Valuation of medicinal plants for pharmaceutical uses

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This paper attempts to review the literature and the emerging policy issues on valuation of plant diversity for pharmaceutical uses. Some of the acclaimed valuation works done in the last 15 years (1985–2000) have been considered for this purpose. Their methodologies have been scrutinized, findings evaluated and policy recommendations examined. Since these studies were meant to address different concerns, it is difficult to arrive at a general conclusion. However, the value of a medicinal plant varies from $ 0.2 to $ 340 million per annum. Conservation of biodiversity based on the benefits of medicinal plants or bioprospecting is the subject of dissenting views. A conservation strategy on the basis of the benefits of bioprospecting alone will need detailed area-specific study instead of a general and large landscape valuation.

VALUATION of biodiversity is desirable, as this not only highlights the contribution of biodiversity to society but also helps in developing an efficient conservation strategy for this precious natural resource. Economic valuation of biodiversity and its different components in terms of use and option values induces efficiency in decision-making criteria. Medicinal plants and herbs are one of the crucial components as far as the contribution of biodiversity to society is concerned. With a progressive loss of biodiversity all over the world, especially in the tropics, society is not only losing present benefits from current use but is being deprived of the option of future availability known as option value. Medicinal plants provide meaningful inputs for drugs. Their loss through extinction could lead to considerable loss to the society. Hence monetization of the components of biodiversity, such as for medicinal plants in a cost–benefit framework helps to understand how the conservation of biodiversity affects the level of human welfare. Medicinal uses of plant and animal species have been practised for centuries in many parts of the world but valuation of such benefits by economists has commanded attention in the last two decades possibly due to the alarming rate of species extinction. Valuation can also help in devising a proper public policy for its conservation and sustainable use. Monetary benefits of biological resources through economic valuation in the context of bioprospecting are a small part of total benefits. Other significant non-monetary benefits could be transfer of useful biotechnology, training of local staff and personnel and support for the biodiversity-rich nation[1].

This paper reviews some of the path-breaking studies on valuation of medicinal plants for drugs and pharmaceutical purposes. In the last 17 years (1985–2002), numerous studies on this theme have been carried out. A few representative studies have been reviewed and the emerging policy issues mapped out. A careful analysis of these studies also provides an indication of the direction in which the valuation of medicinal plants is progressing, and the emerging research agenda in this particular area in the coming years. The author however acknowledges other important work done by economists and economic botanists in this area[2–4] but they are either methodologically not significant or they do not seem to contribute to the valuation literature substantially. Hence these studies have not been considered for review, which in no way lowers their importance and relevance. There have been other similar reviews but with different objective and focus. For example, Godoy *et al.*[5] have attempted to address the valuation of non-timber tropical forest products, of which medicinal plants constitute a very small part. Another study by Cartier and Ruitenbeek[6] deals with the issues pertaining to valuation of genetic resources for pharmaceuticals but the focus remains on the marine ecosystem.

Valuation studies done so far fall into three categories, viz. gross estimation, net estimation and estimation of lead for drug industry.

Estimation of gross economic value

Total contribution of medicinal plants has been estimated on the basis of drug sales. Economic estimates done by Farnsworth and Soejarto[7] (1985), Principe[8,9], and Mendelsohn and Ballick[10,11] come under this category.

Farnsworth and Soejarto

Farnsworth and Soejarto (FS) calculated the value of medicinal plants expected to disappear by 2000 in the US. They estimated the total value of medicinal plants in the US for the years 1973 and 1980. On the basis of the active ingredients of those plants present in the drugs consumed by people in the US, FS rely on the prescription data of the National Prescription Audit (NPA; a product of IMS America Ltd, Ambler, PA 19002). The NPA survey found

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that around 25% of all prescription drugs in the US had one or more active principal derived from higher plants. NPA's figure is partial since it considers community pharmacy only; FS simply doubles it to make it total for the US. Since the US has about 5000 flowering plant species from which 40 have been proved as contributing to drugs, FS conclude that 1/125 is the success rate for drug discovery. Next, they consider the assumption that in 2000, 10% of all species of flowering plants in the US (20,674) will become extinct if appropriate measures of conservation are not undertaken. So, 2067/125 = 16 potentially useful medicinal plants will be lost whose value FS calculate as $ 3.248 billion (16 × $ 203 billion) for the year in 1980 dollars.

