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Illicit exploitation of natural resources: The forest concessions in Brazil

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Abstract

The Brazilian forest sector has undergone crisis with complexities involved in investment in an insecure political environment, a regime of ambiguous property rights, forest sector illegality and enormous pressure for agricultural expansion. To address these challenges, Brazil's Public Forest Management Law was approved in 2006 enabling private forest management on public forestland. Assessing the policy in a dynamic computable general equilibrium framework, we find that household welfare improves and legal forestry grows faster. In the absence of improved monitoring and enforcement, however, forest concessions are shown to have a depressing effect on the price of forestland and accelerate illegal forestry operations.

Keywords: Brazilian forest sector; Forest concessions; Forestland; Illegal forestry operations; Legal forestry; Computable general equilibrium

1. Introduction

Brazil's Legal Amazon occupies approximately 5 million km^2 or 59% of Brazil's total land area; 2.6 million km^2 of the Legal Amazon are forested.[1] This region is home to 22.5 million people (12% of Brazil's total population), 5.3 million of whom live in forested areas (Celentano & Veríssimo, 2007, p. 9). Brazil is the largest producer and consumer of tropical timber products and as such, the forest industry is an important component of the economy and in particular, to

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[1] The Legal Amazon is composed of the states of Acre, Amazonas, Amapá, Pará, Rondônia, Roraima, Tocantins, Mato Grosso, and part of Maranhão (west of the longitude of 44° west) and Goiás (above the latitude of 13° south).

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the economy of the Legal Amazon. The forestry sector is responsible for 3.5% of Brazil's gross domestic product (GDP), generating 2 million formal jobs and accounting for 8.4% of Brazilian exports (Serviço Florestal Brasileiro [SFB], 2007, p. 10). The natural forest management sector in the Legal Amazon accounts for 15% of GDP (Veríssimo, 2006, p. 23) and approximately 500,000 families in the Amazon depend at least in part on forestry for their livelihoods (Lima et al., 2006, p. 33). With 1.15 million km^2 of forests apt for the sustained production of forest goods and services, natural forest management presents a tremendous opportunity for promoting forest-based development and for maintaining environmental quality and economic value in the region (Veríssimo, Junior, & Amaral, 2000, p. 6).

The Brazilian natural forest management sector has undergone crisis in recent years. Complexities involved in investing in long-term management in often unstable political environments and an insecure land tenure regime has driven the industry to operate in a predatory, boom and bust manner. These features coupled with enormous pressure for agricultural expansion have led to the undervaluation of forestland and a situation in which illegal logging and illegal deforestation thrive, accounting for 56% of forest sector output in 2003. Depressed timber prices resulting from this illegality further exacerbate forestland undervaluation.

In efforts to stabilize the industry, gain control of public forest resources, encourage investment and promote forest sector growth, the government of President Luiz Inácio Lula da Silva approved Brazil's first Public Forest Management Law (PFML) in March of 2006. A key feature of this legislation is a framework for creating forest concessions on public lands enabling the state to sell the rights to harvest forest goods and services for a predetermined period of time. Prior to this law, the only significant legal source of timber was from natural and plantation forests on private land.

Forest concessions can counteract some of the negative incentives for forest management. By providing industry and communities with secure tenure, investment in management may increase, while greater transparency in the regulatory environment reduces the risks and costs of doing business. Furthermore, forest concessions as in the case of protected areas, can act as a barrier to deforestation and encroachment (Nepstad et al., 2006, p. 72). Finally, given the state's intention of establishing up to 13 million ha of concessions by the end of the decade, concessions can make a tremendous contribution to fostering sustainable socioeconomic development and growth in the region.

In this paper we employ a dynamic computable general equilibrium (CGE) framework to examine the medium-term socioeconomic and land use impacts of establishing forest concessions in Brazil's Legal Amazon. In light of the economic importance of forest sector illegality and in contrast to previous forest sector applications of CGE models, our analysis explicitly considers both legal and illegal forestry and deforestation sectors. We pay particular attention to the regional dynamics of these sectors, the agricultural sector and the role of deforestation as a supplier of cleared land.

Following this introduction, a brief review of the treatment of illegality in CGE models is provided. Next, the dataset is described and the modeling framework is presented. The experimental design of the modeling exercise is developed and followed by simulation results. The paper closes with a discussion of the key findings and their policy implications.

2. Treatment of illegal behavior in computable general equilibrium models

Illegal activities in CGE models have received little attention in the literature. The closest parallel to modeling illegal behavior has involved distinguishing between formal and informal sectors and labor. Costs involved in engaging in informal activities include fines, penalties, lack of access to public services, unenforceable property rights on capital and output, and the inability to enter into legally binding contracts thus limiting access to capital markets and insurance (Loayza, 1997, p. 3).

Kelley (1994) analyzed the macroeconomic implications of informal sectors and informal labor in Peru considering an increase in government and investment demand and an increase in both formal sector wages and informal sector productivity. In this model, a shortage of formal employment results in a parallel informal sector, employing informal labor and producing a similar, though imperfectly substitutable good or service. Kelley (1994) characterized informal sector production as labor intensive where the producer receives the net product from production rather than a wage and pays little or no taxes. Output from parallel formal and informal sectors is aggregated into a composite good with relative prices and imperfect substitutability between the two similar goods determining output levels (Kelley, 1994, p. 1395).

