

Modeling Forest Sector Illegality in a Dynamic Computable General Equilibrium Framework:
The Case of Forest Concessions in Brazil

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Abstract

The Brazilian forest sector has undergone crisis due to 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. By assessing the policy in a dynamic computable general equilibrium framework we find that household welfare improves and legal forestry grows at an accelerated rate. In the absence of improved monitoring and enforcement, however, forest concessions are shown to have a depressing effect on the price of forest land and accelerate illegal forestry operations.

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1.0. Introduction

Brazil's Legal Amazon occupies approximately 5 million km² or 59% of Brazil's total land area; 2.6 million km² of the Legal Amazon are forested¹. 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 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). 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 km² 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 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 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 of concessions by the end of the decade, concessions can make a tremendous contribution to fostering sustainable socio-economic 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, policy implications and future research directions.

2.0 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 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).

3.0. 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, & Wilcoxon, 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; see Appendix A, equations 50 to 54).

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 (see Appendix A). 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; see Appendix A). 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; see Appendix A). 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.

4.0. 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 sectors 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 capacity². Consequently, in the SAM only deforestation in these regions is considered.

Total deforestation in Brazil's Legal Amazon in 2003 was 2,528,200 hectares (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 hectares (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 as characterized by Lentini et al., (2005a, p. 37) are sawmills established less than 10 years ago on the agricultural frontier where relatively undisturbed forests are logged. 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 et al., 2005a, 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 not to produce timber. Levels of deforestation by municipality were obtained from PRODES while the location of new logging centers was extracted from Lentini, Pereira, Celentano and Pereira (2005a, 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, respectively³. 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 is 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 et al., 2005a, 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 output⁴.

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 reais and 6% respectively (estimated fine based on data from the Brazilian Institute of the Environment and Natural Resources [IBAMA] and Macqueen et al., 2003, p. 54. Estimated rate of collection extrapolated from Macqueen et al., 2003, p. 54; Brito, Barreto & Rothman, 2005, p. 10; Brito & Barreto, 2006, p. 3; and, IBAMA). 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

Subsequent to the removal of the valuable timber on site, deforesting firms clear the area. The deforestation sector makes payments to labor to harvest the timber and to clear the remaining forest. With labor payments for timber harvest calculated above, labor expenditures for land clearing are calculated here. From Cattaneo (2002), clearing one hectare 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 in illegality. 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.

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 enterprises. 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 et al, 2005a, p. 69; Lentini, Veríssimo, & Pereira, 2005b, 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.

5.0. 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 to 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. 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 (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 (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 plantations 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).

Figure 1 represents the relationship between natural forest management, forest plantations, agriculture, forestland, and agricultural land. In this figure, 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.

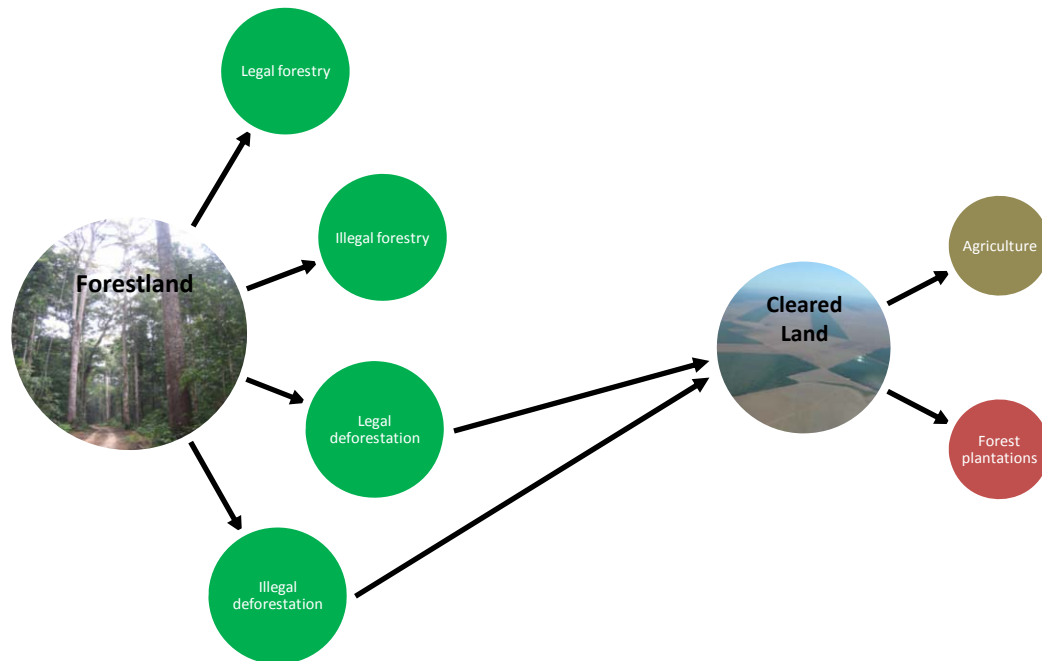


Figure 1. Relationship between forestry, deforestation, forest plantations, agriculture, forestland and agricultural land

Equation 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.

$$QFS_{agriland\ north,a,t+1} = QFS_{agriland\ north,a,t} + QF_{forestland\ north,legal\ deforestation\ north,t} + QF_{forestland\ north,illegal\ deforestation\ north,t} \quad (1)$$

Where:

$QF_{f,a,t}$	= Quantity of factor f demanded by activity a in time t.
$QFS_{f,a,t}$	= 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 hectares of public forests registered in Brazil's Public Forest Registry, 43.7 million hectares (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 hectares may be designated as management units for forest concessions for the 2007 to 2008 period, over 99% of which are located in Brazil's northern administrative region (i.e. in 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 hectares, 3.9 million hectares were designated as priority areas for forest concessions, all of which are located in the states of Pará and Rondônia. One million hectares 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 hectares or 3% of the Brazilian Amazon (MMA, 2005, p. 5). Taking a more conservative estimate of 10 million hectares over the next 10 years the policy scenario introduces 1 million hectares of forestland stock per year in the north beginning in 2008 with the final 1 million hectares introduced in 2017⁵.

