Frontier Expansion and Economic Development

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Abstract

Although finding “new frontiers”, or “reserves”, of natural resources to exploit has been the basis of much of global economic development for the past five hundred years, frontier-based development does not appear to be producing sustained, high rates of growth in today's poorer economies. Through a two-sector model of frontier expansion and economic growth in a resource-dependent small open economy, this paper demonstrates that such expansion will lead inevitably to a "boom and bust" pattern of long-run development, even if the economy's terms of trade or commodity prices remain unchanged. Initially, it is always optimal for the economy to choose the maximum rate of frontier expansion, and thus ensure an immediate economic boom. However, an eventual economic decline is unavoidable. This result provides an alternative explanation of recent empirical evidence that resource-abundant developing countries display lower than expected long-run rates of growth.

Keywords: "boom and bust", frontier-based economic development, frontier expansion, resource booms, resource-abundant economies.

JEL classification: O13, O41, Q32, Q33.

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Introduction

Finding "new frontiers", or "reserves", of natural resources to exploit has been the basis of much of global economic development for the past five hundred years (Cipolla 1976; di Tella 1983; North and Thomas 1973; Toynbee 1976; Webb 1964). Such frontier-based economic development is characterized by a pattern of capital investment, technological innovation and social and economic institutions dependent on "opening up" new frontiers of natural resources once existing ones have been "closed" and exhausted (di Tella 1982; Findlay 1995; Findlay and Lundahl 1994).

However, recognition of the role of the frontier in development has only occurred over the past century, beginning with the first "frontier thesis" on American development as put forward by Frederick Jackson Turner.[1] Turner's frontier thesis was further extended by Walter Prescott Webb to explain not just American but global economic development over the 1500-1900 period of world history.[2] In recent decades, historians, geographers and social scientists have continued to modify the Turner-Webb "frontier thesis" to describe processes of frontier-

[1] In his now infamous 1893 address to the American Historical Association, *The Significance of the Frontier in American History*, Turner argued that "the existence of an area of free land, its continuous recession, and the advance of American settlement westward, explain American development" (Turner 1986, p. 1). Critical to this frontier expansion was the availability of "free" land and resources: "Obviously, the immigrant was attracted by the cheap lands of the frontier, and even the native farmer felt their influence strongly. Year by year the farmers who lived on soil whose returns were diminished by unrotated crops were offered the virgin soils of the frontier at nominal prices. Their growing families demanded more lands, and these were dear. The competition of the unexhausted, cheap, and easily tilled prairie lands compelled the farmer either to go west and continue the exhaustion of the soil on a new frontier, or to adopt intensive culture" (Turner 1986, pp. 21-2).

[2] Webb (1964) suggested that exploitation of the world's "Great Frontier", present-day North and South America, Australia, New Zealand and South Africa, was instrumental to the "economic boom" experienced in the "Metropolis", or modern Europe: "This boom began when Columbus returned from his first voyage, rose slowly, and continued at an ever-accelerating pace until the frontier which fed it was no more. Assuming that the frontier closed in 1890 or 1900, it may be said that the boom lasted about four hundred years" (Webb 1964, p. 13).

based development in many areas of the world, including Latin America, Russia, Canada, South Africa, Australia, and New Zealand (Hennessy 1978; Savage and Thompson 1979; Wieczynski 1976;Wolfskill and Palmer 1983). Although there is considerable debate over whether the original "thesis" envisioned by Turner and Webb is still relevant for all frontier regions, there is a general consensus over both the definition of a "frontier" and its significance in terms of economic development: a frontier area is assumed to be "a geographic region adjacent to the unsettled portions of the continent in which a low man-land ratio and unusually abundant, unexploited, natural resources provide an exceptional opportunity for social and economic betterment to the small-propertied individual" (Billington 1966, p. 25). Or, as di Tella (1982, p. 212) has put it more succinctly, throughout history "processes" of frontier-based development "were characterized by the initial existence of abundant land, mostly unoccupied, and by a substantial migration of capital and people."