Principe

Principe's studies heavily draw on FS's framework although he considers OECD countries apart from the US. He differentiates the market value and the economic value of medicinal plants. The market value of medicinal plants is estimated by using information in the FS[7] study, which was $ 8 billion for the US. He highlights the flaws in this calculation where the figure for the prescription drugs does not include (i) over-the-counter drug sales, (ii) drugs exclusively used in the hospitals, and (iii) traditional and herbal medicines. Principe makes the adjustment by adding 25% values based on empirical observations, and finally arrives at a total figure of $ 6.2 billion for the US in 1985. This figure is based on a sales estimate of the drugs in the US for 1985 which totals at $ 11 billion. For OECD countries the value of medicinal plants is multiplied by a factor of 3 and it reaches $ 33 billion in 1985. He goes a step further and calculates the present value of medicinal plants through the year 2000 by applying two discount rates: 2% and 8%. This gives the range of values of $ 400–600 billion in 1984 in dollars for the OECD countries. In order to calculate the forgone market value of medicinal plants, Principe uses the National Institute of Health (NIH) experience with the screening process in bioprospecting and infers that the probability of a successful prescription drug lies between 1 : 1000 and 1 : 10,000. Next, he borrows ecological data to presume that by the end of 2000 around 60,000 species will become extinct in OECD countries, leading to the estimation of between 6 and 60 species that could have provided the leads for successful prescription drugs. Since the market value of single commercially useful species in the US was $ 200 million[7], the corresponding figure for OECD countries was $ 600 million. Finally, the value of the species threatened with extinction in OECD countries was projected at $ 60 million per year per plant in 1980 dollar.

Principe acknowledges that this value does not include other ecological and aesthetic values of the medicinal plants. He is also aware that the market value does not capture the benefits a society receives out of the medicinal plants. He calculates the economic value of the plants by admitting that the relationship between market value and economic value is not direct but the market price is minimum valuation assuming that (i) the demand for the drug is inelastic, and (ii) it is appropriate to value an essential input at its own cost plus the economic rent obtained from it plus the accumulated consumer surplus. Operationalizing this, the cost of a disease to the society where impact could have been avoided in the future by the drug derived from this plant in consideration was calculated. He then begins with the reference calculation for cancer a disease which causes 500,000 deaths and costs $ 14 billion in treatment and man-days lost in the US alone. The average value of lives is to be taken as $ 1.5–8 million at 1984 dollar totalling to $ 750 billion–$ 4 trillion each year. The anticancer drug saves 75,000 lives in the US annually (15% of 50,000) and plant-based drugs in this segment form 30–50% of total anticancer drugs. Therefore, between 22,500 and 37,500 people are saved due to these plant-based drugs fetching the benefits in the range of $ 34 billion and $ 300 billion for the US and correspondingly it becomes $ 100–900 billion for OECD countries owing to cancerous disease alone. For cancer and non-cancerous diseases Principe estimates this figure as $ 200 billion–1.8 trillion.

In another study, Principe[9] estimates the value of medicinal plants in the USA by extending the value of 1985. He analyses the trend of retail value of prescription drugs, which he finds as $ 62 billion. By applying the 25% factor for plant-based drugs, the value was $ 15.5 billion in 1990. He derives the per plant value ($ 15.5/40) as $ 390 million. Relying on the projection of species loss by the WWF and the IUCN, he finds that between 1991 and 2050 around 62,500 species (25% of 250000) will be lost at a loss rate of 1059 species/year. Thus, the number of medicinally useful species that will be lost is 30, making the species loss one in every two years. Hence the forgone benefits in the first year will be $ 200 million and this would increase every year. The benefit forgone in the year 2050 will be between $ 11 billion and $ 12 billion in the US alone in the 1990 dollar. For the calculation of NPV Principe adopts a 5% social rate so that $ 3.5 billion is the total of benefits occurring through 1991–2050.

