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Land, environment and climate

Contributing to the global public good

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Abstract

This paper discusses global public goods related to the world's land resources, their current provision and likely future provision, their potential impacts on the world's poorest households, as well as prospects for using foreign assistance to enhance these outcomes. Specifically, the paper discusses: carbon sequestration, the provision of biodiversity and ecosystem services, water management, and investments in research, policies, and institutions to facilitate adaptation to climate change. Within this context, access to geospatial analysis tools and information on climate, land use and tenure, poverty and environmental indicators will become increasingly valuable to both public and private decision makers.

Keywords: public goods, global land use, carbon sequestration, environmental services, poverty, geospatial data

JEL classification: Q15, Q24, Q28, Q56

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1 Introduction and historical perspective[1]

Land is arguably the world's most important natural resource. It provides a host of public and private goods. And humankind has played a large role in shaping its evolution over the millennia. Ramankutty et al. (2006) point out that people have been involved in inducing land cover change since the beginning of human history. Foley et al. (2005) note that most societies follow a common sequence of land use regimes, beginning with largely natural ecosystems, followed by frontier clearings for subsistence agriculture and small-scale farms, which in turn gives way to intensive agriculture, the development of urban areas, and the advent of protected lands devoted to recreational activities and biodiversity. The world's present day land cover is clearly at many different points along this continuum, although the portion of the globe devoted to intensive agriculture, managed forestry, protected lands and urban areas has clearly been growing with time. Today, about one-third of the world's land cover is devoted to agriculture, one-third to forests and one-fifth to savannas, grasslands and shrublands; the remainder is either barren or low productivity land, with urban areas comprising about one per cent of the world's land cover (Ramankutty 2010).

Focusing on crop land cover changes over the twentieth century, Ramankutty et al. (2002) document very different patterns of growth across the major regions of the world. In Europe, cropland cover actually declined over this century, and the cropland increases in the US, East Asia and tropical Africa were relatively modest. However, cropland cover expanded dramatically over the twentieth century in Latin America, Canada, Australia and Southeast Asia. These authors also plot national population against total hectares of cropland in 1900 and observe that areas with high populations also had larger total cropland areas, with the global average cropland area equalling 0.76 ha/capita. Indeed, in 1900, most regions of the world fell quite close to this ray from the origin in their graph—suggesting a distribution of cropland which mirrored the distribution of population. By 1990, under the influence of greatly improved agricultural productivity, the slope of this line had declined by more than half, to just 0.35 ha/capita, and, while many regions fall along this new ray from the origin, some have begun to deviate more sharply from this relationship. Both Russia and the US showed much stronger than average cropland area growth, relative to population, and both China and South Asia experienced the reverse, with relatively more rapid population growth. These divergences from the (1990) 0.35 ha cropland/capita line were enabled in part by falling costs of international transport and declining trade barriers, both of which have facilitated increased international trade in food products. They also reflect the inherent responsiveness of innovation and yield growth to population pressure (Hayami and Ruttan 1985).

Over the final two decades of the twentieth century, land cover change accelerated to unprecedented levels. Lepers et al. (2005) document these trends and highlight deforestation 'hotspots'. Most of these hotspots are in the tropics, with the Amazon leading the way, followed by Southeast Asia, Central Africa and Central America. Russia, too, shows some deforestation hotspots in their analysis. These authors also conclude that the areas with the greatest amounts of degradation—often from multiple sources—arise in the Middle East and near Asia.

[1] Parts of this section draw heavily on my AAEA Presidential Address (Hertel 2011).

This degradation of existing crop land, when combined with the seemingly inexorable growth in demand for food, fibre, and fuel has led many observers to suggest that the world may run out of land. Malthus (1888) is perhaps the best known champion of this position. However, he is by no means alone. It seems that every decade or two, the specter of the world running out of land is raised. As recently as 1985, Buringh (1985) wrote in the *Philosophical Transactions of the Royal Society of London* that 'Recent studies show that on a global scale all land reserves will be lost within one century and reserves of highly productive land will be lost in twenty-five years'. Yet 28 years later we are far from this forecast. And again, today, there are numerous studies suggesting that the world's land resources may be hard-pressed to meet the needs of the 9 billion people expected to inhabit the earth in light of slowing yield growth and accelerating climate change, as well as growing demands for other land uses, including bioenergy feedstocks.

While the global area devoted to crops has changed only modestly in the past 50 years, the distribution of these croplands has changed much more dramatically (Ramankutty et al. 2008). And this in turn has had consequences for the associated ecosystem services available at local, regional, and global scales. Much of the cropland expansion during the past 50 years has been in the tropics (Ramankutty et al. 2002). At the same time, cropland has been retired in the US and Europe. There is evidence that the cropland expansion in the tropics has come at the expense of closed tropical forests (Gibbs et al. 2010). These areas are particularly rich in biodiversity as well as carbon (West et al. 2010) and so this expansion has been environmentally costly.

The question of global adequacy of land to meet the world's continuing growth in demand for food, fibre, fuel and ecosystem services has important implications for the world's poor. The bulk of the world's poor reside in rural areas, and many of these households still live 'off the land' in one way or another. Many are smallholder farmers. Others are employed in agriculture or forestry activities. And others still rely of hunting and gathering for a significant portion of their income and/or sustenance (Cavendish 2000). Efforts to increase the provision of land-based public goods will affect these households directly, when they are either displaced (e.g., by a nature preserve) or when they are paid for providing these services themselves (e.g., for carbon sequestration or forest conservation). There are also important indirect effects which arise when the overall availability of land is altered, thereby affecting food prices and rural employment opportunities. In a world in which one billion people still live on less than US$1/day, the implications of any such land-based activities becomes critically important.

This paper begins by reviewing the range of public goods that are tied to the world's land resources—focusing particularly on their role and importance in the context of a changing climate. A necessary first step in discussing the public goods and services tied to land is to define what is meant by 'public good'. I will follow—albeit loosely—the definition from public economics, which is based on two concepts: non-rivalry and non-excludability. Non-rivalry is important because this means that one person's consumption of the good or service does not diminish the value of this good to their neighbour. Clean air, a safe neighbourhood, a stable climate, all exhibit non-rivalry and suggest that, while the benefit to any single individual of providing the public good may be small, relative to its cost, from a collective point of view, considerable expense may be justified, since the entire population can benefit from the good or service's provision. However, if the service is also characterized by non-excludability, then it is unlikely that it will be supplied in sufficient quantity by the marketplace, since any individual household could opt out of contributing to its provision, even as they ‘free ride’ on the benefits of this public good. Hence the strong mandate for government intervention—and potentially foreign assistance—in the provision of such land-based public goods.

In addition to identifying the public goods and the extent to which they are currently provided (Table 1), I consider how this provision affects the poor. I then turn to a discussion of how the demand, supply, and overall provision of these public goods are likely to evolve over the twenty-first century. This provides a useful backdrop for the final section of the paper which offers a discussion of the implications for foreign assistance which might facilitate the increased provision of public goods deemed particularly important between now and the middle of this century.

2 Public goods related to land and climate change

2.1 Carbon sequestration: REDD+

Perhaps the most prominent land-based public good under discussion today is carbon sequestration. Appropriate management of the world’s soils and forests can contribute significantly to slowing the rate of CO_2 accumulation in the atmosphere. Reilly et al. (2012) simulate the case where there is perfect pricing of carbon associated with land use (soils as well as plants), in addition to pricing carbon from energy combustion. They estimate a net gain over the twenty-first century of 178 petagrams of carbon.[2] Golub et al. (2009) estimate that, in the near term, forest carbon sequestration could supply up to 50 per cent of the annual flow of globally efficient greenhouse gas (GHG) abatement. Sohngen (2010) estimates that inclusion of forest carbon sequestration in an optimal climate policy could cut the price of carbon by nearly half in 2100. Clearly there is much to be gained by providing incentives for individual decision makers to modify land cover and land use practices to accommodate additional carbon stocks in the soil and above ground biomass.

While this field is still in its infancy, there are a significant number of carbon sequestration initiatives underway presently, and the number is growing each year. Peters-Stanley et al. (2012) offer an annual snapshot of carbon sequestration projects achieving a total sample of 451 projects across multiple survey years. Voluntary projects dominate their survey, with lesser contributions from the Clean Development Mechanism and other compliance-driven contracts. REDD+ projects dominated transacted volumes in 2010, but were exceeded by afforestation/reforestation projects in 2011. Latin America shows the highest volume of contracts, followed by North America, with the volume of projects in Africa jumping by 150 per cent between 2010 and 2011. The authors find that the majority of these contracts are with private land owners—thereby confirming informal discussions with those working in this area who have observed a strong contracting preference for privately owned land. Given the excess supply of carbon contracts, relative to demand, purchasers gravitate toward the easier contracts—which tend to be with the privately held lands. The data on the price of individual contracts by land tenure type suggests that sequestration on collectively held lands is roughly twice as costly as on privately held lands (Peters-Stanley et al. 2012).[3]

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[2] A petagram is equal to 1.0E12 kilograms.

