Economic and environmental impacts of conventional and reduced-impact logging in Tropical South America: a comparative review

Frederick Boltz*, Thomas P. Holmes, Douglas R. Carter

*School of Forest Resources and Conservation, Institute of Food and Agricultural Sciences, 373 Newins-Ziegler Hall, P.O. Box 110410, University of Florida, Gainesville, FL 32611-0410, USA

Southern Research Station, USDA Forest Service, P.O. Box 12254, Research Triangle Park, NC 27709, USA

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Abstract

Indicators of environmental impact and financial performance are compared for case studies of tropical forest logging from the Brazilian Amazon, Guyana, and Ecuador. Each case study presents parameters obtained from monitoring initial harvest entries into primary forests for planned, reduced-impact logging (RIL) and unplanned, conventional logging (CL) operations. Differences in cost definitions and data collection protocols complicate the comparative analysis, and suggest that caution is necessary in interpreting results. Given this caveat, it appears that RIL can generate competitive or superior profits relative to CL if the financial costs of wood wasted in the harvesting operation are fully accounted for. Increased operational efficiency is an important benefit of RIL, one that largely determines its cost-effectiveness relative to conventional practices. Uncertainties concerning the marginal benefits of RIL relative to familiar, profitable conventional practices pose an obstacle to broader adoption. Moreover, CL firms face few incentives to alter their operations unless they face dramatic changes in market signals. Adoption of RIL techniques as part of a long-term forest management regime faces additional challenges related to the opportunity cost of silvicultural prescriptions and timber set-asides to maintain productivity and ecosystem integrity.

Keywords: Tropical forest; Economics; Reduced-impact logging; Brazil; Guyana; Ecuador

1. Introduction

Natural forest logging is a vital industry for many countries of tropical South America; one that provides means of catalyzing the development of rural areas, and of generating important local and export revenues (e.g. Johnson and Cabarle, 1993). South American forests that were once under little pressure for timber production are now increasingly the focus of logging industry development (e.g. Uhl et al., 1997). Growth in the South American share of tropical timber production will likely continue to the turn of the century and beyond, as few Asian countries have the potential to substantially increase and sustain log production (ITTO, 1996). Recent trends in tropical
timber production, excluding plantations, show a
decrease in the Asia–Pacific region’s share of
global production by 29.6% from 1992 through
1999 (Fig. 1). Production in the Latin America–
Caribbean region, which is dominated by South
American producers, increased 15.8% over this
same period (ITTO, 1996, 1999).

Despite its economic importance, natural forest
logging in tropical South America is rarely sus-
tainable (Bowles et al., 1998), but instead is a
principal contributor to the degradation and ulti-
mate conversion of forests to non-forest land uses
(Bryant et al., 1997, Schneider et al., 2000).
Conventional logging (CL) operations are com-
monly unplanned, selective harvesting in which
merchantable stems are identified by a knowl-
dedgeable timber cruiser, felled by an accompany-
ing sawyer, then later searched for by tractors or
skidders and extracted on impromptu skid trails to
log decks or roadsides. Important environmental
externalities are generated under CL, as commonly
implemented. In sloped areas, CL often causes
heavy erosion and disrupts forest hydrologic cycles
(Douglas et al., 1992; Pinard and Putz, 1996). Wild-
life and forest ecological functions may be
severely impacted by changes in plant community
composition and structure and by modified forest
microclimate (Johns, 1985; Uhl and Vieira, 1989;
Gullison and Hardner, 1993; Cannon et al., 1994).
Changes in structure and microclimate render trop-
cical forests more susceptible to fires (Uhl and
Buschbacher, 1985; Woods, 1989; Nepstad et al.,
1999) and to the invasion of vines and other
undesirable plant species (Putz, 1988; Laurance et
al., 1998). The decreased productivity of forests
following damaging conventional logging entries
results in higher opportunity costs for long-term
forest management and greater incentive for the
conversion of forestland to alternative uses.