Mendelsohn and Ballick

In their earlier study, Mendelsohn and Ballick (MB) choose two simple plots of forest in Central America (Belize in Cayo district). They call it plot I and plot II, which are 30 years and 50 years old, yielding 308.6 kg and 1433.6 kg of medicinal plant (drug) respectively. MB estimated the revenue at the local price of the medicinal plant and then adjusts for the cost (only labour in this case). Then they derive the present value criteria. Presuming a 30-year rotation for plot I and 50 years for plot II, the value was

estimated at $ 726/hectares and $ 3327/hectare respectively. In a subsequent study, MB[10] present a refined and convincing methodology, where they estimate the value of undiscovered pharmaceuticals in tropical forests. MB calculate the number of undiscovered but viable plant species in the tropical forest and they put it as 375. With its limited screening ability, an individual firm can locate 38–56 of these drugs only if all 125,000 flowering plants in the tropical forest are tested. Since 47 drugs of 375 species (12.5%) have already been sourced from these areas, 328 species are still hidden. Therefore, a company could think of finding 33–49 of these new drugs from the sources. MB then rely on the estimate of R&D costs on DiMasi *et al.*[12] and OTA[13] (discussed later). It gives details of cost structure, e.g. basic facility cost (capital cost), manufacturing cost, marketing and administration cost, inventory cost and market expansion costs. The total comes to 3.41 million per year over the first nine years in which a drug is sold. Overall, OTA estimates give present value of net revenue over a 20 year period (and 5% rate of discount) as $ 125 million per drug to a private firm.

The OTA estimates also adjust this figure for average tax (25%), uncertainty about timing, cost and magnitude of sales and arrive at a single figure of $ 50 million. MB estimates gross revenue from each drug based on sales data in the US as $ 96 million. Since a firm can discover 33–49 drugs, correspondingly the gross revenue would be $ 3.2–4.7 billion. MB further assume that the entire sample can be collected at $ 100 each, the total cost would be $ 75 million ($125000 \times 3 \times 2 \times 100$). Adding another screening cost @ $ 100 makes the cost $ 3.6–$ 5.3 billion (corrected in 1997). MB also analyses the search as a collective action by all the firms together doing the screening which reduces the cost substantially and peak revenue of $ 58 billion can be maintained. From the social view the taxes are not revenue loss. In this new scenario, the total value becomes $ 449 million per drug. The aggregate potential social value for undiscovered tropical forest pharmaceutical comes to $ 147 billion (449×328), yielding revenue of $ 48/hectare of tropical forest. This estimate is of social value of forest for medicinal plant but the market value may be lower than this. Recognizing that the market value had been estimated at $ 3–4 billion and $ 1/hectare, MB further raise many pertinent issues falling in the domain of contract for bioprospecting.

These studies do not account for the cost of bioprospecting, however, all of them are aware of the limitations of their studies and they aver that the purpose of their studies has been to highlight the economic significance of the medicinal plants. Possibly the concern for biodiversity destruction and species loss prompted them to estimate the gross value of medicinal plants for pharmaceutical uses thus, justifying the conservation efforts. Moreover, one can also get the feeling that the required database pertaining to the cost structure of R&D process of drug discovery was either obscure or hidden from the eyes of the researcher owing to their confidential nature.

Estimation of net economic value

Various studies under this estimation, try to adjust the cost of drug discovery and marketing and arrive at some sort of net value. Studies by Aylward[14], Artuso[15,16] and Pearce and Puroshothaman[17] fall in this group.

Aylward

Alyward estimates the return to different factor inputs in the R&D process of the pharmaceutical industry. Based on the data primarily in three studies cited above and other contract agreements (e.g. Merck-INBio), he calculates the return for each factor input. Aylward explicitly discerns the cost factors like biodiversity protection, biotic samples extraction and other R&D costs (from sample extraction to regulatory approval) (Table 1). He adopts two different models to capture the return: (i) cost (private and social) model, and (ii) prospecting royalty's model. For estimation of net returns across different factors of prospecting, in each model the expected net return to each factor is assumed equal to its proportional share in the total cost of the prospecting process. In another model of royalty, Aylward estimates the net returns from prospecting royalty. Here the gross revenue comprises sales net of distribution costs up to patent expiration. After making the adjustment in the species success rate and the number of samples used per species, he computes the gross royalty on the biotic samples.