Gibson (2005) developed a dynamic model with an informal sector to evaluate the long-run effects of macroeconomic and trade reform policies on growth, distribution, human capital formation and poverty (Gibson, 2005, p. 61). In this model, non-traded goods sectors have parallel informal sectors which serve as an employer of last resort, absorbing surplus labor during recessions and supplying labor in expansionary periods (Gibson, 2005, p. 62). Fortin, Marceau, and Savard (1997) evaluated the effect of taxation and wage controls in an economy with informal sectors. The informal sector is distinguished from the formal sector by technological and organizational factors which are reflected by the scale of the firm, a wage differential between formal and informal workers and regulatory evasion. In their model, firms operating in the informal sector do not comply with minimum wage and tax laws. It is assumed that informal firms facing the risk of being detected and fined would rather pay a sure cost to avoid penalty. This sure cost function is described by an inverted *L* curve where the cost of detection is zero until firm size reaches a critical limit and the cost of informality rises to infinity (Fortin et al., 1997, p. 298). A model developed by the Australian Bureau of Agricultural and Resource Economics incorporated kidnapping and informal sectors in their framework where fines applied to the criminal sector are treated as production taxes (Levantis & Fairhead, 2004, p. 15).

3. The model: a recursive dynamic computable general equilibrium framework

CGE models provide a consistent theoretical lens through which the trade-offs inherent in policy choices may be evaluated according to socioeconomic and environmental criteria. This class of models is effective in capturing the distributional aspects of policy changes (Buetre, Rodríguez, & Pant, 2003, p. 2) and is particularly appropriate for analyzing policies where inter-sectoral and indirect linkages are important and resource constraints exist.

A CGE model is a theoretical structure of an economy which is formalized by equations representing demand for commodities and factor and intermediate inputs, equations relating prices to costs and market clearing equations for factors and commodities (Dixon, Parmenter, Powell, & Wilcoxen, 1992, p. 87). Supply and demand equations describe the behavior of utility maximizing consumers and profit maximizing producers. The system of equations is solved simultaneously for the economic equilibrium (Bandara, 1991, p. 9).

CGE models are either static or dynamic. Static models are useful for shedding light on the order of magnitude and direction of effect of a policy shock and are typically either short-run or long-run depending on the factor and macroeconomic closures chosen by the modeler. Dynamic models are used to simulate the impact of a policy for definitive period of time. In addition to revealing the magnitude and direction of effect of a policy shock, dynamic models provide information on the economic transition path, the short-term costs and the longer-term gains resulting from policy implementation (Cattaneo, 1999, p. 17). Dynamic models typically involve a deeper treatment of investment behavior and enable the modeler to project key growth parameters such as population, labor force and factor productivity growth as well as project world prices, government consumption and rates of capital depreciation.

The Recursive Dynamic Computable General Equilibrium Model employed in this analysis is a dynamic extension to the static International Food Policy Research Institution's (IFPRI) Standard CGE Model in GAMS (Lofgren, Harris, Robinson, Thomas, & El-Said, 2002) and was developed by Robinson and Thurlow (2004). The within period (year) specification of the model is identical to that of the Standard IFPRI model documented in Lofgren et al. (2002). The between period specification of the dynamic model contains adjustments to account for endogenous investment and exogenous population and labor force growth, depreciation and changes in total factor productivity (Robinson & Thurlow, 2004, p. 1). Endogenous adjustments to account for capital accumulation and exogenous adjustments to population, labor force and total factor productivity are discussed in turn.

Capital supply is based on the previous period's capital stock and the allocation of investment spending. Investment is carried out in proportion to a sector's share in economy-wide capital income and is adjusted by the ratio of a sector's rate of profits and the economy-wide average profit rate. This specification implies that a sector with higher than average profits will receive a larger share of investment than its average share in aggregate capital income (Robinson & Thurlow, 2004, p. 4).

Population growth has a direct and positive impact on household consumption expenditure with the quantity of income-independent consumption increasing at the same rate as population growth (Robinson & Thurlow, 2004, p. 2). The level of minimum household consumption expenditure also increases proportionally with population growth. Growth affects average rather than marginal consumption demand implying that new consumers share the same preferences as existing consumers (Robinson & Thurlow, 2004, p. 3). The subsistence consumption of marketed commodities and the subsistence consumption of commodities produced at home are both adjusted upwards by the rate of population growth. With regards to labor force growth, with a fixed labor supply, flexible nominal wages and full employment, the between period levels of labor supply are adjusted according to the rate of labor force growth (Robinson & Thurlow, 2004, p. 4). Changes in total factor productivity are imposed exogenously by introducing a technological parameter in the model equations for the calculation of the quantity of aggregate value-added (Robinson & Thurlow, 2004, p. 6). Thus, the efficiency parameter in the Constant Elasticity of Substitution value-added function is adjusted upwards by the rate of total factor productivity growth.

The model is programmed and solved as a mixed complementarity problem using the General Algebraic Modeling System (GAMS) and the PATH solver.

4. The data: a social accounting matrix for Brazil

The principal data source for a CGE model is a social accounting matrix (SAM). A SAM is a square matrix representing an economy and empirically describes the structure of production and transactions between sectors, institutions and factors of production. The two main functions of a SAM are to organize data and to provide the statistical basis for the development of an economic model (King, 1985, p. 17). SAMs are typically constructed based on national and regional accounts data and government surveys such as household expenditure surveys, agricultural and industry surveys, and census data.

Illegal sectors are not explicitly described in the national accounts from which SAMs are constructed. In the case of forestry and deforestation, it is reasonable to assume that expenditures and receipts from illegal forestry and illegal deforestation are aggregated with those of the legal forestry sector. The rationale is that once timber is extracted from the forest, it is presented to consumers as a legal product and accounted for as such. The SAM used in the current analysis was developed and documented in Banerjee (2008). What follows is a description of the procedures employed in the regional disaggregation of illegal forestry and illegal deforestation from the legal forestry sector.

