Cease and Disperse: A spatial dynamic programming approach to land use change as a factor in agricultural production

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Abstract

Tropical deforestation accounts for roughly 15% of annual carbon emissions, more than the combined emissions from road, rail, air, and marine transportation, worldwide. Any viable effort to mitigate climate change must address tropical deforestation. This paper assesses the impact of Indonesia's 2011 moratorium on new land concessions for deforestation in Indonesian Borneo. The results suggest that, relative to Malaysian Borneo, the moratorium shifted the spatial distribution of deforestation rather than reducing the overall rate, as intended. The proportion of new clearing activity that took place on the periphery of pre-existing clusters significantly increased with the phased enactment of the moratorium. The overall effect was a significant *increase* in the overall deforestation rate. We model this behavior through a spatial dynamic programming problem, noting that cleared land is an input in the production of agricultural products. The implications of this study are integral to evaluating the efficacy of the moratorium. It is likely that the long-term rate of deforestation may be a better metric of success, given the presence of intertemporal leakage. The results also suggest that the extension of the two-year moratorium will face much greater opposition from industry than was seen for the initial implementation, as it will have a more significant economic effect.

Points to make (in no particular order):

1. Tropical deforestation accounts for roughly 15% of annual carbon emissions, more than the combined emissions from road, rail, air, and marine transportation, worldwide.
2. Borneo is 73% Indonesia, 26% Malaysia, and 1% Brunei (which is not considered in this study to keep it compact). It is home to one of the oldest rainforests in the world.
3. The moratorium constrained investment in new deforestation clusters, shifting the spatial distribution of deforestation and ultimately increasing the overall rate of deforestation.
4. Indonesia announced the two-year moratorium in May 2010 to be enacted in January 2011, but it wasn't actually enacted until March 2011 after disputes between government, industry, and environmental advocates. Three stages of the moratorium.
5. The moratorium was catalyzed by a $1 billion promise from Norway, cash on delivery to Indonesia, contingent on a reduction in the deforestation rate. The promise of aid made the government's previously feeble attempts to manage deforestation much more credible.
6. We use the island of Borneo as a social lab, of sorts, given that Malaysian Borneo is similar in weather and agricultural output as Indonesian Borneo, but was not subject to the moratorium. While the border was drawn based on physical attributes of the land – to divide the watersheds – the similarity of the two sides is reasonable. The one complication may be that Indonesian Borneo is three times the size of Malasian Borneo, potentially affecting the possible spatial dispersion.
7. The overall effect of the moratorium was an *increase* in the rate of deforestation, relative to Malaysia, but to decrease the proportion of deforestation due to new clusters. The spatial pattern of deforestation became more condensed, with clearing occuring disproportionately on the periphery of pre-existing clusters.

8. The new paradigm under the moratorium resembles the short-term response to increased supply of cleared land, on the outskirts of existing clusters. Lower cost to clear, no investment. Short-term response to quick changes in the demand for cleared land are met with deforestation near previously cleared clusters.

9. Intertemporal leakage. Induced short-term behavior in place of long-term behavior, potentially waiting out the two-year moratorium. Similar to spatial leakage: Restrictions on clearing in a certain time or place will just induce clearing in a different time or place.

10. The theoretical structure should have the ability to distinguish between alternatives, to select a model based on testable hypotheses: (a) race to the bottom? (b) lower productivity of land near existing clusters? (c) freed up resources due to a lower fixed cost?

11. Use the physical layout of the land to help distinguish between hypotheses. Examine the attributes of the land that was cleared near existing clusters over time, before and after the moratorium was enacted.

12. Potentially cluster the rate-proportion graph, looking to see if the inclusion in each group was sequenced. A different approach to the standard diff-n-diff, potentially providing more intuition about the way the data are clustered through time.

Model Considerations:

1. Areas around clusters should be modelled with option value, reflecting the fact that short term supply of cleared land is mainly around existing clusters.

2. The return on land cleared around existing clusters is lower than that of new clusters. Thus, to get the same amount of product out of the land, more has to be cleared. **Check this, ask someone else.** Examine the characteristics of land cleared *around existing clusters* to see if the moratorium had an appreciable impact on, say, the slope of cleared land (something related to yield).

3. Dynamic programming problem, with option value and stochastic element. Two types of resources and one investment term that determines the next period's level of new land.

4. Look at the effect of increasing the risk of appropriation associated with new land, drastically lowering the expected return.