[3] A related question has to do with how land tenure interacts with land management in the absence of carbon payments. Chhatre and Agrawal (2009) attempt to provide a systematic analysis of the tradeoff between carbon storage and income/livelihood contributions in communally held forests which comprise 10 per cent of global

Unruh (2008) argues that, despite high biophysical potential, land tenure is a critical barrier to successful carbon sequestration policies, and that this poses a particular problem in Africa. He highlights the social, legal and economic disconnect between statutory land tenure which applies in theory, and the customary systems which are predominant in practice, but which are not recognized by formal laws. As a consequence governments often 'ignore customary tenure systems and regard such areas as part of the public domain, while at the same time lacking the capacity to enforce such a claim or resolve the problems that such a claim produces'. He goes on to assert that 'deriving functioning legal and financial institutions and increasing tenure security for small-scale producers is what international development has been attempting for decades, and the lesson is that the challenges to achieving these are immense' (Unruh 2008). This is hardly a rosy forecast for the future of carbon payments on the world's poorest continent.

Others are more optimistic about the potential for carbon sequestration contracts on communal lands. And the empirical evidence suggests that progress is being made in the establishment of carbon sequestration contracts on communally held lands. Peters-Stanley et al. (2012) report a strong increase in the number of contracts with collectively held lands from 2010 to 2011. Barbier and Tesfaw (2012) point out that sequestration may be an area where such contracting may work especially well in Africa, precisely because tree planting shows a sustained commitment to the land and is therefore one of the ways in which individuals can secure long-run use rights in the context of communally held land. The *TIST* project in Kenya has been successfully exploiting this feature of traditional tenure systems to implement contracts even in the absence of legal property rights.[4]

Another type of institutional innovation for dealing with collectively managed land is offered by the Juma Reserve in Brazil (*The Economist* 2009), wherein each household in this indigenous community in the Amazon forest receives a debit card. Once a month, the forest is monitored for evidence of disturbance. If the forest is not disturbed, then each household gets an additional payment on their debit card. In addition to lending an incentive for collective monitoring of the forest, this programme suggests the potential for poverty alleviation, as the funds go directly to households in a region where poverty is rife and the fixed payment will be most meaningful for the poorest households. However, as with most such projects, the situation is more complex than initially meets the eye. In a *PBS* special on the Juma Reserve, interviews with local residents highlight practical problems, including difficulty in converting the payment to usable cash and also monthly payments which are insufficient to compensate some households for forgone income (*Frontline World* 2010).

Overall, in reviewing this literature, one gets a sense that initially high expectations for REDD+ projects are being gradually eroded, as the demand-side is not forthcoming with contracts and distrust amongst participants increases. This point is echoed in Angelsen and McNeil (2012) who note that: 'the benefits that REDD+ will bring to the local level, where it directly affects people's livelihoods, are uncertain. At the one end of the wide range of

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forest cover. They gathered data on 80 forest commons in 10 countries across Asia, Latin America and Africa. These authors find that local communities restrict their consumption of forest products when they own the forest commons, thereby indirectly increasing carbon storage. On the other hand, where the forest commons and associated rulemaking are controlled by the central government, extraction of forest products is higher and carbon storage is consequently lower. They conclude that decentralization of forest management authority is beneficial for carbon sequestration (in the absence of an explicit carbon policy).

4 http://www.tist.org/i2/

possibilities is that local people will benefit … At the other end, a ‘worst case’ scenario, feared by some villagers and indigenous rights groups, is that, not only will they receive little or no payment, they will even lose their traditional rights to forest resources’.

Even when there are no carbon sequestration payments, or these payments do not reach the poor directly, they can have an impact on poverty indirectly, through higher food prices, impacts on rural wages and land values. One of the most important frontiers for tropical forest protection is found in Indonesia. There, deforestation for timber harvesting, as well as for establishment of oil palm plantations, in extremely carbon-rich regions of tropical forest placed Indonesia third behind the US and China on the list of top GHG emitters in the year 2000 (PEACE 2007). In 2010, Norway pledged US$1 billion to support a pilot carbon payment programme and implement a two-year moratorium on new oil palm and timber concessions in primary forests and peat lands. Busch et al. (2013) evaluate this programme against history, by asking the following question: ‘If this moratorium had been put in place in 2000, what volume of GHG emissions would have been avoided over the decade leading up to 2010?’. They place this estimate at 58MtCO_2e, or about 8 per cent of total emissions. This is a significant savings—particularly when compared to the other voluntary and compliance contracts initiated over this period (Peters-Stanley et al. 2012). However, as a result of forgone economic development in the wake of the moratorium, there is little doubt that palm oil prices are higher in 2010 and rural employment lower, than would have otherwise been the case. Both of these factors disadvantage the poor.

What would the effect of a sequestration policy be, if it were extended throughout the tropics—or even worldwide? Golub et al. (2012) have simulated the impact of a global forest carbon sequestration policy on land use and food prices within the current economic environment. They find that this environmental policy has a particularly strong impact on agricultural land use and land prices in the tropical, non-Annex I countries. And this translates through to higher food prices which adversely affect the poor. Hussein et al. (2013) delve more deeply into the distributional impacts of the same global forest carbon sequestration policy. They conclude that, since most of the benefits of this policy flow to landowners (either private or collective owners of the land), and since the poor generally control relatively little land (and when they do, it is often land of lower value), the predominant impact of a non-Annex I forest carbon sequestration policy on the poor would be through higher food prices. They find that this results in poverty increases in 11 of their 14 sample countries, with most of the impact being driven by the forest carbon sequestration in the tropics.

In addition to the REDD+ programmes, carbon sequestration payments also arise is in the context of broader, national-scale Payment for Environmental Services (PES) programmes, which have been successfully implemented in China, Costa Rica, Ecuador and Mexico, among other countries. Since PES programmes have been around for longer than REDD, they target a variety of public goods, and they tend to be implemented at a national scale, it is useful to treat this in a separate topic.

2.2 Payments for environmental services

PES programmes have targeted not only avoided deforestation, but they have also sought to preserve biodiversity, regulate the water cycle and alleviate poverty. Indeed, the global annual size of the market for biodiversity conservation has grown to nearly US$3 billion

(Madsen et al. 2010). There is now quite a large literature on PES programmes (Gong et al. 2013). One of the most successful examples recently documented is the ‘Socio Bosque’ programme in Ecuador. In addition to targeting biodiversity, water management and poverty, Socio Bosque also part of Ecuador’s REDD+ programme (de Koning et al. 2011). Two years after inception, this programme encompassed more than 500,000 hectares of natural ecosystems, with payments being made to more than 60,000 individuals (de Koning et al. 2011). The targeted areas were those which were: (a) close to roads and rivers (threat of deforestation); (b) important in water provision to lower catchments; (c) had a low percentage of protected natural areas (threat of loss of biodiversity); and (d) a high index of unmet basic needs (poverty).

While the theory of PES suggests that payments should vary over space and time according to the opportunity cost of the land in competing uses, this is often difficult to achieve in practice. In the case of Socio Bosque, data limitations and the desire for transparency dictated instead a simple ‘progressive’ structure in which the first 50 hectares enrolled receives US$30/hectares/year for the 20-year duration of the contract, the second 50 hectares (i.e. 51-100 hectares) receives US$20/hectares/year and so on. As a result, the bulk of the community payments (80 per cent), when expressed on a per household basis, are under US$500/year (de Koning et al. 2011). These community payments are used for investments that address basic needs, as well as for productive activities such as agriculture and community banking.

However, in order to enrol in Socio Bosque, a formal land title is needed, and this has precluded involvement by some poor households and communities who have not yet formalized their land ownership (de Koning et al. 2011). In addition, poor households are poor, in part due to their limited access to land, which in turn limits their potential participation in this land-based contracting arrangement. The difficulty in reaching the poorest households with PES programmes is also evident in the Mexican programme of Payment for Hydrological Environmental Services of Forests which was launched in 2003. Overall, that programme has been reported to reach ‘an important part of the poorest population, but that for reaching the poorest of the poor, special outreach is needed as this part of the population has less contact with government institutions’ (Muñoz-Piña et al. 2008).

Pagiola et al. (2005) evaluate the poverty impacts of payments for environmental services (PES) in Latin America. They conclude: ‘PES programs are not a magic bullet for poverty reduction, but there can be important synergies when program design is well thought out and local conditions are favorable’ (p. 248). Because such payments are tied to land, their distributional impacts are inherently tied to the distribution of land ownership in the target region. Since rural land ownership is highly correlated with income, this immediately biases the programmes towards the wealthier households. Also, transactions costs for the programme (e.g., contracting costs, management plans) are largely independent of farm size and therefore most onerous for small farms. These fixed costs also create an incentive for those administering the programme to work with larger entities—a classic adverse selection problem that reduces the poverty-reduction potential of PES. Of course, if smallholder farmers can organize themselves into co-operatives, some of these problems may be overcome. Pagiola et al. (2005) also highlight the importance of land tenure and credit constraints. In the frontier areas where deforestation is most active, land tenure is often insecure. When coupled with credit constraints, this makes it very difficult for low-income households to participate in such programmes.

In short, as with most programmes and opportunities, the cards are largely stacked against the poor with PES. In addition to the points mentioned above, including limited land-ownership, land tenure and high transactions costs, the poor typically live in more remote locations and therefore are harder to reach with government programmes and the associated transactions costs are higher. The one instance in which the poor may benefit is when (as in Socio Bosque) the payments are made without regard to opportunity cost, in which case one might expect greater participation from the poor at a given offer price (Wunder 2008). However, since this is generally lower quality, lower opportunity cost land, which may also be degraded, such a programme design is also likely to offer lower environmental benefits. This highlights, once again, the tradeoff between environmental efficiency and equity objectives in formulating PES programmes.

