harvest-cost functions, he found that under a wide range of plausible parameter values it would be most profitable commercially for the international whaling industry to agree to a moratorium until the desired long-run population size was reached, and for the industry to subsequently harvest the whales at

[4] The pioneering works on option values are Weisbrod (1964), Arrow and Fisher (1974), and Henry (1974).

a rate equal to the population's optimal sustainable yield.[5] In Spence's analysis, preservation was recommended solely on commercial ground. But if preservation is justified when the shadow price of blue whales is estimated from their market price, the recommendation would, obviously, be reinforced if their intrinsic worth were to be added. This was the point of Spence's exercize.

Commentary

The valuation techniques we have enumerated here are built round the idea that preferences and demands, as they stand, should be respected. There is an enormous amount to be said for this, reflecting as it does a democratic viewpoint. But even when commending it, we shouldn't play down the strictures of those social thinkers who have urged the rich, be they in rich countries or in poor ones, to curb their material demands, to alter their ways so as to better husband Earth's limited resources. Their thought is that we deplete resources without trying to determine the consequences of depleting them, sometimes because we haven't the time to find out, but sometimes because we may not wish to know, since the answer may prove to be unpalatable to us. Being sensitive to ecological processes requires investment in early education on the connection between human well-being and the natural environment. If such strictures as we are alluding to seem quaint today, it may be because we are psychologically uncomfortable with the vocabulary. But that isn't an argument for not taking them seriously.

We sum up:

The social worth of natural resources can be decomposed into three parts: use value, option value, and intrinsic value. The proportions differ. Oil and natural gas aren't usually thought to possess intrinsic value, nor perhaps an option value, but they do have use value. The

[5] During the moratorium the whale population grows at the fastest possible rate. In Spence's numerical computations, the commerically most-profitable duration of the moratorium was found to be some 10-15 years.

great apes are intrinsically valuable; some would say they should have no other value, that they are an end in themselves, not a means to anything. Biodiversity possesses all three types of value. And so on.

6A.2 Human Health

The United Nations' Human Development Index (HDI) is an aggregate of GDP per capita, life expectancy at birth, and literacy. Although the UN has advertised the index vigorously over the years, they have offered no ethical justification for the relative weights they have awarded to the three components of HDI. In contrast, the World Health Organization (WHO) some years ago sought to measure improvements in health by estimating the welfare gains from declines in morbidity at various stages of life. QALY (or "quality adjusted life years"), as the measure is called, adjusts life expectancy by weighting each year of people's lives by the quality of their lives.

Although the theoretical basis for QALY is sound, its use in practice has proved to be controversial. Nordhaus (2002) and Becker et al. (2005) have avoided the controversies by estimating the welfare gains of increased life expectancy, unadjusted for the quality of each year of life. Here we develop the Nordhaus-Becker analysis further. It is an application of CVM to value small reductions in mortality risks.

The method is based on the concept of the value of a statistical life. Suppose there are a thousand people, each of whom has a probability of 0.04% of dying during the next year. Imagine that a pollution control measure would reduce that probability to 0.03%. Imagine also that each person in the group is willing to pay $5,000 for this policy. The total willingness-to-pay is then $5 million. Since on average there would be one less death during the year if the measure were adopted, $5 million would be reckoned to be the value of a statistical life.[6] If V is the value, we can calculate the value of a statistical life year, which we denote as v. The formula that expresses v in terms of V is not straightforward. It depends on expectations of future changes in mortality rates and, in any case, the quality of life itself may depend on age. QALY's are based on those considerations. For simplicity of exposition, we avoid the complications by assuming v to be independent of age.

Demographers estimate age-specific mortality rates in the year a census is taken. As example: "In 1995 the mortality rate of people aged a (a = 0, 1, 2, ...) was N_a per 1000." And so on. The figures reflect age-specific mortality rates in year 1995 (e.g., N_a/1000 for people of age a). Suppose new figures are published for year 2000 and it is found that the mortality rates have declined, say, to N_a* per 1000. The formulae demographers use to estimate life expectancies in 1995 make use of the 1995 figures for mortality rates. But that would be the wrong set of figures to use for estimating the life expectancy of someone, say, aged 4 years in 1995 who survived until 2000, because she would have faced the mortality rate N_9*/1000 in year 2000, not N_9/1000. So, the former figure should have been used in 1995 when projecting her life chances into the future. To rely exclusively on the 1995 mortality rates would be to underestimate life expectancy in 1995, implying that if we use life expectancies as measured by demographers to build a measure of health capital, we would be underestimating health capital. On the other hand, there would be a similar underestimate of health capital in 2000 if the latter were based exclusively on the mortality rates prevailing in 2000. So, there may not be too much inaccuracy in the estimate

[6] The most common method for estimating the underlying "willingness to pay" is to study differential wages for jobs involving differential risks. This and other examples are studied in Freeman (1993), who also summarizes a lively debate that has taken place on basing the value of reductions in the probability of death on statistical lives and their worth. Viscusi and Gayer (2000) is an excellent survey on methods for valuing environmental health risks.

of the <u>growth</u> in health capital over the period 1995-2000. We now develop formulae for life expectancies that take into account the changes to mortality rates that would be expected to take place.

We suppose time is discrete: $t = 0,1,2,3,...$ Let $\pi(a,t)$ be the mortality rate of people aged a at t, where $a = 0,1,2,3,....$ Statisticians call $\pi(a,t)$ the <u>hazard rate</u>. Using $\pi(a,t)$, the probability $f(a,T,t)$ that some aged a at t will die at age T ($> a$) can be calculated to be

$$f(a,T,t) = [1-\pi(a,t)][1-\pi(a+1,t+1)]...[1-\pi(T-1,t+T-a-1)]\pi(T,t+T-a),$$

or $f(a,T,t) = \{{}_{i=0}\Pi^{T-a-1}[1-\pi(a+i,t+i)]\}\pi(T,t+T-a)$.[7] (6A.1)

Let $\mu(a,T)$ be the value of a statistical life of someone aged a who will die at age T. Then

$$\mu(a,T) = {}_{u=a}\Sigma^{T}[v/(1+\delta)^{u-a}]. \tag{6A.2}$$

Combining (6A.1) and (6A.2), we may define the value of a statistical life at t of someone of age a as

$$V(a,t) = {}_{a=0}\Sigma^{\infty}[\mu(a,T)f(a,T,t)]. \tag{6A.3}$$

As mortality rates improve, the age distribution changes. At t let $r(a,t)$ be the proportion of people aged a. Let $Q(t)$ be shadow value of health capital at t. Then, using (6A.3) we have

$$Q(t) = {}_{a=0}\Sigma^{\infty}[r(a,t)V(a,t)], \tag{6A.4}$$

and the shadow value of the change in human capital at t is,

$$dQ(t)/dt = {}_{a=0}\Sigma^{\infty}[(\partial r(a,t)/\partial t)V(a,t) + r(a,t)\partial V(a,t)/\partial t]. \tag{6A.5}$$

$Q(t)$ in equation (6A.4) is a component of inclusive wealth at t, and $dQ(t)/dt$ in equation (6A.5) is a component of comprehensive investment at t.

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[7] The expression for $f(a,T,t)$ in (7A.7) takes a more familiar form if the hazard rates are "small". Taking logarithms of both sides and using the fact that $\ln(1+x) \approx x$ if the absolute value of x is small, we have

$$f(a,T,t) \approx \pi(T,T+t-a)\exp[-{}_{i=0}\Sigma^{T-a-1}\{\pi(a+i,t+i)\}].$$

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