Equations 2 to 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 equation 2. For simplicity, the element of time is dropped.

$$\sum_{a \in A} QF_{f,a} = QFS_f \quad (2)$$

Where:

$QF_{f,a}$	= Quantity of factor f demanded by activity a.
QFS_f	= Quantity of factor supply.
$QFS0_f$	= Initial quantity of factor supply.

As an example, in the first year forest concessions are implemented forestland supply is increased by 46% in the north. Given equation 3, this increase enters the model as in equation 4.

Since:

$$QFS_f = QFS0_f \quad (3)$$

$$QFS_{forestland\ north} = 1.46 \cdot QFS0_{forestland\ north} \quad (4)$$

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 available 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 per unit of activity. Equation 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.

$$QXAC_{ac} + \sum_{h \in H} QHA_{ach} = \varphi_{ac} \cdot \theta_{ac} \cdot QA_a \quad (5)$$

Where:

QHA_{ach}	= Quantity of household home consumption of commodity c from activity a for household h.
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$QXAC_{ac}$	= 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.
QA_a	= Activity level.

In order to calculate the distortion parameter, the area of forest concessions established each year is deducted from the total federal public forests eligible for 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 hectares of public forests designated as forest concessions per year, this distortion parameter is smaller in value and larger in effect year upon year⁶.

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.

6.0. Results

With regards to macroeconomic indicators in the baseline scenario, the annual compound percent change (ACPC) in real GDP at market prices is 5.5%. The ACPC in household consumption, investment, government consumption, exports and imports are 5.9%, 6.2%, 4.4%, 5.1%, and 5.8%, respectively. There is an increase in the ACPC in low, mid and high-income households' consumption (3.7%, 5.6% and 6.6%, respectively). The welfare of all households

improves; the ACPC in equivalent variation is 5.0%, 8.6% and 11.2% for low, mid and high-income households, respectively.

The impact of the forest concessions policy on the economy is calculated as the difference between the value of indicators in the baseline scenario and the policy shock scenario. The policy impact on real GDP at market prices is positive for all years with the exception of 2009. Forest concessions have a large positive impact on the average annual growth rate (AAGR) of legal forestry activity in the north and center west and a negative effect in the north east, south east and south (13.53%, 4.09%, -2.22%, -0.08% and -0.04%, respectively; Table 1). The impact on illegal forestry's AAGR in activity is positive and the highest in the north and center west and negative in the north east (10.59%, 2.93% and -2.78%, respectively).

Table 1. Average annual growth rate in the level of domestic activity between 2003 to 2018

Activity	Baseline (%)	Policy shock (%)	Difference (%)
Agriculture north	1.85	2.29	0.45
Agriculture north east	1.69	2.05	0.36
Agriculture south east	5.06	5.15	0.09
Agriculture south	2.00	2.17	0.18
Agriculture center west	1.65	1.60	-0.05
Legal forestry north	-0.02	13.51	13.53
Legal forestry north east	5.91	3.69	-2.22
Legal forestry south east	1.18	1.10	-0.08
Legal forestry south	1.03	0.99	-0.04
Legal forestry center west	-3.67	0.42	4.09
Illegal forestry north	1.65	12.24	10.59
Illegal forestry north east	5.37	2.58	-2.78
Illegal forestry center west	-2.13	0.80	2.93
Forest plantations north	14.40	11.28	-3.11
Forest plantations north east	12.40	9.75	-2.65
Forest plantations south east	-7.31	-9.19	-1.87
Forest plantations south	2.84	0.27	-2.56
Forest plantations center west	12.40	9.12	-3.28
Legal deforestation north	0.28	9.02	8.74
Legal deforestation north east	-10.52	-0.60	9.92
Legal deforestation center west	-0.55	9.67	10.22
Illegal deforestation north	5.07	-21.01	-26.08
Illegal deforestation north east	-0.70	-8.17	-7.47
Illegal deforestation center west	3.19	-2.00	-5.19
Mining and petroleum	6.28	6.25	-0.02
Industry	5.72	5.73	0.01
Wood processing	4.05	4.43	0.38
Pulp and cellulose	3.49	4.24	0.75
Food processing	3.61	3.71	0.10
Utilities	5.92	5.94	0.02
Construction	6.04	6.07	0.03
Commerce	6.86	6.79	-0.08
Transportation	5.91	5.92	0.01
Private services	5.96	5.97	0.01
Public services	4.39	4.39	0.00

There is a positive policy impact on legal deforestation over the time period, the largest of which occurs in the north followed by the center west and north east (Figure 2). The policy

has a small negative impact on illegal deforestation over time in the north east and a large negative impact in the north followed by the center west. The policy has a large and positive effect on the AAGR in legal deforestation's activity level and is the greatest in the center west followed by the north east and north (10.22%, 9.92% and 8.74%, respectively; Table 1). Illegal deforestation's AAGR in activity is negatively impacted most severely in the north followed by the north east and center west (-26.08%, -7.47% and -5.19%, respectively).