4.1. Illegal deforestation

The starting point for disaggregating the illegal deforestation sector is to estimate the total area illegally deforested in 2003, which is the base year for the SAM. Illegal deforestation in this analysis is defined as the removal of timber and the subsequent clearing of a forested area in the absence of a valid government issued deforestation authorization and the unauthorized transport of timber from the forest to the mill. In Brazil, the majority of deforestation, both legal and illegal, occurs in the north, north east and center west regions due to resource availability and reduced state monitoring and enforcement capacity.[2] Consequently, in the SAM only deforestation in these regions is considered.

Total deforestation in Brazil's Legal Amazon in 2003 was 2,528,200 ha (The National Space Research Institute's [INPE] Program for Satellite Monitoring of the Brazilian Amazon [PRODES]). Deducting 210,032 ha of legally authorized deforestation registered with SISPROF (Integrated Licensing and Control System for Forest Resources and Products), which tracks the approval of deforestation and forest management permits, illegal deforestation in 2003 was approximately 2,318,168 ha or 92% of total deforestation (MMA, 2008).

Next, the forest product output from illegal deforestation is calculated. Forest product output from legal deforestation was obtained from SISPROF. It is reasonable to assume that only timber illegally harvested in proximity to new logging centers can be recovered at the same rate as legally harvested timber, since these areas are typically difficult to access and present limited state monitoring and enforcement capacity (Lentini, 2008, personal communication). New logging centers are areas on the agricultural frontier with sawmills established less than 10 years ago and where relatively undisturbed forests are logged (Lentini, Pereira, Celentano, & Pereira, 2005, p. 37). These centers form an arc from the BR-163 highway in western Pará to the extreme north west of Mato Grosso until the southern reaches of the state of Amazonas close to the Trans-Amazon highway (Lentini, Pereira, et al., 2005, p. 62). Therefore, in calculating illegal forest product output, deforestation occurring in municipalities in which new logging centers are located are assumed to produce the same volume of output per hectare deforested as the legal deforestation sector, while deforestation occurring outside of those municipalities are assumed to produce a negligible quantity of timber. Levels of deforestation by municipality were obtained

[2] Brazil's administrative regions are north, north east, south east, south, and center west. The northern region is composed of the states of Rondônia, Acre, Amazonas, Roraima, Pará, Amapá, and Tocantins. The north eastern region is Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, and Bahia. The south east is Minas Gerais, Espírito Santo, Rio de Janeiro, and São Paulo. The south is Paraná, Santa Catarina, and Rio Grande do Sul. The center west is Mato Grosso do Sul, Mato Grosso, Goiás, and the Distrito Federal.

from PRODES, while the location of new logging centers was extracted from Lentini, Pereira, et al. (2005, p. 63). Illegal deforestation in municipalities in which new logging centers are located amounted to 15.7% and 27.1% of total illegal deforestation in the north and center west, respectively. Therefore, illegal deforestation produces 15.7% and 27.1% of the timber that the legal deforestation sector produces per unit area in the north and center west, respectively.[3] Given the lack of data on logging centers in the north east, it is assumed that illegal deforestation in this region produces 10% of the timber per unit area when compared to its legal counterpart.

The illegal deforestation sector's expenditures on intermediate consumption, labor and capital for producing forest products are identical to that of the legal deforestation sector's expenditure per unit area. In the SAM, these expenditures, along with the value of the illegal deforestation sector's forest product output value, are deducted from the legal forestry sector.

The treatment of the illegal deforestation sector's expenditure on forestland and its payments to the indirect tax account differ from that of the legal deforestation sector. First, with regards to forestland, it is assumed that illegal deforestation operations occurring on 50% of special areas (military zones, quilombola communities, which are areas settled by the descendents of slaves, environmental protection areas, and rural settlements), private land in dispute and land without legal title make reduced forestland payments. This is a reasonable assumption since private land aside, most illegality occurs on land with these tenure types. Furthermore, firms that use land illegally pay less than those that do so legally due to weaker property rights guarantees and the risks inherent in the illegal acquisition of land. As such, it is assumed that these illegal operations pay 75% of the legal deforestation sector's forestland rent per unit of output.

The illegal sector's percentage reduction in forestland payments is the total area in special areas, private land in dispute and land without legal title, divided by the total land area multiplied by 0.5 (area data source: Brazilian Institute for Geography and Statistics [IBGE], 1996, as cited in Lentini, Pereira, et al., 2005, p. 32). The proportion of production that is subject to reduced forestland payments is 0.76, 0.57 and 0.34 in the north, north east and center west, respectively and is indicative of the relative importance of private land in each region. To estimate the illegal sector's forestland payment per unit of forest product output, these proportions are multiplied by 0.75 and then by each region's legal deforestation sectors' payment to forestland per unit of forest product output.[4]

The illegal deforestation sector does not pay indirect taxes. Firms engaged in illegal deforestation are, however, subject to fines if they are detected and successfully prosecuted. It is therefore necessary to estimate the value of fines issued and the collection rate for 2003. The total value of fines issued for illegal forestry and deforestation and the rate of collection is estimated as 636 million Brazilian *Reais* (Brazilian Institute of the Environment and Natural Resources [IBAMA] and Macqueen et al., 2003, p. 54) and 6% (extrapolated from Macqueen et al., 2003, p. 54; Brito, Barreto, & Rothman, 2005, p. 10; Brito & Barreto, 2006, p. 3, and IBAMA), respectively. The value of fines paid by region is calculated according to the weight of the value of each region's illegal forest product output. Under the balanced macroeconomic closure used in the modeling experiments to follow, government savings are flexible and tax rates are fixed. With fines paid to the indirect tax account in the SAM, fines are treated as a fixed share parameter and calibrated from the SAM, where the value of the fine that the illegal sector pays is proportional to its output.

