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Regional interdependence and forest "transitions": Substitute deforestation limits the relevance of local reversals☆

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ABSTRACT

Using case studies and concepts we suggest that constraints upon aggregate or global forest transition are significantly more severe than those upon local forest reversals. The basic reason is that one region's reversal can be facilitated by other regions that supply resources and goods, reducing the demands upon the region where forests rise. Many past forest reversals involve such interdependence. For 'facilitating regions' also to rise in forest requires other changes, since they will not be receiving such help. We start by discussing forest-transitions analysis within the context of Environmental Kuznets Curves (EKCs), for a useful typology of possible shifts underlying transitions. We then consider the historical Northeast US where a regional reversal was dramatic and impressive. Yet this depended upon agricultural price shocks, due to the Midwest US supplying food, and also upon the availability of timber from other US regions. Next we consider deforestation in Amazônia, whose history (like the Northeast US) suggests a potential local role for urbanization, i.e. spatial concentration of population. Yet inter-regional issues again are crucial. For cattle and soy, expansion of global demands may give to Amazonia a role more like the Midwest than the Northeast US. In addition, across-region interdependencies will help determine where reversal and facilitation occur. Finally we discuss the constraints upon very broad forest transition.

Introduction

The global loss of forest and particularly rapid deforestation in the tropics are of great concern to the world community. Forests in general, and tropical forests in particular, represent reservoirs of species habitat and carbon storage whose destruction brings both local and global loss. A very large literature examines both the drivers and environmental implications of forest destruction.

Yet a number of commentators have pointed to cases in which forest area has expanded, typically at the expense of land previously cleared for agriculture. This has been referred to as 'forest transition' and has led to a hope that autonomous land cover processes herald their own 'cure' for deforestation (Chomitz, 2006). A growing body of research examines cases of 'forest transition' and proposes frameworks to understand it. These frameworks, referred to as forest transition theory (FTT, see Perz, 2007) aim to identify causal shifts that reverse forest loss.

In this paper, we add new empirics and emphasize the crucial role within many observed transitions of interdependencies among regions. We start by discussing forest in the context of the broad concept of environmental transitions labeled Environmental Kuznets Curves (EKCs). The EKC idea is that environmental quality may have a U-shaped relationship with development, first deteriorating but then improving as economies develop and create wealth for populations.

The EKC literature provides a typology of shifts required for reversals that is relevant for forest and offers useful perspective on what would be needed for a global forest transition or rise. While others have of course noted the relevance of EKC conceptualizations for FTT thinking (for instance Rudel et al. (2005) and Angelsen (2007) within their economic development stories), we stress that shifts yielding local reversals can arise from interdependence, e.g. shifts in trade. This has not been emphasized in FTT and it implies stiffer constraints upon a global transition.

Two features of EKC descriptions of reversals stand out as relevant for forest transition. First, EKC models acknowledge that there are multiple shifts that could reverse environmental-resource outcomes as the scale of an economy expands. Thus, any single causal

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linkage to forest trends may be neither necessary nor sufficient for a transition to occur. Putting that point another way, conditions provoking forest transition in one set of circumstances may not do so in another.

Second, literature responding to early EKC models highlighted the potential role of trade. This raises spatial scale as a measurement issue. Forest area in a sub-region might rise yet for the region as a whole forest still may fall if in some other sub-regions forest is falling more quickly. We suggest that many observed forest reversals have fit this description because they involved trade between the transitioning region, with rising forest, and a region that facilitated transition by hosting substitute production. Thus, while the conditions for a transition can be met globally in principle, at the global scale it is more difficult due to the lack of such substitute locations.

Given this conceptual background, we consider empirically the case of forest reversal in the New England region of the northeastern US. Using county-level census data for 1790–1930, we document urbanization and changed forest trends: (1) forest area fell during earlier stages of the region's development when population was spreading but later rebounded when population concentrated even as population and output were rapidly rising; (2) concentration occurred as agriculture declined; and (3) industrial aspects of cities also supported the spatial concentration. These points alone might explain why forests could at first shrink but then grow as urbanization proceeds. However, New England's forest increase also appears to have relied heavily on imports of timber from other regions and food from the Midwest arriving on new rail connections. In this case, then, it appears spatial concentration can support but was not sufficient for forest transition.[2]

The Northeast US case suggests that trade, e.g. increases in the availability of substitute food and timber from other sources, matters for the forest transition. Increasing external supply can cause falling prices of food and timber imports and lower the pressure on local resources.

In this light, we entertain the prospect of an Amazonian forest transition. Amazonia has experienced persistent loss of forest for decades, despite concentration of population over time. This suggests the insufficiency of urbanization for forest transition: in New England, a spatial concentration occurred and forest rose but other factors appeared to have been necessary; in the Brazilian Amazon, a spatial concentration occurred and forest did not rise. One possibility is that the other factors, such as Amazonian trade, have not been as supportive. Given that, we consider a set of interdependencies which could help to explain the lack of Amazonian forest transition.

Specifically, Brazil participates in both agropastoral and natural resource global markets in which the Amazon appears to play a role more like the 'facilitating region', i.e. a region which hosts production that substitutes for production elsewhere and thereby reduces resource pressure. Beef, soy and timber are all exported from Brazil and from the Amazon in particular, in order to help to satisfy rising global demand. Looking within Brazil, the Amazon may be substituting for production in other regions of Brazil which could meet global or national demand, which again would make the Amazon a facilitating region not obviously headed for transition even if forest transition occurs in other regions (Baptista and Rudel (2006) present relevant evidence). Further, interdependencies may exist within the Amazon, such that some locations could rise in forest while others could fall. Thus, although Amazonia does not appear headed for forest reversal in the aggregate anytime soon, some parts of the region have shown extensive secondary growth.

The paper proceeds as follows. EKC & FTT section briefly summarizes FTT literature and reviews the elaboration in relevant EKC literature of the kinds of shifts that could permit forest transition. Historical forest transition in the Northeastern United States section presents new analyses of historical data for the region of New England in the Northeast United States. This region experienced a forest reversal during the 1800s and our analysis adds to the growing empirical literature on 'forest transitions'. In light of the role for trade suggested by the New England historical case, The Brazilian Amazon: transitioning or facilitating region? section considers the case of Amazonia's constraints on any forest reversal. Conclusion section concludes with discussion of the implications for a global transition.