As with carbon contracts, PES programmes for biodiversity and other environmental services can have important indirect effects through the market place when undertaken large scale. Britz et al. (2013) explore the global environmental impacts of the EU biodiversity-targeted, agricultural set aside programme which is part of the recent proposal for a reformed Common Agricultural Policy. They estimate that implementation of such a programme would improve the environmental status of the high-yielding regions of the EU, by removing a significant amount of land from production. However, the resulting price increases are expected to trigger intensification of production in the more marginal areas of Europe, with attendant environmental side-effects. With higher world prices, the authors expect an additional 400,000 hectares of cropland conversion in the rest of the world, resulting in GHG emissions of about 20 tonnes CO_2e for every hectare of EU agricultural land set aside for biodiversity (Britz et al. 2013).

In their reviews of the challenges of implementing national PES systems in developing countries, Angelsen (2014) and Gong et al. (2013) highlight several issues. The first is the challenge of defining and measuring the service provided. Given the spatial heterogeneity of ecological systems throughout the tropics, accurate measurement of environmental services can be extremely costly—where do you draw the line? In this context it is interesting that the Socio Bosque programme opted for an extremely simple system (flat payments), as opposed to a more sophisticated one informed by geospatial data on land cover, carbon stocks and measures of ecological diversity. Angelsen (2013) also highlights the challenge of contract design in light of asymmetric information which gives rise to both moral hazard and adverse selection problems. More generally, Gong et al. (2013) highlight the high transactions costs of PES programmes and the need for institutional innovations which can lower these costs and encourage additional participation. Gong et al. (2013) conclude their review of PES programmes by noting that: 'The desire to simultaneously obtain a maximum level of environmental benefits, an increase in economic efficiency and a reduction in inequality is a laudable goal, but project developers must realize there are trade-offs, tough decisions have to be made'.

2.3 Adaptation to climate change

Impacts and the need for adaptation

Regardless of progress with carbon sequestration and other forms of GHG mitigation in the coming years, the dye is already cast for significant warming of the earth's surface between now and 2050. Between the biophysical momentum created by the accumulation of greenhouse gases (GHGs) in the earth's atmosphere, and the economic momentum stemming from the construction of coal-fired power plants, the rapidly growing stock of automobiles in China, India and other developing countries, and, more generally, the growing demands posed by 2 billion more consumers in the world, there is little doubt that climate change will accelerate. This will have important impacts on natural ecosystems as well as on commercial agriculture, forestry and fishing activities.

Impacts on non-market goods and services[5]

While most of the literature on land-based climate impacts focuses on commercial production—particularly of agricultural crops, climate change can affect the poor through its impacts on the availability of non-priced goods such as renewable natural resource endowments. In many cases these ecosystem goods and services may be quite sensitive to climate change. Examples of natural resource goods which are relevant to household consumption, production, and asset accumulation include: wild foods, medicines, consumption/production goods (gum, soap, salt, resins, dyes, etc), construction materials, energy sources, furnishings, tools and utensils, fertilizer, grazing and fodder, clay for pottery, timber, and mineral resources. 'Two characteristics aside from their renewability make environmental resources different from other economic activities: their spontaneous occurrence, and the fact they are so often held under communal tenure' (Cavendish 2000). It is also common for these types of goods to be non-traded, even in local markets. For example, only 19 per cent of surveyed villages bordering the Sariska Tiger Reserve in India had local markets for firewood even though this constitutes 59 per cent of the total biomass energy (Heltberg 2001; Heltberg et al. 2000).

In aggregate, natural resources also provide services for soil conservation, water availability and quality, biodiversity conservation, carbon sequestration, and air quality (Duraiappah 1998). For example, wetlands can filter pollutants from water sources and improve the quality of irrigation and drinking water; forest cover on steep slopes can prevent erosion and loss of top soil for low-land fields; and natural habitats support pollinator and pest predator species which reduce the costs of inputs for cultivation (Sunderlin et al. 2005; Kevan 1999). These ecosystem services affect the quality of life for households as well as the profitability of agricultural technologies. To illustrate, increased erosion from deforestation may increase silt levels in irrigation water, thereby decreasing the efficiency of irrigation canals. Likewise, removal of mangroves and wetlands along coastal areas can increase saltwater incursions into groundwater sources, increasing salt levels in irrigation water and decreasing agricultural yields.

Under most climate change scenarios, changes in rainfall and temperature are predicted to alter the mix of local plant species. Using 23 different climate change scenarios, Battisti and Naylor (2009) found a greater than 90 per cent probability that, by 2100, the average summer temperatures in the tropics and subtropics will exceed the recorded high temperatures from 1900-2006 for those areas. As average and maximum temperatures increase, the productivity and viability of plant species change, particularly above the threshold temperature of 35^{o}C (Schlenker and Roberts 2006; Schlenker and Lobell 2010). Thus climate change is likely to cause species loss as well as altering the types of fauna supported by an ecosystem (Walther et al. 2002; McCarty 2001).

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5 This section is draw from Hertel and Rosch (2010).

Any reductions in natural resource goods and services are likely to have a significant impact on the poor. Empirical evidence from household surveys in Zimbabwe estimate that poor households derive as much as 40 per cent or more of their incomes from environmental goods (Cavendish 2000), and 24 per cent of incomes in Peru (Takasaki et al. 2004). An estimated 31 per cent of household production income derives from bush meat in the Democratic Republic of Congo (de Merode et al. 2004) and 75 per cent of surveyed households in Brazil devoted time to collecting non-timber forest products annually (Pattanayak and Sills 2001). Natural resource goods also represent a significant fraction of cash sales incomes (Cavendish 2000; de Merode et al. 2004). De Merode found that 90 per cent of bush meat and fish caught, as well as 25 per cent of harvested wild plants, were sold in urban markets. On the whole, the contribution to poor incomes from environmental goods can reach levels equal to or greater than income from cash crop production, unskilled labour wages, and small businesses and crafts (Cavendish 2000).

Many factors come into play to determine how much households rely on environmental goods. Proximity to accessible resources is important (Takasaki et al. 2004; Heltberg et al. 2000; Pattanayak and Sills 2001). Households that receive remittance incomes (Eriksen et al. 2005; Cavendish 2000) or have children living away from the village (Pattanayak and Sills 2001) tend to devote less time towards collecting natural resource goods. In their research on Malawi, Fisher and Shively (2005) also noted that younger and male-headed households relied more heavily on environmental resources. Cavendish saw similar findings for households headed by divorced and widowed men in Zimbabwe. He hypothesized that male-headed households relied more heavily on environmental goods for cash income in order to hire women for female-specialized tasks. Heltberg et al. (2000) noted that lower caste villagers in India spent more time on firewood collection and consumed more firewood than higher caste households. (Cavendish 2000) concludes: ‘Lower income households clearly depend proportionately more on the consumption of wild foods than do higher income households, evidence perhaps that these households are unable to allocate as high a share of cash income to purchased foods as better-off households’.

Natural resource goods often have limited substitutes, further complicating the adjustment of households to potential reductions in the availability of these goods in the wake of climate change. Analysing eight developing countries, Heltberg (2004) found that higher incomes are associated with greater adoption of modern fuels, but that households in many countries preferred to use multiple fuels sources including biomass. He also found that households in Ghana and Nepal showed very little tendency to switch away from biomass energy.

To summarize, the link between natural resources and poverty is complex and highly contingent on local endowments and cultural norms. Climate change is expected to alter the goods and services that natural resources can provide in developing countries, which will disproportionately affect consumption, production, and asset accumulation of the rural poor.

Agricultural impacts

Current estimates suggest that temperature increases over the world’s farmlands will be on the order of 0.3-0.4°C per decade (Hertel and Lobell 2012). Lobell and Gourdji (2012) estimate that the impact of these temperature rises will most likely translate into something like a decadal decline of 1.5 per cent in global average crop yields, relative to trend, with the possible range extending from only minor losses (0.3 per cent/decade) to severe impacts (up to 4 per cent/decade). These estimates are large enough to have a marked impact on world food availability and prices—particularly if one ignores the favourable, and offsetting impacts of increased CO_2 concentrations in the atmosphere (Lobell and Gourdji 2012). However, from the point of view of this paper, the most important thing is that these impacts are expected to be very heterogeneous, with yield losses in the tropics, and yield gains in the higher latitudes (Müller et al. 2010).

One of the most troubling aspects of the analyses of climate change impacts undertaken thus far is the fact that most of the crop models used capture only about half of the key mechanisms by which temperature affects crop yields (Hertel and Lobell 2012). And the elements which are most generally omitted are those which are likely to be felt most severely in the tropics, namely the effects of heat stress on grain set and leaf senescence, pressures from pests and disease, and the impact of heightened vapour pressure deficits on photosynthesis (Hertel and Lobell 2012). This suggests that the impacts of higher temperatures on crop yields in the tropics are more likely to be at the extreme end of the potential range. Therefore, agricultural adaptation to higher temperatures will be especially important for farmers in the tropics.