Artuso

Artuso[15] discusses the entire R&D process of the pharmaceutical industry but in different stages. He separates one phase of R&D from another. He analyses the R&D process in terms of phases like formulation of search

Table 1. Results of Aylward's model

Private cost model	US$
Total net return to pharmaceutical prospecting	39.13 million
Total net return to R&D	38.71 million
Total net return to biotic samples	0.42 million
Net return per biotic samples	21.23
Social cost model	
Total net return to pharmaceutical prospecting	33.24 million
Total net return to R&D	30.91 million
Total net return to biotic samples	0.68 million
Net return per biotic samples	33.91
Total net return to biodiversity protection	1.66 million
Net return per tested species	165.79
Royalty model	
Royalty per biotic sample	233.12
Net return to biotic samples	4.91 million
Net return to biotic samples	– 0.98 million

problem to sample collection, extraction of phytochemicals for screening, pre-clinical and clinical stages to the beginning of commercial production of drug. He considers that each phase has distinct characteristics and a corresponding probability to enter into the subsequent phase and hence they have different success rate in the next process. Correspondingly, they yield different costs and benefits. So instead of net present value (NPV) for the entire R&D process, Artuso discerns NPV for each phase separately. However, the success rate of the preceding phase is the relevant rate for calculating the costs in the current phase. In his scheme the expected cost of phase is computed. And then, the expected net present value of a particular number of biological extracts to society is estimated (Table 2). Artuso ignores tax liability but accounts for consumer surplus and additional social benefits such as reduced cost and incremental productivity.

Pearce and Puroshothaman

Pearce and Puroshothaman[17] (PP) begin the valuation of medicinal plants by assuming that the valuation done so far (up to 1990) has been speculative. They are aware of Principe's work which they adopt with some modifications. PP are concerned about the prevailing institutional capability to capture values of medicinal plants in drug discovery. They feel that unless this issue is addressed properly and incorporated in the estimation process, the values of the plants will remain exaggerated. PP refers to Ruitenbeek's[2] analysis where he states that the countries from which bioprospecting in developed countries takes place have no way to appropriate the values themselves. Of course currently many developing countries are provided with royalties in the range of 1–10% of pretax sales of successful drugs but the issue of royalty becomes a bone of contention between the host and prospecting countries. This is further aggravated by the degree of uncertainty related to cost and production in bioprospecting. PP rely on the relationship between capturable production value and expected production value. Under this framework a fraction of rent is captured which is basically the royalty given by the prospecting firm/country to the local or the host country and is generally determined ex ante during the agreement of the contract.

Value of drugs to the society is higher if the avoided cost of diseases due to medicinal plants is considered, e.g. value of life (statistical); and is lower if the market value of the medicinal plants is considered. PP believe that drug price grossly overstates the value of the plants. Also, market prices understate true willingness to pay for drugs because there will be individuals who will be willing to pay more than the market prices for a given drug, since the larger number of drugs tended to be price inelastic and hence the consumer surplus element could be substantial. Here the two forces are working in the opposite directions. PP also provide the value of land on the basis of benefits emanating from medicinal plants alone.

These studies recognize and account for the cost aspect of bioprospecting and arrive at the net value of medicinal plants for pharmaceutical uses. This has meaningful implications for efficiency issues regarding the bioprospecting activities. Studies under this category had the advantage of published research on the cost, risk, and reward to factor inputs in R&D of the pharmaceutical industry.

Estimation of lead for drug discovery

Estimations are based on probabilistic models of search problem for a useful clue to a new drug by the R&D wing of the pharmaceutical firms. Recent works of Simpson *et al.*[18,19] and Rausser and Small[20] come under this category. While the first two sets of studies capture the value of medicinal plants where medicinal plants directly provide inputs in terms of raw materials to the drug industry, the third set of studies value the plant species which provide the lead in the drug discovery process known as bioprospecting.

Table 2. Artuso's estimate

Phase	Phase duration	Success rate	Mean no. of successes	Cost per trial ($)	Expected phase cost ($)	PV expected phase cost ($)
Initial screening	0.75	0.005	750	0.10	15,000	14.548
Secondary screening	0.10	0.400	300	1	750	732
Isolation and dereplication	0.50	0.100	30	20	6000	5712
Synthesis and modification	1.50	0.500	15	250	7500	6585
Pre-clinical trial	1.00	0.400	6	771	11,570	9170
Clinical phase I	1.35	0.750	4.5	3137	18,822	13,557
Clinical phase II	1.88	0.475	2.14	9933	44,698	28,239
Clinical phase III	2.49	0.700	1.50	18,817	40,222	21,282
NDA	3.00	0.900	1.35	1000	1496	633
Cumulative	12.57	9×10^{-6}	1.35	33,930		100,457