Today, frontier-based economic development is very much prevalent in many developing regions of the world, which still have abundant, mainly forested, lands and other natural resources at their disposal. Although Webb's "Great Frontier" may have closed at the turn of the twentieth century, "frontier" areas of various sizes, characterized by a "low man-land ratio and unusually abundant, unexploited, natural resources", still exist throughout the developing world. Exploitation and conversion of these frontier "reserves" clearly influence the overall pattern of economic development.

For example, many low-income and lower middle-income economies not only rely principally on direct exploitation of their natural resources through primary industries (e.g., agriculture, forestry, fishing, etc.) but also over 50 percent or more of their export earnings come from a few primary commodities (World Bank 1992). Natural capital – the value of the natural resource endowment of a country – is particularly important in the developing world. For low-income countries dependent on export revenues from primary commodities (other than petroleum), twenty percent of their national wealth comprises natural capital (World Bank 1997).[3] These economies are also experiencing dramatic land use changes - especially conversion of forest area and wetlands to agriculture – which are symptomatic of classic "frontier expansion" processes (FAO 1997). Over 1970-90, for developing countries, 47% of the increase in crop production in Sub-Saharan Africa, 48% in Latin America and the Caribbean and 41% in East Asia (excluding China) has come from increases in harvested land area, and these trends are projected to continue until 2010 at least (FAO 1995; Fischer and Helig 1997).

However, there is also evidence that the process of frontier-based economic development in many small open developing countries today may not be generating as prodigious or as sustained an economic boom as the Turner-Webb "frontier thesis" would predict. Many resource trade-dependent low-income and lower middle-income economies also currently display low or stagnant growth rates. Cross-country empirical analysis confirms that in recent decades resource-abundant countries - i.e. countries with a high ratio of natural resource exports to GDP - have tended to grow less rapidly than countries that are relatively resource poor (Sachs and Warner 1997; Rodríguez and Sachs 1999). Economies with a high primary product export share of GDP in 1971 also tended to have low growth rates during the subsequent period 1971-89 (Sachs and Warner 1995). This finding is confirmed for the 1970-90 period, even when direct controls for the influence of geography, climate and growth in the previous decade are included (Sachs and Warner 2001).

[3] As a comparison, natural capital comprises only 5% of wealth in North America, and 2% in the Pacific OECD and Western Europe.

Conventional explanations suggest that the comparatively poor growth performance of low-income countries can be attributed to failed policies and weak institutions, including the lack of well-defined property rights, insecurity of contracts, corruption and general social instability (Pack 1994; World Bank 1992). More recent explanations have focused on the *resource curse hypothesis*, i.e. the poor potential for resource-based development in inducing the economy-wide innovation necessary to sustain growth in a small open economy, particularly under the "Dutch disease" effects of resource-price booms (Matsuyama 1992; Sachs and Warner 1995). Other theories have suggested an *open access exploitation hypothesis*, i.e. opening up trade for a developing economy dependent on open access resource exploitation may actually reduce welfare in that economy (Brander and Taylor 1997 and 1998).

The following paper offers another perspective on why the structural economic dependence of a small open economy on exploiting its natural resource endowment – in particular its dependence on processes of "frontier expansion" - may not lead to sustained and high rates of economic growth. We refer to this view as the *frontier expansion hypothesis*, i.e. frontier expansion in a small open economy is associated with a "boom and bust" pattern of economic development, irrespective of what may happen to the country's terms of trade or commodity prices. Faced with an abundant supply of frontier resources, a developing economy is most likely to choose to exploit these resources at the maximum feasible rate possible in order to ensure at least an initial period of economic growth. However, this initial "economic boom" is invariably short-lived. Once the frontier is "closed" and any reserves of land and natural resources available to an economy have been fully exploited or converted, some economic retrenchment is inevitable. Under certain conditions, the "bust" may start even before the frontier resource reserves are exhausted. In short, it is not necessary for the windfall benefits of a commodity price rise to precipitate such a "boom and bust" pattern in a resource-abundant open economy, such a pattern appears inherent to frontier-based economic development.