[3] In the case of the center west, given the high levels of deforestation and the large number of new logging centers, this value is further adjusted downwards since calculated as described above, illegal deforestation on its own would account for over 53% of the total (legal deforestation, legal logging and illegal logging) forest sector output.

[4] As better data becomes available, a closer approximation of illegal sectors' payments to forestland will be possible.

Firms engaged in deforestation first remove the valuable timber on site and then clear the land. With labor payments for harvesting timber calculated above, labor expenditures for land clearing are calculated here. From Cattaneo (2002), clearing 1 ha of forestland requires approximately half a month of low-skilled labor. Therefore, the cost of labor for forest clearing is estimated as the product of half of the average monthly forest sector wage and the number of hectares of forest cleared. The imbalances in labor expenditures generated as a result of this additional labor payment are distributed between all sectors in the SAM according to the relative magnitude of each sector's labor expenditure. The imbalances created in the indirect tax account resulting from the illegal sectors' payment of fines are distributed between all sectors in the SAM according to the relative magnitude of each sector's indirect tax expenditure.

The difference between the illegal deforestation sector and the legal deforestation sector's expenditure to produce a unit of output is referred to as the deforestation product in the SAM. This is considered to be the level of above normal profits earned for operating illegally. Above normal profits are allocated to each labor class according to a matrix describing how these profits are assumed to be distributed, with higher income households receiving a greater share in the profits.

Finally, adjustments to the SAM are made to account for the consumption of the deforestation product. With the disaggregation of the illegal deforestation sector, the size of the deforestation product is larger than when only legal deforestation was considered. The sole consumer of the deforestation product is the deforestation institution, which derives its entire income from the returns to agricultural land. To provide the additional income that the deforestation institution requires to consume the deforestation product, the value of the deforestation product produced by the illegal sector is deducted from the agricultural land rent distributed to households and the enterprise. This value is deducted according to the weight of each institution's share of agricultural land rent and is reallocated to the deforestation institution as income.

4.2. Illegal forestry

To disaggregate the illegal forestry sector from the legal forestry sector in the SAM, the total volume of timber authorized for harvest through forest management plans and deforestation authorizations in 2003 is calculated. Next, total timber consumption for 2003 is extrapolated from data for 1998 and 2004 (Lentini, Pereira, et al., 2005, p. 69; Lentini, Veríssimo, & Pereira, 2005, p. 1). Deducting the authorized volume from total consumption, the total illegal harvest volume from deforestation and forestry is estimated as 56% of total output in 2003. The illegal forestry sector's output is calculated as the difference between total illegal forest product output and the illegal deforestation sector's forest product output.

The illegal forestry sector's expenditures on intermediate consumption, labor and capital per unit of output are assumed to be the same as its legal counterpart and are deducted from the legal forestry sector's expenditures. The illegal forestry sector's payments to forestland and fines are calculated in the same way as for the illegal deforestation sector. Since the illegal sector generally pays less for forestland and makes less payments to the indirect tax account (interpreted as fines) compared with the legal sector, the illegal sector's expenditure for a given unit of forest product output is less than that of the legal sector. As in the case of the illegal deforestation sector, this difference is interpreted as above normal profits and is distributed to labor in the same manner as for the illegal deforestation sector.

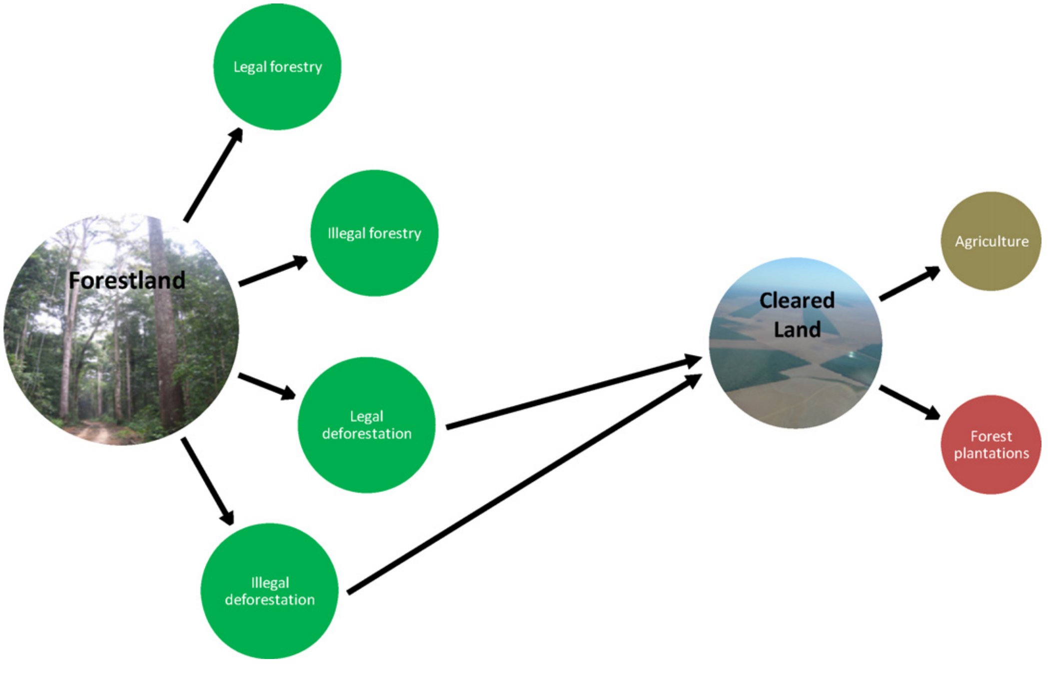

Fig. 1. Relationship between forestry, deforestation, forest plantations, agriculture, forestland and agricultural land.