Reduced-impact logging (RIL) practices com-
prise harvest planning, infrastructure development,
and operational techniques which aim to reduce
the damaging impacts of timber harvest while
improving the production efficiency of logging
operations.1 Throughout the tropics, RIL has prov-
en more ecologically benign than conventional
logging activities (e.g. Boxman et al., 1985; Johns
et al., 1996; Pinard and Putz, 1996; Uhl et al.,
1997; Elias, 1999; Tay, 1999). Furthermore, RIL
has been shown to reduce operational costs (Box-
man et al., 1985) and, in some cases, generate
higher financial returns than conventional opera-
tions (Barreto et al., 1998; Holmes et al., 2002).
RIL systems may provide a low cost method of
maintaining the carbon sequestration functions
(Putz and Pinard, 1993; Boscolo et al., 1997) and
structural diversity of tropical forests (Frumhoff
and Losos, 1998). However, it has not been dem-
onstrated that RIL operations alone are sufficient
for the sustained production of merchantable tim-
ber or for the maintenance of the environmental
service flows provided by tropical forests in their
natural, unaltered state. The distinction between
RIL as an improved system of harvesting practices
and a sustainable forest management prescription
combining RIL and appropriate silvicultural guide-
lines is important in both economic and ecological
terms.

In the following, we conduct a comparative
review of case studies treating the environmental
and economic impacts of CL and RIL in produc-
tion forests of South America. We draw exclusive-

1 The FAO model code of forest harvesting practices (Dyk-
stra and Heinrich, 1996) is a fundamental guide for RIL
system design. It suggests four essential elements of harvesting
operations: comprehensive harvest planning; effective imple-
mentation and control of harvesting operations; thorough
harvesting assessment and communication of results to the
planning team and to harvesting personnel; development of a
competent and properly motivated workforce.
ly upon those projects in which CL and RIL operations are compared and concentrate our analysis on measured impacts and returns from initial harvest entries. Accordingly, the future benefits of RIL, which may include higher merchantable timber stocking in harvested stands relative to CL, are not included in our comparative review. It is expected that important long-term benefits are generated under RIL, as has been shown in selected studies (Barreto et al., 1998; van der Hout, 1999; Boltz et al., 2001). Our restriction to initial harvests is imposed due to the limited sample of studies extending analyses beyond the first cutting entry.

2. Case study descriptions

Although all of the studies examined herein concern logging of mixed, humid to wet tropical forests of South America, considerable variation exists among forest characteristics and logging regimes. One is thus prompted to question what comparisons and contrasts may be drawn from the RIL studies given fundamental environmental, social, and economic variability among sites and logging operations. In the following comparative analysis, we attempt to identify common trends among RIL studies relative to ecological and economic variables, acknowledging that these trends are not uniformly conclusive. In fact, the exceptions are perhaps more revealing of factors influencing the costs and benefits of RIL relative to CL. In order to conduct this analysis, we deconstruct case study results into common measures of damage, productivity, costs and profitability and reexamine findings across all study areas. Direct comparisons are complicated by the fact that standard protocols were not used in the studies. Moreover, considerable variation in harvest intensity across the studies obfuscates meaningful cost comparisons, given that logging cost functions generally decrease, up to some point, as harvest intensity increases. To provide a tractable analysis, we utilize incremental measures, where increments measure proportional changes between CL and RIL systems. We describe CL and RIL operations for each case study in Table 1 and provide further detail in the paragraphs that follow.

2.1. Brazil-B (Barreto et al., 1998; Johns et al., 1996)

The RIL-CL comparison was conducted in private forestland of Fazenda Agrosete, approximately 20 km south-east of Paragominas, Pará, Brazil (3° S; 47.5° W). RIL was conducted on a 105 hectare (ha) plot and CL on an adjacent 75 ha plot. Both operations were conducted by trained operators working with the research team. RIL extracted 4.5 and CL, 5.6 trees ha$^{-1}$. Productivity, cost, damage, and waste measures were drawn from observed operations and plot impacts. Lowland, closed-canopy terra firme forests of Paragominas are humid, evergreen with a canopy height of 25–40 m and emergents extending to 50 m. The terrain is moderately undulating and soils are kaolinitic red–yellow oxisols. Annual rainfall averages 1750 mm with a distinct dry season from June to November. Mean annual temperature is 28°C.