Simpson et al

Simpson *et al.*[18] attempt to test the hypothesis whether it is possible to advocate the conservation of biodiversity on the basis of the benefits from bioprospecting alone. They bring in a useful concept called 'marginal value of species'. What they imply here is the extent of incremental value a species can contribute, let us say, value added from 100 to 101. This has special implications for the planners and conservationists of biodiversity. They start with the introduction of theoretical model as a basis for deriving a demand function for biodiversity of pharmaceutical researchers and to determine their willingness to pay for species as an input into commercial products. Their model characterizes bioprospecting as a process of sequential search on species (or leads) for a discovery of a new product. Each species has potential to provide genetic information useful for the new product, which earns a net revenue. They assume that the probability of a discovery is common to all the species in consideration. With these assumptions, each new sampling is treated as an independent Bernoulli trial with equal probability of success. In valuing the contribution by an additional species, Simpson *et al.* emphasize that discoveries may be redundant; once a successful product is found, further discoveries of the same product become valueless. They made this point clear by explaining why genetic resources may be relatively redundant in practice: the same species may be formed over a wide range; there are numerous instances in which identical drugs have been isolated from different species; and there may be non-organic substitutes for the leads discovered from biological resources[18,19]. However, the same type of benefits derived from different species may have different values owing to differences in quality and cost[21].

Given such potential redundancy of discoveries and the same probability of discovery for all species, they claim that the value of an additional species, is modest at most. One reason is obvious: as sample size increases, the value goes down. Simpson *et al.*[19] also explain another intuition behind their claim: If all species are promising sources of leads, then most would be redundant and the marginal species would be valueless. Conversely, if probability of a hit is low then it is unlikely that any species will prove to have value. As the likelihood of success with any species goes up, the expected payoff in the event that the species is tested increases. At the same time, however, another equally valuable species may be discovered first so that the expected payoff of the species declines. This is the cost generated by redundancy.

Rausser and Small

Contrary to the findings of Simpson *et al.*, Rausser and Small[20] find that if the search is not a brute and random search and is based on the scientific information, it may not only enhance the benefits but cut the cost of discovery drastically, leading to a significant value of genetic resources and not as the vanishingly small value as claimed by Simpson *et al.* Rausser and Small explicitly incorporate this aspect of pharmaceutical research into their model by assuming that the hit probability may vary among species. With otherwise the same model as the one used by Simpson *et al.*, they claim that an optimal search program involves testing a lead with the maximal hit probability among those not yet examined (Proposition 1 : 181). Given this optimal sequence, the incremental value of a lead (the maximum a firm will be willing to pay at the start of a search project for a call option on the lead) is a function of the hitting probabilities of all leads. Their point is that leads that are promising contribute more than the others to the chance of an eventually successful outcome for the project. Moreover, addition of a higher probability lead to the existing lead that reduces the expected total search cost by making less promising leads more redundant. Thus, in addition to the scarcity rents, promising leads command 'information rents' associated with its contribution to the chance of success and the avoidance of search costs. This information rent is zero if and only if all prior samples are equal possibility-wise, the assumption made in Simpson *et al.*[18]. Treating the hit probability the same for all the species can be interpreted as a situation where researchers have no prior information as to which species has a higher likelihood of containing valuable genetic information. If prior information is available (i.e. the success probability varies among the leads), then the value of certain species contain positive information rents and can be high enough to encourage private incentives for habitat conservation.

With a numerical simulation using the same data as in Simpson *et al.*[18], Rausser and Small[20] suggest that, under plausible conditions, the bioprospecting value of certain genetic resources could be large enough to support market-based conservation of biodiversity. In their simulation a lead is given by a unit of land in each of the 18 hotspots. The hit probability of a unit of land is assumed to be proportional to the density of endemic species in the area. They multiply the probability 1.20×10^{-5}, which is the value for p used in Simpson *et al.*[18], by these density values to obtain the hit probability of each land area. Table 3 gives the details of the value of species for Simpson *et al.* and Rausser and Small. N in Simpson *et al.*[18] is the number of all higher plant species whereas in Rausser and Small[20] it stands for the number of ecological sites each of which contains various biodiversity.