5. Scenario design

We implement two scenarios to evaluate the socioeconomic and land-use impacts of forest concessions in the Brazilian Amazon. The first scenario is the baseline scenario which projects the Brazilian economy from the base year of 2003–2018, in the absence of forest concessions. The second scenario, the policy shock scenario, projects the economy from 2003 to 2018 with the implementation of forest concessions beginning in 2008 and terminating in 2017. The difference between the baseline and policy shock scenarios is the policy impact of forest concessions on the Brazilian economy and land use. This section develops the baseline and policy shock scenarios in detail.

The recursive dynamic model enables the updating of factor stocks. In both the baseline and the policy shock scenarios, labor supply is updated based on the estimated labor force growth rate (source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2008). Capital stocks are updated endogenously based on the previous period's allocation of investment and the rate of capital depreciation (source: Organisation for Economic Co-operation and Development [OECD], 2006). In both the baseline scenario and the policy shock scenarios, the stock of agricultural land is also updated each year. Since the legal and illegal deforestation sectors clear forestland, the quantity of forestland cleared in one year is used to update the factor supply of agricultural land in the subsequent year, which becomes available to the agricultural and forest plantation sectors. Finally, total factor productivity growth is updated based on projections from OECD (2006) while an estimate of the average capital to output ratio was obtained from Morandi and Reis (2004).

Fig. 1 represents the relationship between natural forest management, forest plantations, agriculture, forestland and agricultural land. In this figure, the legal and illegal forestry and deforestation sectors use forestland as a factor input in one period. Legal and illegal deforestation convert forestland into cleared land making it available to the agricultural and forest plantations sectors in the subsequent period.

Eq. (1) demonstrates the updating of the agricultural land stock based on the previous period's level of deforestation using the stock of agricultural land in the north as an example.

$$\begin{aligned}\mathrm{QFS}_{\text{agriland north},\, a,\, t+1} &= \mathrm{QFS}_{\text{agriland north},\, a,\, t} + \mathrm{QF}_{\text{forestland north, legal deforestation north},\, t}\\ &\quad + \mathrm{QF}_{\text{forestland north, illegal deforestation north},\, t} \qquad (1)\end{aligned}$$

where: $\mathrm{QF}_{f,a,t}$ = quantity of factor f demanded by activity a in time t and $\mathrm{QFS}_{f,a,t}$ = quantity of factor supply for activity a in time t.

In the policy shock scenario, the forest concessions policy is simulated as an increase in the factor supply of forestland in the north. Of the 193.8 million ha of public forests registered in Brazil's Public Forest Registry, 43.7 million ha (22.5%) are legally eligible to be designated as forest concessions, with 99.8% of these forests located in the Legal Amazon. Of this area, 11.6 million ha may be designated as management units for forest concessions for the 2007–2008 period, over 99% of which are located in Brazil's northern administrative region (i.e. the Legal Amazon with the exception of the state of Mato Grosso). The majority of these forests are National Forests with approved forest management plans or National Forests with management plans in development. Of these 11.6 million ha, 3.9 million ha were designated as priority areas for forest concessions, all of which are located in the states of Pará and Rondônia. One million ha of this area are expected to be designated as forest concessions and put up for bidding in 2008 (SFB, 2007, p. 30). Over the next 10 years the maximum area that the state plans to designate as forest concessions is 13 million ha, or 3% of the Brazilian Amazon (MMA, 2005, p. 5). Taking a more conservative estimate of 10 million ha over the next 10 years, the policy scenario introduces 1 million ha of forestland stock per year in the north beginning in 2008, with the final 1 million ha introduced in 2017.[5]

Eqs. (2)–(4) provide a mathematical formulation of the increase in forestland stock. The sum of all activities' demand for a given factor is equal to the total factor supply as given by Eq. (2). For simplicity, the element of time is dropped.

$$\sum_{a \in A} \mathrm{QF}_{f,a} = \mathrm{QFS}_{f} \qquad (2)$$

where: $\mathrm{QF}_{f,a}$ = quantity of factor f demanded by activity a, QFS_f = quantity of factor supply, and $\mathrm{QFS0}_f$ = initial quantity of factor supply.

As an example, in the first year forest concessions are implemented, forestland supply increases by 46% in the north. Given Eq. (3), this increase enters the model as in Eq. (4).

[5] Forestland in the model is treated as homogenous; specifically, it is not distinguished by tenure type. As a result, forestland that enters the model as forest concessions is technically available to both legal and illegal forestry and deforestation sectors. Deforestation is of course not permitted by law on forest concessions and the illegal deforestation of forest concessions is not likely to occur at any significant level given a concessionaire's vested interest in prohibiting encroachment by third parties. It is thus assumed that within the aggregate forestland base, deforestation occurs on forestland not allocated as concessions.

