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Bird migrations and the international economics of species conservation†

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The conservation economics of protecting bird species which migrate across national boundaries is examined. A case for adopting a global view of the implications of national conservation efforts and for negotiating efficient international conservation agreements is emphasised. The roles of cost constraints, strategic policy substitutabilities/complementarities, policy reactivity and alternative conservation objectives are analysed.

1. Introduction

This article analyses the conservation economics of international bird migrations. The objective is to present national conservation tasks in a strategic setting where policy interactions between nations help determine conservation outcomes. Understanding these interactions can lead to the design of more effective, national conservation policies.

Many resource economists are unaware of the conservation issues arising with species migration. A second section therefore provides background information on migratory birds, the international migratory species agreements that Australia is signatory to and some examples of bird migrations. This provides context for subsequent discussion. A third section examines the policy design problem. Individual countries are assumed to have specific national preferences for migratory bird conservation although conservation outcomes depend upon the joint conservation efforts by different nations along a migration corridor. There are two aspects to this jointness. First, there are strategic substitutabilities and complementarities between the effects of

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different national conservation efforts which influence the marginal effectiveness of the different national policies. An intensified conservation effort in one country can improve or reduce the marginal effectiveness of conservation efforts elsewhere. Related to this, policy selection in one country may be influenced by policy selection elsewhere. If policy efforts tend to be intensified in one country when they are intensified elsewhere, we say policy efforts across these countries are symmetric. For a broad class of national policy objectives there are links between complementarities in policy effects and symmetries of policy reactions.

In this article policy design is considered for one country (Australia) first, from a local viewpoint, when conservation effort is restricted to activity in Australia, and then, from a global viewpoint, when Australian efforts can be directed across an entire migration corridor. Finally, the role of global cooperative agreements is discussed. Local direct cost-benefit rules are used as a reference point for characterising policy, and circumstances where such local rules do not hold are emphasised.

A fourth section considers the role of cost-constraints and non-extinction objectives in policy design. Although consideration of such issues does not have a particularly plausible theoretical rationale, they are important in practical policy design. The final section summarises and draws conclusions.

2. Background

Many animal species are migratory or non-sedentary. Animal migrations occur both within nation-states and, for some bird, fish, marine and non-marine mammal species, internationally.[1] Among the cetaceans (whales and dolphins) there are substantial migrations. Humpback Whales migrate an average of 2 500 km from polar waters to their tropical breeding grounds. Southern Right Whales do not migrate as far as Humpbacks. They migrate in the Southern Hemisphere from the boundaries of the cold Antarctic waters (the Antarctic Convergence Region) to the southern offshore regions

[1] The literature on the conservation economics of bird migrations is sparse: an early exception is Ciriacy-Wantrup (1968) who applied the term *fugitive resource* to (among other things) migratory waterfowl. He also analysed economic issues and the history of international conservation policy. A more recent literature is concerned with fisheries or marine mammal (whale, dolphin) harvesting under open access. For the most part, this deals with inefficiencies of harvesting and policies for reducing these inefficiencies: see e.g. Levhari and Mirman (1980). For migratory birds, property right issues are secondary to those of interdependence in policy effort even if there are well-defined property rights. Finally, recent literature optimises joint land use and conservation objectives for migratory species in forest areas where adjacency issues are concerns: see Hof and Bevers (1998). This is less relevant for long-distance migrants where adjacency issues are of less concern.

of Australia, Africa and South America. Further, some animal migrations in Africa (for example, between Kenya and Tanzania) pose conservation problems analogous to those discussed here. We concentrate on international bird migrations here since these involve clear-cut issues of national sovereignty whereas marine mammal or fish migrations, for example, need not.

About 5 billion land birds of 187 species migrate from Europe and Asia for Africa each year and a similar number leave North America for Central and South America (Gill 1995). Smaller, although significant numbers of migratory birds come to Australia each year from the Northern Hemisphere and return there (Lane and Parish 1991). For example, an estimated 2 million shorebirds visit Australia annually. In terms of Northern Hemisphere seasons, these shorebirds have their wintering grounds in more southern countries and their summer breeding grounds in more northern countries.

Why bird migration arose in evolutionary terms is only a partially solved ornithological issue. Specifically, how sedentary species became migratory is not fully understood. We know that migration occurs to exploit seasonal feeding opportunities linked to favourable climates throughout the year, but how this lifestyle evolved is subject to speculation.[2]

Migration itself is risky to the birds undertaking it. In the Northern Hemisphere more than half of the small land birds never return from their southbound migration (Gill 1995). Migration patterns can also be complex. Birds can lose or acquire migratory habits as food supply circumstances change. They can also undertake opportunistic migrations or irregular movements when conditions suit with unfavourable 'push' or attractive 'pull' factors motivating migration. Local irruptions of bird populations may be caused by fluctuating food supplies. Birds, particularly ocean seabirds, can undertake loop migrations that take advantage of prevailing winds or other climatic conditions. Sometimes only male members of a bird species migrate with females being sedentary. Furthermore, birds of a given species can migrate very different distances from each other and to different destinations: some may migrate while others do not. However, global migratory shorebirds, an important class of migrants, often 'show a high degree of site and route fidelity, returning to their breeding or wintering sites year after year. More surprisingly, they often show a remarkable return rate to the vital "stepping stone" wetlands on the migration route: many birds will return to

[2] Migrations are related to food availability. One theory of how birds became aware of the existence of such disjoint food supplies is related to learning they experienced during the last two Ice Ages. Then birds were forced to live in a band of lands on either side of the equator. As the earth warmed, these regions expanded as did the distances birds had to travel to feed (Attenborough 1998, p. 69; Elphick 1995, p. 10).

the same area of the same beach or estuary each year on migration' (Haymen, Marchant and Prater 1995, p. 30).