These two studies, albeit providing different recommendations deserve serious analysis and attention. Simpson *et al.* show the value of medicinal plants for pharmaceutical purposes as being very small and hence they think that the conservation strategy based on this particular benefit is not tenable; while Rausser and Small, with the

same set of database, show that the value could be much higher provided the search is based on prior scientific knowledge and is opinionated. This finding is concomitant to real life where prospecting firms choose to search the hotspots of biodiversity like Costa Rica, Brazil or India. They do not search the plants for leads anywhere or everywhere.

Other studies

In 1980s and 1990s, a few studies in the realm of industrial and R&D economics, substantially contributed and influenced the valuation of genetic material for bioprospecting. These studies were not intended to value medicinal plants for drug discovery. Their primary objectives were to find the costs, returns and related risk in the R&D process of finding new chemical entities (NCE) of the pharmaceutical industry. However, they become important and crucial to understand the work done on valuation in the 1990s because they greatly influenced the subsequent studies. Therefore a brief glance at these would be necessary.

Joglekar and Paterson[22] analyse the profitability and risks of the pharmaceutical firms based on historical US data. They project the future cash inflow and outflow of an NCE with R&D starting in 1976 with market introduction in 1988. The time horizon of 24 years was also considered as the analysis ended in 2001. They reported that in a time horizon of 36 years the average NCE produces a real internal rate of return of 6.1% and a net present value of $ 76 million in 1976 dollars. The risk attached in the process of pharmaceutical R&D is obvious because after 24 years of sales some two-thirds of NCE return would be no more than that of the bonds.

Grabowski and Vernon[23] investigate the returns to R&D investment for 100 new drugs introduced in the US during the 1970s. This study, by incorporating the latest structural changes in the industry (e.g. higher real drug price and greater degree of generic competition) inferred that the return on R&D for the average new drug is around 9% of cost of capital incurred in the industry. DiMasi *et al.*[12] selected 93 new chemical entities for the US surveying 12 pharmaceutical US firms. They find that the average cost of NCE development was estimated to be $ 231 million in 1987 dollars. This estimate seems to be on the higher side compared to the earlier studies because DiMasi *et al.*[12] covered numerous costs of developing NCE which were unaccounted earlier.

Emerging issues from valuation studies

Each study discussed above has its own advantages and limitations. These estimations were done at different scales and in a different context. The study by FS essentially relies on many crude approximations regarding the availability of species for testing. Success rates of drug discovery, prediction of prescription costs and forecasting of sales data are also not very precise and sophisticated. The bioprospecting activities of many pharmaceutical firms in the US have already exhausted the possibility of useful search by 1980. The same success rate cannot be extrapolated for the period beyond 1980. At the same time, other parts of the plants like roots, stems, leaves can also provide the source of phytochemicals needed for a screening of the compounds. This fact may offset the higher side of the success rate presumed by FS. Further, FS ignore the cost aspect of R&D in the drug discovery process. They do not take into account marketing costs

Table 3. Endemic species densities and bioprospecting values in several ecosystems[18]

	Marginal (incremental) value ($/ha)	
Biodiversity hotspots	Simpson *et al.*[18]	Rausser and Small[20]
Western Ecuador	20.63	9177
Southwestern Sri Lanka	16.84	7463
New Calendonia	12.43	5473
Madagascar	6.86	2961
Western Ghats of India	4.77	2026
Philippines	4.66	1973
Atlantic Coast Brazil	4.42	1867
Uplands of Western Amazonia	2.59	1043
Tanzania	2.07	811
Cape Floristic Province of South Africa	1.66	632
Peninsular Malasia	1.47	539
Southwestern Australia	1.22	435
Ivory Coast	1.14	394
Northern Borneo	0.99	332
Eastern Himalayas	0.98	332
Colombian Choco	0.75	231
Central Chile	0.74	231
California floristic province	0.2	0

and other payments, their estimate therefore is the gross value.

As in the case of the FSs estimation, Principe's estimation also suffers from facts based on crude approximation and guess estimation, where the costs involved in drug discovery remain unaccounted, but Principe's valuation scores over FS in a sense that he tries to improve the sales figure of prescription drugs based on community pharmacy and then he employs the inter-temporal element into the estimate and calculates the NPV of medicinal plants in the US. Principe is not oblivious to the fact that his estimation is far from perfect. He admits that, 'It should be noted that the development of these estimates is not intended to produce exact numerical values for substitution into benefit–cost equations. Rather this is an attempt to estimate broad indicators of the order of the magnitude of these benefits.'