The outline of the paper is as follows. The next section briefly overviews previous economic treatments of the role of frontier expansion in economic development. Although such models may explain past "successful" frontier-based development efforts in the nineteenth and early twentieth centuries, they are less applicable in describing the more typical frontier expansion process found in the small, open and resource-abundant economies today. Instead, what we tend to observe is that economic development in a resource-dependent small open economy displays an inherently "boom and bust" pattern. It is possible to provide some empirical evidence of this phenomenon, by examining the most prevalent form of frontier expansion in developing countries today, which is agricultural land expansion. The rest of the paper is devoted to explaining why such a "boom and bust" pattern of economic development may result from frontier expansion in a resource-dependent small open economy. As an illustration, a two-sector model of frontier expansion and optimal growth in a small open economy with an increasing population is formulated. The model predicts that attaining higher rates of growth at least initially in the economy will always call for maximum conversion of frontier "reserves". However, any such "economic boom" resulting from rapid frontier expansion cannot be sustained indefinitely, and the economy will necessarily experience declines in it capital stock and/or consumption and exports per capita. The conclusion of the paper discusses further the implications of such frontier-based economic development in light of recent empirical evidence that resource-abundant developing countries tend to display low long-run growth rates.

The Frontier and Economic Development: A Brief Overview

As noted by Findlay and Lundahl (1994, p. 70), the analysis of frontier-based development "has been used extensively by historians and geographers for a wide variety of times and places, but has been neglected by economists." The exceptions are the "staples thesis", which has argued that the development of many countries and regions has been led by the expansion of export sectors, and in particular, natural resource exports, and the "vent for surplus" theory, which suggested that trade was the means by which idle resources, and in particular natural resources in poor countries, were brought into productive use (Chambers and Gordon 1966; Myint 1958; Smith 1976; Southey 1978; Watkins 1963). Both theories are relevant to the economic analysis of frontier-based development, because they focus on the existence of excess resources – "land" and "natural resources" – that are not being fully exploited by a closed economy. The function of international trade is to allow these new sources of natural resources that previously had no economic value to be exploited, for increased exports and growth.

However, it is also fair to say that both the staples and vent-for-surplus theses have been mainly concerned with "surplus" natural resources as the basis for the origin of trade and export-led growth. For example, the staples theory was largely an attempt to explain the very substantial inflows of capital and labor into the "regions of recent settlement", i.e. Webb's "Great Frontier of Canada, the United States, Argentina and Australia, that occurred largely in the nineteenth and early twentieth centuries (Findlay and Lundahl 1994). Equally, Myint (1958) argued that the classical vent-for-surplus theory of trade is a much more plausible explanation of the start of trade in hitherto "isolated" country or region with a "sparse population in relation to its natural resources" such as "the underdeveloped countries of Southeast Asia, Latin America and Africa when they were opened up to international trade in the nineteenth century."

More recent theories have focused on characterizing the "endogenous" or "moving" frontier as the basis for attracting inflows of labor and capital into a region or economy (di Tella 1982; Findlay 1995; Findlay and Lundahl 1994; Hansen 1979). Such "surplus land" models essentially postulate a Ricardian land frontier, whereby additional land can be brought into cultivation through investment of labor and/or capital, provided that the resulting rents earned are competitive with the returns from alternative assets. Thus frontier expansion becomes an "endogenous" process within a general equilibrium system of an economy, sometimes incorporating trade and international capital flows, with the supply and price of land determined along with the supplies and prices of all other goods and factors. As a consequence, changes in relative commodity and factor prices, as well as exogenous factors such as technological change and "transport revolutions", induce adjustments in the supplies of the specific factors including expansion of the land frontier. As in the case of staples theory, these "endogenous frontier" models have been used mainly to explain the inflows of capital and labor into the "regions of recent settlement", i.e. Webb's "Great Frontier of Canada, the United States, Argentina and Australia, that occurred largely in the nineteenth and early twentieth centuries, and export-led colonial agricultural development in certain tropical countries.[4]

The analysis of this paper follows in the same tradition of previous theories of frontier-based development, albeit with a crucial difference. Rather than focusing on historical applications where capital and labor inflows into regions and countries with surplus land have