EKC & FTT

Environmental Kuznets curves (EKC) literature

Examples and typology of underlying shifts

Grossman and Krueger (1993), in considering the likely impacts of a free-trade agreement, began this literature by examining urban air pollution's linkage to national income. Other studies (e.g. Selden and Song, 1994; Holtz-Eakin and Selden, 1992) also considered air pollution, tending to find pollution increasing at low levels of income but then decreasing at higher levels of income.

Many sought to extend such empirical exploration to various environmental outcomes, for instance in the World Bank Development Report (1992), one of the earlier examples (which also generated a background report on deforestation and water quality, Shafik and Bandyopadhyay, 1992). Grossman and Krueger (1995) consider a range of outcomes and continue to find declines in environmental quality at first, as income rises, followed by improvements. They hasten to add, though, that one should not interpret such a relationship as automatic, noting that various possible underlying shifts could generate it, ranging from technology through policy. Along these lines, as the empirical literature broadened over time to examine ever more settings, such findings varied.

Since for air pollution exposure at least in developing countries is likely to be dominated by indoor air quality, with cooking exposures comparable to smoking, the micro- or household-level analogs to ambient pollution are worth considering. Pfaff et al. (2004a,b) show that different effects of income growth on household fuel use (e.g. for cooking, heating, lighting) could yield an indoor air quality transition. For instance, the quantity of energy used for such tasks might well rise most rapidly at lower incomes and then, while perhaps still rising, eventually have its impact on air quality eclipsed by a rise in the share of that energy which comes from a cleaner source (e.g., kerosene versus dung or fuelwood). Chaudhuri and Pfaff (submitted for publication) show related empirics. This level of analysis focuses on the breakdown of the relationship into possible component parts and, as in the broad empirical literature just cited, finds that outcomes depend on many factors.

For our examination of possible forest transitions, Grossman (1995) nicely summarizes parts of potential transitions, offering a typology of the underlying shifts that could permit a transition: shifts in total scale of activity; shifts in composition of activity; and shifts in underlying technique. Thinking at the scale of a national economy: 'scale effects' concern the total production of goods (which is importantly distinguished from consumption by trade);

[2] One might naturally then ask whether urbanization was a necessary condition. In keeping with the observation above that many possible shifts within an economy and society could help to satisfy the conditions for transition, generally we would say no. At the same time, that the outcome depends on the relative magnitudes of all the factors implies that sometimes urbanization alone may be sufficient. A range of possibilities is discussed in our conclusion.

'composition effects' concern the mix of goods that are produced; and 'technique' effects concern how those goods are produced. Thus, if agriculture falls and services rise as a share of the economy during development (a shift in composition), or if the catalytic convertor is invented (a shift in technique), even if the scale of an economy continues to rise over time still it may but need not be the case that pollution would fall.

Two key points for forests

A critical point to take away from the EKC literature concerning transitions is that many relevant parts of an economy can be moving at any given time and thus the impact of a shift in any one of them is likely to be dependent on the levels and changes in others. Composition could shift but not be sufficient to overcome rising scale, for instance, unless technique supports transition too. More generally, various changes in real-world parameters could influence any of those three shifts.

Brock and Taylor (2004) offer a useful summary of this point as it focuses specifically on the multiple sources of possible shifts in trend and how each of them may act separately or instead in combination. Any given shift in output, its composition or technology may not yield transition yet in different circumstances, holding others constant, in principle any one of them could be enough. This simple yet important point is an important perspective for considering forest transitions.

A second critical point from the EKC literature that is relevant for forests concerns trade. From the very start, e.g. in St. Paul's discussion of Grossman (1995), the separation between the consumption and production within an economy due to trade is highlighted as a source of shifts. Thus, should a country start to import timber, it might continue to grow and to consume timber-based products but yet its forests could return because the imports had substituted for its use.

This raises the scale at which one measures in looking for transitions. That is distinct from scale of output, the composition of output, and the technique for producing output. If all of those were constant for the globe as a whole, a shift in trade could shift forest trends around the globe. The critical point to highlight is that while in some locations forest trends would shift upward, e.g. transitioning from forest loss to forest gain, in other locations forest trends would shift downward. Within the forest-focused literature, such impacts of trade were anticipated by Walker (1993).

Forest transition theory (FTT)

Forest transition theory (henceforth 'FTT'[3]) is a set of attempts to explain a systematic change in forest cover, observed in many parts of the world, where forest extent first decreases and then increases over relatively long time spans (see Mather, 1990, 1992; Drake, 1993; Walker, 1993; Grainger, 1995). Early work on forest transitions considered the extent of national land covers across many decades and even centuries. Empirical work documented a number of forest "transitions" in northern European countries, North America, and parts of the Pacific Rim (Houghton and Hackler, 2000; Rudel, 2001; Andre, 1998; Mather et al., 1999; Robbins and Fraser, 2003; Clawson, 1979; Staaland et al., 1998; Mather, 2001; Rudel, 1998).

Explanations of forest transition have focused on empirical phenomena that broadly correlate with aggregate changes in land cover (Perz, 2007), including urban industrialization, agricultural intensification, decreasing societal dependence on wood for fuel and materials, and changing preferences for natural area amenities (Walker, 1993). Each of these processes can support a reversal of trends favoring forest retraction provided that countervailing forces do not sustain conversion. The narrative of the forest transition largely tracks processes of economic change that occurred at national scale in European and North American countries. The plot-line starts with industrialization and the creation of high wage, urban jobs, which provided incentives for rural out-migration. As a consequence the distribution of population increased its spatial concentration in urban areas, an effect that released lands from subsistence production.

Accompanying industrialization and the redistribution of the population were processes driven by technological change. First, the energy basis of national economies shifted from wood to fossil fuels, which significantly reduced the daily exploitation of forests for survival (Mather, 1992). Second, the productivity of agriculture increased, allowing for new efficiencies in land use (Walker, 1993). Both of these phenomena evidently reduced pressure on forests. Changing societal preferences for the amenities stemming from natural areas promoted forest recovery as well (Walker, 1993). Taken together, these economic and cultural changes affected land use broadly, allowing for substantial recoveries of the areal domain of forest lands.