Some birds migrate vast distances. Arctic Terns, for example, make return trips annually of over 25 000 kms, from the far North Atlantic to the waters of Antarctica. While Arctic Terns feed as they travel, migratory wader birds accumulate stores of fat before they travel which determines their flight range. Birds such as the Great Knot, the Red Knot and the Bar-tailed Godwit are known to have non-stop flight ranges between North-Western Australia and China of up to 5 500 km. These same birds may have non-stop flight ranges of up to 8 000 km from South-Eastern Australia (Barter and Wang 1990).

Bird migrations pose particular conservation problems. Habitat needs preservation at both wintering and breeding grounds and, in some cases, at stopover sites along migration corridors. With the site and route fidelity shown by migratory shorebirds, there is a peculiar sensitivity to human persecution by hunting.[3] There are also opportunities to conserve such species at relatively low cost by preserving these crucial wetland habitats. However, since the birds pass through areas where people have different attitudes to nature, perhaps because economic development has reached different stages, preferences for conservation may differ.

2.1 Migration to Australia

There is considerable ornithological interest in that class of birds migrating to Australia which breeds in far northern tundra regions of Siberia, Alaska and areas close to the Arctic Circle. The birds fly to and from Australia each year on the East Asian-Australasian Flyway. Along this route, and particularly at stopover sites, there has been extensive destruction of wetland habitat due to the massive economic restructuring of Asia and the hunting of birds for food. Consequently, the Asian-Australian migration segment is probably the world's most threatened bird migration corridor (Higgins and Davies 1996, p. 27).[4]

[3] Information on hunting waterbirds in Asia is summarised in Melville (1997). It may not be poverty or tradition that drives trapping efforts. Eric Jones suggests that trapping in Asia has increased since the 1980s perhaps because rising real incomes have enabled residents to buy protein in this form. With continued development, Jones conjectures that a modernisation threshold may be reached where hunting diminishes because conservationist sentiments arise and the value of trapping time becomes high.

[4] Other important flyways include those covered by the Western Hemisphere Shorebird Reserve Network which extends from the Canadian high Arctic to southern Argentina, and the flyway covered by the African-Eurasian Migratory Waterbird Agreement which extends over all Africa and Europe.

Australia is a signatory to the Ramsar Convention.[5] This was designed to protect wetlands but also involved recognition that certain waterfowl cross national frontiers and hence are an international resource. Australia is also a signatory to the multilateral Bonn Convention[6] that protects all migratory animals. The intent is to preserve endangered species and to persuade countries on migratory corridors to conserve and manage species for which international cooperation would be beneficial — so-called 'range species'. Australia is also a signatory to two bilateral agreements which protect migratory birds, namely, JAMBA (the Japan Australia Migratory Bird Agreement) and CAMBA (the China Australia Migratory Bird Agreement).[7]

There is no multilateral migratory waterbird conservation agreement in the Asia-Pacific area though public conservation agencies are working towards one. The Asia-Pacific Migratory Waterbird Conservation Strategy: 1996–2000 is an attempt by government agencies in Australia, Japan and Malaysia to provide an informal advisory framework that would mimic some of the effects of a formal agreement before the year 2000. This framework would promote research and awareness, improve monitoring, prioritise conservation effort, and promote information exchange. These efforts would include the East Asian-Australasian Flyway. Funding of this strategy has mainly come from the Environment Agency of Japan and Environment Australia.[8]

2.2 Examples of migratory birds

Many common Australian birds are migratory. Some are summer breeding migrants to Australia. They come from the near North each year during the Australian summer to breed. A substantial number of New Guinea's most common birds (for example, the Sacred Kingfisher and the Rainbow Bee-eater) are summer breeding migrants in Australia (Beehler, Pratt and Zimmerman 1989). The Cape Petrel is a winter non-breeding migrant that

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[5] The Ramsar Convention was formulated in Iran in 1971. For a history of early international conservation efforts see Ciriacy-Wantrup 1968, pp. 310–13.

[6] The Bonn Convention was formulated on 23 June 1979.

[7] JAMBA was signed on 6 February 1974 and CAMBA on 20 October 1986. JAMBA includes two annexes that list birds in danger of extinction in Australia and Japan. These agreements involve a commitment to preserve and enhance habitats, encourage joint research and information sharing, report regularly on progress and to develop initiatives and regulations prohibiting (or limiting) the destruction of such wildlife or its eggs.

[8] As of 1997 this network involved 19 sites in 8 countries. Protection of 200 critical wetland sites is sought from governments on the Asia-Australian corridor (Anonymous 1996; Watkins and Mundkur 1997).

moves south to Antarctica during summer and visits Australia during the winter. There are local migrants that migrate over short distances, usually breeding at higher altitudes in summer and moving to lower altitudes in winter — an example is the altitudinal migrant, the Flame Robin. There are trans-Bassian migrants (Swift and Orange-bellied Parrots) which cross Bass Strait each year. There are trans-Tasman migrants, such as the Double-banded Plover and the White-fronted Tern, that breed in New Zealand and migrate to Australia each year. A particularly important class of birds is the summer non-breeding migrants which breed north of Australia and come to Australia during the summer. There are also important summer breeding migrants. Examples of summer breeding and non-breeding migrants include:[9]

- Latham's Snipe. This mainly migrates between Japan and eastern Australia. The world population is around 37 000 birds with 15 000 arriving in Australia each year. It has been claimed that up to 10 000 per year were formerly killed by Australian hunters but the species is now protected.
- Red-necked Stint. This breeds in Alaska and north-eastern Siberia and migrates to Asia/Australasia. The population that visits Australia is about 353 000. This is a common wader: for a discussion of its migration see Minton (1996).
- Sharp-tailed Sandpiper. This breeds in north-eastern Siberia and then migrates to south-eastern Australia. The Australian population is about 166 000.
- Australian Pratincole. This breeds in Australia and migrates to New Guinea and nearby parts of Asia. The population visiting Australia is estimated at 60 000.
- Short-tailed Shearwater (Muttonbird). This breeds in vast numbers off the south-east Victorian coast (Lindsey 1986, p. 296, estimates its population at 20 million) and then follows prevailing winds on an annual 'loop migration' through north-eastern Asian waters to Alaskan waters. Then it migrates back through the central Pacific Ocean to Australia (Burton 1992, p. 33).[10]

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[9] Apart from the Short-tailed Shearwater, population and other data are from Higgins and Davies (1996). The kill figure for Latham's Snipe seems high. Some of this supposed 'kill' may be gunner's 'summer snipe' or what should be correctly identified as Short-tailed Sandpipers. I thank Eric Jones for this observation.