2.2. Brazil-H (Holmes et al., 2002)

Research was conducted in private forestland of the CIKEL timber company on Fazenda Cauaxi, some 120 km south-west of Paragominas, Brazil (3° S; 47.5° W). RIL was conducted by trained operators of Fundação Floresta Tropical (FFT) on 100 ha of undisturbed forest, while CL was implemented by local contractors hired by CIKEL in an adjacent 100 ha plot. CL harvested 39 and RIL 41 timber species, at intensities of 4.25 and 3.31 trees ha$^{-1}$, respectively. Logging intensity, damage and waste measures were collected in the Cauaxi plots. Average productivity and cost measures for the study were calculated from a sample of FFT’s RIL operations and CL operations in the Paragominas region. The study was conducted in lowland, closed-canopy terra firme forests of the Paragominas region. Two RIL operations were examined, one using a bulldozer (Brazil-Bb) for skidding and the other using a rubber-tired skidder (Brazil-Bs). Furthermore, directional felling was conducted by both two-person and three-person teams. We include costs and productivity for two-person felling with RIL bulldozer data and for three-person felling with RIL skidder data.

Interfluvial terra firme forests are distinguished from floodplain varzea forests of the Brazilian Amazon, which are seasonally inundated.
Table 1
CL and RIL components included in cost analysis per case study

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Brazil (Barreto)</th>
<th>Brazil (Holmes)</th>
<th>Brazil (Winkler)</th>
<th>Ecuador (Montenegro)</th>
<th>Guyana (Armstrong)</th>
<th>Guyana (van der Hout)</th>
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<td>CL</td>
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<td>Skidding by bulldozer</td>
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<td>Skidding by rubber-tired skidder</td>
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<td>Post harvest management</td>
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inas timbershed (see Brazil-B (Barreto et al., 1998) above for ecosystem description).

2.3. Brazil-W (Winkler, 1997)

The study examined private forestland 227 km east of Manaus (3° S; 59° W) belonging to Mil Madeireira Itacoatiara S.A., a Brazilian subsidiary of Precious Woods, Ltd. Efficiency and environmental impact studies were conducted in two adjacent 10 ha cutting blocks. Production costs per component were estimated as a proportion of total logging costs, while specific per unit costs were not reported. Both RIL and CL operations were implemented by the Mil Madeireira logging team. CL removed 23 and RIL 6 trees ha⁻¹ and RIL 6, or 78.9% and 26.9% of the available merchantable volume per plot. Sixty-five tree species are merchantable, of which 24 were harvested under RIL and 32 under CL. The lowland, moist terra firme forests lie upon inclined plateaus of Tertiary origin. Steep ravines dissect the plateaus at slopes of 10° to 40°. Soils are oxisols. Canopy height is 30–37 m with emergents extending to 55 m. Annual rainfall is approximately 2200 mm with a dry season from June to October. Mean annual temperature is 26 °C.

2.4. Ecuador (Montenegro, 1996)

The sampled forestland included private lands of the ENDESA plywood industry (RIL) and
private smallholder properties (CL) in and around the La Mayronga production forest in northwestern Ecuador (0° 53' N, 79° 12' W). RIL was implemented by a research institution, Fundación Forestal Juan Manuel Durini. CL was conducted by two private landowners. Both RIL and CL operations extracted eight stems ha⁻¹. Cost and forest impact data were collected from 30 2500-m² plots of La Mayronga for RIL and from continuous strip samples of 10 m width in surrounding, privately owned forests for CL. The lowland tropical wet forest sites are located in the north of Ecuador’s coastal lowlands province, Esmeraldas. The forest contains 17 timber merchantable species at a density of eight to 10 species ha⁻¹ for trees of 50 cm diameter at breast height (dbh) and larger. Mean RIL harvest level was 8 m³ ha⁻¹. CL harvest intensity was not reported. Soils of the region are arenosols (entisols) with a structure classified medium density loamy. Rainfall averages 2500 mm year⁻¹ with a dry season from July to December. Mean annual temperature is 26 °C.

2.5. Guyana-A (Armstrong, 2000)

Studies were conducted in a 1.67 million ha concession granted to the Barama Company, Ltd. (BCL) in north-west Guyana (7° N; 60° W). RIL and CL were implemented by BCL. RIL operations differ in their implementation of map-based planning, vine cutting, and directional felling, and their increased supervision. Moreover, CL operations were implemented earlier in the logging of the BCL concession, thus CL teams received less training. A clear RIL–CL damage comparison was not made; instead, logged and unlogged permanent sample plots were contrasted in the study. Consequently, we were unable to utilize damage findings from this study in our comparative review. Waste, productivity and cost measures were drawn from eight 100-ha blocks. We focus on data describing CL operations on blocks 1 and 2 and RIL operations on blocks 7 and 8, given that logging of blocks 3–6 utilized a mix of RIL and CL techniques and these data were not utilized in cost analyses. The sampled forests are moist, evergreen on undulating to hilly terrain. Productive forest is interspersed with unproductive swamp and steep terrain. Baromalli (Catostemma spp.) represents 6% of stand basal area and nearly 90% of the total harvest volume under both logging methods. Of over 40 timber species, only Baromalli and Trysil (Pentaclethra odorata) were harvested. An average of 8.1 m³ ha⁻¹ or approximately 2.4 trees ha⁻¹ were harvested under both CL and RIL.