Such transitions have been documented in a number of developed, temperate countries, and also for regions within them. However, concerns about the impacts of tropical deforestation have generated interest in, and questions about, forest transitions within the developing world. Critiques of FTT have stemmed in large part from the observation that the conditions leading to forest transitions historically may not be replicated elsewhere. If not, then FTT cannot be relied upon as describing a "natural" process which is destined to occur wherever forest stands.

Early commentators noted the conditionality of forest transition and pointed out a lack of forest transition in the Mediterranean world as well as in parts of the tropics such as Amazônia as evidence that forest recovery was by no means guaranteed (e.g. Mather, 1990; Walker, 1993). Yet recent research has documented specific cases of forest reversal in tropical countries, as well as substantial areas of secondary forest regrowth in recently cleared regions (Moran et al., 1996; Rudel et al., 2002; Perz and Skole, 2003; Baptista and Rudel, 2006). New drivers of forest-area change – such as integration into global labor markets with return remittances – may affect the tropical forests, even with continuing dependence on agricultural production by wide segments of resident populations (e.g., Rudel et al., 2002; Klooster, 2003; Hecht et al., 2006).

Historical forest transition in the Northeastern United States

This section examines New England's regional development from 1790 to 1930 for evidence of forest transitions and of their causes. The main contribution is that, unlike in many tropical cases, this case permits long-term analysis of regular, historical census measures. It also permits us to examine the effects of a shift away from agricultural/extractive production and toward both cities and industry.

[3] There are legitimate questions about what constitutes "a forest transition." Many parts of the tropics show evidence of forest regrowth, i.e. a transition in vegetative cover from deforested to forested. However, if such transitions are temporary, or if they reflect the systematic fallowing of fields, should they be interpreted as "forest transition"? Does the observation of secondary regrowth necessarily mean that a transition is underway (Perz, 2007; Walker, 2008)? The present paper adheres to the notion of forest transition as reflecting the spatial outcomes of long-term structural changes in an economy and associated settlement patterns. It does not consider forest regrowth associated with cyclic agriculture, or short-run field abandonment linked to price fluctuations in product or capital markets, although such phenomena could herald the onset of forest transition as we are conceiving of it.

Table 1
Trends over time in New England, from 1850 to 1930.

Year	Density of total regional population (people/acre)	Density of estimated[b] forest area (acre/acre)	Density of improved (i.e., cleared) land on farms[a] (acre/acre)	Density of manufacturing employment (people/acre)
1850	.07	.66	.28	.008
1860	.08	.63	.31	.010
1870	.09	.63	.30	.013
1880	.10	.60	.33	.016
1890	.12	.66	.27	–
1900	.14	.72	.21	.024
1910	.17	.73	.18	–
1920	.19	.76	.15	.034
1930	.21	.78	.13	.028

[a] The census divides total land on farms into improved and unimproved. The latter includes both woodland and other unimproved land. At least roughly, improved land would appear to include all crop land plus plowable pasture land.
[b] This version of Harper's (1918) estimate is: (county area × .95) – (population × .2 acres) – (improved land on farms).

Apparent importance of population concentration

While this case has been considered before, here novel data suggest: (i) spatial concentration of population can contribute to increased regional forest levels, (ii) declining agriculture leads to spatial concentration, and (iii) industrial aspects of cities facilitate spatial concentration.

The data are for New England, from decennial U.S. censuses for 1790–1930 at county and town levels, for population and land use on farms.[4] Farm area is not a direct measure of deforestation but it permits an estimate using "improved" lands (see Table 1 and Harper, 1918).[5]

Demographic variables in the Census include numerous breakdowns of the population by age, gender, ethnicity, and origin. Of these, other than perhaps some form of age-weighted index, the most natural measure of economic activity and land demand is the total population. Finally, the measure of manufacturing activity used below is total employment in manufacturing.

Spatial concentration of population can support increased forest

Table 1 aggregates county data to New England data, from 1850 to 1930, for population, estimated forest area, farm area and manufacturing employment. Total population grew steadily. Improved land on farms was fairly flat from 1850 to 1890, and shrank from 1890 to 1930. The shrinking farm area suggests potential for reforestation, and the estimated forest area turns upward after 1890, even though this estimate takes into account not only farm area but also population.

Thus, the oft-cited negative correlation between population density and forest does *not* hold for New England in this period at this spatial scale of analysis.[6] However, each person surely does create demand for food and shelter, and thus cleared land. Thus, the first column of Table 1 leads us to ask what factor might lower clearing *per person*, permitting a rise in forests in the second column.

[4] Unfortunately the land use is only from 1850 onward. Other data such as forest inventories may exist, but if so they will be even harder to collect, in particular for anything like this complete coverage at regular time intervals.

[5] The categories of land use on farms that could consistently be found, though no land-use data exist before 1850, were 'improved' and 'unimproved' (an exhaustive breakdown). In 1870, 1910 and 1920, unimproved is broken down into woodland and other unimproved land. For 1930, three sub-categories of crop land, three of pasture land, plus woodland and other land were aggregated into improved and unimproved. It would appear that improved land can be thought of as all crop land plus plowable pasture land.

[6] Some examples of this correlation, in particular within cross-country empirical analyses, can be found in Lugo et al. (1981), Allen and Barnes (1985), Palo et al. (1987), Rudel (1989), Cropper and Griffiths (1994), and Deacon (1994).

Table 2
Distribution of county population densities in New England gini coefficient and decennial concentration ratios.

