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Getting REDDy
Understanding and Improving Domestic Policy Impacts on Forest Loss

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Getting REDDy:

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Abstract (185 words)

Many constraints upon REDD+ policies' ability to reduce forest loss are common across settings, inherent in the fact that agents making key choices respond also to other factors that influence the overall incentive to clear or to degrade a forest instead of conserving it. The record is mixed, at best, with regard to past public interventions to reduce forest loss, signaling the need to disseminate and to improve conceptual models of policy responses. We summarize 3 distinct models employed by economists to assess policy effectiveness: (1) producer profit maximization in choosing spatial extent and distribution of land uses, given complete markets; (2) rural household optimization given both incomplete markets and varied household assets and tastes; and (3) public optimization within interconnected choices about concessions, corruption and decentralization, all important for degradation ('D+' in REDD+). Each model's perspective on impact leads to a review of the evidence. We consider the impacts of forest-conservation and forest-relevant-development policies for the settings and decisions, and at the scales, for which each of the models best applies. Theory and evidence suggest options to increase the impacts of domestic REDD policies.

Keywords deforestation, forest degradation, parks, evaluation, REDD

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1. Introduction

Policies to reduce tropical forest loss have had some impacts yet generally failed to substantially slow losses. The recognition that deforestation and forest degradation generate about one sixth of greenhouse-gas emissions has joined concern about losses of other eco-services, e.g. habitat and water quality, to motivate new global policy like REDD+ payments to reduce tropical forest loss. Domestic initiatives by countries that receive such global incentive payments should be informed by the mixed record of public interventions in addressing the local incentives in two key sectors.

Agriculture is the first key sector. Its expansion, including the supporting infrastructure, is the primary driver of tropical deforestation. Cleared forest land is almost always converted to crops or pasture driven by expected benefits of producing staple foods for local and national use plus internationally valued commodities like biofuels, pulp, and fiber. Deforestation pressure is exacerbated by government supports for agriculture from road investment to provision of cheap credit, sanitary programs, and easier access to titling for lands that have been cleared of forest.

Forest extraction is the second key sector, including logging and collection of wood fuel. Forest loss is partially driven by low net benefits of sustainable forest management. Low prices for timber, in part due to the supply of logs from unsustainable and illegal operations, discourage investments in long-run forest management. So do a lack of credit and secure tenure for private forest lands, or concessions on public lands, with insecurity requiring costly private protection. Services provided by forests often do not generate private revenues and therefore do not affect private landowners' decisions. While this lack of incentives for sustainable forest management mainly drives forest degradation, it also indirectly raises deforestation, as since standing native forest is often left more accessible for clearing, as well as more vulnerable to disturbances such as fire, as a result of both poorly planned and implemented logging and collection of wood fuel.

We consider these sectors using 3 'generic' model types to illustrate incentives relevant for policy impacts on forests. Their microeconomic perspectives are relevant for deciding across possible "nationally appropriate mitigation activities" (NAMA), complementing Kerr and Streck plus Lubowski and Rose in this Symposium which presume local knowledge of efficient NAMA. Angelsen and Rudel in this Symposium ask what policies each specific country can manage and will choose, focusing on differences among countries and the development paths or 'transitions' between countries' distinct settings. That complements our highlighting of incentives issues that are common across space and time for each model, i.e. each decision agent and market structure.

The 1st model is "profit maximization by producers who are well integrated in markets". This framework has been applied to many decisions about best locations for profitable land uses; predictions have been widely studied empirically, including using large-scale secondary datasets with considerable variation in travel time to major markets. Our 2nd model, which we refer to as "household optimization with both production and consumption motivations", has been applied to more isolated settings featuring transactions costs that generate incomplete market integration. Thus its predictions of policy impact link to variation in household assets and preference and are tested with household and village surveys. Our third model, labeled "public optimization", aims to integrate elements of literature on concessions and corruption, focusing on forest degradation and with immediate implications for decentralization as parameters vary with government scale. Predictions can be tested using observed policy, while impact can be examined at various scales.

Our focus is the incentives underlying whether or not policies affect land use and forest. We review the existing empirical impact analyses for both 'forest' or 'conservation' policies, i.e. domestic efforts to impede the clearing or degradation of tropical forest, and shifts in key driving forces, including 'non-forest' or 'development' policies. Changes in either type of policy could help a forested country achieve commitments under REDD and be part of the domestic NAMA.

We find that incentives driving forest loss often were not addressed in past policy design. That both helps to explain limited previous impacts of policy and suggests shifts in future policy. It will be critical to base policy on the relevant model for a given setting, as shifting any specific incentive may reduce forest loss in one setting but not another. In sum, both theory and evidence suggest that REDD+ policy success will rely upon our understanding of the full set of incentives. While respecting the potential complexity that implies, we end by drawing on past experiences to suggest ideas for increasing policy's reduction of emissions from deforestation and degradation.

Below, Section 2 gives a brief complete-market model of producer profit maximization and our review of empirical evidence for a suite of policies for which this generates predictions. Section 3 presents a model of household optimization given incomplete markets and a review of the empirical evidence which focuses on how and when that incompleteness shifts policy impact. Section 4 provides a summary model integrating key pieces of public optimizations concerning concessions and corruption, with a focus on degradation and implications for decentralization. Finally, Section 5 looks forward at REDD+ policy choice in light of the findings in the review.

2. Producer Profit Maximization

2.1 Simple Core Model

Tropical deforestation is driven by demand for land in agriculture, with few exceptions. Thus, changes that influence agricultural profit from cleared land, relative to profits from forest management on that same land, will affect the rate of deforestation. Some such changes in social and economic settings certainly affect forest but yet are highly unlikely to be adopted as REDD policy, including recessions, currency revaluation, and violent conflict (Rudel 2000, Lopez and Galinato 2005, Morton et al. 2008). Other policies that influence relative profits, though, might shift if global REDD payments make reduced loss of tropical forests into a domestic policy goal.

As a first step in assessing whether and when domestic policies might reduce forest loss, i.e. produce REDD, we present briefly the very standard model of producer profit maximization integrated with perfect markets which has so often been the basis for considering policy impacts. This framework is implicit in predictions and empirical examinations of land use, and forest loss, in many literatures. Once we have laid out its elements, we draw connections to various policies.

For any forested site the producer chooses the use of the land, in forested or cleared state, to maximize the expected profit. Expected revenue from that site is affected by the output prices, transport and other costs and a risk of expropriation of land in forest if forest tenure is not secure. The cost of producing any unit of output is affected by the prices of labor, capital and land and by the productivity of land. Sites' heterogeneity is often emphasized in this framework, i.e. one important feature is significant spatial variation in profits from agriculture or forest management. Many have applied these ideas in varied ways, so we keep our 'generic' summary model simple:

(1) maximize$_{\{D\}}$ site profit$_i$ = $D \bullet \pi_{clear}(p,\tau,d_i,c_i,\varepsilon_i) + (1\text{-}D) \bullet (1\text{-}r_i) \bullet \pi_{forest}(p,\tau,d_i,c_i,\varepsilon_i)$

where:

D	=	1 if deforested or degraded, 0 if managed for forest output
p	=	prices of outputs at market, including the price of timber
τ	=	transport cost per unit distance to market
d_i	=	distance from the market to the site
c_i	=	cost of producing a unit of output given rain, slope, soil
ε_i	=	privately (or locally) observed factors in profit (with cdf F)
r_i	=	risk of public expropriation or private trespass, if still in forest

This can be applied to a producer's decision to clear any given site. Across the landscape, this is just a form of the familiar von Thunen prediction. Fixing c and ε, if net agricultural profit is positive at $d = 0$ and falls with d_i there is clearing up to a given market distance, beyond which forest stands (Ehui and Hertel 1989, Barbier and Burgess 1996). Allowing spatially stochastic ε_i to vary for any given market distance, the probability of deforestation falls with market distance.