2.6. Guyana-H (van der Hout, 1999)

Research was conducted in West-Piribiri forests of central Guyana (5° N; 58° W) in part of a concession granted to Demarara Timbers Ltd. (DTL). RIL harvesting was implemented by trained DTL teams, while CL was conducted by untrained DTL loggers. Harvesting operations focused on the extraction of Greenheart (Chlorocardium rodiei), which comprised 53% and 91% of gross harvest volume for RIL and CL, respectively. RIL logging intensities of 4, 8, and 16 trees ha⁻¹ were assigned according to randomized block design with three replicates and three controls in 12 240×240-m² plots. Conventional logging of eight and 16 trees ha⁻¹ was measured in three 200×600-m² plots. We examined results from RIL and CL trials at 8 and 16 stems ha⁻¹ (Guyana-H8, Guyana-H16). Detailed efficiency and cost studies were conducted for felling and skidding activities, while the remaining logging components were estimated from data provided by DTL. Efficiency studies were conducted within the experimental layout, rather than an operational scale, thus infrastructure development was influenced by the configuration of the research plots. The West-Piribiri forests are situated on an undulating sedimentary plain with an altitudinal range of 50–100 m. Forest composition is characterized by Greenheart-dominated patches on upper slopes, interspersed with other forest types. The forests are evergreen with a canopy height of 30–40 m and emergents to 50 m. Soils are ultisols and arenosols, consisting of excessively drained, coarse sand. RIL and CL were conducted on brown sand ridges of the forest landscape. Mean annual rainfall is approximately 2700 mm and mean temperature is 26 °C.
3. Forest impacts

Case studies reveal that CL causes 90–129% greater canopy loss and up to four times as much ground area disturbance as RIL (Fig. 2). Planned, spatially efficient extraction of timber effectively reduces stand damage caused by roaming bulldozer and skidder extraction methods and vine-laden stem felling. An exception is found in the West-Piribiri forests, Guyana-H (van der Hout, 1999), where total canopy disturbance was equal or higher under RIL. This is attributed to harvest restrictions requiring RIL to distribute felling spatially across the logging block according to silvicultural criteria, whereas CL felled groups of Greenheart stems in large, concentrated gaps which mitigated total and per stem canopy impact levels (Figs. 2 and 3).

At similar harvest levels, CL results in higher damage per stem harvested (Fig. 3). Ground area disturbance is 32–139% greater per stem under CL given inefficient road and trail layout and skidder roaming (Brazil-H, Brazil-B and Guyana-H). The number of trees damaged per stem felled is also consistently lower under RIL, attributable primarily to directional felling and reduced skidding damage to the residual forest. Winkler (1997) (Brazil-W) presents an interesting anomaly in which CL stem and canopy damages per stem felled are lower than RIL, due to greater CL harvest intensity (23 stems ha\(^{-1}\) under CL and six stems ha\(^{-1}\) under RIL) (Fig. 3). The comparative benefits of CL in this instance are expected to result from the tendency of marginal damage measures to decrease with increasing level of harvest (Jonkers, 1987; Verissimo et al., 1992; Panfil and Gullison, 1998).

4. Operational efficiency

Directional felling is more time consuming, more labor intensive, and thus less productive under RIL in most cases (Fig. 4). CL sawyers were 10–58% more productive in volume (m\(^3\)) produced ha\(^{-1}\) than comparable RIL felling teams. Importantly, Barreto et al. (1998) (Brazil-B) found that gains in directional felling productivity by a three-person team rendered RIL more efficient than CL two-person felling (Fig. 4). On average, the three-person RIL team felled 34 stems per day relative to the 22 stems per day felled by two-CL sawyers. Financial gains due to higher productivity exceeded the increased cost of labor and equipment for the three-person team. Winkler (1997) (Brazil-W) found that although felling time per stem was higher under RIL, greater volume per stem was recovered in RIL felling operations, resulting in its greater efficiency relative to CL.