[10] Evidence for the precise form of this migration path (loop or figure 8) is elusive since short-tailed Shearwaters spend their entire time in the Northern hemisphere at sea. Recoveries of banded birds are at best equivocal about their flight path. I thank Tom Scotney for this observation.

These are only examples — the JAMBA and CAMBA agreements protect a total of 80 bird species that migrate between Australia, Japan and China.

3. Policy problem

Conservation efforts may be costly both in terms of the resources required to protect species and the commercial opportunities foregone due to conservation. While conserving wetlands for biodiversity preservation also helps sustain commercially important fish and shellfish feeding habitats, such conservation makes it impossible to drain wetlands to support commercially viable agriculture or fish-farming. At least, as has long been recognised, fauna authorities may need to regulate the design of water conservation and irrigation structures used in agriculture (Frith 1973, p. 372). Also, while specific national land use and fauna resource use laws are the major means by which migratory birds are conserved, an important factor determining the effectiveness of law is the information available about migrants. Where do birds migrate to, what are their staging areas and what is their current conservation status? Collection of such information is costly and is a form of conservation effort. Finally, residents who persecute migratory birds by hunting them may be persuaded to change their habits by the offering or fostering of new vocations or opportunities. Activities involving information provision, the restoration and protection of wetlands and the reorientation of economic activities are all costly conservation activities.[11]

Migratory birds need to be conserved at their breeding grounds (call this location A), their staging or stopover sites B and their wintering grounds C. To simplify the following analysis a single stopover site is assumed — it would not alter the argument to allow for distinct (and multiple) stopovers on south- or north-bound migrations. Nor would the argument change substantially if there were no stopover at all — as is the case for migrants to Australia from New Guinea. For specificity, take the wintering grounds C as Australia, the location where policy decisions are taken by the authority we focus on. The policy task is the optimal management of the species by cost-efficient conservation.

[11] Conservation efforts might also involve public education campaigns as argued by Ciriacy-Wantrup (1968, p. 305). National conservation agencies might direct such efforts locally and internationally.

A plausible public objective is national government optimisation[12] of conservation benefits (taken to be species population-dependent) less costs of conservation effort. This specification of objectives reflects our pure 'speciesist' perspective that what is important here is that human decision-makers enjoy welfare gains from knowing that birds survive: compare Singer (1977).[13] It might also reflect the intrinsic value that humans see stemming from the knowledge that birds survive but this seems observationally equivalent to the first viewpoint. We consider other objectives (for example, those placing high weight on non-extinction) later.

Suppose then the Australian objective is to maximise its welfare which depends positively on species survival S which, in turn, depends positively on conservation effort as described by the cost E_j of conservation effort at stage j of the migration ($j = a, b, c$ for countries A, B, C). Then it is natural to suppose, for country C, 'Australia', the conservation welfare function:

$$S = S(E_a, E_b, E_c) \tag{1}$$

where

$$S_a = \partial S/\partial E_a > 0, S_b = \partial S/\partial E_b > 0, S_c = \partial S/\partial E_c > 0,$$
$$S_{aa} = \partial^2 S/\partial E_a^2 < 0, S_{bb} = \partial^2 S/\partial E_b^2 < 0, S_{cc} = \partial^2 S/\partial E_c^2 < 0.$$

Here S is assumed increasing and strictly concave in its arguments. Increased spending on conservation increases species survival and conservation welfare but, plausibly, there are diminishing returns to effort for diminishing marginal utility reasons.[14] Further as:

[12] Note that conservation effort (particularly the provision of information) is provided by volunteer groups and private individuals as well as by national government agencies and agencies of other levels of government. Contributions are also made by hunting groups (such as Ducks Unlimited in the United States) who do much to improve habitat. The Australasian Wader Studies Group, associated with the private group Birds Australia, plays an important role in providing population and other information about wader species. As a specific example of the extent of private contributions note that the Recovery Program for the migratory Orange-bellied parrot has had officially-funded costs of less than \$90,000 annually since 1984 but that Starks (1997) estimates 'in kind' costs associated with the provision of volunteer labour and transport services at \$22,275 in 1995. This is one quarter of total costs. For tractability, the present study ignores volunteer efforts although it recognises their importance.

[13] 'Speciesism' (or 'homocentrism') is an animal liberationist term describing the prejudice humans have in favour of their own species. Here we use this term more generally to describe ethical values positing only instrumental reasons for conserving species. Such objectives here specifically include conservation.

[14] This is a simplification. For tourism, very large flocks of birds at Kakadu in Northern Australia have special appeal which suggests non-diminishing returns. In addition, rarity itself can create value: see Clarke (2000).

$$S_{xy} = \partial^2 S/\partial E_x \partial E_y < \text{(respectively} >) \; 0$$

we say conservation efforts in countries X and Y are strategic substitutes (respectively, structural complements).[15] Thus, if expenditures in country B increase (decrease) the marginal effectiveness of conservation efforts in country C, these expenditures are structural complements (substitutes).[16]

The direction of strategic effects is difficult to assess *a priori*. Efforts are substitutes if a reduction in one country's conservation effort boosts the marginal value of another country's effort. Efforts are complements if expenditures in (for example) country C become more effective as countries A or B become more conservationist. For example, birds breeding in Australia (C) which migrate from New Guinea (A) may be subject to hunting pressure in A. Reducing this hunting pressure at A increases numbers surviving at C but the marginal effectiveness of conservation efforts in C might *a priori* rise or fall. Marginal effectiveness rises in C if an extra dollar spent there now yields additional highly-valued offspring but policy effectiveness falls if the utility from increased numbers is sharply diminishing.