The above framework is relevant for predicting the forest impact of a large set of policies. Tenure regimes where title is easier to obtain and defend after clearing (e.g., $r = 0$ if D=1 above) will increase the rate of forest clearing, as would supports that raise agricultural p and/or lower c. Deforestation avoided by perfectly enforced protected areas is lower far from market (higher d_i). REDD payments for carbon storage ($p > 0$ if D=0) can directly encourage additional forest and, for binary clearing choice, also reduce the marginal clearing impact of changes in other factors.

Of course, not only unobservable quality ε but also observable costs c vary considerably. Consequent spatial variation in expected profits implies spatial heterogeneity of policy impacts. Consider, for instance, the paving of an unpaved road, which lowers τ from the market to a site. This increases profit and should affect land use at *marginal sites* which would almost have been worth clearing with just the unpaved road. Again fixing c and ε, to consider this most intuitively, these are the sites just beyond the prior market-distance threshold for clearing of the forest. As in fact the ε varies for any given distance d_i, impacts vary as a function of the probability density f. If ε is normally distributed about zero then impact is highest at the threshold (Pfaff et al. 2011a) and new roads (lower τ) deforest less if they go where old roads already led to clearing (low d_i).

It is worth highlighting a wide range of choices (beyond **(1)**) to which such logic applies, from allocations between clearing and forest to choice about management such as the use of fire. Responses to tenure insecurity include site protection and less investment in future forest stocks, at least when tenure has been less secure for forest, such as when clearing is required for tenure. For PES programs, producers decide whether to participate and, if so, which lands to volunteer. Within a concession, a firm chooses how and how much to harvest, plus whether to fully report. Monitoring of clearing, and of corruption, affects whether to violate agreements or to pay bribes.

Finally, note that ε is not observed by an analyst or a federal agency located in the capital. Yet at least some of private information ε is likely to be observed by local government, so federal 'one-size-fits-all' policies based upon observables can be less efficient than local policy choices.

2.2 Reviewing Empirical Evidence

2.2.1 Development ('non-forest') Policies

We consider policies not aimed at forests but still relevant due to their impacts upon agriculture. These 'non-forest' or typical 'development' policies significantly influence the clearing pressure that must be addressed by any conservation policy. They could be shifted to reduce forest losses, if that becomes a domestic goal as a result of global payments based upon REDD measurements. Following Kerr and Streck in this Symposium, we note that without an explicit contract based on REDD measures, still global funds could cover the cost of shifts in development policies that are believed to generate REDD -- very much in the spirit of GEF funding for 'incremental costs', i.e. the marginal cost incurred by a forested country of a policy shift that generates global ecobenefit.

Transport / Infrastructure / Development

New road investments improve access and lower commodity transport costs and thus can lead to greater forest loss (a rise in forest-management profit would have a countervailing effect). This general prediction from **(1)** is supported by analyses of broad-scale, secondary data on the biogeophysical and socioeconomic factors in profits (Chomitz and Gray 1996, Kaimowitz and Angelsen 1998, Pfaff 1999, Geist and Lambin 2002, Pfaff et al. 2007). While government roads open new regions, logging operations greatly expand access by building unofficial roads (for the Brazilian Amazon Veríssimo et al. 2002, Brandão and Souza 2006, Perz et al. 2007; for Congo basin, Laporte et al. 2007). REDD payments can lead to reconsideration of whether and where governments should build roads and of whether to allow new private roads (Arima et al. 2008).

Applying **(1)**'s logic to new road investments given prior road infrastructure suggests that new road impacts vary over space so the spatial structure of development affects forest loss rates. Nelson and Hellerstein 1997 find that the existence of a prior road affects impacts of new roads and Andersen et al. 2002 find that higher prior deforestation lowers forest impact of new roads. Pfaff et al. 2011a,b show that **(1)** predicts low short-run impacts also within isolated regions and confirms these predictions looking across the Brazilian Amazon (see also Conde and Pfaff 2008 and Delgado at al. 2010). Given spatial variation in the forest impacts of roads, REDD payments could reward 'clean' locations. Angelsen and Rudel in this Symposium suggest that shifting new roads from frontiers to 'mosaic' developed settings could increase both REDD and rural welfare.

These implications of profit maximization from **(1)** apply to other infrastructure impacts. Governments also boost local profits with agricultural credit infrastructure and support for small-farmer settlements near forest (Fearnside 2005c, Barreto 2008) that can be spatially targeted too. Energy pipelines are sure to increase within the western Amazon – within and outside of Brazil – and Finer et al. (2008) show that the many 'blocks' newly zoned for energy development overlap with species-rich forest. We note that pipeline development often is accompanied by new roads, for construction and maintenance. They could follow and extend prior paths or create new paths; again the spatial structure of these and other development policies is likely to affect forest losses. Finally, another implication of **(1)** is that not only prior roads but also other policies influence the marginal impacts of roads. Sills et al. (2006) describe Acre State in the Brazilian Amazon, where policies including protection, payments and monitoring aim to lower road impacts on the rate of deforestation while still harnessing benefits of market access for sustainable forest management.

Agriculture

Considering different elements of profit in **(1)**, governments subsidize agriculture through support for higher output prices (e.g., using import tariffs upon competing products, subsidized processing) and through support for lower input prices (such as interest rates and fertilizer costs) as well as through lower taxes. Governments also help to reduce pests and disease risks through investments in research and development. Without off-setting public support for forested lands, such policies that raise yield and profit in agricultural land uses will generate more loss of forest. Such ties are well known, longstanding features of policy in developed and developing countries. Yet such policies and relationships may be reconsidered under REDD, especially given domestic constituencies (Keohane and Levy 1996 and Ross 1996 stress the local stakeholders' interests).

Biofuels merit mention given recently increased attention to, and action within, that area. If they are cultivated on croplands, profit maximization can imply a rise in forest clearing as the supply of the displaced agricultural commodity (e.g. soy) will fall and thus its price will increase. Biofuels subsidies on land not currently in agricultural production might lower carbon emissions from the production of fuel without more forest loss, though it may not be very productive land.

Tenure / Security

As in **(1)**, clearing is promoted if it yields squatter's rights and eventually title (Fearnside 2005a; Simmons et al. 2009 on 'direct action land reform' note similar and ongoing incentives). Even clearing that is not followed directly by a profitable land use may allow acquisition of title, facilitating credit for future profitable production as well as permitting a future profitable resale.

Incomplete and overlapping records that do not recognize traditional land tenure permit powerful actors to acquire titles to vast tracks of land (Fearnside 2005a; Brito and Barreto 2009) Such risks to one's land, from either public expropriation or private trespass (as noted in **(1)**) can reduce the incentive for long-term, sustainable management of forested land (Araujo et al. 2009). Exploitation by illegal loggers and trespassers is widespread in tropical forest regions (Armsberg 1998, van Kooten et al. 1999, Blaser and Douglas 2000, Bohn and Deacon 2000, Contreras-Hermosilla 2000, Putz et al. 2000, Guertin 2003, Cerutti and Tacconi 2008, Honey-Rosés 2009). Alston et al. 2000 argue that in the Amazon, in the past, only land clearing for at least five years protected against expropriation risk. This risk, and clearing's key role, promoted deforestation.

Yet security could increase profitability of clearing, for instance investments in clearing for oil palm. In general, security raises the weight on long-term payoffs (Mertenes et al. 2002) and may or may not support sustainable timber management. Its effect also can be changed by household differences as in **(2)** below but even in **(1)** its impact depends on the suite of payoffs.

Another profit maximizing reaction to insecurity is to physically defend one's land rights. This is costly and likely cheaper in agriculture (Armsberg 1998), influencing choice of land use. Such costs are key if government enforcement is poor, due to budgets, remoteness or corruption and will reduce investment in intensive sustainable forestry (e.g., plantations) as well as in other forest capital (see Wibowo and Byron 1999, Bohn and Deacon 2000, Barbier and Burgess 2001).

Finally, security can affect profit-maximizing migration and thus forest when agricultural frontiers spill into forests (Perz et al. 2005 correlate rural population growth with deforestation).

In tropical forest areas in the Americas, fertility rates are high but in-migration is the main driver of population growth and both are partly driven by tenure insecurity (Carr 2004; Carr et al. 2006; Bilsborrow 2002). Others identify a lack of tenure as a "pull" as people go where access is clear but tenure not, so as to obtain plots (Amacher et al. 2008, Barnes et al. 2002, Merry et al. 2008).