Skidding operations are more productive under RIL due to efficient planning and infrastructure development that facilitates stem extraction (Fig. 5). RIL utilizing rubber-tired skidders on the moderately undulating sites of Brazil and Guyana has been shown to increase productivity by 28–49% over CL bulldozer operations. Unplanned, conventional skidding is less efficient and thus more costly due to delays and damage caused in roam-
ing, or searching for felled stems in an uncharted forest.

RIL skidding was not found to be more productive in La Mayronga, Ecuador, however. Montenegro (1996) (Ecuador) compared RIL and CL skidding by teams utilizing Franklin 170 skidders. He found that despite RIL efficiency gains in reduced skidding distance to log deck, RIL machine and labor downtime and maintenance demands resulted in low skidding productivity relative to CL. A complicating factor in this analysis was that the quality of the skidders varied considerably between CL and RIL, which imposed unanticipated delays and costs on the RIL operation. It is not expected that this result will be found under conditions of equivalent skidder quality. Winkler (1997) (Brazil-W) found lower RIL skidding productivity in Itacoatiara; however, the components of RIL skidding comprised skid trail layout, winching, and extraction to log deck whereas traditional skidding only comprised extraction.

5. Costs

RIL requires investments in inventory, planning, vine cutting and infrastructure development up to 1 year before logging, which equals 2–18% of total CL harvest costs (Fig. 6). The incremental pre-harvest costs of RIL are expected to be an important disincentive to RIL adoption by the conventional logging industry (Barreto et al., 1998; Hammond et al., 2000; Holmes et al., 2002). van der Hout (1999) (Guyana-H) estimated relatively low incremental RIL costs in comparison with a CL operation that conducted some planning and infrastructure activities before logging. Armstrong (2000) (Guyana-A) found that CL pre-harvest costs were higher in north-west Guyana, due to higher costs of skid trail layout. Armstrong’s CL sample is exceptional, however, in that skid trails were marked and cleared prior to CL harvest. All other cases found higher RIL pre-harvest costs attributable to more intensive planning and infrastructure layout. Inventory, vine cutting and road planning are found to generate the highest incremental costs to RIL.

RIL direct costs are in most cases lower than or competitive with those of CL due to gains in operational efficiency and reduced wood waste (Fig. 7). RIL direct costs are consistently lower in Paragominas, Brazil (Barreto et al., 1998; Holmes et al., 2002), while in central Guyana (van der Hout, 1999), RIL costs are slightly higher, but remain competitive with CL. A substantial cost increase (41%) was found for RIL implementation in La Mayronga, Ecuador, however. The important incremental cost of RIL in La Mayronga is attributable to its lower felling productivity (Fig. 4) and its exceptionally high costs of pre-harvest planning.

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4 Direct costs include planning, vine cutting, infrastructure development, felling, skidding and log deck operations. We exclude transport from deck to mill as not all studies reported this measure.

($5.11 per m³ increment over CL). Notably, Montenegro (1996) did not explicitly account for costs incurred for wood waste under CL or RIL.

Our accounting of RIL and CL harvesting includes those costs generated in wood waste. Wood waste incurs direct costs associated with felling, bucking, skidding, and log deck activities and indirect costs by increasing the effective stumpage price (Holmes et al., 2002). Waste comprises logs felled and lost, high stumps, bucking waste, logs split during felling, and logs left unutilized on the log deck. In Paragominas, CL wasted 4–8 m³ more felled timber ha⁻¹ than RIL, which equaled 23% of CL felled volume (Holmes et al., 2002; Barreto et al., 1998). Armstrong (2000) (Guyana-A) found a total bucking and lost log waste reduction under RIL of approximately 3%.

When waste is not considered, direct costs appear deceptively lower for CL (Fig. 8). It may be expected that waste costs are commonly not accounted for in CL operations, given that inventory and monitoring activities necessary for such accounting are not conducted. Although this asymmetric information effectively biases estimates of returns to logging, the exceptional profitability of timber harvest provides conventional firms the luxury to function inefficiently and to ignore such losses.

Lower indirect costs may be generated under RIL due to gains in efficiency and thus lower support, maintenance, and overhead expenses relative to CL. Reduced indirect costs in central Guyana (van der Hout, 1999) render RIL more competitive with CL and add to RIL savings for one case in Paragominas (Holmes et al., 2002) (Fig. 9).