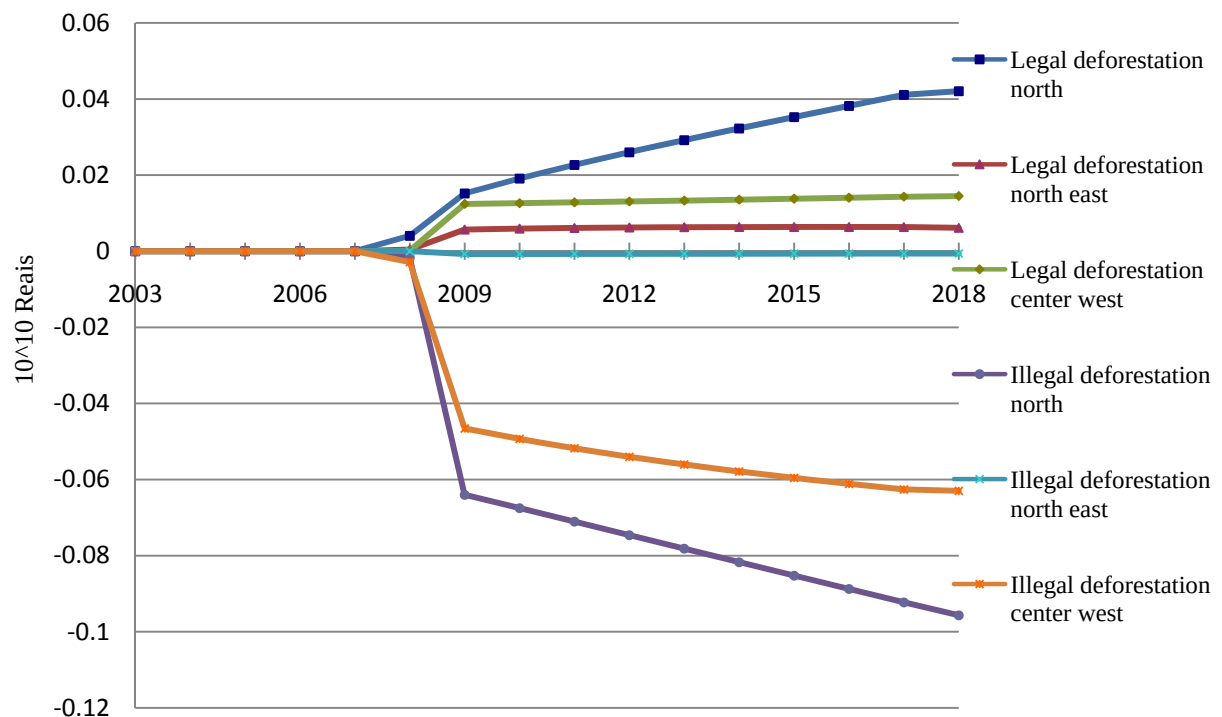


Figure 2. Policy impact on the level of legal and illegal deforestation activity in the north, north east and center west

Forest concessions have a negative impact on the AAGR of the forest plantations sector's activity with the largest effect in the center west followed by the north, north east, south and south east (-3.28%, -3.11%, -2.65%, -2.56% and -1.87%, respectively; Table 1). The impact on the AAGR in agricultural activity is positive in the north, north east, south east and south and negative in the center west (0.45%, 0.36%, 0.09%, 0.18% and -0.05%, respectively).

The AAGR in domestic demand of agricultural and forestry products increases by 0.10% and 1.10%, respectively while the AAGR in exports for these products increases by 0.21% and 2.53%, respectively (Table 2). The policy impact on the AAGR in agricultural and forest product prices is -0.09% and -0.94%, respectively.

Table 2. Average annual growth rate in the quantity of domestic and export sales between 2003 and 2018

Good or service	Baseline	Policy shock	Difference	Baseline	Policy shock	Difference
	Domestic sales (%)	Domestic sales (%)	Domestic sales (%)	Exports (%)	Exports (%)	Exports (%)
Agriculture	3.56	3.66	0.10	0.91	1.12	0.21
Forestry	2.17	3.27	1.10	-4.28	-1.75	2.53
Deforestation	3.34	-9.19	-12.52	0.00	0.00	0.00
Mining and petroleum	5.95	5.95	0.00	7.03	6.96	-0.07
Industrial products	5.82	5.84	0.02	6.10	6.07	-0.03
Processed wood	5.16	5.31	0.15	2.36	3.22	0.86
Pulp and cellulose	3.78	4.54	0.76	3.39	4.13	0.74
Processed food	4.67	4.73	0.05	1.01	1.16	0.15
Utilities	5.91	5.92	0.02	0.00	0.00	0.00
Construction	6.04	6.07	0.03	6.25	6.27	0.02
Commerce	6.04	6.03	0.00	5.35	5.43	0.08
Transportation	5.90	5.91	0.01	6.10	6.08	-0.02
Private services	5.96	5.97	0.01	6.12	6.11	-0.01
Public services	4.39	4.39	0.00	0.00	0.00	0.00

Figure 3 depicts the positive policy impact on the stock of agricultural land in the north and north east and the negative effect in the center west. With legal and illegal deforestation sectors generating agricultural land, the increased growth in the stock of agricultural land in the north and north east are the result in increased rates of growth in deforestation due to the implementation of forest concessions.

