Supplementary Materials: ‘National REDD+ outcompetes gold and logging: the potential of cleaning profit chains.’ Overman, Cummings, Luzar and Fragoso.

S1. Guyana background.

Guyana is considered a High Forest Low Deforestation (HFLD) country (Da Fonseca et al. 2007) and ranks 151st worldwide in per capita GDP (CIA 2015). Guyana has 83.3% forest cover (18.4M ha), with much of its non-forest area covered by natural savannah. It has a population of around 750,000 people, the large majority of whom live in the Caribbean coastal zone (Guyana Bureau of Statistics 2002, GFC and INDFOR 2015). The country has been at the forefront of REDD development since 2006 and is a partner country of both the UN-REDD Programme and the World Bank’s Forest Carbon Partnership Facility (UNFCCC 2017, FCPF 2017, The REDD desk, 2016). In late 2009, Guyana signed a five-year bilateral performance-based REDD+ agreement with Norway worth $250M to facilitate REDD+ readiness and low-carbon projects, and is currently in the process of extending the collaboration (Government of Norway 2016, Joint Concept Note 2015, The REDD desk, 2016). One of the results of the Norway-agreement is Guyana’s UN-submission ‘The reference level for Guyana’s REDD+ program’ (GoG 2015), the core document for this paper.

S2. Costs of deforestation and logging a tree, and calculating annual emissions.

Clearing a hectare of forest in Guyana (detected nationwide from time-series satellite imagery with 5-meter resolution) will reduce revenue in the next assessment by $5,201 due to forfeited REDD+ revenue incurred by the associated emissions. The value is derived from the reported mean carbon density of Guyana’s forests, which is 283.7 tC.ha$^{-1}$ (above- and belowground live
biomass components, 16% variation across forest types, Government of Guyana [GoG] 2015),

multiplied by the C – CO₂ conversion factor [the ratio of the molecular weights: \((12 + 2\times16) / 12 = 3.667\)]

and the price per tCO₂ (US$5 in this paper), which gives $5,201 per hectare.

Conversely, not clearing a hectare yields this same amount (more explanation in S3 below).

Logging. Pearson et al. (2014) conducted detailed field studies in six timber-producing countries, including Guyana, to relate the annual extracted volume of logs with total associated emissions (from the log itself, incidental damage and residue [stump, roots, branches, damage to adjacent trees] and infrastructural damage [skid trails, logging roads, loading decks]), with the goal of quantifying degradation emissions from logging. In Guyana the mean dbh of logged trees in four sampled concessions was 54 cm, producing 1.3 tC in extracted volume, accompanied by 3.3 tC collateral damage and 3.4 tC infrastructural damage, for a total of 8 tC per logged tree. Hence logging a tree corresponds on average to $147 in lost REDD+ revenue \([8 \times (44/12) \times US$5 = $147]\).

Pearson et al.’s findings were used in Guyana’s UN-FREL submission (GoG 2015).

The country’s emissions rate in a given year \(x\) derives from converting cleared hectares and logged volume in year \(x\) into CO₂ units, and dividing this annual total by the country’s total CO₂ stock in year \(x-1\) (forest area * carbon density * (44/12)).

S3. Missed gold revenue from under declaration and recovery inefficiency.

Guyana has a post-mining tax system, where extracted gold is self-declared and bought by the government at the daily gold price minus 7% taxes. From 2001 through 2012, declared gold was \(~2\) kg per deforested hectare (weighted mean of annual gold production, divided by mean annual deforestation (excluding deforestation from mining infrastructure), Bank of Guyana 2015, GoG 2015), worth \(~$70,000\) (Kitco 2016). Using an average mining depth of 10m (Swiecki 2011),
this figure for declared gold implies that during 2001—2012 a medium scale operation
(processing up to 1,000 m³ soil per day) earned on average $700 per day in gold to cover costs
(e.g. wages for six workers, fuel, state tax, permit holder fee, and repayment of any equipment
loans), and make a profit. A small operation (200 m³/day) would earn $140 per day. These
figures are improbably low to run mining operations. Yet since mining did occur, this means
more than 2 kg/ha gold was produced by operations, but did not subsequently end up in the
Treasury (ignoring where along the gold supply chain gold went missing).