5. There is intertia in the data, allow for time to adjust expectations and to realize gains from previous investment.

6. Is the elasticity of supply of cleared land near *existing* clusters greater than the elasticity of supply of cleared land in *new* clusters. Different cost structures of clearing. If so, then a shock in demand will have a more than proportionate effect on the land around existing clusters. (This is seen in the data.) The greater supply elasticity may be due to (a) less time to mobilize resources and (b) excess capacity or inventory of land near existing clusters. Lower marginal costs will imply a greater elasticity of supply.

7. The supply shock that came with restricting new clearing will induce a more than proportionate response in supply (?) Inelastic demand for cleared land. Why doesn't the new supply just flood the market, immediately driving back down the price?

8. Ultimately, the firms will have to invest in new clusters; but they are content to use up their reserves now, knowing that the moratorium is set to expire in May 2013.

Basic results:

1. The moratorium had the unintending consequence of *increasing* short-term clearing activity by shifting the spatial ditribution of deforestation to the periphery of exisiting clusters. Potential cause: lower returns on land around existing clusters, and steady demand for the yield from cleared land.

2. Deforesters are treating the set moratorium period as a short term hit to investment activity, such that they are responding as if there was a short-term increase in the demand for cleared land (which would and has happened in the past). This can be seen from the stratified scatter plots.

3. The implication is that if the moratorium is lifted after two years, then there will be temporal leakage – restricting clearing in one period only pushed it into another. If the moratorium is maintained, however, it may actually reduce long-term clearing, since investment hasn't been made. Another prediction: way more outcry from industry over a long-term moratorium extension than for the initial two-year enactment to respond to the Norwegian aid promise.

4. Much of the effect happens when the moratorium was *supposed* to be enacted, the other half, so far, has occured after the moratorium was *actually* enacted.

Let $x_1(t)$ and $x_2(t)$ be the amount of land cleared in time t, where the subscript 1 indicates that the land is on the periphery of an existing cluster and the 2 indicates that the land constitutes a new cluster. Let $p_1(t)$ and $p_2(t)$ be the respective prices for the cleared land, which are functions of the physical characteristics of the land. We expect that $p_1(t) < p_2(t)$, since new sites of land clearing will tend to locate in land with the highest net return. Landowners will progressively clear less valuable land according to an option value approach, effectively storing the forested land until the return is high enough to merit the marginal cost of clearing. For now, though, consider the simple dynamic programming problem to

$$\max_{x_1,x_2,I} \int_0^T \pi_1(x_1(t)) + \pi_2(x_2(t)) - I(t)\,dt \quad \text{subject to} \quad \dot{R}_2 = f(I(t)) \quad \text{and} \quad \dot{R}_1 = f(I(t-1)) - x_2(t) \tag{1}$$

where $I(t)$ indicates the level of investment in infrastructure or exploration costs in order to create new clusters of cleared land in the following period. For a given amount of land, $\bar{x}$, we assume that $\pi_2(\bar{x}) > \pi_1(\bar{x})$. The profit from the newly cleared land is greater than that of land near older clusters. This gives landowners an extra incentive to clear new land, above and beyond the incentive to expand production. The function f is increasing and maps investment costs into the amount of land available in the new area.

Project structure and computation

This entire empirical project is open source, including the text write up. The paper is published as an `org-mode` document along with the source code, so that the results are entirely reproducible. The source code is based on three different languages: Clojure, R, and Stata. The Clojure code relies on Cascalog, an abstraction over Hadoop to parallelize operations on big data. The R code is used for the statistical analysis and graphics, using the famed `ggplot2` package.

Tables and figures

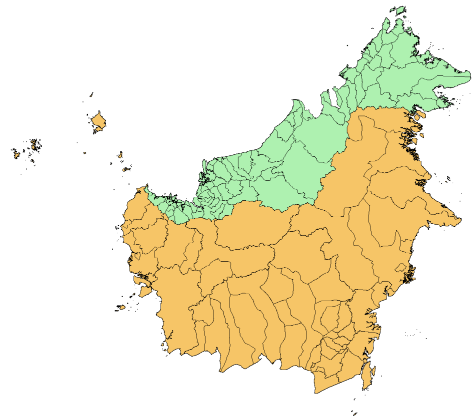

Figure 1: Sample area, Malaysia in green and Indonesia in orange. Borders indicate subprovinces.