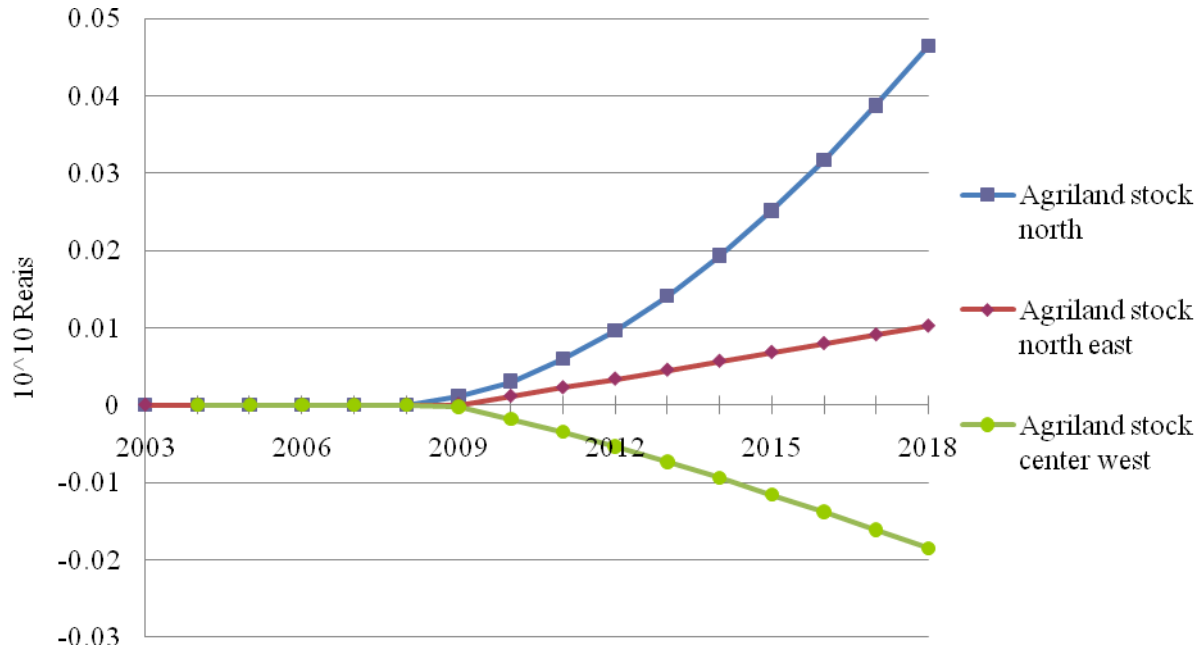


Figure 3. Policy impact on agricultural land stock in the north, north east and center west

In the north east, the AAGR of legal deforestation's demand for forestland increases while legal and illegal forestry and illegal deforestation demand decrease (9.93%, -2.16%, -2.77% and -7.45%, respectively). The policy impact on the AAGR in demand for forestland is positive for legal forestry, illegal forestry and legal deforestation in the north while illegal deforestation in this region suffers a marked negative impact (13.69%, 10.67%, 8.92% and -25.78%, respectively). In the center west, the AAGR of legal forestry, illegal forestry and legal deforestation demand for forestland is positively affected while illegal deforestation's demand is negatively affected (4.14%, 2.95%, 10.27% and -5.10%, respectively). The effect on the agricultural sector's AAGR in demand for agricultural land is positive in the north, north east, south east and south and negative in the center west (0.48%, 0.50%, 0.18%, 0.22% and -0.04%, respectively). Forest concessions result in a negative effect on the AAGR of the forest plantation

sector's demand for land in all regions (-3.06%, -2.54%, -1.87%, -2.55% and -3.27% in the north, north east, south east, south and center west, respectively).

Table 4-6. Average annual growth rate in the quantity of factor demand by industry between 2003 and 2018

Activity	Factor	Baseline (%)	Policy shock (%)	Difference (%)
Agriculture north	Agricultural land north	0.91	1.39	0.48
Forest plantations north		13.41	10.35	-3.06
Agriculture north east	Agricultural land north east	-0.05	0.45	0.50
Forest plantations north east		10.84	8.30	-2.54
Agriculture south east	Agricultural land south east	2.25	2.43	0.18
Forest plantations south east		-8.45	-10.31	-1.87
Agriculture south	Agricultural land south	-0.15	0.07	0.22
Forest plantations south		1.60	-0.95	-2.55
Agriculture center west	Agricultural land center west	0.56	0.51	-0.04
Forest plantations center west		11.34	8.07	-3.27
Legal forestry north	Forestland north	-1.13	12.56	13.69
Illegal forestry north		0.75	11.42	10.67
Legal deforestation north	Forest land north	-0.69	8.24	8.92
Illegal deforestation north		4.01	-21.78	-25.78
Legal forestry north east	Forestland north east	3.55	1.40	-2.16
Illegal forestry north east		4.19	1.42	-2.77
Legal deforestation north east		-11.56	-1.64	9.93
Illegal deforestation north east		-1.92	-9.37	-7.45
Legal forestry south east	Forestland south east	0.00	0.00	0.00
Legal forestry south	Forestland south	0.00	0.00	0.00
Legal forestry center west	Forestland center west	-4.75	-0.61	4.14
Illegal forestry center west		-3.02	-0.07	2.95
Legal deforestation center west		-1.51	8.76	10.27
Illegal deforestation center west		2.15	-2.96	-5.10

High-income households gain the most from policy implementation followed by enterprise, mid and low-income households. 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. The AAGR in income increases for low, mid and high-income households and the enterprise (0.01%, 0.02%, 0.03% and 0.02%, respectively). Policy impacts on household expenditures follow the same trends as those described for household income.