Year	Gini[a]	CR-5[b]	CR-15[b]	CR-25[b]
1790	0.24	0.18	0.45	0.73
1800	0.21	0.15	0.38	0.64
1810	0.18	0.09	0.39	0.61
1820	0.16	0.09	0.37	0.58
1830	***0.13***	***0.12***	***0.34***	***0.57***
1840	0.13	0.12	0.37	0.58
1850	0.14	0.20	0.40	0.59
1860	0.15	0.22	0.46	0.60
1870	0.18	0.26	0.52	0.63
1880	0.20	0.29	0.56	0.69
1890	0.23	0.32	0.60	0.73
1900	0.26	0.34	0.65	0.77
1910	0.27	0.35	0.68	0.79
1920	0.28	0.35	0.71	0.81
1930	0.29	0.35	0.72	0.82

[a] This measures the difference between the actual distribution of densities over counties and a hypothetical distribution in which all counties have equal densities. It is an aggregate inequality measure that considers the entire distribution.
[b] The "CR-*x*" variables are the sum of the *x* highest county population densities over the sum of all county densities. The set of counties that made up the *x* with highest densities changed over time, as the shifts discussed were occurring.

The trends of Table 2 in the spatial concentration of population suggest an answer. Concentration was decreasing until about 1830, when the trend reversed (the timing of this crucial shift shows the value of the pre-1850 demographic data). The first measure is a Gini coefficient (this is a single aggregate measure of how skewed the distribution of the densities is away from being equal in all counties). Also, five-, 15-, and 25-county concentration ratios are calculated for each year using the population densities of the 67 counties in New England (these concentration ratios sum the 5 (or 15 or 25) highest population densities, and divide that by the sum of all 67). None of the concentration measures falls in any decade after 1830 (this is true in levels as well).

The shift in trend in spatial concentration coincides well with the data in Table 1 and our knowledge that, before shifting trends, New England was deforested as its population grew from the mid-1700s. (Unfortunately, land data is not in censuses before 1850.) Decreasing concentration until 1830 matches that forest clearing. Increasing concentration since 1830 matches the eventual increase in forest in Table 1. Thus, the explicit concentration measure in Table 2 could explain how the rising estimated forest in Table 1 could occur, despite the rising population in Table 1.

Spatial concentration occurs when agriculture declines

If concentration mattered, we would like to explain why it occurred.[7] Economic theory suggests that land will be allocated between uses to obtain the greatest expected total return. Thus, factors which affect relative returns should affect land allocation. This implies that trade should affect land use, as trade affects returns, given comparative advantage based on regional factor endowments.

Of relevance to New England forests, the Midwest has an absolute advantage over New England in agriculture (given high soil quality in the Midwest, and hills and rocky soils in New England). Given that, if Midwest transport costs were to drop we would predict an increase in agricultural imports by New England, where high costs would imply low returns and thus little agricultural land use (potentially even if all of the forested land uses' returns were zero).[8]

In light of this basic theory, and that we know that transport costs to and from the Midwest dropped in the early 1800s, Tables 1 and 2 suggest that agricultural decline did contribute to spatial concentration. The perfect correlation of the timing of the transport cost shock and the reverse in Table 2 in the trend in spatial concentration in New England suggests that the transport shock drove the reversal in concentration. The obvious mechanism is a reduction in agriculture and a migration to New England's cities, given the drop in regional agricultural profitability. This idea is supported by Table 1—the third column's direct measure of the land in agriculture drops over time, while the fourth column's measure of manufacturing employment rises steadily over time.[9] Thus, a decline in agriculture occurred alongside and could have caused spatial concentration in New England.

To support this argument, agriculture must be less concentrated than manufacturing. This is corroborated by Table 3, which shows that manufacturing employment is more concentrated than is the agricultural land. Thus, the decline in agriculture contributed to the spatial concentration.[10]

Industrial aspects of cities also facilitate spatial concentration

While replacement of agriculture with manufacturing helps to explain spatial concentration, households will demand land for daily life, such as for shelter, whatever the exact nature of their employment. Thus, we must fully consider the effect on land use of the post-agricultural regime.[11]

Many have shown that industry facilitates concentration; here we consider land-use/forest impacts. For an equivalent level of population or output, manufacturing implies less cleared land than agriculture. This may be due to lower ratios of land to labor and capital, or agglomeration with increasing returns to scale, cross-firm externalities, and the idiosyncratic location of factors of production or distribution.[12] The link to cleared land for agglomeration is less direct than for land ratios, as for a given output, fewer sites need not imply less total land use. However, agglomeration may reduce manufacturing-related but non-production land use, such as for workers' shelter (e.g., urban apartments house manufacturing factory workers on little land).

The rest of the tabular evidence then provides our final evidence that the industrial nature of employment in cities facilitated spatial concentration of the population. Not shown is that of all the population of the five largest towns in each county, summed over counties, about 40% lived on the coast and of the non-coastal pop-

Table 3
Distribution of improved land and manufacturing employment decennial concentration ratios of densities.

Year	CR-1[a]	CR-5[a]	CR-15[a]	CR-25[a]
Sector average:	*0.04*	*0.14*	*0.37*	*0.55*
Improved land				
1850	0.03	0.13	0.36	0.56
1860	0.03	0.12	0.34	0.53
1870	0.03	0.12	0.35	0.55
1880	0.03	0.12	0.33	0.52
1890	0.03	0.13	0.34	0.53
1900	0.04	0.15	0.37	0.55
1910	0.04	0.15	0.37	0.55
1920	0.05	0.17	0.41	0.58
1930	0.05	0.18	0.42	0.59
Year	CR-1[a]	CR-5[a]	CR-15[a]	CR-25[a]
Sector average:	*0.47*	*0.68*	*0.87*	*0.94*
Manufacturing employment				
1850	0.50	0.70	0.86	0.94
1860	0.36	0.59	0.82	0.91
1870	0.49	0.69	0.86	0.94
1880	0.53	0.72	0.88	0.95
1890	–	–	–	–
1900	0.49	0.69	0.88	0.94
1910	–	–	–	–
1920	0.45	0.69	0.90	0.96
1930	0.46	0.69	0.90	0.96

[a] The "CR-*x*" variables are the sum of the *x* highest county improved land (or manufacturing employment) densities divided by the sum of the improved land (or manufacturing employment) densities for all New England counties.

[7] Others have considered migration and urbanization at length: Kuznets et al. (1957) on population and growth in the U.S. (Harris and Todaro, 1970) and several papers in van der Woude et al. (1990). Also, de Vries (1984) analysis of migration processes, city growth and the evolution of a European urban system depicts a period of de-urbanization of smaller cities as metropolises expanded, followed by a period in which smaller cities grew disproportionately.