When thinking about agricultural adaptation to climate change, it is useful to distinguish between three broad types of adaptation: (i) on-farm biophysical adaptation, such as changing varieties and planting dates; (ii) on-farm economic adaptation, including changing the crop mix, investing in irrigation, and altering management practices; and (iii) market adaptation, including changes in consumption, production location, trade, etc. The potential for on-farm biophysical adaptation has been extensively studied by crop modellers. Deryng et al. (2011) use the Pegasus crop model to investigate the impacts of higher temperature (+2°C) on maize, soybean and spring wheat yields across the globe. They find that, absent adaptation, the declines in yield are relatively similar between high-income (generally high latitude) countries and low-income (generally tropical) countries. However, when they account for adjustment in crop varieties and planting dates, the North-South divide is far more striking, with yields for maize and soybeans rising in the high-income countries, whereas the yields for all three crops in the low-income countries continue to show a sharp decline, even in the wake of these biophysical adaptations. The scope for biophysical adaptation is simply much lower in the tropics, where planting dates are typically dictated by rainfall and not temperature (and therefore cannot be easily adjusted in the face of higher temperatures), and where crops are already being grown at, or above, their optimal temperature range.

Research into on-farm economic adaptation is much more limited (Antle and Capalbo 2010), due to the difficulty of generating experimental data, coupled with the fact that observational research must rely on responses to the relatively modest changes in climate to date. One point which is clear is that farm-level economic adaptation will hinge critically on access to markets, including those for credit, purchased inputs, knowledge about new practices, and markets for potentially new products (Lybbert and Sumner 2012). Unfortunately, limited access to inputs and credit is one of the reasons many of the world's poor—particularly those living in rural areas—remain poor.

In summary, not only are researchers likely *understating the adverse impacts of higher temperatures* on crop yields in the tropics, it is likely that, by ignoring some of the biophysical constraints as well as limited access to markets by those in developing countries, they may be *overstating the potential for adaptation* in the poorest countries.

Markets, policies and adaptation

In an interesting historical study of rainfall and famine in colonial India, Burgess and Donaldson (2010) find that the arrival of railroads—and hence ready access to national markets—in Indian districts 'dramatically constrained the ability of rainfall shocks to cause famines in colonial India' (p. 450). This finding further underscores the potential contribution of 'climate smart' investments in infrastructure. Market integration of all sorts offers promise for facilitating adaptation to increasingly frequent and intense supply shocks in agriculture. By moving goods and services between regions that are less affected by extreme events and those regions that do experience significant losses, much of the associated human suffering can be alleviated.

Aisabokhae et al. (2012) seek to assess the relative importance of the three different sources of adaptation, within the context of the FASIM model of US crop and forest production. They find that it is the third channel of adaptation—namely market adaptations—which are dominant, accounting for two-thirds to three-fourths of total US adaptation benefits in the climate change scenarios considered. Of course, the extent to which markets actually facilitate adaptation depends on government policies and investments.

Verma et al. (2012) examine the interplay between government policies and market-based adaptations in coping with the agricultural impacts of increasingly frequent and intense extreme climate events. They consider two types of integration: intersectoral market integration (i.e., closer integration of agricultural and energy markets through biofuels) and international market integration (i.e. more intense trade relations between countries). They find that, when it is market-driven, intersectoral integration offers the potential for mitigating a significant amount of the commodity price volatility emanating from the corn markets. However, if this integration is achieved via mandates (e.g., the US biofuels mandate for ethanol), then the opposite is true, with government-mandated integration exacerbating corn price volatility under climate change. On the international front, the authors estimate the benefits of closer integration through stronger international trade disciplines—thereby preventing countries from implementing trade policies to isolate their domestic markets from world prices (i.e. export bans and variable import tariffs). They find that this type of policy reform also offers an avenue to reduced market volatility. They suggest that, in the absence of such disciplines, the world is likely to repeat more episodes such as that experienced during the 2007-08 commodity crisis, when many countries imposed export bans on staple grains, thereby exacerbating the world price rise during this period and likely throwing many additional households around the world into poverty (Anderson and Nelgen 2011; Ivanic and Martin 2008).

Closer integration into international markets may also offer some unexpected benefits for those developing countries whose climate shocks run counter to those in major exporting countries. For example, Ahmed et al. (2012) examine the predictions of climate models for occurrences of severe dry conditions in Tanzania and in the country's major trading partners over the course of the twenty-first century. They find that Tanzania is likely to be only mildly affected in years where many of the major maize exporters experience drought. In the wake of the expected higher than normal prices, they find that Tanzania could benefit from boosting exports—but only if the country refrains from imposing export bans as has often been the case in the past.

Weather forecasts and index insurance[6]

Farm households' strategic decisions are influenced by many factors including risk aversion, wealth levels, climate variability, and the surrounding policy and institutional environment. However, one critical, yet often overlooked factor is the availability of information. As noted by Quiggin and Horowitz (2003): 'Another way of looking at [climate change] is that the information held by economic actors about the climate becomes more diffuse, and hence less valuable in the presence of a new source of uncertainty. *Thus climate change may be regarded as destroying information….* [such as] the informal knowledge of particular local climates that is acquired by attentive individuals over a long period'.

Because sensitivity to climate risks decreases with increasing wealth, policies to provide better information and thereby reduce the effective level of climate risk, should be particularly beneficial for poor farmers in the context of increasing climate extremes. Empirical studies, however, offer conflicting assessments of the potential for either of these types of investments in climate change adaptation to affect the decision-making process of the poor. Gine et al. (2007) found that farmers in India with fewer risk-coping mechanisms invested more effort in acquiring accurate weather prediction information. Other studies, however, have concluded that farmers give relatively little weight to climate forecasts when making planting decisions due to poor spatial and temporal resolution, and lack of trust for the institution issuing the forecast. In a case study of 200 farmers in Argentina, Letson et al. (2001) found that farmers rely on price expectations (33 per cent), crop rotation patterns (22 per cent), and climate projections (16 per cent) in making planting decisions. Older farmers relied less on climate projections, but experience of farming during the 1997-98 El Niño event shifted farmers toward a greater confidence in climate projections. This suggests that farmers may increase their demand for accurate climate forecasts as climate change renders their traditional information sources and experience less reliable.

Herders in southern Ethiopia and northern Kenya also made little use of modern forecasts, even when they had confidence in the forecast, because of the inherent flexibility of herding and an abundance of grazing lands (Luseno et al. 2003). Those herders who did rely on forecasts preferred to use traditional methods, e.g. animal intestines, clouds, birds, etc., over modern forecasts. Herders had confidence in these methods because they were spatially detailed, transmitted in local languages by trusted local experts, and focused on the onset of the rains rather than total precipitation.

Increasing the usefulness of modern climate forecasts depends on 'developing focused knowledge about which forecast information is potentially useful for which recipients, about how these recipients process the information, and about the characteristics of effective-information delivery systems and messages for meeting the needs of particular types of recipients' (Stern and Easterling 1999). The majority of herders studied by Luseno et al. (2003) had no access to modern forecasts transmitted through radio and newspapers. This suggests an opportunity for an extension of services from agricultural ministries, NGOs, or donor agencies to work with local farmer groups to develop and deliver effective forecasts targeted at the poorest groups. In their study of the value of season climate forecasts in Mozambique, Arndt and Bacou (2000) suggest that getting this information to those working in the marketing system may have even greater value than that generated by getting it to the farmers.

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6 The subsequent text draws heavily on Hertel and Rosch (2010).

Insurance is the canonical solution for managing risks such as changing climate conditions, and one option is for farmers to use traditional methods 'insurance'. However, Dercon (2005) found that, due to the covariate nature of shocks from droughts, households were unable to insure against them using traditional risk sharing mechanisms such as local credit, asset markets, transfers from local households, and networks. Unlike idiosyncratic shocks—such as illness or accidental death, which can be insured through informal networks of families in the community or through the sale of livestock—droughts affect the entire community and depress the prices for livestock, as all families are pressed to maintain consumption levels.

Yet evidence suggests that the poor rarely include insurance as one of their strategies for diversifying risks. This lack of insurance can be partially explained by undeveloped insurance markets in many rural areas. Even when insurance markets exist, however, the poor do not always choose to purchase insurance (Kiviat 2009). One method of increasing insurance coverage for the poor is to provide public weather index insurance (also referred to as parametric insurance). Index insurance pays out when certain trigger events occur, such as rainfall levels measured by local rain gauges fail to meet an established threshold. Indeed, with the increased frequency and availability of satellite imagery, weather index insurance is increasingly based on remote sensing (Lybbert and Sumner 2012). Weather insurance is often provided as a public good because the risks from weather events are highly correlated across households. Further, publicly provided insurance has low transactions costs, can be more transparent than private insurance, has low administrative burdens, can provide rapid payouts, and minimizes asymmetric information problems (Gine et al. 2008). Pilot programmes are currently underway in Mexico, Peru, Nicaragua, Honduras, and Guatemala to introduce index insurance into existing insurance markets (Arce 2008).

Few studies exist yet of the adoption of index insurance by poor farmers. In one such study, farmers in Andhra Pradesh who devoted a large share of their cultivation to castor and groundnuts—both highly profitable and highly sensitive to drought—were more likely to purchase rainfall insurance from a microfinance institution (Gine et al. 2008). Wealthier households were also more likely to purchase weather insurance as credit constraints were a significant barrier for the poor. Reputation of the microfinance institution played a large role in household decisions to purchase insurance; insurance purchases increased with household familiarity with the microfinance institution and with increasing participation from other members of the household's social networks.

Gine et al. (2008) offer criteria for a well-designed index insurance mechanism. First, it should be transparent and verifiable to policyholders. It should be based on a measure which can be determined cheaply and quickly, whose calculation is not vulnerable to tampering or manipulation, and whose ex post measures are highly correlated with household incomes and consumption risks. Index insurance also requires an underlying probability distribution which can be estimated with some accuracy. Such distributions, however, are likely to be highly sensitive to climate change. Finally, they note the importance of offering credit for the poorest households seeking such insurance, as the timing of the premium payments can present a real obstacle to the purchase of insurance by the poor.