The policy impact on the AAGR in forestland prices is negative in all regions (-6.20%, -0.66%, -1.32%, -1.14% and -2.39% in the north, north east, south east, south and center west, respectively). The impact on the AAGR in agricultural land prices is also negative in all regions (-0.36%, -0.78%, -0.47%, -0.30% and -0.07% in the north, north east, south east, south and center west, respectively).

7.0. Discussion and Policy Implications

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 the land use in the Brazilian Amazon. In the absence of forest concessions, legal forestry activities contract in the north and center west. Increased demand for forest products is met by large growth in forest plantations activity with the exception of the south east. Introducing the concessions policy, legal forestry in the north and center west expand which may be 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.

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. However, since the legal deforestation sector's level of activity and 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. 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 of forest product output. Overall with regards to illegality, forest concessions reduce illegal forestry in the north east and illegal deforestation in all regions, particularly 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. 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 increase for forestry and agricultural products while agricultural and forest product prices grow at a slower rate.

Agricultural activity grows in all regions in the baseline; the policy impact is also positive in all regions with the exception of a small reduction in growth in the center west. 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 generating agricultural land.

Forest concessions have a positive impact on household income. 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 income increase. 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.

The positive policy impact on household welfare, household income and growth in the legal forestry and agricultural sectors imply on balance positive changes to the Amazon's

economy and forestry and agricultural sectors. Forest concessions reduce illegality in the case of deforestation which is positive from both a societal, political and environmental perspective. Less desirable is the disappointing response of illegal forestry and legal deforestation to the forest concessions policy. Although forest concessions result in a reduction in the rate of growth in illegal forestry in the north east, the contraction of illegal forestry in the center west in the baseline is reversed and illegal forestry expands. The illegal forestry sector in the north also experiences a considerable increase in growth in the policy scenario. In the case of legal deforestation the contraction experienced in the baseline in the north east and center west is reversed in the policy scenario and legal deforestation expands faster in the north.

The disappointing policy impact on illegal forestry must be qualified. In the modeling exercises forest concessions are implemented in the absence of any increases in the detection and prosecution of illegality. Improved monitoring, enforcement and successful prosecution of violators would increase the costs of doing business illegally. The consequences of improvements in this area are intuitive- higher costs of illegality would force firms into legal compliance or out of business. Although this would result in an expansion of the legal forestry sector, the overall level of forestry activity when compared to the results of the policy experiment conducted herein would likely be somewhat lower. The forest plantation sectors would probably not experience such a negative policy impact and forest product prices might increase somewhat. With increased availability of forestland for management, complimentary policies to improve monitoring, enforcement and prosecution of illegality could go a long way in reducing illegality in the forestry sector without paralyzing the industry as in the past.

Another result that signals the need for complimentary policies as forest concessions are implemented is the negative effect on low and mid-income households in the early years of

policy implementation. From 2009 to 2012 in the case of low-income households and from 2009 to 2010 in the case of mid-income households, the policy impact is negative. This result is likely driven by the negative policy impact on low-skilled labor wages between 2009 and 2016. Economic development and social programs could be effective in counteracting the negative impacts on income growth experienced in the initial years of policy implementation.

Three areas for promising future research may be mentioned. First, policy experiments may be conducted to examine the effect of improved monitoring, enforcement and prosecution of illegal deforestation and illegal forestry by varying the value of the fine paid per unit of illegal output. Determining the level of fines that would be required to reduce illegality to the socially optimal level would be useful to policy makers in their decisions on budgetary allocations for monitoring and enforcement.

Second, policy makers may be interested in the longer run (10+ years) distributional socioeconomic and environmental impacts of forest concessions. The debate surrounding Reduced Emissions from Deforestation and Degradation can significantly increase the demand for this information. A greater disaggregation of households in the SAM and projections of changes in world prices of goods and services would enable more realistic, longer-term analysis of the impacts of forest concessions.

Finally, the modeling exercises treat forestland as capable of producing the same quantity and quality of forest product output through time. Brazilian forestry law sets diameter, species and volume constraints on forest harvesting operations. Whether these limits result in sustainable harvest yields is an open question though recent research appears to indicate that they are not. In the short and medium term as modeled in the current analysis, declining quantity and quality of timber stocks may not present any measurable impact. If the policy is modeled in the longer-

term, however, interesting results may be borne out of modeling changes in the characteristics of future timber supply.

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APPENDIX A: CORE MODEL EQUATIONS

Table A-1. Model sets and parameters

Symbol	Explanation	Symbol	Explanation
Sets			
$a \in A$	Activities	$c \in CMN(\subset C)$	Commodities not in CM
$\alpha \in ACES(\subset A)$	Activities with a CES function at the top of the technology nest	$c \in CT(\subset C)$	Transaction service commodities
$\alpha \in ALEO(\subset A)$	Activities with a Leontief function at the top of the technology nest	$c \in CX(\subset C)$	Commodities with domestic production
$c \in C$	Commodities	$f \in F$	Factors
$c \in CD(\subset C)$	Commodities with domestic sales of domestic output	$i \in INS$	Institutions (domestic and rest of world)
$c \in CDN(\subset C)$	Commodities not in CD	$i \in INSD(\subset INS)$	Domestic institutions
$c \in CE(\subset C)$	Exported commodities	$i \in INSDNG(\subset INSD)$	Domestic non-government institutions
$c \in CEN(\subset C)$	Commodities not in CE	$h \in H(\subset INSDNG)$	Households
$c \in CM(\subset C)$	Imported commodities		
Parameters			
$cwts_c$	Weight of commodity c in the CPI	$\overline{qinv_c}$	Base-year quantity of private investment demand
$dwtsc$	Weight of commodity c in the producer price index	$shif_{if}$	Share for domestic institution i in income of factor f
ica_{ca}	Quantity of c as intermediate input per unit of activity a	$shii_{ii'}$	Share of net income of i' to i ($i' \in INSDNG$; $i \in INSDNG$)
$icd_{cc'}$	Quantity of commodity c as trade input per unit of c' produced and sold domestically	ta_a	Tax rate for activity a
$ice_{cc'}$	Quantity of commodity c as trade input per exported unit of c'	te_c	Export tax rate
$icm_{cc'}$	Quantity of commodity c as trade input per imported unit of c'	tf_f	Direct tax rate for factor f
$inta_a$	Quantity of aggregate intermediate input per activity unit	$\overline{tins_i}$	Exogenous direct tax rate for domestic institution i