2.2.2 Conservation ('forest') Policies

Protected Areas (PAs)

PAs have been the most common policy for explicitly targeting forest conservation. They have grown substantially over recent decades. They are also close in spirit to carbon-storage set-asides some have envisioned for REDD (Brandon and Wells 2009). To this point, protection has gone to sites with relatively low current threats (Joppa and Pfaff 2009 for global documentation) and thus it has reduced deforestation much less within park borders than seems to be presumed. This follows from **(1)** given that, for whatever reasons, on average PAs have avoided pressures. While isolated PAs could be optimal, including due to the cost of acquiring and protecting land, far from roads and from cities and on high slopes and poor soil one might expect standing forest even in the absence of protection (as in **(1)**), so even a fully forested PA may not indicate impact.

Joppa and Pfaff 2010a highlight the lack of application of **(1)** in construction of baselines for impact evaluation. Many use clearing on all unprotected sites to estimate the counterfactual. Others use the clearing of a 'spatial buffer', using proximity as a proxy for measured similarity; this could work but may not, especially if boundaries are drawn using geographic distinctions, for example drawing the boundary where slope starts to rise or on the far side of a broad river. Andam et al. 2008 for Costa Rican PAs use matching on site characteristics and find an impact under half the other two estimates for 1963-1997. Pfaff et al. 2009 confirm this average impact and test the implication from **(1)** that PA impacts in a given country can vary a lot across space while global results in Joppa and Pfaff 2010b, for over 100 countries, support both conclusions. Ongoing Brazilian Amazon work confirms both too (Delgado et al. 2008, Pfaff et al. 2011c,d,e).

Finally, we consider implications of **(1)**'s profit-maximizing reactions *outside* of the PAs. PA spillovers have implications for net forest impacts and socioeconomic impacts, e.g. lowering the labor demand within agriculture (Robalino 2006) or raising it in tourism (Andam et al. 2010). The sign of net spillovers from PAs is also unclear for forest. In Costa Rica, Robalino et al. 2011 find higher clearing in spatial buffers (specifically in subsets where spillovers are most expected) than for matched controls whereas for the Brazilian Amazon, Pfaff et al. 2011f find less clearing.

Different spillovers are consistent with **(1)**, given that the two are very different settings. That serves to nicely highlight the differences between **(1)** and **(2)**, i.e. our second model below, and links to Angelsen and Rudel in this Symposium, which is focused precisely upon differences in countries' settings and the transitions between those settings. Our second model is for settings that are more isolated, on the forested frontier, where various markets are not always integrated; that describes the Brazilian Amazon much better than Costa Rica. Also, in such frontier settings public optimization (as in our model **(3)**) interacts with private within the development dynamic. Combining perspectives, Pfaff et al. 2011f suggests that within such a dynamic public protection could signal a lack of future public development infrastructure and thus influence private actions. This creates an additional channel, not present in the Costa Rican setting, to lower loss of forest.

Payments for Ecosystem Services (PES)

Payments for ecosystem services such as water quality, species habitat, or carbon storage can reward owners for conserving the forest, instead of clearing (by creating p>0 for D=0 in **(1)**). While services generated by payments are likely to benefit those who are paying, gains in forest stocks could also benefit those who are collecting non-timber forest products including fuelwood (Kohlin and Amacher 2005, Arnold et al. 2006, Cooke et al. 2008) and thereby also be providing some type of 'natural insurance' in the face of varied income shocks (Pattanayak and Sills 2001).

We emphasize why payments may not have significant impacts. Two obvious reasons are that they might be too low to sway the decision, especially if aiming for very high pressure lands, and that if like PAs they go to relatively low-pressure lands that could reduce payments' impacts. Additionally, though, PES programs tend to involve landowners volunteering the land and for an identical payment **(1)** suggests lands with low profit, and thus less clearing threat, may be offered (this and other relevant points on PES were made previously in REEP in Pattanayak et al. 2010).

For early Costa Rican PES, participants differ significantly from others in characteristics that affect land use (Ortiz et al. 2003; Miranda et al. 2003; Zbinden and Lee 2005); clearing may be lower on paid parcels for reasons unrelated to payments (de Camino et al. 2000; Brockett and Gottfried 2002; Miranda et al. 2003; Sánchez-Azofeifa et al. 2007; Arriagada et al. 2009). Yet a larger constraint on impact was a low national clearing rate. Not only the recent matching studies (Arriagada et al. 2011, Robalino and Pfaff 2011) but also prior work (Sierra and Russman 2006) find that a great majority of the paid land would have remained in forest even without payments.

Still , it is worth understanding what if any conditions and rules for allocation of payment generated higher (albeit still low) impacts than average. Arriagada et al. 2011 focus on a location where a NGO played a strong role in targeting threats; this seems to have clearly raised impacts. Robalino et al. 2008 focus on how PES selection rules varied across time and space after 2000.

In Mexico, early payments were for hydroservices and it is suggested (Munoz et al. 2008) that they went to sites facing relatively low threats. Again, even without knowing why this arose, our model **(1)** implies that the impacts are somewhat constrained conditional on those locations. A recent investigation of these payments used matched controls from the set of volunteers to set the counterfactual baseline, i.e. the estimate of what would have occurred without the payments (Alix-Garcia et al. 2011a). That nicely controls for some of the ε, i.e. private information in **(1)**, that likely differs between volunteered and not. Consistent with greater national clearing rates in Mexico, they find statistically significant and small-to-moderate avoided-deforestation impacts.

Finally, just as for PA spillovers, the full set of the profit-maximizing responses by actors to having payments can imply impacts *outside* of the paid parcels. The same recent Mexico study tested for two types of slippage, or leakage: increased deforestation on other property belonging to program recipients (substitution slippage); and increased deforestation within markets where there are high levels of program participation (output-price slippage). Much as for PA spillovers, the setting in which these payments were made appears to affect the magnitude of the spillovers. In the Mexico study, output-price slippage was significant when relatively isolated from markets, i.e. the case when we would expect the demand for outputs to be addressed through local supply. That motivates model **(2)** below and links to themes of Angelsen and Rudel in this Symposium.

3. Household Optimization Given Incomplete Markets

Where markets are complete as in **(1)**, and all above, deforestation often is modeled with careful empirical attention to spatial heterogeneity but less attention to heterogeneity across producers (Mertens et al. 2002 bridges **(1)** and **(2)**, applying a model like **(1)** to different household types). But on forest margins, farmers typically are not fully integrated with some markets -- often rural households whose income is farm profit and who consume goods similar to those they produce.

These two features of forest margins, incomplete markets and integration of production and consumption, can affect REDD+ by changing policy impacts and creating new policy levers. They imply that the household's endowments and preferences influence production choices like the clearing of land and harvest of forest products, through impacts on households' incomes and marginal values of inputs such as labor and land. Thus, heterogeneity of household producers is often a central feature in models, while spatial heterogeneity is limited by geographic constraints upon the household-level surveys that often provide the data for empirical testing of predictions.

3.1 Conceptual Shifts Relative To Producer Profit Maximization

On forest margins, high transaction costs yield incomplete or effectively missing markets. Most rural economies are thought to be characterized by incomplete markets for both labor and land (Sonoda and Maruyama 1999, Carter and Yao 2002). Limited access to formal credit and insurance plus limits on informal mechanisms for addressing contingencies within communities (Besley 1995, Barrett 1999, Bhattamishra and Barrett 2010) as well as shallow markets for forest products are also the norm in many tropical forest regions (Shanley et al. 2002, Sills et al. 2011).

Household-production models have been widely applied to the agricultural and the forest production behavior of rural households. Theoretical models typically focus on labor allocations, e.g. between clearing of forest, agricultural production on cleared land, harvest of forest product, domestic chores and wage employment. Allocation to clearing and harvesting of forest products are of interest for REDD+. They are influenced by biophysical characteristics and market access, such as highlighted in **(1)**, but also endowments and preferences because markets are incomplete.