A determinant of whether marginal effectiveness rises or falls here is absolute population size. If population numbers are low, then the effects of diminishing utility in C from increased numbers due to reduced hunting pressure in A will be outweighed by the increased productivity of applying conservation effort in C to a larger population. If, however, population size is substantial, increased survivorship in A will lead to less utility gain in C so that costly conservation efforts there will be reduced. Thus, conservation efforts are likely to be strategic complements for rarer species and strategic substitutes for more common species. This means that concepts of strategic complementarity and substitutability are local, not global, characteristics of the conservation welfare function.

How should Australia (country C) design its conservation programs? First, suppose that C observes conservation efforts E_a, E_b in countries A and B. How much should C spend on conservation given its observations of policy elsewhere and its expectations of how other national policies might change

[15] The nomenclature here follows Bulow *et al.* (1985) who analyse a distinct oligopoly problem using similar nomenclature. See also Dixit (1986).

[16] Clem Tisdell observes that $S(.)$ can be interpreted as a social welfare function (SWF) of Bergson type. While traditional SWFs involve conflicts when income distribution or equity issues arise, the SWF here involves problems of assessing the conservation preferences of a human population. Weight is placed in our formulation on the preferences of conservationist individuals rather than those who see no value in conservation. Rather than dwelling on the interpretation of $S(.)$ we seek a plausible function here that rationalises active, though not unbounded, conservation effort. For a discussion of conservation ethics see Randall (1987, pp. 406–18).

once Australian policies are announced? We can ask this question both when C is restricted to make conservation efforts only within its borders and, when it can expend resources anywhere along the migration corridor. Finally, we can ask how much C should spend if it can enter into cooperative conservation agreements with other countries. These issues are considered in turn.

3.1 Local conservation efforts

A starting point is to suppose countries optimise conservation efforts individually (after perhaps accounting for policy reactions in other countries) and then make conservation efforts only locally. Then, if Australian authorities optimise by spending E_c only in Australia they maximise:

$$S(E_a, E_b, E_c) - E_c. \tag{2}$$

To analyse this task assume differentiability with respect to conservation expenditure choice and interiority. The former assumption allows us to take partial derivatives while the latter implies it is worthwhile to spend something on conservation. We relax the interiority assumption later. Then, given the strict concavity of $S(.)$ in E_c, equation 2 is maximised when:

$$S_c + R_{ac}S_a + R_{bc}S_b = 1 \tag{3}$$

where, for any two countries X and Y, $R_{xy} = \partial E_x/\partial E_y$ indicate the conservation expenditure reaction in country X given changed expenditure in country Y. $R_{xy} > 0$ (respectively $R_{xy} < 0$) if X increases (reduces) its expenditure when Y does. If $R_{xy} = 0$, countries X and Y are non-reactive. These various reactions are expectations (or conjectural variations) by country Y of how country X will react to changed conservation effort by Y. In equilibrium these expectations correspond to actual changes.

If countries A and B are non-reactive to increased expenditure in country C in the neighbourhood of C's optimum expenditure then:

$$R_{ac} = R_{bc} = 0 \tag{4}$$

so country C should simply expand its expenditures until a marginal dollar of expenditure yields one dollar's worth of conservation benefits. Thus:

$$S_c = 1 \tag{5}$$

This is a simple closed-economy cost-benefit rule requiring that local (direct) marginal benefits enjoyed in Australia be aligned with their associated marginal costs for optimality. If countries A and B are simultaneously optimising their own species-size-dependent objectives, then equation 5 defines country C's Nash equilibrium strategy.

In this case of non-reactivity by other governments to increased expenditure by country C, the effects on optimal expenditure by C of exogenous, additional expenditure by another country, for example of ∂A_a by country A, can readily be calculated. Supposing country B is non-reactive to country A (so $R_{ba} = 0$) optimal expenditure by Australia is altered by:

$$R_{ca} = -S_{ca}/S_{cc} \tag{6}$$

With S concave in E_c the expression R_{ca} has the sign of S_{ca}. Therefore, under these conditions, Australia (C) will increase (respectively decrease) expenditures on conservation as A's expenditures are strategic complements (respectively substitutes) for those of C.

More generally, conservation policy reactions will tend to be positive if, when one country experiences an increased desire to conserve and other countries are maximising a species-size-dependent welfare function of form (1), conservation efforts are strategic complements: see Appendix. If policy reactions are positive, so that each country expands conservation effort as others do, the effort equilibrium is symmetric. Thus if increased spending by another country increases the marginal effectiveness of Australian conservation efforts, then Australia will spend more. If policy reactions are substitutes, individual countries may see opportunities to free-ride on the conservation efforts of others and the equilibrium pattern of efforts is asymmetric. In general, conditions for asymmetry call for what we term simple forms of interdependence: see Appendix. Finally, as we shall discuss below, while countries have 'public good' incentives to formulate cooperative agreements, there are particular incentives, in the asymmetric case, to then cheat on such agreements by funding less effort than claimed. Therefore, a prisoner's dilemma then arises with associated problems of enforcing a sustainable, cooperative agreement.[17]

[17] Consider an example of two countries A, B each with 'low' and 'high' conservation effort options and the associated net payoff matrix:

(A's conservation payoff, B's payoff)		Country B	
		high	low
Country A	high	(4,4)	(1,5)
	low	(5,1)	(1,1)

Here when one country unilaterally moves from a low to a high conservation effort the marginal reward to the other country falls. Efforts here are therefore strategic substitutes. Hence the Nash equilibrium of this game (low effort, low effort) yields Pareto inefficient conservation utilities to the countries (1,1). This is a prisoner's dilemma since cooperation via a mutually binding agreement increases the conservation welfare in each country to 4. For further discussion see Dasgupta and Heal 1979, pp. 18–21.