[4] Hansen (1979) suggests that his Ricardian land surplus model is mainly applicable to the agricultural development "under old-style imperialism" (i.e. colonialism) whereby "subsistence agriculture by illiterate and uneducated native farmers takes place exclusively on vast expanses of marginal land, whereas intramarginal land is occupied by colons – knowledgeable Europeans capable of picking up and applying technical progress." Findlay and Lunduhl (1994) show how their basic "endogenous frontier" model can be modified closer to the "vent-for-surplus" theory to explain the process of rapid export expansion in key plantation and peasant export economies, such as smallholder rubber in Malaya and bananas and coffee in Costa Rica in the late nineteenth and early twentieth century, cocoa in Ghana in the early twentieth century and rice in Burma in the second half of the nineteenth century.

led to export booms and growth, here the emphasis will be on describing the present-day process of frontier expansion and optimal growth paths in a typical low and lower middle income open economy with abundant resources but a rapidly growing population. As the next section makes clear, in the typical developing economy of today the most prevalent form of frontier expansion is the "classic" process of land conversion, especially conversion of forest area and wetlands to agriculture. Thus, using the example of agricultural land expansion, the following section explores empirical evidence of the main thesis of this paper: rather than leading to sustained economic growth and "take-off", frontier expansion tends to generate a "boom and bust" pattern of economic development in a resource-dependent small open economy.

Agricultural Land Expansion and Economic Growth: Empirical Evidence

As noted previously, resource-dependent developing economies contain around 20% of their national wealth in natural capital, and are typically located in the Caribbean, East and Southern Africa, the Middle East, South Asia and West Africa (World Bank 1997). The most important source of this wealth is agricultural land. For example, in the poorest countries, agricultural cropland comprises around 80% of the natural capital. Expansion of this agricultural land base through conversion of forests, wetlands and other natural habitat is therefore the most prevalent form of frontier expansion in developing countries today.

More specifically, López (1998) identifies most of Sub-Saharan Africa, parts of Asia and the tropical forests of South America as regions with "abundant land" and open-access resource conditions that are prone to agricultural expansion. Widespread land and resource conversion is also occurring in Central America, parts of Mexico and tropical South America and some East and South East Asian countries, mainly due to the high degree of integration of rural areas with the national and international economy as well as population pressures. Agricultural land expansion in many tropical regions is also spurred by the prevailing structural conditions in the agricultural sectors of many developing countries, such as low irrigation and fertilizer use as well as poor crop yields (FAO 1997).

Table 1 indicates the dependence of developing countries on agricultural land expansion for crop production. Over 1970-90 increased harvested area accounted for 31% of the additional crop production in these countries, and over 1990-2010 this contribution is expected to rise to 34%. However, some of the increase in harvested area is likely to come from cropping intensity (i.e. multi-cropping and multiple harvests on the same land area). Although improvements in cropping intensity and yields are expected to reduce the developing world's dependency on agricultural land expansion over 1990-2010, about 19% of the contribution to total crop production increases in poorer economies are likely to be derived from expansion of cultivated land. Cropland expansion is expected to be particularly prevalent in Sub-Saharan Africa, East Asia (excluding China) and Latin America (including the Caribbean).

Fischer and Heilig (1997) combined the results of the FAO (1995) study summarized in Table 1 with recent UN population projections to estimate the demand for additional cultivated land in developing countries in 2050. Their results are indicated in Table 2. All developing countries are expected to increase their demand for cultivated cropland considerably, leading to extensive conversion of forests and wetlands. Throughout the developing world, cultivated land area is expected to increase by over 47% by 2050, with about 66% of the new land coming from deforestation and wetland conversion.

The rapid frontier land expansion that is occurring in developing countries appears to be serving mainly as an outlet for the rural poor. For example, the World Bank has launched a major study of the concentration of rural populations in developing economies on "fragile lands", which they define as "areas that present significant constraints for intensive agriculture and where the people's links to the land are critical for the sustainability of communities, pastures, forests, and other natural resources" (Word Bank 2003, p. 59). The main findings of the study are:

- Since 1950, the estimated population on fragile lands in developing economies has doubled.
- Currently one quarter of the people in developing countries – almost 1.3 billion – survive on fragile lands. More than 1.2 billion people on fragile lands are in the developing regions of Latin America, Africa and Asia.
- The developing country populations on fragile lands include 518 million living in arid regions with no access to irrigation systems, 430 million on soils unsuitable for agriculture, 216 million on land with steep slopes and more than 130 million in fragile forest systems.
- These populations living on fragile land in developing countries account for many of the people in extreme poverty, living on less than $1 per day.