Aylward improved upon the earlier studies on valuation by considering the cost component in the picture and brings the whole analysis closer to reality and within the ambit of acceptability. At the same time many of his calculations and modus operandi can always be questioned. For example, the cost of taxonomic information, net royalties, etc. do not seem convincing. Pearce and Purushothaman[17] also do not go beyond the flaws of earlier studies as far as the assumptions about different parameters are concerned. However, possibly for the first time they recognize the institutional set-up in the estimation and consider 5% as the rate of royalty. But this figure at the same time impairs their estimate because in a large number of cases of contract for bioprospecting, this rate remains secret and is not determined on sound calculation and logic but political power and other non-economic factors which influence the bargaining strength of the concerned parties.

With numerical examples using data on 18 ecologically distinctive ecosystems (the biological 'hotspots')[24,25] Simpson *et al.*[18] demonstrated that the value of an additional unit of land in these ecosystems is modest even under optimistic assumptions on the profitability of discoveries. It implies that bioprospecting alone does not provide private pharmaceutical companies with sufficient incentives for habitat conservation.

Their result suggests that the bioprospecting information rents shall be large enough to affect land use decisions. For example, the bioprospecting value of a land area (1000 m^2) in Western Ecuador (which is on the top of the list of the hotspots) was, for instance, calculated as $ 20 by Simpson *et al.*[18] and $ 9177 by Rausser and Small[20]. As Rausser and Small emphasize, they agree with Simpson *et al.* that the value of marginal species would be vanishingly small. However, taking into account the prior information on the success probability of the species, the value of the most promising ones may be high enough to enhance market-based preservation of biodiversity.

Conclusions

Studies on valuation of medicinal plants have progressed significantly in the last one and a half decades. In all the valuation studies, the area and locations are different, so are the success rates (hit rate) of finding a useful drug and this makes the comparison of the value somewhat difficult. Most of the dataset have been taken from the US pharmaceutical industry; the source of phytochemicals has been found in the flowering plants alone, these do not give a comprehensive view of the whole scenario. Many developing countries like China, India, Brazil and Argentina have well-developed pharmaceutical R&D capabilities and they have a different cost structures.

Economic valuation of medicinal plants has proved to be one of the major economic benefits of bio-diversity. This in no way reduces the significance of other benefits of bio-diversity, for example, functioning and dependence of various ecosystems. By and large all studies are discussing the medicinal plants derived from the forest ecosystem. Medicinal plants of other ecosystems like marine ecosystem and animal species have not been considered. Increasingly, it has been felt that marine ecosystems are a rich source of medicinal plants for miracle drugs. In spite of these meaningful works, the specific policy relevance of these studies is limited. In most cases, the ecosystem or other ecological functions of these medicinal plants are unaccounted for, making the valuation a partial one, which may not withstand the benefits of other land uses. Even the most refined studies by Simpson *et al.*, and Rausser and Small have limited policy relevance because they are silent on the market structure of biotic samples for prospecting. They presume that they are easily and readily available to the firm. This is a serious lacuna in the studies. In all likelihood, the market for the biotic samples could be monopolistic in nature coupled with local ethnographic and sociological features. Further, greater awareness among the bio-diversity-rich countries regarding the issues of patent and ownership has not been brought into the picture. The issue has become important in the light of the convention on biodiversity. Exclusive right and access to the genetic resources of the local government have implications for both models of Simpson *et al.* and Rausser and Small, because sovereignty of the local government increases the transaction cost of negotiation for supply of quality samples. In many cases, the negotiation needs the approval of some agency in the host country creating a situation of quasi-monopoly[26].

In a nutshell, studies on medicinal plants valuation signify its economic importance and biodiversity. A local or area-based study taking into account its features of species and genera and its ecological function should be the preferred approach. For example in India, instead of a thumb rule study for the entire country, valuation of species in a particular landscape or habitat like Western

Ghats or North-East Himalayas give better insights. This will help provide a meaningful direction to the policy makers for efficient land use planning. Going by the medicinal value alone, a bio-diversity-rich area can be argued for preservation or otherwise. Valuation studies will need more refined ecological data such as detailed taxonomic information on plants and animals and R&D information such as real costs and transfer pricing data that can enhance the quality of the estimate and make the policy recommendations more convincing and meaningful.

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