The costs of RIL training and more careful logging administration, however, may outweigh indirect cost savings derived from greater RIL efficiency. Barreto et al. (1998) (Brazil-B) found RIL indirect costs to be higher due to investments in training and road maintenance, while Montenegro (1996) (Ecuador) found training and overhead costs to dramatically increase relative indirect costs of RIL in La Mayronga (Fig. 9).

RIL training may be expected to cost up to 5% of total harvest costs (Montenegro, 1996; Holmes et al., 2002). Training costs vary considerably among the studies, though methods of calculation were not uniform, nor were these data reported by all. Barreto et al. (1998) reported much higher training costs (15–18% of total costs), utilizing an immediate wage increase for RIL trained personnel as a proxy for training investments, which may account for higher proportional measures. Holmes et al. (2002) amortized training costs over...
5 years of logging operations and found RIL training cost only 1–2% of total costs. The methodology utilized in Montenegro (1996) (Ecuador) was not made explicit.

RIL prescriptions define the pattern and intensity of harvesting and the resulting opportunity costs of RIL relative to CL. When RIL is designed to mimic CL harvesting in terms of harvest level, species, size classes, and spatial distribution, gains in operational efficiency and waste reduction render RIL environmentally and economically superior to CL for initial harvest entries (Barreto et al., 1998; Holmes et al., 2002; Armstrong, 2000). However, when RIL is implemented as part of a more constrained forest management prescription, in which areas and stems are set-aside to maintain productivity and ecosystem integrity, the opportunity costs relative to conventional liquidation harvest of all merchantable stems may be too great for RIL to be competitive. For instance, van der Hout (1999) (Guyana-H) found the cost and damage savings in spatially restricted harvest of ‘clumped’ species under CL were superior to those under a RIL prescription requiring spatially distributed, selective harvest under RIL. Winkler (1997) (Brazil-W) notes that one-third of the RIL forest area was set-aside as preservation forest, while no such set-asides were designed under CL.

The bottom line for loggers will often be whether or not RIL is more cost-effective than CL, to wit: do the benefits derived in greater harvest efficiency under RIL outweigh the incremental costs? The answer is clearly case-dependent. Gains in timber recovery and skidding efficiency under RIL do not conclusively offset investments in training, planning, and careful felling during initial harvest entries (Fig. 10). Several studies have shown that the additional costs of planning, infrastructure development and increased investment in directional felling are offset by savings attributable to the increased efficiency of RIL skidding activities alone (Mattsson-Marn and Jonkers, 1981; Hendrison, 1990; Holmes et al., 2002; Armstrong, 2000). Barreto et al. (1998) (Brazil-B) found that gains in operational efficiency only offset approximately 13% of incremental RIL costs; however, this efficiency increment together with benefits derived from waste reduction significantly outweigh incremental logging costs. Van der Hout (1999) (Guyana-H), found that increased investments in pre-harvest planning and directional felling were only partly offset by reduced skidding costs. Montenegro (1996) (Ecuador) found that skidding costs were greater under RIL, adding to the total incremental cost of planned logging.

6. Profitability

Tropical timber harvesting is highly profitable for the case studies examined in this review. CL demonstrates profit margins of 63% to an extraordinary 1238% in those studies reporting timber costs.
price measures (Fig. 11). Still, RIL has been shown to generate competitive or superior profitability due to gains in operational efficiency and reduced waste.

Given reasonable expectations of equivalent or superior profitability of RIL, economic theory suggests that logging firms would adopt such practices out of financial self-interest. Financial risk associated with the adoption of RIL may be high, however, given practitioner uncertainty concerning the production efficiency of RIL relative to conventional practices. Further investment risk derives from the uncertainty of tenure, market conditions, and forest productivity for long-term management (Boltz et al., 2001).

Imperfect information concerning the benefits of RIL relative to profitable conventional logging practices likely impedes its broader adoption. Moreover, current market signals of stumpage and timber prices do not seem to provide incentive to adopt practices that appear immediately more costly. If stumpage is treated as a ‘free good,’ or if it is under-priced, economic theory maintains that it will be over-utilized from a social perspective. This appears to be occurring in the areas of South America currently experiencing intensive timber exploitation.

7. Conclusions

RIL appears competitive with or superior to CL in financial returns to initial harvest entries. This finding is not without exception, but rather is dependent upon several key environmental, social, and economic factors. Case studies from tropical South America reveals that the comparative advantages of RIL relative to CL are determined in large part by harvest prescription and implied opportunity costs, operational efficiency, staffing and training costs, and resource use efficiency.