Since:

$$QFS_f = QFS0_f \tag{3}$$

$$QFS_{\text{forestland north}} = 1.46 \times QFS0_{\text{forestland north}} \tag{4}$$

Illegal forestry operations produce less timber and generate more wood waste than their legal counterparts. Following Gutierrez-Velez and MacDicken (2008, p. 252), planned forestry is used as a proxy for legal forestry and unplanned forestry is used as a proxy for illegal forestry. Barreto, Amaral, Vidal, and Uhl (1998, p. 13) found that planned forestry operations yield 30% more timber than unplanned operations since they generate less waste during timber harvest. To account for inefficiencies in illegal operations and the increasing scarcity of forestland for use by illegal sectors as forest concessions are implemented, a yield distortion parameter is introduced into the illegal forestry and illegal deforestation sectors' equations for forest and deforestation product output. Eq. (5) represents the impact of the distortion parameter on a sector's activity level. In this equation, as a sector's activity level increases, its output increases at a slower rate as determined by the yield distortion parameter.

$$QXAC_{ac} + \sum_{h \in H} QHA_{ach} = \varphi_{ac} \times \theta_{ac} \times QA_a \tag{5}$$

where: QHA_{ach} = quantity of household home consumption of commodity c from activity a for household h, $QXAC_{ac}$ = quantity of marketed output of commodity c from activity a, φ_{ac} = yield distortion parameter for activity a and commodity c, θ_{ac} = yield of output of c per unit of activity a, and QA_a = activity level.

To calculate the distortion parameter, the area of forest concessions established each year is deducted from the total federal public forests eligible to be designated as forest concessions. The proportion of this value and the total federal public forests eligible for forest concessions is calculated and is interpreted as the distortion parameter. With 1 million ha of public forests designated as forest concessions per year, this distortion parameter is smaller in value and larger in effect year upon year.[6]

With regards to model closure rules, the modeling experiments are conducted in a balanced macroeconomic environment. Investment is a fixed share of absorption and the nominal absorption shares of investment and government consumption are fixed at their base year levels (Lofgren et al., 2002, p. 15). Government savings are flexible and direct tax rates are fixed. A flexible real exchange rate is chosen for the rest of the world closure and the domestic price index is chosen as the numeraire. Labor, capital, agricultural land and forestland are fully employed and mobile between sectors.

5.1. Results

The overall policy impact of forest concessions on the Brazilian macroeconomic environment is relatively small, while the policy results in substantive changes in the dynamics of land use in the Brazilian Amazon. In the absence of forest concessions, legal forestry activities contract

[6] The yield distortion parameter calculated in this way likely underestimates the inefficiency of illegal operations as well as the increasing scarcity of forestland for illegal operations as forest concessions expand. As data on the real economic effects of forest concessions become available, the ability to estimate this parameter will improve.

Table 1
Average annual growth rate in the level of domestic activity between 2003 and 2018 in Brazil's north (N), north east (NE), south east (SE), south (S) and center west (CW).

Activity	Baseline (%)	Policy shock (%)	Difference (%)
Agriculture N	1.85	2.29	0.45
Agriculture NE	1.69	2.05	0.36
Agriculture SE	5.06	5.15	0.09
Agriculture S	2.00	2.17	0.18
Agriculture CW	1.65	1.60	−0.05
Legal forestry N	−0.02	13.51	13.53
Legal forestry NE	5.91	3.69	−2.22
Legal forestry SE	1.18	1.10	−0.08
Legal forestry S	1.03	0.99	−0.04
Legal forestry CW	−3.67	0.42	4.09
Illegal forestry N	1.65	12.24	10.59
Illegal forestry NE	5.37	2.58	−2.78
Illegal forestry CW	−2.13	0.80	2.93
Forest plantations N	14.40	11.28	−3.11
Forest plantations NE	12.40	9.75	−2.65
Forest plantations SE	−7.31	−9.19	−1.87
Forest plantations S	2.84	0.27	−2.56
Forest plantations CW	12.40	9.12	−3.28
Legal deforestation N	0.28	9.02	8.74
Legal deforestation NE	−10.52	−0.60	9.92
Legal deforestation CW	−0.55	9.67	10.22
Illegal deforestation N	5.07	−21.01	−26.08
Illegal deforestation NE	−0.70	−8.17	−7.47
Illegal deforestation CW	3.19	−2.00	−5.19

in the north and center west. Increased demand for forest products is met by growth in forest plantations with the exception of the south east. Introducing the concessions policy, legal forestry in the north and center west grow faster (Average Annual Growth Rate [AAGR] of 13.53% and 4.09%, respectively; Table 1), which is an indication of the current scarcity of forestland for legal forestry operations. Illegal forestry activities increase in the baseline in the north and north east and decrease in the center west. In the policy scenario, illegal forestry activity growth increases dramatically in the north and to a lesser degree in the center west, while growth is reduced in the north east (AAGR of 10.59%, 2.93% and −2.78%, respectively).

Legal deforestation in the baseline expands slightly in the north and contracts in the north east and center west. Forest concessions have a positive and large impact on growth rates of legal deforestation (AAGR of 10.22%, 9.92% and 8.74% in the center west, north east and north, respectively; Table 1; Fig. 2). However, since the legal deforestation sector's demand for forestland is initially quite small, the area cleared by legal deforestation remains relatively small compared with that cleared by the illegal deforestation sector. Illegal deforestation grows in the north and center west and contracts in the north east in the baseline; the policy impact, however, results in a contraction in all regions (AAGR of −26.08%, −7.47% and −5.19% in the north, north east and center west, respectively). This contraction in illegal deforestation is a function of the increasing scarcity of forestland on which firms may operate illegally and the reduced returns to agricultural land which finance land clearing. In addition, since legal deforestation has a higher timber recovery rate than its illegal counterpart, it is able to out-compete the illegal sector in terms