[8] Note that the comparative advantage in livestock may not equal that in crops, and that livestock could also be detrimental to forest. Still, farm area encompasses both activities to large extent, so when it falls it likely represents a fall in livestock area as well. To the extent that livestock co-exist with forest but perhaps degrade the forest over time, we face the issue of our crude, 1/0 measure of the dependent forest variable, one lacking quality gradations.

[9] While it would be better to have direct evidence regarding profitability, that is suggested by the fall in area.

[10] Note that agriculture did become somewhat more concentrated over time as it shrank. An interesting suggestion we have received concerning this result is that is may be due to spatial autocorrelation in the topography of the region.

[11] As to why it was industry, there exists extensive discussion of development and industrialization including links both to and from agriculture and urbanization. A broad discussion is beyond the scope of this paper's simple sketch of relevant theory, but work relevant for considering land use includes Boserup (1966) and Hymer and Resnick (1969) on agriculture, and historical analyses of urbanization and cities' relationships to society, such as de Vries (1984).

[12] Regarding increasing returns to scale, for any firm this will push toward fewer locations of production.
Regarding externalities, in Krugman (1991) locational externalities between firms arise from transport costs and the fact that one firm's employees are another firm's customers. Another possible interaction between firms is informational spillovers, usually assumed to decrease with distance (see Marshall, 1961; Henderson, 1974; Rivera-Batiz, 1988; Fujita, 1993; Krugman, 1991, as well as Ellison and Glaeser, 1997; Hanson, 1997 for empirics).
Regarding the fixed, idiosyncratic location of important factors, these may be important for explaining any given example. Ellison and Glaeser (1997), e.g., offer the wine industry's concentration in California as an effect of a site-specific climate effect. Also, along New England's lengthy coast, the non-uniformity of population density is striking, with big cities found in natural harbors. River location is also important, as rivers provide not only transport but also water power, at least during the period considered here. There exist analogous agricultural features, including the idiosyncratic location of agriculturally relatively productive areas, such as areas of good soil (regarding the Northeast, Hutchinson (1985) ascribes some industries' location to regional resource advantages). Finally, pre-existing railways could be determinants of location. However, historical accounts suggest that the causality was more likely to run from town location to railroad location (see, for example, Tanner, 1840 or Harlow, 1946, chapters 3 and 5).

Table 4
Concentration of population along the Merrimack and Connecticut.

	CR-1[a]	CR-3[a]	CR-5[a]
Merrimack[b]			
1850	0.03	0.13	0.36
1860	0.03	0.12	0.34
1870	0.03	0.12	0.35
1880	0.03	0.12	0.33
1890	0.03	0.13	0.34
Connecticut[c]			
1850	0.50	0.70	0.86
1860	0.36	0.59	0.82
1870	0.49	0.69	0.86
1880	0.53	0.72	0.88
1890	–	–	–

[a] The "CR-*x*" variables are the sums of the populations of the *x* largest towns on the Merrimack (Connecticut) divided by the sums of the populations of all the towns (see footnotes below) on the Merrimack (Connecticut).
[b] The total number of towns counted as on the Merrimack for this table is 26.
[c] The total number of towns counted as on the Connecticut for this table is 111.

ulation about 40% located on large rivers[13] with 75% on a river of some type. This suggests the importance of fixed manufacturing inputs, since rivers were used for power and the coasts and rivers provided transport.[14]

Table 4 also shows high and increasing concentration even within the set of such relatively advantageous locations. The spatial heterogeneity of river services (e.g., locations of waterfalls) might simply take the idiosyncratic-inputs argument one step further. However, this table could also suggest that, in addition to spatially fixed river services, other features of manufacturing such as increasing returns to scale or externalities affect spatial concentration.

Essential roles of within-US regional linkages

For interpreting what these data tell us, some regional background may well be helpful. In short, while the conditional causal linkages suggested in section 'Apparent importance of population concentration' above all seem valid, nonetheless New England's forest transition was, very clearly, facilitated by some other regions.

Walking through a time line of land-use decision making in New England is informative. When the Pilgrims landed in the early 1600s, at least 90% of New England's area was in forest.[15] Native Americans had long burned to clear fields and fight insects but at low population density. Colonists imposed small, fixed areas for individuals (Cronon, 1983) and by the early nineteenth century, permanent colonization and greater population density in a European-style agricultural system put New England on a path of semi-permanent clearing. This continued until about 1830.[16]

During the first half of the nineteenth century, the United States' boundaries expanded greatly. However, for inter-regional economic linkages to arise, transport costs between regions had to be drastically reduced.[17] By the 1830s, both steamboats and railroads had started to proliferate, facilitating the transport of both people and cargo.[18] In addition, stimulated by the success of the Erie Canal, total canal mileage grew rapidly, nearly tripling in the two decades from 1830 to 1850.[19]

This engendered trade; evidence exists that wages and commodity prices converged across regions as smaller, differentiated regional economies were linked.[20] Agricultural output rose in the Midwest and fell in New England,[21] which was relatively well endowed with rivers and thus power, and appeared to find a niche in the trade system by moving towards factories and industry.[22] Thus a basic pattern emerged of agriculture in the Midwest and manufacturing in the northeast.[23]

Both households and industry created a growing demand for timber.[24] As a result, timber production shot up in the mid-1800s, at a rate more than double that of population (MacCleery, 1992). This led to two types of substitution for New England timber: first, substitute timber was generated at an enormous rate from other regions of the country, such as the Lake States and the South[25]; and second, various materials were substituted for timber within a number of tasks.[26]

Legislation is also a potentially significant factor in land use. In the U.S., from about 1850 on, debate over such legislation was inspired by both economic and ecological rationales for forest conservation.[27] However, much of the debate over national parks, the conditions for homesteads, and public versus private ownership was centered on land west of the Mississippi.[28]

For our purposes, then, what do we see? Facilitation by other regions of the forest transition in New England. The flip side of collapsing agriculture in New England was increasing use of land to produce food in the Midwest. This appeared to guarantee the Midwest would not have any such transition anytime soon after. Further, the flip side of the coin of decreasing supply of timber from much of New England was, despite technological innovation, increased supply from other regions.