Proposition 1: Taking a local view of the conservation task and assuming non-reactivity, Australian authorities should increase expenditure on species protection until the value of the marginal dollar's conservation expenditure is one dollar. If expenditures on this corridor are strategic complements in advancing Australian conservation objectives, this implies an Australian conservation bill that increases with conservation expenditures by other countries on a migratory corridor. If expenditures are strategic substitutes, and patterns of independence simple, countries may have a propensity to free-ride on the conservation efforts of others and there is potential for a Prisoner's Dilemma with respect to conservation effort.

Retaining the local view but allowing for policy reactivity, equation 3 can be written:

$$S_c = 1 - (R_{ac}S_a + R_{bc}S_b) \tag{3*}$$

By hypothesis $S_a > 0, S_b > 0$. Thus in a symmetric equilibrium where each country increases effort if others do because of complementarities, $R_{ac} > 0, R_{bc} > 0$, so, from equation 3*:

$$S_c < 1 \tag{7}$$

and so, commencing with initial observed expenditures E_a, E_b elsewhere, country C should be less demanding in terms of its conservation effectiveness requirements than it would be with non-reactivity. Applying the closed-economy cost-benefit rule is excessively stringent[18] when reactions are symmetric. Generally, the effectiveness of local conservation expenditures must be assessed both in terms of their direct effects in improving conservation outcomes and their indirect effects in inducing more conservation effort elsewhere. Equilibrium conservation effort by country C will be greater in a symmetric than in a non-reactive equilibrium.

If countries A, B behave asymmetrically and decrease their conservation efforts when country C increases its efforts (perhaps because they perceive substitutability between efforts and therefore seek to 'free ride'), then inequality 3* may be reversed. Country C may need to be more conservative in designing conservation programs than in the non-reactive case — local marginal benefits should exceed local marginal costs because local efforts have adverse impacts on conservation effort elsewhere. Sufficient conditions for this to be so are that simple forms of interdependence prevail. Thus, there are either no effects on C's actions on A or B (so S_{ac} or $S_{bc} = 0$) or no cross-effects S_{ab} or S_{ba} between A and B (see Appendix).

[18] This rule is also excessively stringent if uncertainty is involved in the cost benefit comparisons and decisions not to conserve are irreversible. The excess of cost over benefits at an optimal non-conservation rule is the quasi-option value (Arrow and Fisher 1974).

Proposition 2: Taking a local view of the conservation task, but assuming reactivity among national conservation policies, Australian authorities should expand protection beyond the level that is optimal with non-reactivity provided countries behave symmetrically in relation to their mutual conservation efforts. Symmetrical behaviour implies an Australian conservation bill that increases with increased conservation efforts by other countries on a migratory corridor. If countries behave non-symmetrically, then, with simple forms of interdependence, Australia should restrict conservation effort to a level below that with non-reactivity.

The assumption of interiority is maintained above. Without it, the policy task is trite. However, in some instances a lower boundary solution will be appropriate. If other countries expend so little effort that species survival is impossible, it may be appropriate for Australia to redirect or cease conservation effort — 'good money should not be thrown after bad'. Also, for those species for which conservation is secure through established laws and restrictions, it may be difficult to recover a dollar in benefits from an additional dollar spent and optimal conservation effort will again be zero.

3.2 A global view of the implications of local efforts

Here expenditures E_c by Australia are viewed as being potentially dedicated to areas at any phase of the species' migration. We retain, however, the view that national conservation decisions are taken by individual nations rather than as part of a cooperative international agreement. Implicit in the notion that funds can be dedicated to different areas is the notion that costs are fungible. Thus expenditure shifts from Australia to other countries reflect real resource shifts. Costs in Australia cannot merely reflect opportunity costs incurred in Australia due to conservation. Allowing a McDonald's store (or a shrimp farm) to set up operations on a pristine wetland reduces conservation effort at home but does not, in itself, release resources for overseas efforts. Apart from fungibility, suppose also that different national resources used for conservation in a country are perfect substitutes.[19] Therefore Australian dollars can be converted into Chinese yuan and used as effectively for conservation purposes in China as Chinese-supplied yuan. Then let $E_c = E_1 + E_2 + E_3$ denote expenditure at stages A, B and C respectively. Then the Australian policy authority's task is to select E_i to maximise:

[19] As discussed below, even ignoring the high costs of managing funds spent abroad, an Australian dollar spent there might merely displace a dollar that would have been spent by a local authority.

$$S(E_a + E_1, E_b + E_2, E_3) - E_1 - E_2 - E_3 \tag{8}$$

First-order necessary conditions for a maximum here require:

$$(1 + R_{a1})S_a + R_{b1}S_b = 1 \tag{9a}$$

$$R_{a2}S_a + (1 + R_{b2})S_b = 1 \tag{9b}$$

$$R_{a3}S_a + (1 + R_{b3})S_b + S_3 = 1 \tag{9c}$$

where, for any two countries X and K, R_{xk} refers to the marginal reaction by X to a marginal increase in spending by C in country K. For example, R_{a2} indicates how country A's conservation effort reacts to an increased conservation effort by country C in country B. Note that equations 9a–c are not independent since spending on conservation at A or B affects the marginal value of conservation spending at C and vice versa. If conservation efforts are non-reactive, so that foreign government conservation spending is not influenced by Australian government spending at home or abroad, then:

$$R_{a1} = R_{b1} = R_{a2} = R_{b2} = R_{a3} = R_{b3} = 0$$

and optimal Australian effort in each area is determined by a local cost-benefit rule:

$$S_a = 1, S_b = 1, S_3 = 1. \tag{10}$$

Again, these rules are interdependent because conservation outcomes in each area depend on efforts elsewhere. These rules shift the emphasis of individual national policy authorities from considering local conservation outcomes towards global outcomes. Note the optimality conditions for C's efforts in A and B must hold independently of local conservation effort levels in these latter countries. Thus if A and B are less conservationist than C but know C's objectives, they can minimise their own efforts (and even harvest populations!) leaving C to offset such actions with its foreign conservation efforts. Note also that this equilibrium can also be understood as the outcome achieved when countries have the same net benefits function $S(.)$ but where each country optimises only locally.