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Table 1: Proportion of deforestation from new clusters

	(1)	(2)	(3)
(Intercept)	0.04552^{***}	0.06408^{***}	0.06506^{***}
	(0.00192)	(0.00536)	(0.00746)
cntry	0.03790^{***}	0.03790^{***}	0.02947^{***}
	(0.00271)	(0.00263)	(0.01055)
post	-0.01117^{***}	0.00047	-0.01334
	(0.00346)	(0.00460)	(0.04075)
cntry:post	-0.04021^{***}	-0.04021^{***}	0.11524^{**}
	(0.00489)	(0.00475)	(0.05763)
pd		-0.00530^{***}	-0.00558^{***}
		(0.00144)	(0.00207)
pd:cntry			0.00241
			(0.00292)
pd:post			0.00253
			(0.00732)
pd:cntry:post			-0.02822^{***}
			(0.01035)
R^2	0.64452	0.66756	0.68762
Adj. R^2	0.63913	0.66081	0.67635
Num. obs.	202	202	202

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

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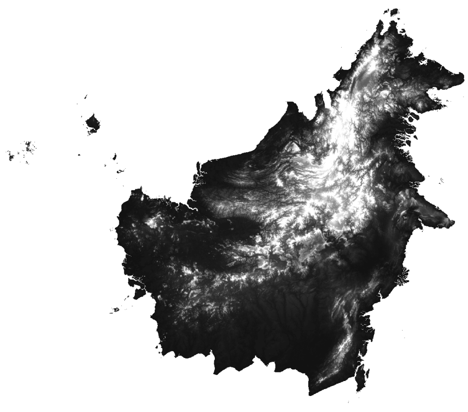


(a) Elevation

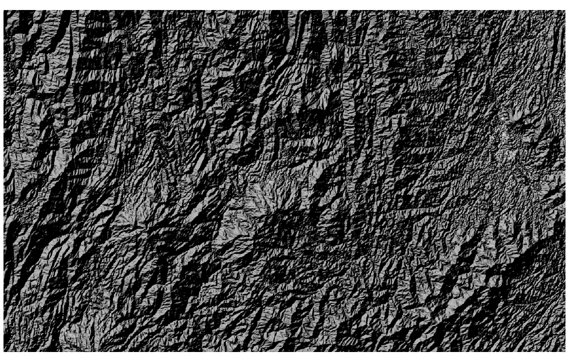
(b) Slope

(c) Flow

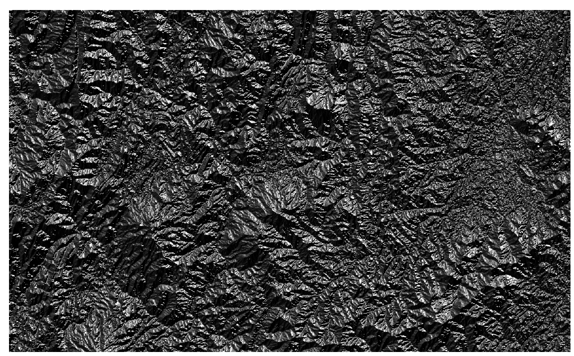
(d) Aspect

(e) Drop

Figure 2: Map of the digital elevation model (left) with derived data sets (right) indicating slope, hydrology, and terrain roughness, 90m resolution.



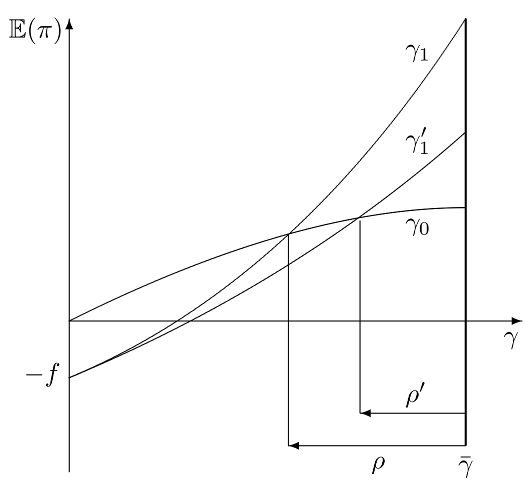
(a) Hillshade



(b) Flow direction

Figure 3: Detailed images of two derived data sets for the same area.