Binswanger-Mkhize (2012) emphasizes the importance of credit constraints in preventing the poor from benefitting from insurance of any type. In fact, he argues (p. 193) that:

> We therefore, have a sad paradox for agricultural insurance in the semi-arid tropics of India. The better-off farmers will have little demand for insurance because they are already sufficiently well insured via their informal mechanisms to achieve profit maximization. On the other hand, the poor farmers could benefit from agricultural insurance, but are too poor and credit constrained to translate the potential benefit into effective demand. Therefore, unless an insurance contract is offered that provides equal or better insurance than the self-insurance mechanisms at a very low cost, little demand for any agricultural insurance product should be expected in these environments, no matter whether it is an individual or an index-based insurance.

Water management

In addition to index insurance and more effective climate forecasting, investment in water storage and irrigation is likely to be particularly important for agricultural households. While such investments are not strictly public goods, as water is non-rival in consumption (i.e., consumption by one household generally precludes use by another). However, the open access nature of many of the world's water supplies, and high level of market failure in delivering water to its most efficient uses, seems to justify significant public sector involvement in water management in many developing countries.

Climate models project that rainfall events will become increasingly concentrated, leaving longer periods of continuous dry days (IPCC 2007), thereby posing additional challenges to farmers and increasing the value of deficit irrigation, water conservation and water harvesting (Lybbert and Sumner 2012). Case studies in Asia and the Middle East have shown that farmers react to water scarcity by challenging the water allocation environment, including tampering with infrastructure, colluding with water officials, organizing protests, and lobbying political connections (Molle et al. 2009). Water scarcity can be countered by a range of policy options, from low-capital techniques, such as promoting strategic fallowing and shifting planting calendars in order to capitalize on residual soil moisture, to high capital techniques aimed at augmenting water supplies. Institutional changes have also been observed to improve conservation efficiency and equity of water allocation, including setting up rotation irrigation, creating water user associations to negotiate during times of water scarcity, collective pumping operations, and policies to improve river-basin management (Molle et al. 2009). Given the wide range of costs and technological capacity required for the various policy alternatives, dialogues between stakeholders may be helpful in identifying the combination of policies with the most potential at the local level to address water scarcity for the rural poor.

Research and development for adaptation

The public good which has most profoundly shaped global land use over the past century is agricultural research and development. This has fuelled sustained productivity growth to an extent rarely matched in other sectors. Indeed, over the past 50 years, global crop production has more than tripled, with expanded area only accounting for 14 per cent of this increase (Bruinsma 2009). Nonetheless, there has been a slowdown in publicly funded research in some regions over the past two decades (Alston et al. 2009). This was particularly pronounced in the 1990s. Since 2000, public spending on agricultural R&D has picked up again—particularly since the commodity price boom. GFAR (2011) reports a 22 per cent rise in public spending globally over the 2000-08 period. While this has been led by strong growth in China, India and Brazil, public agricultural R&D in low-income countries—particularly those in East Africa—has also grown over the period, averaging 2.1 per cent/year

(GFAR 2011). And, after a long period of slow growth, the same report documents a 41 per cent increase in real spending by the CGIAR Consortium. All of this growth seems to have been spurred by the commodity price boom and increasing concern with climate change and its impact on the agricultural sector. This rebound in investment is good news, given the long lag-time between investment, innovation, commercialization and adoption of new technologies; e.g., 20 years for straightforward improvements, and more than 70 years for hybrid corn (Alston et al. 2008).

Which types of investments are likely to be most important in the context of a changing climate? Hertel and Lobell (2012) argue in favour of investing in innovations which have high value under current climate, but which may have even greater value under future climate. For example, crop varieties which exhibit heat and drought tolerance deserve high priority in light of projected higher temperatures, increased heat waves, and longer periods of continuous dry days. But somewhat ironically, cold tolerance is also important, as this will facilitate the migration of crops to higher latitudes in an effort to adjust the growing season and avoid extreme heat. Similarly other technologies which permit earlier planting will be more valuable under future climate, as will crop varieties which are tolerant to rainfall inundations. Finally, improved pest and disease resistance will be important, as climate change is expected to favour pests and invasive species in many of the world's ecosystems (Ziska and Dukes 2011).

In many cases, the tools for achieving these new varietal traits will come from biotechnology (Lybbert and Sumner 2012). For example, pest-resistant Bt crops have played an important role in reducing costs and increasing yields in many parts of the world, as has herbicide tolerance. Lybbert and Sumner (2012) also draw attention to water and salt tolerant traits the development of which has been facilitated by biotechnology in the context of private-public partnerships such as the Water Efficient Maize for Africa Project. They note that genetically modified (GM) crops are currently grown on only 7 per cent of arable land, and therefore offer great potential for expansion if objections and resistance to such crops can be overcome. In this case, the issue is not just one of scientific research—there is also a public goods aspect to helping developing countries sort through the pros and cons of adopting biotechnology in their own agricultural sector.

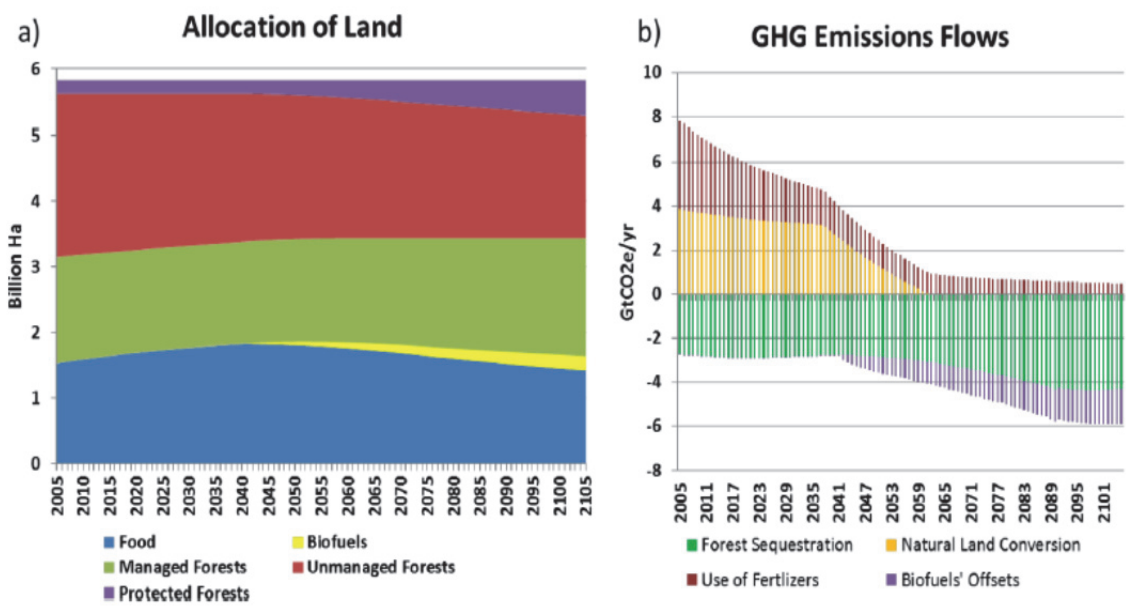
Lobell et al. (2013) draw a link between research and development leading to successful adaptation to climate change on the one hand, and climate change mitigation on the other. They start by developing crude, continental scale estimates of the cost of offsetting the expected adverse yield impact of changes in temperature and precipitation by 2050. They figure this to be in the neighbourhood of US$225 billion, globally. They then incorporate this into model projections of global land use change between 2006 and 2050 and find that the avoided yield losses result in 61 Mha less land conversion, and 15 Gt CO_2e less emissions over the 2006-50 period. This translates into mitigation benefits which accrue at a cost of just US$15/tonne CO_2e—a price which is quite competitive with many carbon markets over the past few years. To these mitigation benefits, the estimate that the ensuing reduction in food prices would allow 17 million people to rise out of malnutrition. In short, this is another case where providing one public good (R&D for adaptation) can enhance the supply of other public goods—in this case food and environmental security.

3 The evolving global supply and demand for land-based public goods in the twenty-first century

The introduction to this paper discussed some of the major changes in global land use over the past fifty years. How do we expect the next fifty years to look? And how might these changes alter the supply and demand for public goods related to land use? Before turning to a discussion of specific foreign aid opportunities, it seems sensible to think a bit about the fundamental drivers behind global land use and the associated public goods.

Figure 1 reports one set of projections for global land use change and land-based GHG emissions over the twenty-first century. This is taken from a recent publication by Steinbuks and Hertel (2013) and is based on a global scale model which seeks to characterize long run competition for land between food, biofuel, forest products, carbon sequestration, and other land-based ecosystem services. The model used is 'forward-looking', which means that land use change today will be influenced by expectations of developments in the future, including energy prices, population and income growth, new technologies and government policies. In the baseline scenario, real fossil fuel costs rise at an annual rate of 3 per cent (Energy Information Agency 2010), population growth continues to slow, plateauing at 10 billion people in 2100 (Bloom 2011), global per capita income grows at just over 2 per cent/year, and, in the absence of climate mitigation policies, GHG accumulation in the atmosphere causes global temperatures over agricultural areas to rise at an average rate of 0.3 degrees C/decade (IPCC 2007).

Figure 1: Optimal paths of (a) global land use and (b) GHG emissions in the FABLE model baseline



Source: Author's illustration.