Much of the intuition here can be captured by conceiving of market incompleteness as the existence of 'price bands' between the purchase prices and the sale prices for outputs and inputs (Sadoulet and de Janvry 1995, Pendleton and Howe 2002, Sills et al. 2003). Thus, a household pays more to purchase a good than it receives if selling the same good. This could be because of transportation costs, e.g. not only a fixed cost of getting oneself to market but also a unit cost of getting one's goods there or inputs back to the farm, or information costs, for instance a lack of market experience or communications making it difficult to find the best purchase or sale price.

These costs depend on general conditions like quality of roads and cell-phone networks, but also household characteristics like numeracy or vehicle ownership. Thus, the price band for outputs and inputs including labor varies by household. Depending on the internal valuations of goods and labor relative to market prices, a household might produce primarily for consumption and/or mostly or only use family labor for on-farm production, instead of hiring or selling labor.

Thus households in such settings may respond differently to shifts in price or technology. As in **(1)**, higher agricultural profits encourage households to deforest more land for production.

But when clearing uses household labor, in the style of backward-bending labor-supply curves a rise in labor's value marginal product and household income can raise leisure demand, reducing time allocated to clearing. That could offset some or all of the direct price or technology effect (more dramatically so if households satisfice rather than maximizing utility, as in the "full belly" model Angelsen 1999 argued was implicit in much of the policy discussion over deforestation).

More generally, market imperfections (e.g., price bands) can influence the net effects of shifts in relevant prices and production technologies (Angelsen 1999, Pendleton and Howe 2002, van Soest et al. 2002, Muller and Albers 2004, Caviglia-Harris and Sills 2005, Takasaki 2007) by creating roles for household preferences and endowments (see Walker et al. 2002, Caldas et al. 2007, and de Sherbinin et al. 2008). These additional channels for varied behavioral impacts can affect net impacts of REDD+ policies, or pilots, that change conditions for rural households: dissemination of new agricultural technologies; clarification of tenure; improvements in access to credit; adjustments to prices; creation of employment in tourism or processing forest products; and influences on household preferences across farming, forest harvest, and off-farm production.

Another important example is localized markets, where the imperfection is broader scale. Households may be integrated in local markets that at larger scales are isolated by transport cost. This intermediate case underlies, for instance, Alix-Garcia et al. 2011a's PES spillovers (2.2.2). As in **(1)**, PES raise opportunity costs of clearing forest for producers and can reduce forest loss. But shifts in preferred household consumption given the increase in income from these payments can matter (Alix-Garcia et al. 2011b find such impact from a conditional cash transfer program). With the payment income in hand, a household may prefer to consume more of what is produced through local clearing of forest, for instance more beef or milk. This can encourage both leakage, e.g. keeping the enrolled land in forest to earn the ecopayments while clearing other forest lands, or simple violation of payment terms by clearing enrolled land (cf., Muller and Albers 2004).[i]

This intuition can be formalized in household production models (see Singh et. al 1986). Variants on **(2)** below have been used to describe farm households on forest margins who are one key group for reducing deforestation, e.g. colonists in the Amazon and farmers in Southeast Asia who utilize lowland and/or upland farming systems. Such a modeling framework has also been applied to interventions that seek to promote forest use as a sustainable alternative (see Weber et al. 2011 and Sills et al. 2003) or to deter collection of forest products that leads to degradation (e.g., Muller and Albers 2004, Fisher et al. 2005, Amacher et al. 1999, and Baland et al. 2010).

Following Sills et al. (2003) and Fisher et al. (2005), consider a typical rural household on the forest margin maximizing utility from consumption purchased (q_o) and produced (q_a , q_f) plus home time (t_H) given heterogeneous preferences (Φ) and technologies or fixed inputs ($\Psi_{a,f}$).[ii] Households produce agriculture (Q_a) and forest products (Q_f) with purchased inputs (i_c at cost c) and hired time in clearing (t_w), where effort can be observed, by allocating their time (T) among: home time; agriculture (t_a); clearing for agriculture (t_D+t_w); gathering of forest products (t_f); and off-farm wage labor ($t_o>0$). A common variation is to include the time required to walk to work, based on distance from the household residence to the agricultural fields or the forest (Angelsen 1999, Brown 2008, Maertens et al. 2006, Fisher et al. 2005, Robinson et al. 2002), which yields local landscape predictions similar to 'von Thünen patterns' around markets as described in **(1)**. Model **(2)** below makes some particular choices to convey basic intuitions (also see endnotes):

(2) maximize$_{\{q, t\}}$ $U(q_o, q_a, q_f, t_H; \Phi)$

subject to these constraints:

$T + t_w \geq t_H + t_a + t_D + t_f + t_o$ Household Time Constraint

$Q_f = f(t_f, L_D; \Psi_f)$ Forest Product Collection

$Q_a = a(i_c, t_a, L, L_D(t_D, t_w); \Psi_a)$ Agricultural Production

$I(L_D) + \Sigma_{i=a,f}(p_i - \xi_i)\bullet Q_i + (w-\xi_t)\bullet t_o \geq p_o q_o + p_a q_a + p_f q_f + c i_c + w t_w$ Household Budget

Forest production (f) rises with time collecting and with deforestation because slash-and-burn results in both cleared agricultural land and forest products, e.g. timber or fuelwood (Fisher et al. 2005). We model collection in abundant open-access forest, not diminished by agriculture. Forest output is affected by endowments such as human capital and biophysical conditions (Ψ_f).[iii]

Agricultural output rises with time in agriculture (t_a) and own and hired clearing (t_D, t_w), given fixed household production endowments and technologies, including human capital (Ψ_a). Land may have been cleared in the past (L) and may be cleared in the period that we model (L_D). That is, in this one-period model, land is cleared and farmed in the same period (L_D adds to Q_A).[iv]

The budget requires that expenditures on consumption (q_i), inputs (i_c) and labor (t_w) be no greater than the value of production plus labor earnings (t_o), unless net external income (I) from remittances, social welfare programs or REDD payments, e.g., permit additional consumption of goods or home time. To focus on REDD+, income I depends on L_D to represent a transfer that is conditional on not clearing land.[v] Price bands for goods and labor are per-unit transaction costs (ξ_a, ξ_f, ξ_t) that could be transport cost or could be the losses from imperfect market information.[vi]

3.2 Reviewing Empirical Evidence

3.2.1 Development ('non-forest') Policies -- Additional Household Perspectives

Transport, Transitions & Development Policies

Travel cost from the household residence to a parcel, or the nearest road or market center, is a very robust predictor of deforestation. While household endowments and preferences matter, empirically they do not swamp the effects of market access. This is confirmed at household level by linking remote sensing data on deforestation with agent surveys (Fox et al. 2003, Verburg et al. 2004, Sills and Caviglia-Harris 2008, Caviglia-Harris et al. 2009), with Maertens et al. 2006 providing a story, based on issues raised in **(2)**, for heterogeneous road impacts (see also 2.2.2).

This may seem inconsistent with our focus here upon more isolated settings with market incompleteness. However, that focus actually highlights the key role of transport / infrastructure investments in integrating such areas more fully with the markets. Thus, road construction may effectively move a region from our model **(2)** setting into our model **(1)** setting, emphasizing the dynamics of development paths that are the focus of the Angelsen and Rudel Symposium article (and Tachibana et al. 2001 find impacts shift with development and integration of labor markets while Pfaff and Walker 2010 and Meyroidt et al. 2010 highlight transport's roles in goods trade, which can bring great change in one locale that relies on opposite changes within other locales).

Yet in **(2)**, economic integration may expand off-farm labor opportunities (Barrett 1999) that increase households' incomes (Zwane 2007). Thus, at first integration via new roads might raise pressures for clearing but then if labor shifts off the farm pressure could fall again, e.g. an 'environmental Kuznets curve' for household land use (Atmadja and Sills 2008). Shively 2001 finds reduced labor allocation to farming as hiring in falls with higher wages while the hiring out of family labor rises; improved integration may yield migration towards external labor demands. Yet if migrants are pushed out of home regions into frontier subsistence settings, where income effects arise with the reliance on household labor, the latter drop in pressure may not materialize. Education that raises opportunity cost of home labor is commonly found to reduce deforestation, offering a long-term development lever if those paying for REDD hope to phase out payments.