Table A-1. Continued

Symbol	Explanation	Symbol	Explanation
iva_a	Quantity of aggregate intermediate input per activity unit	$tins0I_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates
$\overline{mps}_i$	Base savings rate for domestic institution i	tm_c	Import tariff rate
$mps0I_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates	tq_c	Rate of sales tax
pwe_c	Export price (foreign currency)	$transfr_{if}$	Transfer from factor f to institution i
pwm_c	Import price (foreign currency)	tva_a	Rate of value-added tax for activity a
$qdst_c$	Quantity of stock change		
$\overline{qg}_c$	Base-year quantity of government demand		
Greek letters			
α_a^a	Efficiency parameter in the CES activity function	δ_c^t	CET function share parameter
α_a^{va}	Efficiency parameter in the CES value-added function	δ_{fa}^{va}	CES value-added function share parameter for factor f in activity a
α_c^{ac}	Shift parameter for domestic commodity aggregation function	γ_{ch}^m	Subsistence consumption of marketed commodity c for household h
α_c^q	Armington function shift parameter	θ_{ac}	Yield of output c per unit of activity a
α_c^t	CET function shift parameter	ρ_a^a	CES production function exponent
β^a	Capital sectoral mobility factor	ρ_a^{va}	CES value-added function exponent
β_{ach}^h	Marginal share of consumption spending on home commodity c from activity a for household h	ρ_c^{ac}	Domestic commodity aggregation function exponent
β_{ch}^m	Marginal share of consumption spending on marketed commodity c for household h	ρ_c^q	Armington function exponent
δ_a^a	CES activity function share parameter	ρ_c^t	CET function exponent
δ_{ac}^{ac}	Share parameter for domestic commodity aggregation function	η_{fat}^a	Sector share of new capital (dynamic model)

Table A-1. Continued

Symbol	Explanation	Symbol	Explanation
δ_c^q	Armington function share parameter	ν_f	Capital depreciation rate (dynamic model)
$\varphi_{a,c}$	Yield distortion parameter		

Source: Lofgren et al. (2002); Robinson and Thurlow (2004).

Table A-2. Model variables

Variable	Explanation	Variable	Explanation
Exogenous variables			
$\overline{CPI}$	Consumer price index	$\overline{MPSADJ}$	Savings rate scaling factor (= 0 for base)
$\overline{DTINS}$	Change in domestic institution tax share (= 0 for base; exogenous variable)	$\overline{QFS}_f$	Quantity supplied of factor
$\overline{FSAV}$	Foreign savings (FCU)	$\overline{TINSADJ}$	Direct tax scaling factor (= 0 for base; exogenous variable)
$\overline{GADJ}$	Government consumption adjustment factor	$\overline{WFDIST}_{fa}$	Wage distortion factor for factor f in activity a
$\overline{IADJ}$	Investment adjustment factor		
Endogenous variables			
AWF_{ft}^a	Average capital rental rate in time period t (dynamic model)	QF_{fa}	Quantity demanded of factor f from activity a
$DMPS$	Change in domestic institution savings rates (= 0 for base; exogenous variable)	QG_c	Government consumption demand for commodity
DPI	Producer price index for domestically marketed output	QH_{ch}	Quantity consumed of commodity c by household h
EG	Government expenditures	QHA_{ach}	Quantity of household home consumption of commodity c from activity a for household h
EH_h	Consumption spending for household	$QINT_a$	Quantity of aggregate intermediate input
EXR	Exchange rate (LCU per unit of FCU)	$QINT_{ca}$	Quantity of commodity c as intermediate input to activity a
$GOVSHR$	Government consumption share in nominal absorption	$QINV_c$	Quantity of investment demand for commodity
$GSAV$	Government savings	QM_c	Quantity of imports of commodity c
$INVSHR$	Investment share in nominal absorption	QQ_c	Quantity of goods supplied to domestic market (composite supply)
MPS_i	Marginal propensity to save for domestic non-government institution (exogenous variable)	QT_c	Quantity of commodity demanded as trade input
PA_a	Activity price (unit gross revenue)	QVA_a	Quantity of (aggregate) value-added