Few accurate data are publicly available on the cost and yield of alluvial mining in Guyana. One
study on operating costs in 2005 (cited by Thomas 2009) results in mining sector costs 2.4 times
higher than the value of declared gold that year. A professional operation in a remote alluvial site
in Guyana in the early 1990s stated an overall gold recovery grade of 0.456 g.m⁻³ with a 0.1 g.m⁻³
cut-off grade (at a gold price of $350/oz., Swiecki 2011). The cut-off grade is the minimal gold
content of soil for economically viable mining. Substituting $350 with the historic period’s
average gold price of $996, it implies a professional operation requires soils with a minimum
0.035 g.m⁻³, or 3.5 kg.ha⁻¹, to be (minimally) profitable. If we take 0.456 g.m⁻³ as the highest
gold grade in Guyana, it implies economically mineable grounds contain between 3.5 kg and
45.6 kg.ha⁻¹ recoverable gold (rich grounds are not depleted since the 1990s since still advertised

If the average ground across Guyana over 2001—2012 contained 25 kg.ha⁻¹ (rounded mean of
3.5 and 45.6), and the average recovery efficiency of all operations was half that of this
professional operation, then mean recovery of the small and medium gold mining sector was
12.5 kg.ha⁻¹. Anchoring this back into reality, it implies that gross gold yield per day averaged
$4,323, respectively $865 for medium and small-scale operations. It would imply that the State
missed out on royalty revenue over 4.79 times the declared amount (2.16 kg.ha$^{-1}$), through under
declaration along the supply chain and inefficient recovery of gold.

Clearly, the 12.5 kg.ha$^{-1}$ is not an accurate or precise number but it *is* very far from the declared
12-year country wide average amount (2.16 kg.ha$^{-1}$), which simply does not cover operational
costs, indicating large losses of gold revenue for Guyana. Moreover, the large returns and low
risks on smuggling (see next) push towards the higher end of the 4.79 estimate.

Based on our estimate (479%), missed state revenue may have averaged $76 million per year
(4.79 * $15.8M, Table 2, ranging from $8M in 2001 to $245M in 2012, the latter equating to
35% of the 2014 State Budget). Adding the full gold value (without production costs and fees) of
4.79 times the declared amount, implies that average private net profit over this period was, or
could have been with professional mining, $264,200 per hectare, i.e. not 7x but 65x more than
the gross revenue for the state ($4,100, Table 3).

**Is cross-border smuggling worthwhile?**

Smuggling stems from peoples’ general inability to resist high return-low risk opportunities.
Guyana’s 7% tax on gold is higher than in neighboring countries (Suriname 3-4%, Venezuela
3%, Brazil 1%, Heemskerk 2010, Otto et al. 2006), risk is minimal with porous borders, poor
interior law enforcement and corruption (Falloon 2001, Harvard Law School 2007, Stabroek
News 2015), and high gold prices may tip the scale toward smuggling. For example (taking the
‘worst’ country to smuggle to), at a $1,000 oz$^{-1}$ gold price, declared gold per hectare (2.16 kg, or
69.4 troy oz.) would fetch only ~$2,400 more in Suriname, but $14,000 more with a 12.5 kg.ha$^{-1}$
recovery. If State taxes can be avoided altogether (Stabroek News 2015), the extra profit doubles
to $28,000 ha$^{-1}$ (on top of profits made from the other 93% of the gold value). These are
attractive sums, more so in a country with ~$200 per month minimum wage. Guyana also has diamonds. Diamonds are 5.5 times lighter than gold (3.5 vs. 19.3 g.cm$^{-3}$) and worth at least around 150 – 3,000 times more (Ajediam 2017).

**Professionalism**

Our example (Swiecki 2011) demonstrates the high merit of professional efficient mining with exploration. Swiecki reported that reserves estimated by exploration were just 5% under actual production. This is very different from the often hit-and-miss approach in Guyana’s gold mining sector (Lowe 2006). Further, this operation was profitable under a $350 gold price, with costs as low as $77 oz$^{-1}$ (the cut-off grade, 0.01 g.m$^{-3}$ at $350$ oz$^{-1}$, implies soil processing costs of $1.13$ m$^{-3}$ (1 troy oz. = 31.1 g). The average recovery of 0.456 g.m$^{-3}$ implies an ounce of gold was obtained from 68.2 m$^{3}$ soil. 68.2 * 1.13 = $76.75$ oz$^{-1}$). At the other end, many operations were forced to close down with gold prices around $1,250 (Kaieteur News 2014, Guyana Times 2015, largely due to over optimism regarding the gold price remaining high). Costs may have gone up since the 1990s, but such large differences in production cost ($1,250 vs. $77$ oz$^{-1}$) show that professional, and rational, mining practices would optimize and stabilize the sector, and remove a current motivation, if not obligation, for smuggling. REDD+ will further reduce state acceptance of inefficient gold extraction given the $5,200$ ha$^{-1}$ opportunity costs of deforestation to the State (at a $5$ carbon price; at $40$ it becomes $41,600$ ha$^{-1}$, CPLC 2017).

**References (Supplementary materials)**


FCPF (Forest Carbon Partnership Facility), 2017. REDD+ Country Participants. https://www.forestcarbonpartnership.org/redd-countries-1