Another development policy suggested by the importance of household labor within **(2)** is family planning (Pan et al. 2007). Household sizes or the adult males often are linked to clearing. In contrast, Van Wey et al. (2007) find the number of women has higher impact on deforestation and land-use choices in their case study region in the Brazilian Amazon. They hypothesize that these effects of household composition on forest are due to off-farm employment opportunities (Barbieri and Carr 2005) as well as social welfare payments to women and girls that relax cash constraints and allow the purchase of inputs (including hired labor) for expanding agriculture.

That raises in turn an increasingly common development policy, conditional cash transfer to provide an incentive for development, e.g. for attending school. As noted above, Alix-Garcia et al. 2011b find for Mexico that an increase in exogenous income from the conditional transfers increases deforestation in local areas not integrated into broader markets and this results is quite consistent with Foster and Rosenzweig 2003's finding of localized impacts of income if markets are incomplete, with positive or negative impacts on forest depending on the income elasticities.

Agricultural Policy Impacts Given Household Income & Labor

Model **(1)** predicts that higher output prices and improvement in agricultural technologies raise clearing. Yet with incomplete markets in **(2)** shifts in output prices and technology can have income effects that increase leisure's value for goods net sellers, thus reducing a rise in clearing. But for net buyers, higher output prices clearly encourage clearing -- through both substitution effects from **(1)** and income effects on leisure demand from **(2)** -- while price variation may lead the risk-averse to produce more of their own food, implying more deforestation (Barrett 1999; many of the poorest rural households in Africa may be net buyers (see also Fisher et al. 2005)). Thus predictions from **(2)** depend on not only how well but also how households are integrated.

Improvements in agricultural technology that raise labor intensity can compete for labor to clear land, potentially even decreasing deforestation, if labor markets are incomplete as in **(2)**. Takasaki (2007), for example, predicts that increased returns to labor within current agricultural production could draw labor out of clearing land for future sale (land speculation or "sell-out"). Maertens et al. (2006) and Klasen et al. (2010) find more labor-intensive paddy rice production (e.g., terracing investment) in lowland areas draws labor out of deforestation in highland areas.[vii]

Another policy commonly debated is improving access to credit. Zwane (2007) suggests that the impact may depend upon initial household income due to differences across households in the marginal rate of substitution of consumption and leisure. At lower incomes, more clearing is likely, while at high incomes a rise in demand for leisure could dampen this effect. Zwane also predicts larger households would be more likely to use the credit for extensification, i.e. clearing. It is commonly argued that cattle are a 'walking savings account' if access to credit is limited, so that better credit access could reduce reliance on land-intensive ranching. Yet preferences may drive cattle ownership beyond roles of limited credit access and risk aversion (Merry et al. 2004, Siegmund-Schultze et al. 2007 for the Brazilian Amazon). Preferences may not easily be shifted.

Tenure Security -- Household Evidence

In much of the household production literature, the tenure regime is implicit in the model. The most common structure has the household acquiring additional farm land solely through the investment of labor in clearing. This implicitly assumes clearing confers tenure, i.e. zero private property rights to forest but secure rights to cleared land. The degree to which this is true varies.

Thinking on tenure's impacts, often regime does not vary in a household surveys dataset. Deininger and Jin (2006) and Ayalew et al. (2011) for Ethiopia do find insecure tenure decreases tree planting. Shively (1998) shows investments in trees are sensitive to price fluctuations and to risk preferences, with application to the Philippines. Thus, policies that increase wood fuel price (such as reduced access to public forests for charcoal production) and increase security of tenure can be important for raising the supply of wood fuels from private sources (Köhlin et al. 2011). If woodfuel substitutes for fossil fuels, this has implications for total greenhouse-gas emissions. However plantation trees have multiple uses and use as woodfuel may not be the most valuable.

3.2.2 Conservation (Forest) Policies

In conservation applications of **(2)**, again heterogeneity is a big theme for forest margins (see Campbell et al. 2010, Muller and Albers 2004, Blom et al. 2010, Brandon and Wells 2009). Coomes et al. 2004 say a weakness of past conservation-development initiatives "lies in their founding on a limited understanding of the microeconomic logic that gives rise to livelihood heterogeneity among forest peoples". That fits our themes well, although another limit has been a lack of sustained funding or donor attention (Sills et al. 2011, Bauch 2010, Blom et al. 2010). This constrains local participation, hampering 'buy-in' commonly recognized as one key element of success (Brandon and Wells 2009, Brooks et al. 2006). Finally, the lack of careful monitoring and evaluation, including in light of varied actors and goals, limits our ability to generalize and to predict (Brooks et al. 2006, Brandon and Wells 2009, Blom et al. 2010, Jagger et al. 2010).

ICDPs (Integrated Conservation and Development Projects)

ICDPs have been the dominant attempt to reconcile conservation with local livelihoods (Brandon and Wells 2009). They focus on increasing local incomes in new economic activities such as ecotourism, beekeeping, or sustainable harvesting and the processing of forest products. Activities are intended to: [i] require intact ecosystems as inputs; [ii] draw labor out of activities that are environmentally harmful; and/or [iii] compensate for and thus encourage acceptance of legal restrictions on previously accessible natural resources (see, e.g., Weber et al. forthcoming).

Concerning [i], the objective is to increase household demand for quality standing forest, in the spirit of **(2)** as well as incomplete markets focusing on local forest supply. The mechanism is the introduction of a production function that requires the local forests (shadow p>0 for D=0).

If usable forest is limited by the amount of land a household owns, or distance from a residence, then creating new derived demand for forest could increase opportunity costs of clearing forest.

Concerning [ii], the link to **(2)** and to incomplete labor markets is explicit and immediate. The objective is to increase the demand for household labor or, as in Ferraro and Simpson's 2002 critique of ICDPs, "distract" households from deforestation. Muller and Albers 2004 show this is most likely to have impact if labor markets are incomplete so households use their own labor.

Concerning [iii], the motivation for compensation could simply be ethical but also could leverage local notions of fairness in order to encourage local 'acceptance' of forest conservation. Within **(2)**'s isolated forest margins, a value of acceptance derives from on limits on monitoring. That buy-in matters accords with the results of behavioral experiments on 'motivation crowding' where attempts to restrict from the outside end up backfiring (for instance Cardenas et al. 2000).

Prior literature reviews have found little evidence of ICDP effectiveness (McShane and Wells 2004, Naughton-Treves et al. 2005, Brooks et al. 2006, Garnett et al. 2007). Reviewing interventions to alleviate poverty while conserving biodiversity, Leisher et al. (2010) do provide some evidence that community forest management for timber[viii], nature tourism, and mangroves can have significant benefits for both poverty alleviation and conservation. They note, however, that both participation and the benefits often are concentrated among the better-off households.

For forest-based microenterprise in the Tapajós National Forest in the Brazilian Amazon, Weber et al. (forthcoming) and Bauch 2010 find households with more durable assets and less pasture were more likely to participate. Controlling for selection, participation did increase cash income and asset accumulation but there is no evidence of reduction in activity requiring clearing (e.g., growing manioc or raising cattle). This ICDP may not generate enough income, a common issue as on forest margins there may be barriers to NTFP sales (Shanley et al. 2002 and below). Ecotourism has been most successful where charismatic species are a key attraction to tourists and a conservation concern (Krüger 2005), which is often not the case for dense tropical forest. This does not rule out the possibility that this ICDP either reduced forest conflict or increased local acceptance of conservation regulations, both of which are relevant concerns for REDD+.

NTFPs (Non-Timber Forest Products)

Sills et al. 2003 broadly categorizes a large NTFP literature as about either on low-value, high-volume products (e.g. wood fuel, fodder) or high-value, low-volume products (Brazil nuts, chicle). The former is focused on reducing collection and degradation pressure, e.g. alternative wood fuel sources or alternative fuels, while the latter is focused on NTFPs and incentives (e.g., $p > 0$ with $D=0$ in **(1)**) that raise opportunity costs of labor and land in agricultural production. Recent literature discounts both possibilities, suggesting that fuelwood is not a major driver of forest degradation to start (except charcoal for a market setting more like **(1)** (Arnold et al. 2006, Ahrends et al. 2010)) and NTFPs have limited ablility to alleviate poverty and to shift incentives (Wunder 2001). The latter can be linked to **(2)** and isolated forest margins (Shanley et al. 2002).