Table A-2. Continued

Variable	Explanation	Variable	Explanation
PDD_c	Demand price for commodity produced and sold domestically	QX_c	Aggregated quantity of domestic output of commodity
PDS_c	Supply price for commodity produced and sold domestically	$QXAC_{ac}$	Quantity of output of commodity c from activity a
PE_c	Export price (domestic currency)	RWF_f	Real average factor price (dynamic model)
$PINTA_a$	Aggregate intermediate input price for activity a	$TABS$	Total nominal absorption
PK_{ft}	Unit price of capital in time period t (dynamic model)	$TINS_i$	Direct tax rate for institution i ($i \in$ INSDNG)
PM_c	Import price (domestic currency)	$TRII_{ii'}$	Transfers from institution i' to i (both in the set INSDNG)
PQ_c	Composite commodity price	WF_f	Average price of factor
PVA_a	Value-added price (factor income per unit of activity)	YF_f	Income of factor f
PX_c	Aggregate producer price for commodity	YG	Government revenue
$PXAC_{ac}$	Producer price of commodity c for activity a	YI_i	Income of domestic non-government institution
QA_a	Quantity (level) of activity	YIF_{if}	Income to domestic institution i from factor f
QD_c	Quantity sold domestically of domestic output	ΔK_{fat}^a	Quantity of new capital by activity a for time period t (dynamic model)
QE_c	Quantity of exports		

Source: Lofgren et al. (2002); Robinson and Thurlow (2004).

Table A-3. Model equations

$PM_c = pwm_c \cdot (1 + tm_c) \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'c}$	(1)
$PE_c = pwe_c \cdot (1 - te_c) \cdot EXR - \sum_{c' \in CT} PQ_{c'} \cdot ice_{c'c}$	(2)
$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} \cdot icd_{c'c}$	(3)
$PQ_c \cdot (1 - tq_c) \cdot QQ_c = PDD_c \cdot QD_c + PM_c \cdot QM_c$	(4)
$PX_c \cdot QX_c = PDS_c \cdot QD_c + PE_c \cdot QE_c$	(5)
$PA_a = \sum_{c \in C} PXAC_{ac} \cdot \theta_{ac}$	(6)
$PINTA_a = \sum_{c \in C} PQ_c \cdot ica_{ca}$	(7)
$PA \cdot (1 - ta_a) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a$	(8)
$\overline{CPI} = \sum_{c \in C} PQ_c \cdot cwtsc$	(9)

Table A-3. Continued

$$DPI = \sum_{c \in C} PDS_c \cdot dwts_c \quad (10)$$

$$QA_a = \alpha_a^a \cdot \left(\delta_a^a QVA_a^{-\rho_a^a} + (1 - \delta_a^a) \cdot QINTA_a^{-\rho_a^a} \right)^{\frac{1}{\rho_a^a}} \quad (11)$$

$$\frac{QVA_a}{QINTA_a} = \left(\frac{PINTA_a}{PVA_a} \cdot \frac{\delta_a^a}{(1 - \delta_a^a)} \right)^{\frac{1}{1 + \rho_a^a}} \quad (12)$$

$$QVA_a = QA_a \cdot iva_a \quad (13)$$

$$QINTA_a = QA_a \cdot inta_a \quad (14)$$

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{fa}^{va} \cdot \left(\alpha_{fa}^{vaf} \cdot QF_{fa} \right)^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \quad (15)$$

$$W_f \cdot \overline{WFDIST}_{fa} = PVA_a \cdot (1 - tva_a) \cdot QVA_a \cdot \quad (16)$$

$$\left(\sum_{f \in F'} \delta_{fa}^{va} \cdot \left(\alpha_{fa}^{vaf} \cdot QF_{fa} \right)^{-\rho_a^{va}} \right)^{-1} \cdot \delta_{fa}^{va} \cdot \left(\alpha_{fa}^{vaf} \cdot QF_{fa} \right)^{-\rho_a^{va} - 1} \quad (17)$$

$$QINT_{ca} = ica_{ca} \cdot QINTA_a \quad (17)$$

$$QXAC_{ac} + \sum_{h \in H} QHA_{ach} = \theta_{ac} \cdot QA_a \quad (18)$$

$$QX_c = \alpha_c^{ac} \cdot \left(\sum_{a \in A} \delta_{ac}^{ac} \cdot QXAC_{ac}^{-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac} - 1}} \quad (19)$$

$$PXAC_{ac} = PX_c \cdot QX_c \cdot \left(\sum_{a \in A'} \delta_{ac}^{ac} \cdot QXAC_{ac}^{-\rho_c^{ac}} \right)^{-1} \cdot \delta_{ac}^{ac} \cdot QXAC_{ac}^{-\rho_c^{ac} - 1} \quad (20)$$

$$QX_c = \alpha_c^{ac} \cdot \left(\sum_{a \in A} \delta_{ac}^{ac} \cdot QXAC_{ac}^{-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac} - 1}} \quad (21)$$

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1 - \delta_c^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t - 1}} \quad (22)$$

$$QX_c = QD_c + QE_c \quad (23)$$

$$QQ_c = \alpha_c^q \cdot \left(\delta_c^q \cdot QM_c^{-\rho_c^q} + (1 - \delta_c^q) \cdot QD_c^{-\rho_c^q} \right)^{-\frac{1}{\rho_c^q}} \quad (24)$$

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1 - \delta_c^q} \right)^{\frac{1}{1 + \rho_c^q}} \quad (25)$$

$$QQ_c = QD_c + QM_c \quad (26)$$

$$QT_c = \sum_{c' \in C'} (icm_{cc'} \cdot QM_c + ice_{cc'} \cdot QE_{c'} + icd_{cc'} \cdot QD_{c'}) \quad (27)$$