With international policy reactivity we have:

$$S_a = [1 - R_{b1}S_b]/(1 + R_{a1}) \tag{11a}$$

$$S_b = [1 - R_{a2}S_a]/(1 + R_{b1}) \tag{11b}$$

$$S_3 = 1 - [R_{a3}S_a + (1 + R_{b3})S_b] \tag{11c}$$

Thus:

$$S_a < (\text{respectively} >)\ 1 \text{ as } R_{b1}S_b + R_{a1} > (\text{respectively} <)\ 0 \tag{12a}$$

$$S_b < (\text{respectively} >)\ 1 \text{ as } R_{a2}S_a + R_{b1} > (\text{respectively} <)\ 0 \tag{12b}$$

$$S_3 < (\text{respectively} >)\ 1 \text{ as } R_{a3}S_a + (1 + R_{b3})S_b > (\text{respectively} <)\ 0 \tag{12c}$$

Conditions in equations 12a–c show that local cost-benefit rules should be relaxed or tightened depending on whether Australian conservation spending induces additional or less conservation spending elsewhere. For example, in equation 12a, if both R_{b1} and R_{a1} are positive, increased spending by country C in country A induces higher conservation spending by local governments in countries A and B. Therefore in designing its conservation effort in country A, country C does not need to drive the direct marginal benefits to the level of its marginal costs there — country C's efforts will in themselves induce greater local efforts. Note that if Australian efforts simply displace local efforts so $R_{a1} = -1$ and $R_{b1} = -1$, equations 9a–c imply:

$$R_{b1}S_b = 1 \text{ and } R_{a2}S_a = 1 \tag{13}$$

so that the only possible rationale for spending abroad is the limited one of attempting to induce conservationist reactions in third countries. To summarise:

Proposition 3: Taking a more global view and assuming non-reactive national conservation policies, optimal Australian conservation efforts involve expenditures by Australian authorities at each point in the migration corridor in accord with local cost-benefit rules. Taking a global view with policy reactivity suggests a relaxation or tightening of such rules depending on whether Australian conservation spending induces additional or less conservation spending by other national governments. In the particular case where local spending simply displaces foreign spending the only limited rationale for Australian contributions arises if such spending induces conservationist reactions outside the nation where the resources are directed.

Two further propositions are straightforward consequences of this.

Proposition 4: Taking a global viewpoint always yields not less welfare to Australia than taking a local viewpoint, provided other nations do not simply offset increased Australian foreign effort by proportionately reducing their own national efforts.

Proof: Optimising with respect to E_3 yields equation 3 which ensures the level of net welfare given by a pure local view. Then choosing E_1 and E_2 to optimally meet Australian conservation objectives cannot yield less additional welfare unless the foreign country offsets the impact of increased

Australian effort with less of its own. Provided expenditures are positive, which is the case with less-than-perfect asymmetry, there is strictly higher Australian welfare. A nation can never be worse off by expanding its conservation effort horizon to include the prospect of funding high productivity conservation effort externally.

Proposition 5: If countries A and B spend less on conservation than would be spent by a centralised authority optimising Australian welfare, it is optimal for Australia to spend non-zero amounts in countries A and B for conservation provided policy reactions are not perfectly asymmetric.

Proof: This is an implication of $\partial S/\partial E_k - 1 > 0$ for $k = a, b$.

This last result is simple but worth stressing. Asian and former Soviet bloc countries have a lower preference for protecting migratory bird species than Australia. The Vietnamese and Chinese people often see migratory bird species mainly as food. They may also see drained wetlands as providing more efficient food supplies than the harvesting of migratory waders. Thus, these nations will underspend on conservation from an Australian viewpoint. If Australian-funded conservation efforts can be effective in these countries they should therefore be undertaken. Australia should generally adopt a global view with respect to migratory bird conservation unless efforts are offset by reduced efforts outside Australia.

3.3 Global cooperative agreements

We have examined the implications of individual nations optimising their conservation efforts either in their own country or anywhere along a migratory corridor. We have identified welfare gains to individual countries in expanding their range of conservation options across an entire migration corridor. However, even in this latter case we have supposed that nations optimise policy settings independently. A further issue is that of deriving an efficient cooperative agreement among nations involved along a corridor. This is of practical importance on the East-Asian Australasian Flyway because, as discussed, there have been attempts to derive an agreement on this corridor. This can potentially generate further welfare gains to countries with conservation concerns.

In pursuing Pareto-efficient global conservation agreements it is inadequate for individual countries to independently optimise their conservation utilities. Such programs, as shown, involve equating marginal conservation benefits in each country (perhaps calculated after accounting for policy reactions elsewhere) with marginal conservation costs in that country. From the viewpoint of global efficiency, however, this neglects the consumption benefits accruing to other countries from such conservation effort. These consumption benefits should be included because of the non-rival nature of conservation outcomes — existence values derived from species conservation are, for example, entirely non-rival. In short, conserving migratory birds involves the provision of a non-rival (and non-excludable) global public good which will be underprovided if countries focus only on their own marginal conservation benefits: see any public economics text, for example, Laffont (1988, p. 33).

The determination of a global conservation agreement involves first equating the marginal cost of conservation effort across countries. It makes no sense, from an efficiency viewpoint, to make conservation efforts in areas with high conservation cost (or low productivity) when areas with higher conservation returns exist. To determine globally optimal conservation efforts the common marginal conservation cost across countries should then be equated to the sum of the marginal benefits accruing to all the countries in accord with public goods theory.