Research on NTFPs has shifted to another perspective on household utility related to **(2)**, in particular considering the common case of incomplete -- or just missing -- insurance markets. This suggests roles for NTFPs as safety nets. More generally, the focus has shifted to the various ‘livelihoods’ roles of the NTFPs used for subsistence and traded within local markets and, thus, actively managed in forests (Sills et al. 2011). Local forest access offers “natural insurance” to help buffer income shocks that could increase with climate change (Pattanayak and Sills 2001, Shackleton and Shackleton 2004, Marshall et al. 2006). Fitting **(2)**, there is great heterogeneity in household reliance on forests for insurance (Paumgarten 2005) given varied shocks (Takasaki et al. 2004), incomes alternatives (Fu et al. 2009), human capital (Fisher et al. 2010) and policies (McSweeney 2005). Klasen et al. (2010) find clearing of forests to smooth consumption in the face of shocks. While the ‘livelihood’ roles of forest are clearly important for many households, though, they seem unlikely to serve as the primary incentive for conservation in REDD+ policy.

Fuelwood Collection Restrictions

Restrictions on fuelwood collection (many in South Asia) historically were motivated to protect forest health and to ensure the potential for ongoing timber production in public forests. Recently, ‘community’ or ‘joint’ forest management initiatives also have effectively restricted collection (Cooke et al. 2008, Robison and Lokina 2011). Looking ahead, in light of REDD+, some commentators focused on livelihood goals fear that private forest owners seeking REDD funds also will impose restrictions to avoid the emissions from degradation. In evaluating what impact such an intervention might have, it is important to consider baseline fuelwood collection.

Consistent with household time scarcity, as in **(2)**, some household models assume that households collect the bare minimum for daily use. For a range of market and shadow prices for fuel and labor, households who collect may shift to purchasing fuelwood as relative prices shift. Thus restricting access could impose costs but not reduce total collection. Empirically, there is evidence that households do lower fuelwood consumption as market or shadow prices increase but not a lot (Cooke et al. 2008, Hyde and Köhlin 2000, Heltberg et al. 2000, Linde-Rahr 2003, Pattanayak et al. 2004, Van’t Veld et al. 2006). In South Asia, where much of the research about fuelwood collection has been conducted, households spend more time collecting if wood is more costly in terms of market price (Amacher et al., 1999), shadow price (Cooke 1998a) or in terms of the forest stock or accessibility (Amacher et al. 1993, Köhlin 1998 and Heltberg et al. 2000).

Some evidence, especially from African settings, suggests that households also respond to fuelwood scarcity with increased tree planting and more reliance on private fuelwood supplies (Arnold et al. 2006, Van’t Veld et al. 2006). In the Western Ghats of India, Sills et al. 2003 find that determinants of collection vary across private and public access forests and that ownership of fuel substitutes and livestock substantially reduces wood collection from private access forest. That is consistent with the premise that such private forest resources are treated with greater care. For REDD+, we must consider all likely household responses and all the costs households bear.

4. Public Optimization & Forest Degradation

REDD+ payments will most likely go to governments. This could be irrelevant if incentives were passed on to agents as in **(1)** and **(2)** but effectiveness will depend on government policy choices. Further, global payments could also target the behavior of government itself, e.g. be conditional upon changes in public policy choices (roads, tenure, PAs) or address uses of public forest lands. Within the tropics, most forests continue to be officially owned by some level of government and they are largely managed through the design, agreement on, and implementation of concessions.

For concessions, and generally, "big" actors such as logging firms, commercial ranchers and plantation companies may not accept a public determination of parameters, as in **(1)** and **(2)**. They may engage with the public sector to influence those parameters, including via corruption. Both the default parameters and such interactions are likely to vary with the level of government, suggesting that REDD+ impacts should vary with decentralization and private-state interactions. We focus in **(3)** below on degradation impacts of concessions, corruption, and decentralization.

4.1 Summarizing Theoretical Perspectives

In the large native tropical forests of Amazonia, Western and Central Africa and in parts of Asia, logging is often within concessions allocated by government owners of forest. Given their scope, we might conceive of REDD as 'carbon concessions' which mirror forest-harvesting concessions (for example, there are now ecosystem-restoration concessions in Indonesia). REDD+ should be informed by literature on the design of forest policy instruments including terms of concessions.

While the specifics differ by country, concessions are contracts between the government and a forest harvester, usually awarded through bidding. Designating a specific volume, or area for harvest, these contracts cover small or large areas and can be short or long term (Gray 2002). Firms winning harvest rights pay royalties, lump sum or based upon areas or volumes or species. Contracts have more recently also specified environmental sensitivity including the preservation of certain species, selection to prevent 'high grading' and minimizing damage to the environment (or 'reducing impact'). Public rent capture from these royalties often has been less than adequate. In most cases, the harvesters bidding for concession rights are large firms with enough capital to undertake the concession management obligations and, perhaps, also enough political capital to influence government choice, especially in corrupt administrations (Merry and Amacher 2005).

Nearly all REDD-relevant concessions research has been theoretical as obtaining detailed data on many concessions is difficult, especially on illegalities. In models, governments act first, considering firm response in terms of harvest and employing environmentally sensitive methods. In reality, higher government levels (political layers) determine concession number and location, firms' eligibility (e.g. domestic v. international) and allocation mechanisms (sometimes bidding). Lower government levels choose concession size and length (by zone), taxes, and types and rates of royalties. Models aim to predict forest-user response. Within a typical model, the government maximizes social welfare, a combination of public goods from forests (g below) and the rents to harvesters (π) and others affected by concessions. In maximizing such a function, like V in **(3)**, the government is assumed to face any (or many) of several possible constraints on its choices. Most common is a binding budget target, like B in **(3)**, that depends upon harvesters' choices.

The harvester chooses harvest level (l) and method (h), affecting royalties paid (given R, the government royalty function) and public goods from forest $g(l,h)$. The harvester also can pay bribes (b_i) and/or can report harvest levels (x) below the actual levels (l) implying illegal logging. By nature, **(3)** is a two-player strategic model, as the best public choice is a function of expected harvester response which is a function of both observed and expected future government choices. For example, given effective bribery of inspectors, higher government may not monitor ($m^*=0$). However, the determination of optimal bribes is strategically complex. Were higher government to spend a lot upon 'corruption proofing' of officials with high salaries and also high monitoring, optimal bribes could be zero, as could be the optimal deviations of reported harvests from actual.

$$\textbf{(3)}\quad \text{maximize}_{\{m,k1,k2;R(.);F(.)\}} \quad E[V] \;=\; g(l,h) + \beta_1 \bullet \pi$$

$$\text{s.t.} \quad B \;\leq\; I(g) + R(x) + m \bullet (1-\beta_2) \bullet F(x-l,h) - e(m,k_1,k_2)$$

where:

$$\text{harvester influence} \equiv \beta_1 = \beta_0 + b_1 \bullet (1-k_1) \text{ and } \beta_2 = b_2 \bullet (1-k_2)$$

$$\text{harvester profit} \equiv \pi = p \bullet l - c \bullet h - R(x) - m \bullet (1-\beta_2) \bullet F(x-l,h)$$

	$g(.)$	= public goods (falls with area l, rises with method h)
	β_1	= relative weight on harvester profit ($\beta_0 \geq 0$ is default)
	p	= price of the concession output received by harvester
	c	= costs of the more environmentally sensitive methods
	I	= external income, perhaps $I(g)$ with REDD payments
Concessions Parameters	l	= harvest level, chosen by the harvester (with h and x)
Concessions Parameters	h	= costly harvest methods to raise g ('reduced impact')
Concessions Parameters	$R(.)$	= royalty revenue function, harvester pays government
Concessions Parameters / Corruption Parameters	x	= reported harvest level, equal to or less than the level
Concessions Parameters / Corruption Parameters	$F(.)$	= fine paid if $x<l$ or if methods deviate (h < agreed h)
Corruption Parameters	m	= probability that any illegal logging will be detected
Corruption Parameters	b_1	= level of bribery at the political layer of government
Corruption Parameters	b_2	= level of bribery (0-1) at lower layer of government
Corruption Parameters	k_1	= bribe effect at political layer (k_1=1 guarantees none)
Corruption Parameters	k_2	= bribe effect at lower layers (k_2=1 guarantees none)
Corruption Parameters	e (.)	= public enforcement costs, rising in m and k_1 and k_2

Boscolo and Vincent 2007 and Amacher et al. 2007 find that a revenue-neutral (given B) steeper royalty function R decreases harvest volume (l). The B constraint yields less-than-perfect enforcement ($m^* < 1$); governments far from forests choose not to detect illegal logging (low m) and harvesters may then under-report ($x < l$), from **(1)** if gains exceed expected fines ($m \bullet F(x,l)$).