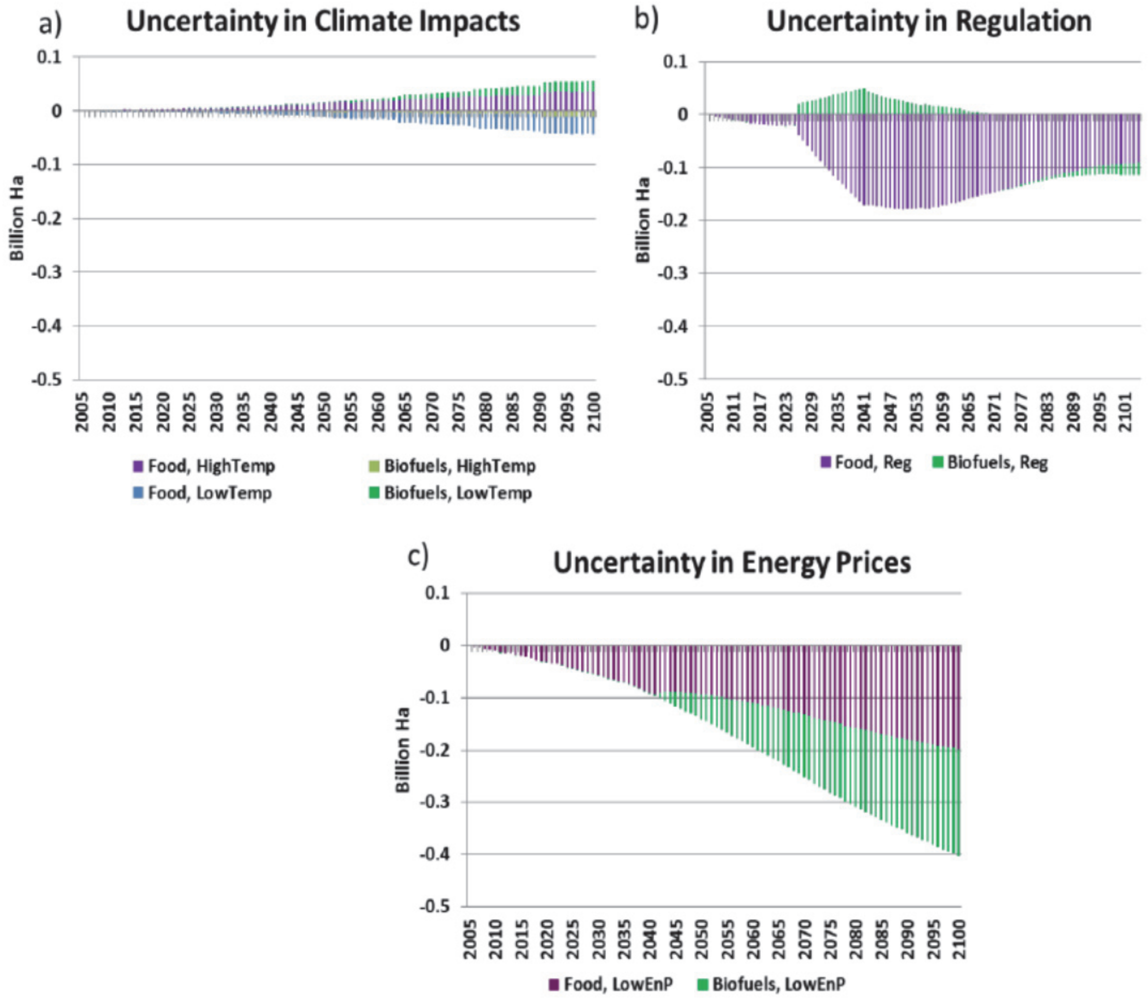
Figure 1a shows the evolution of land area devoted to cropland and forests over the twenty-first century. Area devoted to food production continues to rise as demand growth, driven by rising population and dietary upgrading, outpaces productivity growth. However, by 2040, the combination of slowing population growth, and competition from second generation biofuels, results in cropland for food declining, with cropland devoted to food production ending the century below current levels. Under the baseline growth in fossil fuel prices, second generation biofuels become commercially viable in 2037, and expand to encompass 200 million hectares by 2100, assuming energy prices continue to rise throughout the century. Managed forests expand modestly, while protected forests (nature preserves and parks) grow strongly as developing countries' governments seek to enhance public access to these natural amenities and international efforts to preserve biodiversity expand. All of this squeezes forest lands which are current unmanaged and largely inaccessible.

This pattern of land use carries with it significant implications for GHG emissions which are highlighted in Figure 1b. Here, the major sources of land-related emissions between now and 2040 are the continued conversion of natural lands for commercial purposes, and the fertilizer applications. (The authors do not incorporate livestock into their analysis, and other crop-based emissions such as methane emissions from paddy rice production are also ignored.) These dominate forest carbon sequestration until mid-century, when the combination of slowing population growth leads and continued agricultural productivity bring an end to large scale cropland conversion. After this point, the world's land resources become a net carbon sink—first due to forest carbon sequestration, and second due to carbon offsets from second generation biofuels. So, even in the absence of climate policy, this model predicts that the world's land resources will be an important contributor to global carbon sequestration after mid-century.

Of course, no model is going to deliver accurate predictions of global land use 50-100 years from now. And, so it is interesting to consider how global land use is likely to be affected by the major uncertainties discussed previously in this paper. Figure 2 reports changes in the optimal path of land use when we perturb, alternately: climate impacts on agriculture, climate policy and baseline energy prices. Thus, the upper left hand panel (a) in Figure 2 shows how changes in the path of global temperature affect land use. At higher temperatures, food crop yields face a higher penalty and yields grow more slowly, therefore requiring more land area to meet global food demands. On the other hand, second generation biofuels (e.g., switchgrass) thrive at higher temperatures (Brown et al. 2000) so that yields grow significantly faster than baseline, and somewhat less land area is demanded for biofuels (more is produced, as it becomes cheaper). So, these two effects work in opposite directions. However, the food crop impacts dominate, and the high temperature scenario generally results in greater land scarcity. At low temperatures, these effects are reversed, with somewhat lower land use for food and fuels, relative to baseline. This low temperature scenario has similar effects as would a scenario in which additional research and development funds were expended on agricultural adaptation to higher temperatures—namely lesser temperature-induced yield losses (Lobell et al. 2013).

The upper right hand panel (b) of Figure 2 reports how a global climate policy, announced today, but not implemented until 2025 and encompassing land-based emissions, alters the optimal path of global land use. The first effect is to slow conversion of natural land because such conversions release carbon and are therefore taxed. This results in a considerable reduction in global cropland, which reaches a peak of nearly 200 million hectares by mid-century. However, there is a second effect which works through second generation biofuels. The tax on GHG emissions, favours second generation biofuels, relative to fossil fuels, and causes these biofuels to become profitable earlier on, resulting in increased land area devoted to these energy crops up until late in the century.

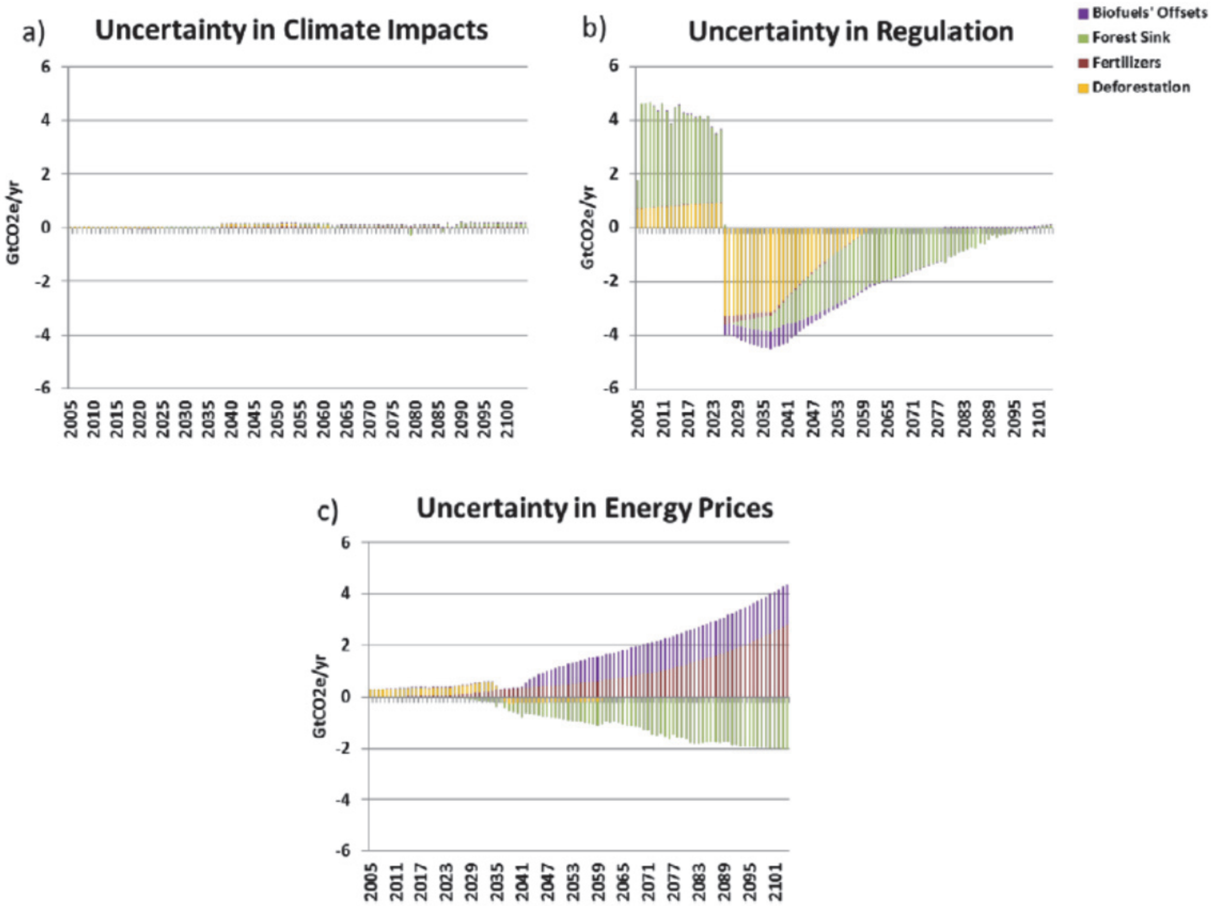
Figure 2: Land use changes relative to baseline owing to uncertainty in (a) temperature (b) GHG regulation, and (c) energy prices



Source: Author's illustration.