[13] The "large" rivers are defined for these purposes as the Connecticut and the Merrimack rivers in particular, in addition to the Housatonic and, Maine, the Androscoggin, Kennebec, Penobscot, and Saco rivers.

[14] Also of interest is the Erie Canal, along whose path across relatively empty land Rochester and Syracuse boomed because of their sudden access to transport. The development of those urban centers was distinct from the persistent lower population density along much of the canal. As Harlow (1926) points out, most of New York State was so thinly settled that it was quite a gamble to spend what was at that time the huge sum of 8 million dollars on this canal.

[15] Harper (1918), citing a U.S. Forest Service circular by Kellog (1909).

[16] Raup (1966) discusses late 1700s clearing in Petersham, MA (from 10% to 15% during 1770–1790). On one 600 acre farm, e.g., clearing was 11% in 1770, 77% in 1830, and 90% in 1850, indicating faster clearing in the early 1800s.

[17] Improvements in communication, such as in the telegraph, also matter. See, e.g., Duboff (1982) and Field (1992). In addition, the development of a system of property rights may play a crucial role. See, e.g., Alston et al. (1995).

[18] Steamboats sailed the rivers and coasts, while railroads offered east–west transport. As north–south transport along the coasts had long existed, railroads probably had greater effect on trade (see Williams, 1989).

[19] Taylor (1951).

[20] See Slaughter (1997) on commodity prices. Rosenbloom (1996) finds a well-integrated labor market by the late 1800s in the Northeast and North Central regions, but large and persistent north–south differences into the 1900s.

[21] See, e.g., the discussion of the expansion and commercialization of Midwestern agriculture in Gregson (1993).

[22] Raup (1966) tells of living in the Midwest and receiving fish products from the northeast in the early 1900s within wooden barrels and buckets that were crafted in factories, from forests grown up on formerly agricultural lands.

[23] From 1820 to 1850, total employment in New England per thousand people in the national population grew; agricultural employment fell, while manufacturing employment rose (Census (1850), including the Compendium).

[24] Household demand for wood for heating tailed off only after 1900 (MacCleery, 1992; Cronon, 1983). Industries used wood for fuel, charcoal, railroad ties, shipbuilding, and eventually pulp. Pitch was also used, for making ships.

[25] While in 1840 the northeast accounted for over two thirds of timber production, by 1860 this share was about one third and still falling, although regional output was more or less constant (Williams, 1989, including Fig. 7.5).

[26] E.g., coal and oil in generation of energy, and cement and steel in construction. Although the absolute peak for wood harvested occurred in about 1930, the fraction of total U.S. energy produced by wood fell from 90% in 1850 to about 10% in 1930. In contrast, coal's share rose from about 10% in 1850 to 70% in 1910, but fell 50% by 1930 as oil increased in popularity (Williams, 1989, Fig. 10.2, p. 333 (based on Schurr and Netschert, 1960, p. 36-7)).

[27] See Starr (1865), Pinchot (1919), Marsh (1864) and Muir (1876), all cited in Williams (1989).

[28] See, for instance, Libecap (1981) and Libecap and Johnson (1979).

The Brazilian Amazon: transitioning or facilitating region?

The Northeast US case suggests conditions which enable forest reversal by increasing the availability of substitute food and timber from other sources. Increasing external supply, yielding falling prices of food and timber imports, can lower the pressure on local resources.

In this light, we entertain the prospect of an Amazonian forest transition, observing that Amazonia has experienced a persistent loss of forest spanning decades. We note that models not taking interdependence into account suggest that Latin American countries lower deforestation when per-capita GDP rises above $6300 (in 1996 US dollars). Given Brazil's per-capita GDP in 2000 of $6900 (1996 dollars), economic growth should reduce deforestation (Barbier, 2001).[29]

However, within Amazônia this certainly is not the case. Deforestation has remained remarkably persistent in absolute terms since the mid 1990s. The question at this aggregate basin scale, then, is what drives the current deforestation process. We will consider a set of interdependencies which could help to explain the apparent lack of transitional processes.

Brazil participates in both agropastoral and natural resource global markets in which the Amazon appears more to be playing the role of a "facilitating" region. Beef, soy and timber are all exported to rising global demand. Looking within Brazil, the Amazon may be substituting for production in other regions of Brazil which could meet global or national demand, again making it a facilitating region not obviously headed for transition. That said, interdependencies also may exist within the Amazon. Thus, although Amazonia does not appear headed for forest transition soon, some parts of the region do show extensive secondary growth, which we also consider.

Amazonia and global food/resource markets

Agropastoral production

The current positioning of the agricultural economy of Amazônia within global markets casts doubt on predictions of overall forest transition within Amazônia in the near to mid-term. Deforestation in the region has for many years been driven by cattle ranching. Although soy now competes with pasture for land in Mato Grosso, the expansion of herds throughout the Amazon continues to represent the premier, proximate cause of forest loss (Morton et al., 2006).

In recent years, the Amazon region has emerged as Brazil's premier cattle producing region, with over 70,000,000 cattle, a population that has grown precipitously in only a few decades in response to domestic and global demand (Walker et al., 2008). Although local beef used to accommodate only regional cities such as Belém and Manaus due to foot and mouth disease and transportation costs, this is no longer the case (Faminow, 1997; Simmons et al., 2007).

The Amazonian herd may well continue its march across the entire basin given that (1) demand for beef is likely to continue growing worldwide, (2) that global export of Amazonian beef is now possible with disease controls and transportation cost reductions, and (3) that soy competes with ranching for Amazonian land, thereby exacerbating the demand for land overall.

Thus world markets for beef, along with demand for soy, at least as seen at this moment are transforming Amazônia into a global pasture, a process that works against forest transition. Further, an expanded Brazilian biofuel economy would additionally slow forest restoration.

Natural resource production

Other extra-regional demands also exert pressure on the forest. In early research on forest transition, a factor said to promote forest recovery was the reduced demand for wood as societies increasingly depended on fossil fuels (Mather, 1992). Yet Amazonian forests may not benefit from this shift as it has already occurred throughout the world (though poor farmers in the region do depend on wood for cook fires). Whatever the case may be globally, demands for Amazonia's forest resources are complicated by the tropical hardwoods sector and a logging industry that is large and growing.