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6 Profit margin calculated as the mark-up on cost, (profit – cost)/cost, expressed as a percentage (Pappas and Hirschey, 1990).

7 van der Hout (1999) (Guyana-H) notes that the exceptional profitability of the CL case was due to its ‘mining’ of high-value species whose FOB mill price was $212 m⁻³, while RIL extracted a mix of merchantable species in conformity with silvicultural prescriptions and received a weighted average FOB mill price of $149 m⁻³.

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Fig. 10. Operational and recovery efficiency benefits of RIL relative to incremental pre-harvest costs. Positive RIL efficiency benefits result from lower RIL costs of skidding and felling operations and gains in timber recovery. Negative RIL efficiency benefits (Guyana-H, Ecuador) indicate higher RIL operational costs. Incremental RIL pre-harvest costs are expressed as negative values, unless RIL costs are lower (Guyana-A). The graphic thus portrays positive efficiency gains and negative pre-harvest costs as offsetting values, and indicates the relative magnitude of net benefits or net costs largely attributable to pre-harvest planning.

The opportunity costs of foregone merchantable timber in set-asides may lead to inferior RIL financial competitiveness relative to unconstrained liquidation harvest of merchantable stems under CL, despite gains in operational and resource use efficiency. Similar conclusions were drawn from RIL-CL studies in Sabah, Malaysia, in which RIL was found financially inferior due in large part to foregone timber excluded from RIL due to environmental harvesting restrictions (Tay, 1999; Pinard et al., 2000).

Increased operational efficiency is an important benefit of RIL, one that largely determines the relative cost-effectiveness of RIL under conditions in which the opportunity costs of set-asides and foregone ‘seed trees’ are not excessively high. Gains in skidding productivity and corresponding cost reductions have been shown to offset the incremental costs of RIL implementation (Matssoon-Marn and Jonkers, 1981; Hendrison, 1990; Armstrong, 2000; Holmes et al., 2002), especially when timber recovery gains are included in the analysis of harvest benefits (Barreto et al., 1998).

RIL training costs appear to be recovered in RIL efficiency gains, especially when training costs are amortized over several years of harvest.
operations. Retention of trained staff may be difficult, however, and will likely require wage increases and long-term engagement of logging teams, as opposed to temporary hiring of low-wage laborers now common in CL operations.

Waste reduction generates important efficiency benefits to RIL, which result in lower per unit costs of management and greater profitability at equivalent harvest intensity. RIL appears competitive with or superior to CL in financial returns to initial harvest entries if wood wasted in the harvesting operation is fully accounted for. If the logger is constrained to maximizing resource use and profitability from a fixed area, waste reduction benefits are expected to provide incentives for adoption of those RIL activities that enable greater resource recovery.

Without land availability constraints and clear market signals of scarcity, however, loggers will not likely be drawn to the marginal increments in resource use efficiency that may be gained under RIL. In a broader landscape without resource constraints, the opportunity costs of more careful RIL management relative to maximizing forest turnover and timber processing by conventional means may be too high and the benefits too uncertain for firms to change their logging behavior.

Uncertainties concerning the marginal gains in efficiency and profitability of RIL systems relative to familiar, highly profitable practices likely create a resistance to change among logging firms (Boltz et al., 2001). Greater dissemination of relevant information concerning the benefits of RIL and the provision of technical assistance may reduce the perceived risk of adoption.

CL firms face few incentives to alter their operations unless they face dramatic changes in market signals such as increases in stumpage prices or decreases in product prices. The institution of stumpage and timber price reporting series would facilitate better resource planning and provide incentives for more informed and conservative use of timber resources.

Ultimately, despite relatively greater expected profits for RIL, it is unlikely that the full set of RIL techniques will be adopted without additional incentives. It is expected, rather, that those RIL components that result in immediate cost savings, such as infrastructure planning and development, may be adopted by the logging industry without compulsion. Those components that imply higher immediate costs for uncertain benefits, such as vine cutting and directional felling, will not likely be adopted in the absence of financial incentives and effective harvest regulation. The implementation of RIL as part of a sustainable forest management system faces further challenges related to the opportunity costs of silvicultural prescriptions required to maintain timber productivity and ecosystem integrity.

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