The final source of uncertainty in global land use is highlighted in Figure 2c, which shows the effect of flat energy prices throughout the twenty-first century. If energy prices do not rise in real terms from current levels, then second generation biofuels never become commercially viable, and all of that land conversion no longer takes place, thereby reducing cropland in 2100 by 200 million hectares. But cheap energy also has another important effect, and this is to make fertilizer cheaper. Cheap fertilizer allows for greater intensification of production and higher yields, therefore resulting in less land required for food production. While the path is somewhat different, the end result in 2100 is quite similar to second generation biofuels, namely 200 million hectares less crop land required in 2100. The combined impact of these two effects amounts to 400 million hectares of cropland in 2100. Based on this result, Steinbuks and Hertel (2013) label energy prices as the real ‘wildcard’ of global cropland use in the twenty-first century.

Figure 3: Change in land-based GHG emissions relative to baseline under uncertainty in (a) temperature, (b) GHG regulation, and (c) energy prices



Source: Author's illustration.

Since they affect global cropland use, all of these uncertainties affect the availability of land for other public goods as well. Land set aside for nature preserves in 2100 is higher by 20 million hectares under the climate regulation scenario, and it is 90 million hectares higher under the low energy price scenario. Figure 3 reports the changes in land-based GHG emissions under these three different scenarios. From this figure, it is clear that the emissions impacts of differing temperature trajectories are small relative to the other two sources of uncertainty. Not surprisingly, an aggressive GHG policy has a big impact on emissions. However, there is also considerable 'intertemporal leakage' if the policy is pre-announced, since forward looking landowners have a strong incentive to convert cropland in anticipation of the future regulation. And uncertainty in energy prices also has a significant impact on the trajectory for land-based emissions, due to the strong impact on biofuels, fertilizer use and incentives for forest conversion. So, while the low energy price scenario results in less cropland conversion and more lands set-aside for nature, it also results in higher land-based GHG emissions (and undoubtedly higher fossil fuel emissions as more energy is combusted at these low prices).

In summary, it is reasonable to expect significant changes in the public goods supplied by the world's land resources over the coming century—even in the absence of explicit government intervention to increase the supply of such public goods. Government intervention aimed at carbon sequestration can have a significant impact on GHG accumulation, but those implementing such policies need to be cognizant of the potential for 'leakage'—both across space and across time. Finally, in a world of low energy prices, land conversion will be lower than under a business as usual baseline, however, GHG emissions will likely be higher, due to increased use of fertilizers and reduced biofuel offsets.

4 Implications for foreign aid

With this background in mind, I turn now to a discussion of the potential implications for foreign assistance: what can aid agencies do to promote local, national and global public goods associated with land use? Let us start this discussion with carbon sequestration, which is a prominent global public good, the provision of which is in disarray in the absence of agreement on a new international framework for climate change mitigation.

4.1 Advancing global carbon sequestration

At present, the supply of carbon sequestration vastly exceeds the demand and the price has collapsed. Nearly all of the remaining projects moving ahead in this area are voluntary in nature—as opposed to being tied to compliance standards. This greatly limits activity in this important area. However, these issues notwithstanding, the REDD+ experiment must be seen as an important innovation—one which deserves to be further refined and built upon. The idea that carbon sequestration—a global public good—would be regulated and paid for at global scale is very appealing. Can foreign assistance do something to reinvigorate these markets?

Angelsen and McNeil (2012) offer an excellent analysis of the evolution of REDD+ as an institution—first as an idea (RED) at COP11 in 2005—and then as a matter for practical implementation. They conclude one reason for the initial popularity of REDD+ was because it was poorly defined. Each interest group envisioned it somewhat differently, and it was thereby seen as a 'win-win-win' proposition, encouraging the flow of funds from North to South, preserving forest carbon and biodiversity, and alleviating poverty. However, as REDD+ has taken shape, significant opposition has emerged. This, coupled with the absence of a global carbon market to fund REDD+ has led to what the authors term the 'aidification of REDD+'. As they put it (Angelsen and McNeil 2012: 49): REDD+ 'risks losing the essential feature of result-based payments and national level reforms and become merely another form of <project-based> development assistance'.

With the REDD+ agenda being broadened to include multiple dimensions, the distinction between REDD+ and other, local PES programmes is being eliminated. This raises all the challenges which have been faced by PES activities in the past. While this may be seen by some advocates at the only practical way of moving carbon sequestration forward, from a conceptual point of view, this is a pity, since the concept of REDD+ under the UNFCCC allowed for a much better matching of the global public good provided with the sources of funding. As seen above, PES programmes typically target a wide range of public goods, as well as local externalities such as watershed management. And they appear to be most effective when locally funded and managed. Mixing global carbon sequestration in as an explicit goal blurs the link between funding source and public goods' beneficiaries.

Looking forward, an optimist cannot help but believe that the world must reach a new agreement to limit GHG emissions. Given the likelihood of increasingly frequent natural disasters, as well as the fact that the worldwide growth will eventually rebound, one might expect that the world will return to supporting such an agreement. And when this happens, we will once again be drawn to REDD+ as a low cost option for achieving GHG mitigation. Therefore, it will be important to have a viable, global REDD+ programme ready for implementation, so that it could be rolled out relatively quickly. This concept is still quite young, and therefore, not surprisingly, has many limitations. Addressing these in a serious fashion, via a set of carefully monitored case studies would be a worthy activity for foreign aid aimed at ultimately facilitating an operational programme to deliver this global public good with a global scale programme.

Which of the issues plaguing REDD+ deserve attention? In his recent review of REDD+, Angelsen (2013) identify several key issues which must be addressed. The first is determination of reference levels—how do we know that deforestation rates have actually dropped? This is particularly difficult in light of the fact that baseline deforestation rates hinge on a variety of economic and political variables which are themselves nearly impossible to forecast. Finding an acceptable approach to this problem would greatly benefit future implementation of avoided deforestation programmes. A second problem has to do with determining the interaction between REDD+ programmes and other abatement incentives—most notably fossil fuel combustion. When REDD+ is included in a larger basket of mitigation options, there is concern that it will dilute the stringency of the overall emissions constraint. A third problem falls into the more general category of implementation of performance-based aid when the funding agency is evaluated on the successful disbursement of funds and not on the outcome of the project. What do you do if programme participants do not comply? For a detailed discussion of these points, the reader is referred to Angelsen's (2013) REDD+ review as well as the companion paper which he is writing for this conference.

In addition to efforts devoted to sorting out the practical implementation of REDD+ programmes, there are other investments which could be made today, which will improve potential outcomes from future REDD+ programmes. One of these is land tenure and titling. While REDD+ may never become a poverty-friendly programme, the opportunities for low-income communities and households to benefit from this, and other PES programmes, hinges in many cases on their ability to document legal title to the land. Therefore, aggressive investments in land titling today will position such communities to benefit in the future from such programmes. Such investments will also yield additional benefits that come with households or communities having formal title to their land, including: access to credit, improved incentives for managing the land, and increased likelihood of long term investments in land improvements.

4.2 Advancing regional and local environmental services

As with REDD+, securing funding for PES programmes has been a continuing challenge. Funds can come from the national government (as is the case with Socio Bosque). It can come in the form of foreign aid, administered by national programmes. Or it can come in the form of foreign aid for specific projects—a feature often preferred by results-oriented donors. Alternatively, as with REDD+, support can come from voluntary markets in which individuals or corporations are simply seeking to 'do the right thing'. In the case of the China

Green Carbon Foundation, the national government is involved in launching an initiative which then taps into funds from the private sector—in this case for implementation of reforestation projects (Gong et al. 2013). Finally, in some cases PES schemes are user financed—for example the Water Trust Funds in Ecuador, Colombia and Peru which seek to connect payments from urban water users to rural landowners providing the watershed services (Stanton et al. 2010).

Given the macro-economic projections of increased global demand for ecosystem services from land by the end of this century, presented in the previous section, there is great merit in putting in place institutions and tools for delivery of these public goods. However, unlike carbon sequestration, many of these are local or national in nature. Here, the role of foreign aid is more likely to be in the background. Emphasis should be on building capacity for local institutions to manage their natural resources in a manner consistent with their own goals and long run aspirations. It should also be borne in mind that most of the PES schemes involve community planning exercises which are extremely labour-intensive and cannot be readily 'scaled up' to national or international levels.