This determines a globally efficient conservation program. Provided conservation efforts can be directed anywhere along a corridor it remains to specify how such a program will be funded. Adopting a 'benefits approach', the obvious funding mechanism is to split the funding bill in proportion to the net marginal benefits enjoyed from conservation in each country. Then 'strongly conservationist countries' (those enjoying high marginal benefits), should supplement efforts by those less conservationist by at least partly funding programs in the latter countries. It is generally inappropriate to try to offset deficiencies in other conservation programs purely by spending more at home. If highly conservationist countries offset low levels of effort elsewhere, then, with the objectives so far specified, an impact of divergent conservation preferences will be distributional. The financial cost of conservation will be borne mainly by those who value conservation most.

The 'public good' inefficiencies here are intrinsic to negotiating international wildlife protection (or indeed greenhouse gas emission[20]) arrangements. They occur even without disagreement on the intrinsic desirability of conservation and even if conservation can be directed anywhere along a corridor. Determining efficient international approaches to conserving wildlife that migrates across national boundaries is analogous to the task of determining efficient public good provisions in a closed economy where individuals (rather than nations) have different preferences. A coordinated agreement is necessary to ensure efficiency.

[20] Hoel and Schneider (1997) utilise this approach.

An interesting instance of designing an efficient global agreement arises if those living in migration staging areas see little value in conserving migratory birds. It has been suggested that those living in the Asian countries, which provide the main staging areas for many species, place relatively low priority on conservation and more on directly improving material living standards. Developed countries, like Australia and Japan, already enjoy high living standards and are more 'conservationist'. The Asian staging areas, however, may provide high returns on conservation effort because population pressures and rapidly expanding economies in the Asian area are threatening most of the wetland habitats there which serve as stopover sites. These relatively higher returns are even more plausible if conservation efforts in countries like Australia already ensure good survival prospects for birds and if there are few threats to birds during their breeding season in sparsely populated, northern regions.

Then the main national benefits included in the computation of an efficient conservation program are those relevant to high income countries such as Australia and Japan. The main conservation needs, however, lie outside the national boundaries of these two nations. Thus, the relevant optimal conservation rule is of the form in equation 10. Applying a 'benefits approach' suggests that most funding of such programs should come from high income countries and be directed toward low income countries. There is, in this instance, an efficiency argument for foreign aid directed to conservation in developing countries which reflects conservation concerns of developed countries: these ideas are set out further in Clarke (1999).

4. Other objectives: cost constraints and extinction issues

In the analysis above, conservation expenditure is determined by the effectiveness of conservation efforts relative to cost. A narrower approach is to allocate a fixed budget K to the protection agency in C and then to instruct it to optimise conservation efforts subject to this budget. In addition, because conservation efforts are directed toward *many* competing species, these efforts may be prioritised toward actions which prevent species extinction rather than building up numbers. A prioritisation plan for conserving Australian avifauna, based on extinction risks, is provided in Garnett (1992, pp. 222–30). While cost and extinction issues are related, we treat them separately for convenience.

4.1 Cost constraints

Suppose Australia takes a local view and maximises $S(E_a, E_b, E_C) - E_C$ subject to the cost constraint $E_c \leq K$. If this cost constraint does not bind, the solutions described in Propositions 1 and 2 obtain as before. If the constraint binds, then it determines optimal aggregate expenditure in a local setting.

Taking a global viewpoint so independent optimisation of conservation effort can occur anywhere along a corridor, the same analysis applies to aggregate spending, but there remains the issue of allocating this aggregate expenditure across the three conservation areas. The conservation task posed then is to select $E_i(i = 1, 2, 3)$ to maximise $S(E_a + E_1, E_b + E_2, E_3)$ subject to $E_1 + E_2 + E_3 = K$. The first-order necessary conditions for optimality are:

$$S_a + K_a = S_b + K_b = S_3 + K_3 \tag{14a}$$

where

$$K_i = R_{ai}S_a + R_{bi}S_b \tag{14b}$$

and where

$$E_1 + E_2 + E_3 = 1 \tag{14c}$$

There are several possibilities here. If policies are non-reactive then $K_i = 0$ and optimality requires $S_a = S_b = S_c$ with $E_1 + E_2 + E_3 = 1$. Conservation effort should be allocated across regions to equalise their marginal direct contributions to Australian conservation welfare. This will yield less conservation welfare than unconstrained welfare maximisation because the marginal benefits of conservation will now exceed marginal costs. If conservation rewards are low enough in certain areas this could result in a specialised allocation of expenditure outside or inside Australia. For example, if $\partial S/\partial E_1 \geq \partial S/\partial E_2|_{C2=0} \geq \partial S/\partial E_3|_{C3=0}$ for all $E_1 \leq K$, then conservation expenditure should be allocated to A in amount K with nothing spent in B or C.

With policy reactivity, a similar analysis applies. Equation 14a requires equating direct and indirect benefits of policies across locations. This can again potentially yield a specialised allocation. However, a specialised allocation is by no means inevitable. If low levels of spending are productive enough in each location so, that for example,

$$\lim_{c_k \to 0} \frac{\partial S}{\partial E_k} = \infty$$

for all k, then spending will always be non-specialised.

Proposition 6: A binding budget constraint on Australian conservation expenditures does not complicate a local view of migratory bird conservation though it may complicate a more global view. If cost constraints bind, then optimal marginal conservation benefits will exceed marginal conservation costs. In the latter setting, both in reactive and non-reactive policy environments, there may arise a particular case for a specialised allocation of all conservation effort either in or outside Australia.