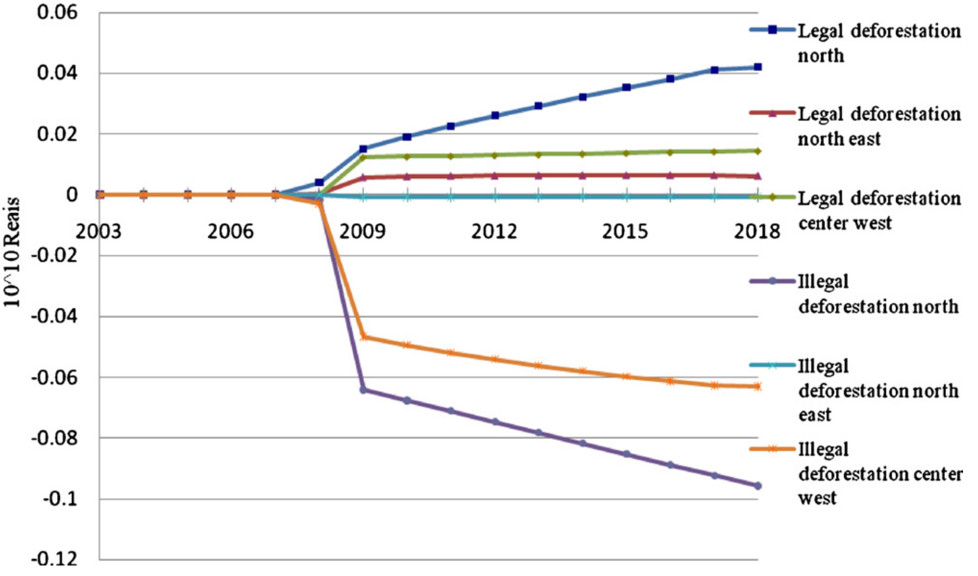

Fig. 2. Policy impact on the level of legal and illegal deforestation.

of forest product output. Overall with regards to illegality, forest concessions reduce the growth of illegal forestry in the north east and cause illegal deforestation to contract in all regions, especially in the north.

Given increased forest product output from legal and illegal forestry and legal deforestation in the north, the forest plantations sectors experience a negative policy impact in all regions (AAGR of −3.28%, −3.11%, −2.65%, −2.56% and −1.87% in the center west, north, north east, south and south east, respectively; Table 1). Nonetheless, forest plantation activities continue to grow with the exception of the south east. With increased supply of raw materials from forest product producing sectors, the processed wood and pulp and cellulose sectors grow at a faster rate. Both domestic and export demand grow faster for forestry and agricultural products, while agricultural and forest product prices grow at a slower rate as a result of the policy shock.

Agricultural activity grows in all regions in the baseline; the policy impact accelerates growth slightly in all regions with the exception of the center west where growth is negatively affected (AAGR of 0.45%, 0.36%, 0.09%, 0.18% and −0.05% in the north, north east, south east, south and center west, respectively; Table 1). While the greater rate of expansion in the north and north east are a function of increases in the agricultural land supply resulting from deforestation and the forest plantations sectors' reduced demand for agricultural land, the decline in the center west is the result of a large decrease in illegal deforestation given the importance of this sector in clearing land for agriculture.

High-income households gain the most from policy implementation, followed by the enterprise and mid and low-income households (AAGR of 0.03%, 0.02%, 0.02% and 0.01%, respectively). From 2009 to 2012, the policy impact on low-income households is negative; from 2009 to 2010 the policy impact on mid-income households is negative. The impact on high-income households is always positive, though the difference between the baseline and the policy shock also dips slightly in 2009. Since high- and mid-income households receive a greater share of income from legal and illegal deforestation among other things, their incomes grow at a faster rate. Low- and mid-income households experience an adjustment period to the policy shock with their incomes negatively affected for a short period in comparison to the baseline. The overall impact on income growth over the time period, however, is positive.

In the baseline scenario, labor and capital are shown to increase income. The policy impact is also positive for the income of all labor classes and capital due to increased growth in labor and capital demand and higher rates of growth in wages. The policy impact on growth of forestland income is positive and large in the north and negative in other regions. With the price of forestland negatively affected by the policy in all regions, the increase in income in the north is explained by greater supply and demand for forestland as forest concessions are implemented. Agricultural land income grows in all regions in the baseline, while the policy impact is positive in the north and negative in all other regions. With all regions experiencing growth in demand for agricultural land in the policy scenario, with the exception of the center west, the negative impact on agricultural land income in all regions but the north is explained by the magnitude of the decrease in the price of agricultural land.

5.2. Discussion and policy implications

Our findings indicate that establishing forest concessions on public forestland resulted in greater household welfare and accelerated growth in the legal forestry and the agricultural sectors in most regions, implying positive and balanced changes to the Brazilian economy. Forest concessions also resulted in reduced illegality in the case of deforestation. Less desirable, however, was the disappointing response of the illegal forestry and legal deforestation sectors. Although the policy reduced the growth rate of illegal forestry in the north east, the contraction of illegal forestry in the center west in the baseline scenario was reversed and the illegal forestry sector in the north grew faster. In the case of legal deforestation, the contraction experienced in the baseline in the north east and center west was reversed and in the north, legal deforestation grew more rapidly.

The illegal forestry sector's disappointing response must be qualified, however. In the modeling exercises, forest concessions are implemented in the absence of any increase in the government's ability to monitor, enforce and prosecute illegality. Improving state capacity in this area may go a long way in tackling forest sector illegality, the consequences of which are largely intuitive: higher illegal operating costs would force firms into legal compliance or out of business. To compensate for reduced output from the illegal forestry sector, the legal forestry and the forest plantations sectors would likely expand more rapidly. Nonetheless, with potentially less timber on the market, forest product prices could increase somewhat. The model developed in this research is amenable to examining the effect of improved state capacity; determining the level of fines that would be required to reduce illegality to socially optimal levels would be useful to policy makers in their decisions on budgetary allocations for monitoring and enforcement.