Figure 4: Illustration



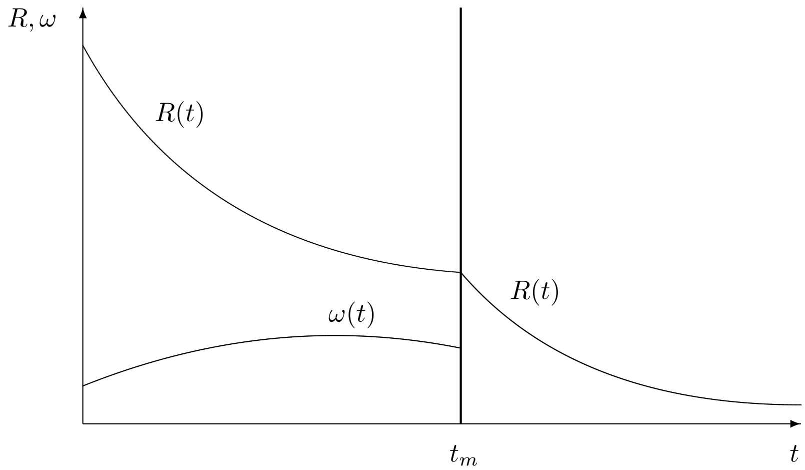
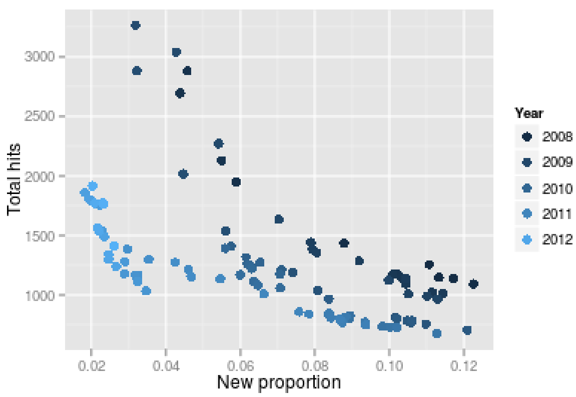
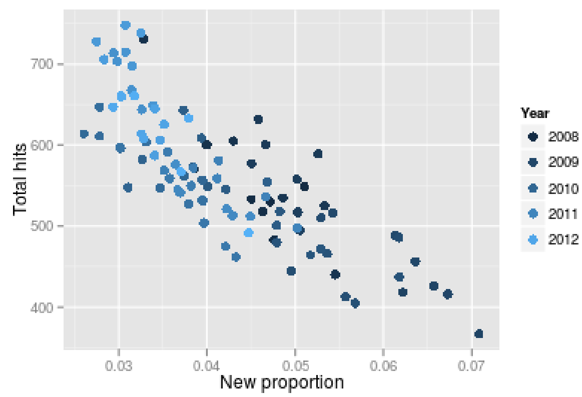


Figure 5: Dynamic programming illustration; t_m is time of moratorium

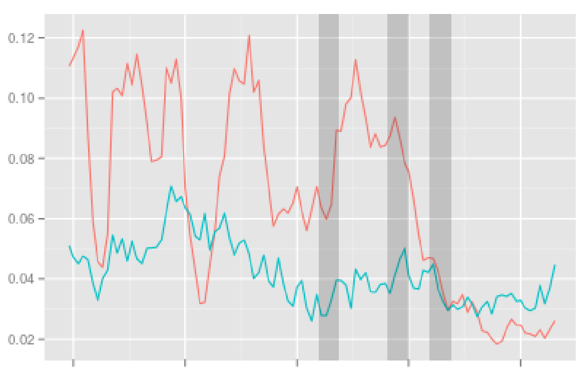


(a) Indonesia

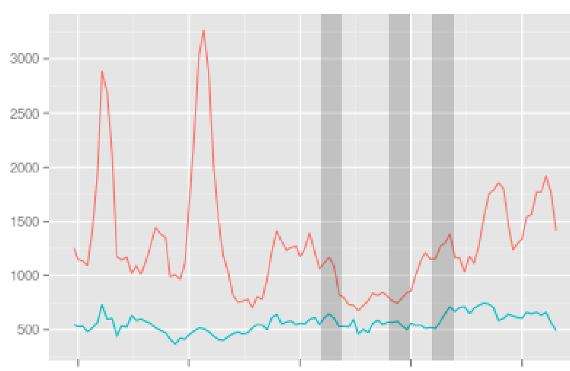


(b) Malaysia

Figure 6: Relationship between total rate and proportion of new clearing activity, stratified by time period.



(a) Proportion of new cluster deforestation



(b) Overall deforestation rate

Figure 7: Time series for Malaysia baseline (blue) and Indonesia (red); grey areas indicate the three phases of the moratorium, allowing for uncertainty in the deforestation data.