Between 30 and 40 million m^3 of roundwood are taken annually from the Brazilian Amazon, yielding gross revenues of US $2.5 billion (IBGE, 2009; Lentini et al., 2003). This magnitude has led to an estimated 9400 km^2 logged in 1996, growing to 23,400 km^2 by 1999 (Matricardi et al., 2001). About 1600 sawmills operate in Pará state alone (Lentini et al., 2003). Such numbers represent considerable impact on the forest, and such output can be expected to intensify with Brazil's move to a system of concession logging (Rohter, 2007). Though intended to concentrate extraction of national forests under management control, rationalization of the sector will also build capacity in the region, and opportunities for incursion on lands outside the national forests. In sum, the external demand for Amazon wood is not likely to diminish in the foreseeable future.

Amazônia within Brazil—regional interdependencies

Substituting for other regions' outputs

Concerning the predictions linking GDP to national deforestation noted above, it is fair to say that at this point the potential for inference is limited concerning the validity of the turning-point prediction. National GDP is just passing the indicated threshold and all such expectations should be treated somewhat more generally than is suggested by the specific extrapolations from analysis. Further, predictions are for the national aggregate anyway, and Amazonian deforestation could well continue unabated even with high incomes. The reason, of course, is that other regions in Brazil could feature falling forest pressure as a result of what is transpiring in the Amazon. Thus, Amazonia could be facilitating other forest transition in Brazil.

As noted above, the Amazon region has emerged as Brazil's premier cattle producing region, possibly in response to globalization demands. However, even if global demand did not increase Brazilian production, production from the Amazon could still rise if the region has substituted for cattle production in the South. The same is true for soy. Brazilian soy production is rising at the national scale, but the Amazonian share of that production is rising too. Without such a redistribution in production, other parts of Brazil would face higher pressure on forests.

Should this be significant, then land use elsewhere in Brazil (i.e. outside the Amazon) should reflect lower pressure for agropastoral production than would be expected given all local, national and global markets. And in fact, some transitions of other forests in Brazil appear to be underway, particularly in the southern Atlantic rainforest (see for instance Baptista and Rudel, 2006 concerning Santa Catarina, where the growth of tree plantations played a big role, as well as others looking at southern Brazil). In fact, interstate trade data suggests domestic linkages within Brazil suggestive

[29] This particular number comes from Barbier (2001, p. 164), which places the income associated with maximum deforestation in Latin America at $4946 in 1987 US$. This is $6354 in 1996 US$ (based on a price deflator from the US Department of Commerce). In 2000, Brazilin GDP per capita was $7400, or $6915 in 1996 US$.

Table 5
Brazilian Interstate Trade—1999[a] Amazonian States[b] with Santa Catarina (SC) and São Paulo (SP).

Sector 1	
Amazônia → SC	SC → Amazônia
20.5 million $R	3.0 million $R
Amazônia → SP	SP → Amazônia
83.3 million $R	19.7 million $R
Sector 2	
Amazônia → SC	SC → Amazônia
0.0 million $R	0.0 million $R
Amazônia → SP	SP → Amazônia
4.2 million $R	0.3 million $R
Sector 15	
Amazônia → SC	SC → Amazônia
159.7 million $R	90.0 million $R
Amazônia → SP	SP → Amazônia
1041.0 million $R	746.9 million $R
Sector 20	
Amazônia → SC	SC → Amazônia
95.1 million $R	6.8 million $R
Amazônia → SP	SP → Amazônia
335.9 million $R	9.7 million $R

[a] Using the Classificação Nacional de Atividade Econônomic—Fiscal (or Cnae—F). *Sector 1*: Agricltura, pecuária, caça e serviços relacionados com essas atividades. *Sector 2*: Silviculture, logging, and related services. *Sector 15*: Food and beverage processing. *Sector 20*: Furniture and other wood products.

[b] Amazônian States consists of Amazonas, Mato Grosso, Pará, and Rondônia, largest trade partners with the rest of Brazil, for the purposes of this table.

of facilitation, with Amazônia providing land-based commodities and manufactured goods (Romeo de Vasconcelos and Augusto de Oliveira, 2006). Table 5 presents data covering trade relations in 1999 between key Amazonian states and the southern states of Santa Catarina and São Paulo. For sectors covering agricultural and wood-based products, Amazônia enjoys a position of net-exporter to the south in the four sectors presented.

The role of inter- versus intra-regional transport

The critical role of regional interdependencies for any predictions of transition certainly was emphasized in the story of the historical Northeast US. One way to see this is to consider a prediction of what happens when investments in transport infrastructure lower transport costs for any given region. The often-hypothesized effect of lowered transport costs is that deforestation will rise and thereby reduce the extent of forest. However, exactly the opposite happened in the Northeast US. Railroad investments that linked to the Midwest US lowered transport costs but increased forest. The reason, of course, is that this particular lowering of transport cost served to bring agricultural substitutes to the area. Putting that another way, that this specific rail provided *inter*-regional connections made all the difference.

The same type of thinking is relevant for the Brazilian Amazon. In general, as seen in Pfaff (1999), Caldas et al. (2007), Pfaff et al. (2007) and other work, roads constructed in the Amazon have increased deforestation. However, it is possible for trade to matter as well. As transport to the rest of Brazil from the north improved, many agricultural commodities (e.g., oranges, rice, beans) from the South of Brazil were sold throughout the basin. Thus, for a number of commodities, the South plays a role as agricultural supplier, which could facilitate Amazon transition. Be this as it may, as just noted current trade relations between north and south favor transition in the south but facilitation with continuing deforestation in Amazonia (Table 5).

However, even allowing for the possibility of trade the details matter. In beef, as noted, productivity in the Amazon has been rising. This is so much so the case that now beef produced in the Amazon is consumed in the Southeast (the large cities of Sao Paulo and Rio de Janeiro) and the South. When the Amazon is the supplying region, its forest transition is more difficult.