Table A-3. Continued

Institutions

$$YF_f = \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{fa} \cdot QF_{fa} \quad (28)$$

$$YIF_{if} = shif_{if} \cdot [YF_f - transfr_{rowf} \cdot EXR] \quad (29)$$

$$YI_i = \sum_{f \in F} YIF_{if} + \sum_{i' \in INSDNG'} TRII_{ii'} + transfr_{i'gov} \cdot \overline{CPI} + transfr_{i'row} \cdot EXR \quad (30)$$

$$TRII_{ii'} = shii_{ii'} \cdot (1 - MPS_{i'}) \cdot (1 - \overline{tins}_{i'}) \cdot YI_{i'} \quad (31)$$

$$EH_h = \left(1 - \sum_{i \in INSDNG} shii_{ih} \right) \cdot (1 - MPS_h) \cdot (1 - \overline{tins}_h) \cdot YI_h \quad (32)$$

$$PQ_c \cdot QH_{ch} = PQ_c \cdot \gamma_{ch}^m + \beta_{ch}^m \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot \gamma_{c'h}^m - \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} \cdot \gamma_{ac'h}^m \right) \quad (33)$$

$$PXAC_{ac} \cdot QHA_{ach} = PXAC_{ac} \cdot \gamma_{ach}^h + \beta_{ach}^h \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot \gamma_{c'h}^m - \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} \cdot \gamma_{ac'h}^m \right) \quad (34)$$

$$QINV_c = IADJ \cdot \overline{qinv}_c \quad (35)$$

$$QG_c = \overline{GADJ} \cdot \overline{qg}_c \quad (36)$$

$$YG = \sum_{i \in INSDNG} \overline{tins}_i \cdot YI_i + \sum_{a \in A} ta_a \cdot PA_a \cdot QA_a + \sum_{c \in CMNR} tm_c \cdot pwm_c \cdot QM_c \cdot EXR + \quad (37)$$

$$\sum_{r \in R} \sum_{c \in CMR} tmr_{cr} \cdot pwmr_{cr} \cdot QMR_{cr} \cdot EXR + \sum_{c \in C} tq_c \cdot PQ_c \cdot QQ_c + \sum_{f \in F} YF_{govf} + transfr_{govrow} \cdot EXR$$

$$EG = \sum_{c \in C} PQ_c \cdot QG_c + \sum_{i \in INSDNG} transfr_{i'gov} \cdot \overline{CPI} \quad (38)$$

System constraints

$$\sum_{a \in A} QF_{fa} = QFS_f \quad (39)$$

$$QQ_c = \sum_{a \in A} QINT_{ca} + \sum_{h \in H} QH_{ch} + QG_c + QINV_c + qdst_c + QT_c \quad (40)$$

$$\sum_{c \in CMNR} pwm_c \cdot QM_c + \sum_{r \in R} \sum_{c \in CMR} pwmr_{cr} \cdot QMR_{cr} \cdot \sum_{f \in F} transfr_{rowf} \quad (41)$$

$$= \sum_{c \in CENR} pwe_c \cdot QE_c + \sum_{r \in R} \sum_{c \in CER} pwer_{cr} \cdot QER_{cr} + \sum_{i \in INSD} transfr_{i'row} + FSAV$$

$$YG = EG + GSAV \quad (42)$$

$$TINS = \overline{tins}_i \cdot (1 + \overline{TINSADJ} \cdot tins01_i) + \overline{DTINS} \cdot tins01_i \quad (43)$$

$$MPS_i = \overline{mps}_i \cdot (1 + \overline{MPSADJ} \cdot mps01_i) + \overline{DMPS} \cdot mps01_i \quad (44)$$

$$\sum_{i \in INSDNG} MPS_i \cdot (1 - \overline{tins}_i) \cdot YI_i + GSAV + EXR \cdot FSAV = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \quad (45)$$

Table A-3. Continued

$$TABS = \sum_{h \in H} \sum_{c \in C} PQ_c \cdot QH_{ch} + \sum_{a \in A} \sum_{c \in C} \sum_{h \in H} PXAC_{ac} \cdot QHA_{ach} \quad (46)$$

$$+ \sum_{c \in C} PQ_c \cdot QG_c + \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c$$

$$INVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \quad (47)$$

$$GOVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QG_c \quad (48)$$

Capital accumulation (dynamic model)

$$AWF_{f,t}^a = \sum_a \left[\left(\frac{QF_{f,at}}{\sum_{a'} QF_{f,a't}} \right) \cdot WF_{f,t} \cdot WFDIST_{f,at} \right] \quad (49)$$

$$\eta_{f,at}^a = \left(\frac{QF_{f,at}}{\sum_{a'} QF_{f,a't}} \right) \cdot \left(\beta^a \cdot \left(\frac{WF_{f,t} \cdot WFDIST_{f,at}}{AWF_{f,t}^a} - 1 \right) + 1 \right) \quad (50)$$

$$\Delta K_{f,at}^a = \eta_{f,at}^a \cdot \left(\frac{\sum_c PQ_{ct} \cdot QINV_{ct}}{PK_{f,t}} \right) \quad (51)$$

$$PK_{f,t} = \sum_c PQ_{ct} \cdot \frac{QINV_{ct}}{\sum_{c'} QINV_{c't}} \quad (52)$$

$$QF_{f,at+l} = QF_{f,at} \cdot \left(1 + \frac{\Delta K_{f,at}^a}{QF_{f,at}} - \nu_f \right) \quad (53)$$

$$QFS_{f,t+1} = QFS_{f,t} \cdot \left(1 + \frac{\sum_a \Delta K_{f,at}}{QFS_{f,t}} - \nu_f \right) \quad (54)$$

Source: Lofgren et al. (2002); Robinson and Thurlow (2004).

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).

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.

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.

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.

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.