In addition to PES schemes, assistance in the planning and establishment of national parks in low and lower middle income countries would seem to be a far-sighted use of foreign aid. While the demand for such amenities may not be large amongst households living at the subsistence level today, we know that the demand for such amenities will grow strongly with income, and, by mid-century, such parks will be very meaningful for their children. Yet the land which can offer such amenities is being rapidly developed and degraded in many parts of the developing world, making future establishment of natural reserves and parks difficult, if not impossible. Providing resources—and a voice—for these future generations of citizens in the developing world would be a worthy activity. Indeed, this is already an area in which some private foundations and NGOs are actively engaged. However, the level of investment which they are able to make is just a drop in the bucket compared to the level of demand for such amenities we will see from the 10 billion people expected to populate this planet in 2100.

Of course, any programme of support for national parks in the developing world could be seen as distracting foreign aid agencies from their mission of alleviating poverty today. And, since it is reasonable to assume that many in these future generations will likely be wealthier than their parents are today, this raises questions of equity. Indeed, the entire literature on the provision of environmental services is rife with efficiency-equity tradeoffs. It is very difficult to achieve environmental goals while also alleviating poverty. This point is made quite effectively by Pagiola et al. (2005) in their survey of PES programmes. They point out that *even those programmes which are explicitly designed to reduce poverty* in developing countries have limited success. Citing Coady et al. (2004), they note that the median targeting rate for poverty reduction programmes across a large sample of countries is only 1.33 (i.e. the median programme transfers only 33 per cent more income to the bottom decline than would a uniform transfer programme to all households in the economy). Any programme with the primary objective of enhancing environmental quality cannot hope to do much better than this, and will likely do worse. In order to be effective foreign aid aimed at enhancing the availability of public goods associated with land will likely have to be satisfied with targeting their main objective.

4.3 Investing in climate adaptation

In light of the inexorable changes in climate which the world is facing over the coming decades, investment in adaptation certainly deserves attention. And many aid agencies are initiating programmes in adaptation. High on the list of public goods related to adaptation is research aimed at maintaining productivity of land-based activities in the face of higher average temperatures and increasingly frequent and intense weather events. As noted previously, in the area of new crop varieties, heat and drought tolerance will be important, as will cold tolerance (to permit early planting), tolerance to flooding and pest and disease resistance, will all be increasingly valuable traits. To the extent that yield losses can be avoided, these improved varieties will not only enhance food security, but also environmental security, as the area devoted to world agriculture can be restrained, thereby avoiding excessive land conversion. In this case, the mechanism is already in place to support this kind of research (the Consultative Group on International Agricultural Research) and efforts are already underway in this direction. However, research lag times are long, and these are hard problems to solve. They will undoubtedly require support beyond current levels.

Where adequate heat and drought tolerance is not available in current varieties, supplementary irrigation will be a key vehicle for adaptation. By providing moisture at critical times periods in the growing season, as well as cooling the plant through evapo-transpiration, irrigation can allow producers to avoid catastrophic losses. While irrigation is a private good (it is rivalrous in consumption), the institutions surrounding water management in many countries currently result in inferior allocations of what is becoming an increasingly precious resource. Reforming these institutions and assisting communities in finding ways to improve the efficiency with which they manage their water resources is another area in which investments will bear high (and indeed higher) returns in the future.

In the absence of successful on-farm adaptation, crop market volatility is expected to increase—in some cases quite significantly (Diffenbaugh et al. 2012). This will raise the value of being able to 'arbitrage' commodities across space and time. One of the companion papers to this discusses commodity storage options, which allows for arbitrage over time. However, equally, and perhaps more important is the ability to move commodities geographically in response to regional shortages. For this to be effective adequate infrastructure is needed. This is an area of investment in which foreign assistance—often mediated by the World Bank—has a long track record. Indeed, as with agricultural research, such investments are likely to become even more important under climate change.

Of course having the capacity to readily import commodities is of no use if all of the potential exporters have banned exports! So such infrastructure must be accompanied by a set of market policies—both domestic and international which emphasize flexibility. Unfortunately, the international trade negotiations under the auspices of the WTO have languished in recent years. And further reductions in agricultural support have been resisted by many countries. However, it is important to point out that, *from the viewpoint of adaptation, what is needed first and foremost is not a reduction in average subsidy levels, but rather guarantees that existing policies will not be manipulated to insulate domestic markets*. This is a more modest and potentially achievable goal that would be worth pursuing in the future.

As noted earlier, one key characteristic of climate change is the fact that it destroys information. This is particularly damaging for traditional societies in which traditional information about climate and land use acquired over many years—indeed centuries—may no longer be useful. These same individuals often face high costs of acquiring modern climate information. They likely live in locations where there is no nearby weather station gathering and storing climate data, and, seasonal weather forecasts are not available. In this type of situation, there is a high value on such forecasts, but first some basic investment in data collection and modelling is required. Supporting such infrastructure is a local/national activity which would greatly aid agricultural producers' successful adaptation to climate change.

Where agricultural producers do not have the capacity to fully adapt to climate change, they are likely to experience increased volatility in earnings—particularly if market integration allows for commodities to be imported during periods of production shortfalls (if price doesn't rise when output falls, revenues will drop sharply). This heightens the value of access to weather index insurance. In a previous section, I discussed the pitfalls and promise of such instrument. But it is clear that the value of successfully implementing such insurance products will become increasingly important in the future.

5 Conclusion: investing in information and decision tools

In closing, let me bring up one global public good which is rarely discussed, but which is implicit in most of the analysis undertaken throughout this paper, namely publically accessible, high-quality data on land cover, land use and the distribution of economic activity across the landscape. To an outsider, it seems obvious that such information must be available. After all, we live in a world of 'big data' with satellites monitoring the Earth's entire surface with high frequency, high-performance computers crunching these numbers and Google Earth serving up interactive maps. However, when it comes to usable data for decision making and policy analysis, the situation is nothing short of embarrassing.[7] The latest peer-reviewed, gridded dataset for global cropland area and yields by crop type (things that cannot yet be measured accurately from space) is for the year 2000 (Monfreda et al. 2008). And this is not compatible with the latest peer-reviewed dataset for irrigated areas and yields, which is also for the year 2000 (Portmann et al. 2010). There is a great deal of land cover and land use data out there in cyberspace, but there is no mechanism for co-ordinating these activities and ensuring that the resulting product is interoperable and freely available for the global community.

Even when it comes to the apparently straightforward task of assessing how much land is available for conversion to agriculture, the scientific community has not yet been able to provide a reliable answer. In a forthcoming paper, Lambin et al. (2013) seek to provide a global-scale estimate of potentially available cropland on a 5-10 year time scale for six key regions of the world: the Chaco region in the Southern Cone of South America, the Brazilian Cerrado, the Amazon, Congo, Indonesia and Russia. In these case studies they account for a variety of constraints, including biophysical ones—ruling out very low-productivity lands, ecological constraints due to high-carbon stocks or high-biodiversity, and socio-economic constraints—including land which is already in use and not available for conversion. With the exception of the Amazon, they come up with estimates that are far below those provided by the FAO and other sources which have thus far been taken as definitive. They conclude that most previous studies of global land availability are far too optimistic about how much land

7 For a recent review of the state of play for global land use data, see Hertel et al. (2010).

is available for conversion to cropping activities without inflicting serious environmental damage.

As a consequence of this lack of high quality, interoperable information about the world's land resources and related public goods, it is extremely difficult for decision makers in developing countries to make intelligent decisions about any aspect of land use—whether it is the price for leased land or climate adaptation investments. Information is indeed the ultimate public good, and this is an area where additional investment would pay large dividends—particularly for the poorest countries of the world.

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Table 1: Global public goods related to land use, challenges facing the poor, and associated policy and research needs

Public good	Challenges facing the poor	Policy implications	Research needs
Carbon sequestration (REDD)	Market for credits has collapsed Land tenure as a basis for contracting Can lead to higher food prices	Establishing land tenure/titling Institutional innovations Re-invigorate market for carbon credits	Impacts of large scale carbon sequestration on the poor Establishing baseline Targeting REDD payments Geospatial data/analysis tools
Environmental services (PES)	Land payments by-pass poor High fixed costs of contracting Measurement of service	Progressive payment schedules Simpler guidelines Institutional innovation	Estimating future demand for environmental services Identifying areas to be set-aside for future generations Geospatial data/analysis tools
Policies and institutions for climate adaptation	Impacts on non-market services Access to markets Credit constraints Small scope for altering planting dates/varieties in tropics Limited R&D in tropics	Improved integration into regional and global commodity markets Improved access to credit Increased support for R&D in tropics	Assess climate impacts in tropics and constraints to adaptation Focus R&D on heat and drought tolerance; resistance to pests and disease Geospatial data/analysis tools
Weather forecasts and index insurance	Climate change destroys traditional information No buffer against losses Covariate shocks hit entire community Credit constraints limit adoption	Funding for weather forecasting Public weather index insurance Micro-finance to allow poor to purchase insurance	Improved weather forecasts Understanding constraints to adoption of insurance by poor Geospatial data/analysis tools
Water management	Rainfall expected to become increasingly concentrated Limited access to irrigation Competition with other sectors for scarce water	Dialogue between stakeholders Small scale irrigation Adoption of water-conserving technology	Understanding institutions governing allocation of water Development of appropriate water management technologies Geospatial data/analysis tools

Source: Author’s compilation.