Subregions within Amazonia—spreading versus specialization

Urbanization/spatial concentration

An important fact about the Amazon is the presence of two cities which have long housed over one million people, Belém and Manaus. Thus, spatial concentration of the regional population is simply a fact. Further, it may well support forest, such that a trend towards cities could support forest transition. Pfaff (1999), for instance, found that only when the marginal impact of new people within a county were allowed to differ in impact from early migrants is there evidence of impacts upon forest of greater population. In particular, later arrivals had much less impact, as one might expect for the millionth arrival to a large city. In visual support of this concept, a simple glance at Amazonas state's forest cover shows one point of intense clearing, Manaus, but otherwise forest.

Population dynamics too would seem to favor Amazonian transition at the present time. The available data shows a concentration of Amazonian population in both absolute and relative terms. The urbanization of the aggregate population has been long in evidence, with explosive growth in both large and medium sized cites (Browder and Godfrey, 1997). Perz (2002a) studied long-run trends in the distribution of Amazonian population, and found that by the 1990s, net-migration within Amazônia favored urban location. Specifically, between 1991 and 1996, the rural population declined absolutely on average one percent a year, compared to an urban growth rate approaching four percent (Perz, 2002b). The urbanization has continued, as has the decline in the rural population. In 1991, rural people in the states of the north region (Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins) together with Mato Grosso had a population of 4,650,103, which declined to 4,402,966 by 2000 (IBGE webpage). These numbers give a slower average rate of about .5% over the decade of the 1990 s than the calculations of Perz (2002b). The Perz number includes Mato Grosso do Sul and Goais, however, in order to maintain data comparability over a time series back to 1970. These two states are not typically included in geographic definitions of Amazônia, and their location much closer to the economic core of the country in the south might bias the rural out-migration counts upward relative to Amazônia.

The engines of urbanization in Amazonian cities now include manufacturing and – beyond a free-trade zone in Manaus – both wood and food processing which sustain substantial urban workforces throughout the basin. As a result, one can imagine that while those urban areas will slowly become close to fully cleared of forest, if development is not evenly spread across space but instead is specialized in development 'hotspots' then in principle even if the Amazon region grows overall still particular Amazonian subregions could undergo a forest transition.

Looking for spatially differentiated forest outcomes, we can see that while the basin as a whole continues to experience net forest loss of a very high magnitude, previously cleared land in the Amazon basin actually does shows signs of forest regrowth in some areas (see Moran et al., 1994; Perz and Walker, 2002; Walker, 2003). Moreover, Rudel et al. (2002) have now identified local-scale transitions for communities in eastern Ecuador, while Perz and Skole (2003) note some limited indications of forest recovery already underway in the lower Amazon basin.

Intensification

In keeping with other household-level analyses in the literature, the term "intensification" here refers to, e.g., the replacement of cattle (a "non-intensive system") by soy (an "intensive system"), and to increasing productivity of pasture-based systems using improved technologies of production and range management. We focus on this latter use of the term, given the current pre-eminence of ranching in the basin and its role as a deforestation driver. Thus, for Amazonia, agriculture intensifies if new technologies or management yield higher production per unit area.

It does appear that productivity of Amazônia ranching has increased over decadal times spans. In fact, ranching in Amazônia is now more productive than in the traditional ranching areas to the south, which translates into higher Amazon profits (Arima et al., 2005). To predict the implications of such a development requires care. First, intensification is a two-edged sword. Although FTT often posits benefits for forest from intensification, it can just as easily promote deforestation if new technologies generate higher rents (White et al., 2001; Arima et al., 2005).

Also, higher productivity ranching is by no means universal in the Amazon basin. It is in key locations in already settled areas. In active deforestation frontiers, colonists often depend on primitive approaches to pasture and herd management, with lower productivity, given abundant land (Caldas et al., 2007). Indeed, studies suggest land scarcity drives intensification, in which case intensification's forest restorative powers may be somewhat misconceived (Boserup, 1965).

Still, at the scale of deforestation hotspots versus pristine areas, one could well think that "intensification" of a different sort would make sense. For instance, if Avança Brasil only paved over unpaved roads that were linking city centers and not roads through pristine areas, it is possible that economic activity would remain concentrated in urban areas with low impact on uncleared lands (this point links to Ozorio de Almeida, 1992 on the lowering of within-region migration). Even if at a microeconomic (or household) level yield intensification actually raises net clearing, this form of "regional or macro intensification" could lower clearing for any level of production.

Conclusion

When addressing FT, it is critical to consider the scale issue. One man's transition may rely upon another man's deforestation, two sides of the same coin when seen at more encompassing scale.

Perhaps despite such interdependencies all regions could transition. However, that many of the observed transitions did depend on facilitation (i.e., various kinds of substitute supply such as of food or natural resources) suggested that the challenges to achieving conditions for forest to transition in every region are much greater. That is even so for the much weaker outcome of transition in the aggregate at a global scale. At the global scale, as suggested in numerous recent commentaries, trends in grains demand (New York Times Magazine) and biofuel demand will make the growth in the scale of pressure on forest not an easy one to offset through other shifts.

Scale is not the only definitional issue to be considered: a focus on forests may obscure the actual impacts on ecology, given that grasslands are converted to agriculture as well.

Returning to the issue of critical interdependencies and the fate of specific regions, though, whatever the growth in scale to be addressed our case evidence and conceptual discussion suggest strongly that the details of regional interdependencies are critical. Considering Brazilian Amazonia for instance, the relevant details of resource supply and use are many and are critical. How timber will be supplied in and demanded by Asia has long mattered in the Amazon and that will continue. Also, looking within South America and Brazil, how hydropower will be supplied by different regions will matter for the Amazon. Within the Amazon, from where cities are fed will matter.

Looking at trends more generally, a phenomenon increasingly recognized as importantly linking regions across the globe is remittances, i.e. the supply of capital from a region where it is earned through production of some type to another region where it is spent on consumption and investment. Such funds surely could either fuel or retard forest clearing and researchers are now starting to assemble relevant evidence. From our perspective, what impact funds have could in part depend on what role each region plays in other interdependencies (such as within agricultural trade or natural resource transfers). Ongoing and future research may shed light on whether that matters.

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