REDD payment conceivably could be conditional (I(g)), helping to meet budget target B. That could lower pressures to permit more harvest in order to raise revenues through royalties R. Also it could permit more enforcement (m) that lowers illegal logging (Amacher et al. 2008) and, at a cost of internal process (e), could lower the influence of bribes on public choice (raise k_1, k_2).

Illegal logging is always a problem within concessions. Boscolo and Vincent suggest that with low enforcement (m), there is little impact of the royalty rates (R(.)) upon logging practice[ix], consistent with results in Clarke et al. 1993. Amacher et al. 2008 find, in two different systems, that under-declaring harvest volume ($x<l$) rises with royalties (R) but falls with enforcement (e).

Bribery enters **(3)** in two ways. At higher layers (b_1), it raises the social weight upon $\pi(.)$, potentially influencing high-level policy. Bribes to inspectors (b_2) to overlook any illegal logging changes overall detection success even when the government is seeking to punish bribery. A key feature in the impact of bribes may be inspectors' wages (Jain 2001, Amacher et al. 2011). Thus, the government might pay inspectors more (e) to counteract such low-level bribes (by raising k_2). Nonetheless, clearly any influential bribes could hinder the implementation of REDD+ policies.

Decentralization is implicitly modeled as different governments face variations upon **(3)** including varied weight on g versus π. In classic decentralization models, federal actors put more relative weight on g externalities versus local cost. Sensitivity of policy process to bribery (k_1,k_2) surely varies by government. This affects whether or how REDD-concession fees have impact as such payment may filter down from federal to local government levels following particular rules; e.g., across-government transfers from REDD funds $I(g)$ might cover local enforcement costs (e).

Previous modeling suggests lower levels of public goods g, e.g. worse REDD outcomes, are expected if the governments levels do not cooperate closely in setting and enforcing policies, especially when each level has its own binding revenue constraint (B) or separate constituencies. Amacher 2002, for a model like **(3)**, finds that even if government levels coordinate completely, different revenue constraints can lead to greater concession size if revenue needs are important. One idea for addressing such constraints has been to allow government levels to share revenues.

The revenue-constraints issue also leads back to corruption because revenue-constrained central governments may be unable or unwilling to enforce the rules of the concession contracts or agreed revenue sharing or decentralization. There are undoubtedly incentives for corruption that would change the outcomes from REDD payments. Worse, the nature of corruption differs across countries (Karsenty 2008), so best REDD design in one place may not apply to another.

4.2 Reviewing Empirical Evidence

4.2.1 Concessions

Often large foreign firms bid for concession contracts stating a volume or area to harvest in a given period and, increasingly, tree selection and logging methods (Karsenty 2008, Cerutti and Tacconi 2008). Illegal logging erodes revenue capture and ability to enforce these practices. Illegal logging within the tropics typically means too much removal outside of the agreed areas and failure to declare the true harvest volume or use agreed methods (Barr 2001; Richards 1999; Hardner and Rice 2000). One common policy idea is to raise royalty rates to raise revenue and to reduce the excess harvest (Vincent 1990, Merry et al. 2002, Palmer 2003). Other ideas include greater enforcement (Pinard and Cropper 2000) as well as area-based, lump-sum royalties (yet Boscolo and Vincent 2007 note that even high area fees could induce unsustainable harvesting).

That better design can improve outcomes is easy to imagine but the exact actions required neither are clear nor are well studied over the full range of conditions within the forested tropics. Greater enforcement, e.g., swims against the historical tides; several studies document low rates of detection and fine collection (Contreras-Hermosilla 2002 for a country-by-country review). In light of the important budget constraint B in **(3)**, REDD payments might not only lower pressure to increase harvests for royalties but also permit more spending on enforcement (Amacher 1999).

In this role, REDD payments would function like debt relief, which Kahn and McDonald 1995 suggest can lower deforestation. As unlike past debt relief (but as *I(g)* implies in **(3)**) such REDD payments could be conditioned on forest outcomes through the establishment of baselines as well as remote monitoring, this could further shift local policy incentives. On the other hand, any new protected areas created for REDD are just concessions, i.e. particular designations for the use of public lands with specified outputs (carbon storage versus timber), and corruption issues remain.

4.2.2 Corruption

Previous studies have found clear evidence of corruption in forest sectors and associated pressure on the forest from the resulting illegal activities in Africa, in Asia and in Latin America (Contreras-Hermosilla 2002). Bribes have been singled out as a factor that confounds attempts to promulgate improved forest policies; e.g., officials accept bribes for allowing illegal timber trade (Palmer 2005 and Smith et al. 2003 for Asian cases, Siebert and Elwert 2004 for cases in Africa).

A large economics literature has considered when, and how, corruption could be reduced. Considering first when it exists, Jain (2001) sees more corruption when there are higher rents to government-owned resources and low probability of detection and punishment. This implies that corruption can be limited by a well-financed enforcement system. Jain suggests that high wages for public officials can be effective in curbing corruption if there is a relatively high probability of detection. Yet that could raise the debt burden and lower the ability to enforce property rights. Contreras-Hermosilla (2002) finds high corruption with underpaid government forest inspectors, complex regulations around property rights, many bureaucratic steps in obtaining permits to use or establish productive forests, low penalties for illegal logging, and open-access native forests.

Despite some evidence, specific mechanisms by which corruption leads to deforestation need further study, even though it may be widely accepted that 'rule of law' affects deforestation (Deacon 1994). One example of policy-corruption interaction is that shifting royalty function (R) or reducing concession size may be circumvented through adjusted bribes. Analogs could apply to REDD. Better understanding how policy is undermined by corruption surely will be relevant.

4.2.3 Decentralization

Most tropical forests are state-owned, so millions who live in them have "use" rights but no legal right to own, manage or block others' exploitation of forest. Recently governments have devolved forest ownership and management to local institutions. As of 2001, at least 60 countries had reported some decentralization reforms in natural resources (Agrawal 2001) and increasingly this includes granting to local communities property rights to the forests (Sunderlin et al. 2008).

Individual or state ownership were long the only forest options considered but there is increasing interest in property rights regimes with management responsibility held by groups of forest users (Ostrom 1990). Common property regimes with local controls in principle can be the most efficient management, given group monitoring and enforcement or higher productivity for large units (McKean 2002). Decentralization could increase the participation and accountability of government (Larson 2004). Also, as noted concerning the ε in **(1)**, local actors may have better information on conditions and preferences (Andersson and Lehoucq 2006), though whether local institutions are accountable to all locals is critical (Ribot 2002; Ribot and Larson 2005) as states unable or unwilling to enforce contracts leave communities vulnerable (Engel and Palmer 2008).

Concerning decentralized forest-management success, in Amazonia indigenous areas are managing to exclude people, even within relatively highly pressured areas (Nepstad et al. 2006). Also, forests under community management in India have been sustainably managed for decades (Agrawal 2001) and there is evidence that community councils conserve forest more effectively than state agencies (Somanathan et al. 2009 and see results from Nepal, Mexico and Nicaragua).