4.2 Extinction

Australian politicians may not experience substantial welfare gains from knowing that 350 000 rather than 150 000 Red-necked Stints successfully arrive in Australia each summer. They might be more moved to promote conservation if they know that species extinction is a possibility without preventative action. This is the case for birds such as the migratory Orange-bellied parrot which is ranked by Garnett (1992, p. 223) as the eleventh most important bird conservation priority in Australia (see also Clarke 2000). For such species it makes sense to focus on avoiding extinction. In addition, the JAMBA agreement places particular emphasis on the case for conserving threatened species. Ecologists might adopt non-extinction perspectives if populations get low and the general conservation situation becomes desperate enough.[21]

Suppose that on phase j ($j = A$, B or C) of a migratory corridor, species survival levels depend on the population on arrival and on the amount spent on conservation during this phase. Then, in a country like Australia where there is extensive species protection, additional amounts spent ensuring survival may have low impact. It may be best to spend it at other bird migration phases if achieving survival is the objective. If, for political or other reasons, this is impossible, then two extreme situations may occur. The species may be destined for extinction at some other migratory phase because of failure to conserve it in that phase. Then, if achieving survival is the policy objective, it may be rational to abandon conservation efforts elsewhere. Spending on conservation may not ensure long-term viability of the species and it may be more efficient to switch conservation efforts to other species which are not doomed to extinction. On the other hand, low survival rates across a particular phase may be compensated for by increasing conservation efforts at other phases (not necessarily at home).

Proposition 7: Given a non-extinction objective by Australian conservation authorities, it may be optimal to specialise the application of all conservation

[21] There is not strong evidence of extinction (or even of population decline) threats for the migratory waders which regularly visit Australia. This might reflect species resilience to the destruction of Asian wetlands or problems of measuring species abundance. Bibby *et al.* (1992, pp. 147–50) discuss estimation of wader population sizes. Collar *et al.* (1994) provide a global survey of threatened bird species.

expenditures in countries outside Australia. Immutably poor conservation efforts in one centre may be offset by increased conservation efforts elsewhere but this situation might also lead optimally to the abandonment of all conservation effort.

As noted, the type of specialisation observed here can also occur when pursuing species-level-related objectives. However, this type of specialisation is likely to be particularly relevant for extinction issues if poor conservation practices in a particular country are damaging survival outcomes across an entire migration corridor.

5. Conclusion

The international conservation economics of migratory bird species have been examined. This is a substantial conservation issue on the East Asian-Australian Flyway, particularly because of threats at stopover sites in Asia during migrations.

Conservation objectives are defined in terms of a welfare function on species numbers. These numbers are in turn determined by conservation efforts. The objective then is maximisation of welfare less conservation costs. Local views of the conservation task are then compared with more global views and the role of international strategic substitutability and complementarity in policy, as well as symmetries or asymmetries in policy reactions, accounted for. International links between conservation efforts depend on how the marginal value of policy action in one country is influenced by increased effort elsewhere. The circumstances under which very simple local cost-benefit rules can be relied on to optimally specify policy are shown to be restrictive. Ideal approaches to conservation require international agreements and resource transfers from developed 'conservationist' countries to 'developing' less conservationist countries.

Some difficulties of formulating cooperative international agreements are highlighted. Extinction issues and cost constraints are likely to be the immediate concerns of conservation bureaucrats and their consideration yields policies that are related to the more theoretically satisfactory objective of net benefit maximisation.

Conservation policy toward migratory birds emphasises the international cooperation required for good conservation outcomes. This article draws attention to two difficulties in achieving such cooperation. First, such agreements involve implicit weights reflecting various national conservationist preferences. Then countries with strong conservation preferences, such as Australia, need to account globally for the effectiveness of international programs in advancing these objectives. International agreements with countries having low interest in conserving wildlife may need, on efficiency grounds, to be supplemented by foreign aid to promote conservation. In addition, international agreements are subject to free-rider and prisoner's dilemma difficulties, particularly if conservation policy efforts are strategic substitutes. This theme can be developed further and is the subject of further work.

Appendix

If a country seeks more intensively to conserve and other countries maximise welfare functions of form (1) then: (i) If all countries are strategic complements, then all countries will also experience increased incentives to conserve; (ii) If all countries are strategic substitutes, then other countries may face increased or reduced conservation incentives: sufficient conditions for reduced conservation incentives are that increased conservation in the initial country only directly affects another country without indirect effects via conservation reactions of other countries.

Proof: For three countries A, B, C denote the respective maximands $S^1(E_a, E_b, E_c)\ (1+\varepsilon) - E_1$, $S^2(E_a, E_b, E_c) - E_2$ and $S^3(E_a, E_b, E_c) - E_3$. Here $\varepsilon > 0$ parametrises a multiplicative increase in preference by A for conservation. The respective FONCs are $S^1_a(1+\varepsilon) = 1$, $S^2_b = 1$, $S^3_c = 1$. These three equations determine E_a, E_b and E_c given ε. Moreover, the Jacobian J of this system is negative if we assume that the 'own' second partial derivatives are much larger in absolute value than the 'cross' second-partial derivatives. Then the effect of increased conservationist preference in A on conservation in C is:

$$\frac{\partial E_c}{\partial \varepsilon} = \frac{1}{J}\begin{vmatrix} S^1_{aa} & S^1_{ab} & -S^1_a \\ S^2_{ba} & S^2_{bb} & 0 \\ S^3_{ca} & S^3_{cb} & 0 \end{vmatrix} = \frac{(S^3_{ca}S^2_{bb} - S^2_{ba}S^2_{cb})S^1_a}{J} \tag{a1}$$

which is positive if $S_{xy} > 0$ for countries $X \neq Y$ (all countries' strategic complements) and $S^2_{bb} < 0$ (by concavity). If $S_{xy} \leq 0$ then the numerator of this expression has indeterminate sign. It is non-positive (so $\partial Ec/\partial\varepsilon \leq 0$) if either:

$$S^2_{cb} = 0, \quad \text{or} \quad S^2_{ba} = 0 \tag{a2}$$

so the effects of the strengthened conservation motives in country A impact on country C only directly. QED.

Condition (a2) describes what we refer to in the text as simple forms of interdependence of country A's policies on country C. All indirect effects on country C via country B are zero either because the change in C's preferences have no impact on country B and/or, if they do have an impact on B, because B's conservation preferences have no effect on C.

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