Improving capacity for monitoring and enforcement has become a priority for the Brazilian government, weighing heavily in the state's Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (Presidência da República, 2004, p. 22/23) and Brazil's Public Forest Management Law. Created through the law, The National Forestry Development Fund aims to allocate resources to strengthen monitoring and enforcement capacity. Recent efforts by the Brazilian government have demonstrated that increased monitoring and enforcement can play an important role in reducing deforestation – between 2003 and 2008, deforestation in the Legal Amazon dropped from 2,539,600 to 1,291,100 ha (INPE, 2009). In 2009 alone, the state reports to have confiscated 230,000 m^3 of illegally harvested wood, halted the development on almost half a million hectares of forestland and issued \$1.6 billion USD in fines (New York Times, 2009).

Although positive from an environmental perspective, given the importance of illegal logging and deforestation to the regional economy, many workers have been stripped of their livelihoods as a result of the crackdown on illegality. Parallel efforts to design policies and programs for worker retraining, new income generating activities and insuring access to low-cost credit will be critical if the reduction in illegality is to prove to be one that may be sustained.

The results of this modeling exercise have shown that one of the key drivers of forest sector illegality and deforestation is the undervaluation of forestland. Mechanisms to increase the value of standing and managed forests are therefore fundamental to reversing this trend. Three recent developments provide an optimistic outlook for combating illegality and deforestation, namely Payment for Environmental Services (PES), Reduced Emissions from Deforestation and Degradation (REDD) and the voluntary carbon market. These mechanisms are discussed in turn.

Brazil's *Bolsa Floresta*, or Forest Allowance Program, is a form of PES program developed by the state government of Amazonas. *Bolsa Floresta* provides direct financial support to families and community associations that commit to no new deforestation in undisturbed forests and supports the development of income generating activities, technical training and the improvement of community services (Viana, 2008, p. 146). In operation since 2007, the program has shown encouraging results with a large area of influence and high levels of participation; the program encompasses 14 Conservation Units totaling 10 million ha, while 6804 families have benefited directly from the program (FAS, 2009). With the multiplicity of actors involved and diverse interests, one of the key challenges for this program is to improve coordination between communities and institutional actors (Viana, 2008, p. 150). With lessons learned and internalized through this pilot experience, this model may be applied to other states and areas outside of state conservation areas. Furthermore, since this program is funded through the Amazonas state government budget, additional creative financing mechanisms will be needed to insure sustainability of the program. Identifying agents that benefit significantly, although indirectly, from the conservation of this and other potential project areas would be an important first step.

Reduced Emissions from Deforestation and Degradation (REDD) is a mechanism to financially compensate countries for reducing their carbon emissions from deforestation and forest degradation below an established baseline; REDD may be included as a component of a post-Kyoto Protocol or a stand-alone agreement. With 17% of global and 75% of Brazil's carbon emissions resulting from deforestation and forest degradation, REDD presents Brazil with an enormous opportunity for increasing the value of forests, both managed and protected. Embedded in the *Bolsa Floresta* Program is Brazil's first REDD project, the Juma Reserve. This project aims to protect almost half a million hectares of Amazonian forest which would otherwise have been deforested in a business as usual scenario. The strengthening of environmental monitoring and enforcement is a cornerstone component of the program (Governo do Estado de Amazonas, 2008, p. 6). In addition, the project seeks to increase local capacity in sustainable forest management enterprises, promote scientific research and education, and finally, traditional and indigenous communities will have access to *Bolsa Floresta's* benefits (Governo do Estado de Amazonas, 2008, p. 7).

The third emerging market mechanism that may be applied to increasing the value of standing, well-managed forests is the rapidly emerging voluntary carbon market. A forest may be certified under one of the various carbon certification schemes (e.g. the Voluntary Carbon Standard (VCS) or the Climate, Community and Biodiversity Standard (CCB)) if it is shown to reduce carbon emissions below a baseline through improved management, avoided deforestation or additional carbon sequestration. Landowners, or the state in the case of public land, may then sell the verified emissions reductions (VERs) or *offsets* in the voluntary carbon market. This market is growing rapidly and has doubled in size over the last year (Hamilton et al., 2009, p. i). Financing for forestry projects has also grown considerably; in 2007, forestry projects accounted for 1% of registered projects in the Chicago Climate Exchange (CCX), while in 2008, their share increased to 22% (Hamilton et al., 2009, p. 32).

For the voluntary carbon market to become an effective mechanism for creating value in standing and managed forests, a number of challenges need to be overcome. Given the complex dynamics of forest carbon, investment in methodologies to establish baselines is needed. In order to generate funding through this market, demand must be created; to this end, the assurance of the quality of the offsets that are generated by forestry projects is of critical importance. Methodological rigor, however, must be balanced with the maintenance of low transaction costs (Harris, 2007, p. 34). Increasing the transparency of projects as well as of market transactions is also necessary to create demand and maintain investor confidence. Furthermore, the development of a universal registry for carbon offset projects is required to avoid the double counting of the offsets generated.

Finally, our research identified a need for complimentary policies to stabilize the incomes of low- and mid-income households as forest concessions are implemented. Low-income households experience negative income growth from between 2009 and 2012 while mid-income households are negatively affected between 2009 and 2010. Considering the enormous effort required to implement forest concessions at the scale proposed by the government (13 million ha of concessions over the next decade), there is significant need for trained forestry managers and technicians. The private sector will require forest managers and technicians to assess potential concessions, develop bids and manage concessions on the ground in accordance with the high environmental standards demanded by the Public Forest Management Law. Public sector officials trained in forest management and economics are required to develop management plans for National Forests and monitor and enforce contracts. Establishing programs to retrain individuals involved in illegal forestry and deforestation can aid in counteracting the negative impacts on income growth experienced in the initial years of policy implementation as well as meet a very real and pressing demand.

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