Yet decentralization is not a panacea and clearly it can increase deforestation if attention is not paid to all key incentives. There is no reason to assume that traditional communities all are inherently focused on conservation (Fearnside 2005b, Asner et al. 2005). Rapid and destructive logging can occur, e.g. if communities' tenure or rights are not secure and residents think rights will be revoked. This encourages them to grab forest profits while they can (Oyono 2004, 2005).

Concerning REDD, decentralization and tenure are two-edged swords. A secure tenure that raises willingness to invest in the future could lead either to more forest or to more oil palm. Secure devolution that raises local control could lead to either more forest management or more clearing of the forest. As in each of our models **(1)**, **(2)** and **(3)**, incentives are key. Consider, for instance, the implications for REDD of the Brazilian Amazon state of Pará being split into three following a recent plebiscite. Is it clear three states would lower forest loss relative to one state?

Bringing this back to concessions and to corruption, i.e. the other foci of this sub-section, REDD success from decentralization is likely to require high levels of cooperation across levels of government. REDD may shift the policy environment but the related past outcomes are mixed. For instance, revenue-sharing agreements between government entities are common for publicly owned forests but they do not always work (Floyd 1999). Smith (2003) argues that in Indonesia the allocation of harvesting permits by district government rarely is consistent with the intentions of the national government**.** For Africa, Siebert and Elwert (2004) note how central government officials in Benin are resistant to local controls and power over rent capture from the harvesting of government forests, legal and illegal, that would follow from reallocation by decentralization.

5. Discussion

5.1 Neither Too Easy Nor Too Hard

Among many positions, there are certainly members of two opposite schools of thought regarding a role for policies to reduce forest loss. One school appears to at least implicitly assert that to stop deforestation one need merely pay the opportunity cost of foregone land uses (e.g., profits not being generated by agriculture). This supports a focus on regions where the profit from forest loss is perceived to be low and thus a conclusion that REDD will be relatively cheap.

An opposing school of thought at least implicitly asserts that more is required for REDD, with the implication that the actual total cost is considerably higher (though often not quantified). Underlying this view is pessimism about the possibilities for actually reducing deforestation, often based in part upon the significant failures of many previous policy efforts (see above) and for many countries the lack of governance capacity to effectively implement appropriate policy.

We believe reality lies between these extremes. There are indeed opportunities to avoid tropical deforestation at relatively low cost compared to other options for reducing C emissions. Yet claims about conservation opportunities immediately available have likely been overstated. The costs of reducing deforestation include costs to reform land tenure, to distribute payments, and to establish, manage, and monitor protected areas. Continued demand for commodities due in part to population pressures, weak governance, and other institutional factors constrain options for reducing deforestation. Opportunity costs of land are merely a lower bound on REDD's costs.

That may sound like the second school of thought. Indeed, our review of the past efforts is sobering: many policies did not target, address or even clearly identify critical incentives; interventions lacked local engagement and stakeholder participation; weak governance and lack of title or enforcement limited effectiveness; and the many forest conservation programs almost universally lacked self-evaluation mechanisms, limiting learning and incremental improvement. However, many features of past policies could be drastically improved. Future REDD policies could avoid historical defaults and lead local actors to value additional forest services, making it profitable to manage the forest for the many local and global goods that intact forests provide.

5.2 Designing For REDD Feasibility

A prospect of rewards for international forest carbon conservation under future U.S. and international climate policies has brought new energy to the protection of tropical forests. Yet the debate has not been informed by close consideration of all the international and domestic policies required if REDD is to play a large role. We believe that international and domestic interventions can lower deforestation given both the support of local actors and well-informed policy designs.

Past failures suggest gains from designing to encourage locally appropriate interventions. For instance, if comprehensive monitoring can accurately capture GHG emissions reduction, the requirements and incentives can be based on that aggregate outcome and many other details may be left to local actors better placed to significantly and sustainably shift relevant local processes. Generally, consultation with those affected can aid in finding effective and sustainable policies.

Moving forward:

- the U.S., in concert with international actors, can help forested countries with the costs of conserving forest carbon, including with costs of strengthening the relevant institutions
- international forest carbon policies can adopt performance indicators so that incentives can be effectively applied; monitoring and evaluation will permit ongoing learning
- forested countries can rethink not only forest policy but also how agriculture and infrastructure policies affect forests; strategies will differ as a function of context
- international and domestic actors can re-examine whether actions work well in concert, e.g., policy influences on commodity demands vs. subsidies for agriculture or biofuels

In summary, it is possible to identify incentives driving deforestation and to align local, regional, national, and international incentives in many settings. Climate protection provides a new way for forest protection to contribute, and to succeed, if we learn lessons from the past.

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ENDNOTES / APPENDIX

[i] Payments could affect migration decisions. In a region well integrated into markets, these effects of household consumption would be spatially dissipated. But on the other hand, an increase in income and resulting increase in returns to labor could attract more households to the region. Similar concerns have been raised regarding ICDPs.

[ii] These parameters include household demographics that affect both demand for consumption and supply of labor. Note that in our generic model, we assume that labor is hired only for clearing forest. This is a logical use of hired (non-family) labor, as deforestation effort is easier to monitor than other agricultural or forest production activities. However, the model can also be generalized further to allow for hired labor in all household production activities.

[iii] With multiple periods, Ψ_f can reflect prior collection that degrades forest and/or builds forest skill and knowledge (Pattanayak and Sills 2001). It could include total forest area available, perhaps a function of the initial land minus A (e.g.,for agricultural colonization projects in Brazil) or, for common property or open access, a function of clearing by the entire village. Where households live on the margin of large open access forests, the distance to collect could increase with prior agricultural clearing, but most relevant literature considers competition for labor in agriculture and forest production without the competition for land, essentially assuming zero local opportunity costs of forest.

[iv] Others model two seasons (Zwane 2007), two periods (Takasaki 2007) or multiple periods (Tachibana et al. 2001). This introduces soil depletion and discounting. Because credit markets are typically thin or missing, they are often omitted from such models. Assets Ψ grow through investment or purchase or may be specified as a technology for intensification. Inputs from forest (e.g. poles, fodder) could enter agricultural production functions (Sills et al. 2003). Land can be differentiated by distance from a residence and primary/secondary forest (Pendleton and Howe 2002) or upland/lowland (Shively 2001, Coxhead et al. 2001, Klasen et al. 2010, Maertens et al. 2006, Tachibana et al. 2001).

[v] External transfers for refraining from deforestation could also be probabilistically conditioned on time allocation, e.g. a chance of not receiving payment if a caught spending time on deforestation (see Muller and Albers 2004).

[vi] On the forest margin, households are likely to have limited off-farm employment opportunities, even if generally well integrated into other markets. This could be represented in such a model by assuming either of the following constraints: (i) households use only their own labor for everything (t_w=0); (ii) there is a constraint on the amount of hired labor ($t_w < z$ (Weber et al. 2011)). Various models alternatively assume that t_w and t_D are fully substitutable or that hired labor has lower productivity, e.g. due to significant supervisory costs in many tasks. Finally, we have omitted from this basic household budget the possibility of selling cleared land at end of the first period or in future periods. That would create an additional value generated by clearing forest (Takasaki 2007, Caldas et al. 2007).

[vii] In evaluating policy impacts in light of this point, we must also consider the impact of all such characteristics upon the baseline household behavior without policy interventions. For instance, Pendleton and Howe 2002 find that more patient households clear more forest as an investment in future production. Caldas et al. 2007 reviews work at the household level in Brazil, in Peru and in Ecuador which links households' attributes to land use and land cover.

[viii] Community forest management for timber is typically not part of ICDPs, which tend to be focused in and around the protected areas, but instead is more aligned with various initiatives to decentralize forest management. That includes Mexico's ejido system (see Bray et al. 2003, e.g.) as well as India's panchayat system (see Baland and Platteau 1996 as well as Somanathan et al. 2009).

[ix] Note that illegal practice surely could involve not only under-reporting harvest level but also misreporting method. Note also that 'leakage' can include logging outside the agreed boundary, which here we assume is not reported in x. Also even if purely reputable firms follow concession terms, 'leakage' can involve other firms following (see 2.2.1).