In sum, agricultural land expansion, and natural resource exploitation by primary sector activities more generally, appears to be a fundamental feature of economic development in many of today's poorer economies. Yet, as discussed in the introduction, developing countries that are highly dependent on exploiting their natural resource endowments tend to exhibit a relatively poor growth performance. This poses an intriguing paradox. Why is it that, despite the importance of natural capital for sustainable economic development, increasing economic dependence on natural resource exploitation appears to be a hindrance to growth and development, particularly in today's low and middle-income economies?

One possible explanation is the *resource curse hypothesis*. According to this view, the limits of resource-based development stem from the poor potential for such development in inducing the economy-wide innovation necessary to sustain growth in a small open economy. This phenomenon is often linked to the "Dutch disease" effect arising from some exogenous influence, such as trade liberalization or a resource price boom. For example, Matsuyama (1992) has shown that trade liberalization in a land-intensive economy could actually slow economic growth by inducing the economy to shift resources away from manufacturing (which produces learning-induced growth) towards agriculture (which does not). Sachs and Warner (1995, 1997 and 2001) also argue that the relative structural importance of tradable manufacturing versus natural resource sectors in an economy is critical to its growth performance, i.e. when a mineral or oil-based economy experiences a resource boom, the manufacturing sector tends to shrink and the non-traded goods sector tends to expand.

A second explanation is the *open access exploitation hypothesis*. Brander and Taylor (1997 and 1998) note that over-exploitation of many renewable natural resources – particularly the conversion of forests to agricultural land – often occurs in developing countries because property rights over a resource stock are hard to define, difficult to enforce or costly to administer. They demonstrate that opening up trade for a resource-abundant economy with an open access renewable resource may actually reduce welfare in that economy. As the resource-abundant country has a comparative advantage in producing the resource good, the increased demand for the resource good resulting from trade openness leads to greater exploitation, which under conditions of open access produces declining welfare in the long run.[5]

An alternative explanation put forward in this paper is the *frontier expansion hypothesis*.[6] In the next section, we develop a model of a small open economy dependent on frontier reserve exploitation to illustrate the frontier expansion hypothesis. However, it is worth outlining the key features of the hypothesis here: The structural economic dependence of a small open developing economy on exploiting its natural resource endowment – in particular its dependence on frontier land and resource expansion – precipitates a "boom and bust" pattern of development that is simply not conducive to sustained and high rates of long-run economic growth. Although frontier-based economic development can lead to an initial "economic boom", it is invariably short-lived and the economic benefits are dissipated. The key to this phenomenon is that the small open economy faces a trade off between allocating the production from additional frontier resources either to increase domestic consumption and exports (in exchange for imported consumption), or alternatively for capital accumulation. If the additional frontier "reserves" are used mainly to expand consumption and exports, then there will be little additional capital

[5] Brander and Taylor conclude that, as the problem lies with the "open access" nature of exploitation in the resource-abundant economy, then the first-best policy would be for the developing country to switch to more efficient resource management policy through simply establishing property rights. However, as they acknowledge, and as we discuss further in Section 5 below in the case of Latin America, there are many policy and institutional distortions that currently work against such solutions in developing countries. Consequently, Brander and Taylor (1997, p. 550) argue in favor of "second best approaches" such as the country imposing "a modified 'Hartwick's rule' (see Hartwick 1977) under which an exporting country that experienced temporary gains from selling a resource good on world markets might re-invest those proceeds in an alternative asset."

[6] Note that the frontier expansion hypothesis and the open access exploitation hypothesis share some similarities. For example, Brander and Taylor (1997) show that a small, open and resource-abundant economy that produces a resource product through open access resource exploitation and a manufacturing good will also have a "boom and bust" pattern of development in the long run. That is, the economy will experience early gains from trade, followed by a period of declining utility. With the specific case of Latin America in mind, in which raw materials are often inputs into semi-processed or processed exports, López (1989) also develops a two-good model of a resource-rich open economy in which the open access renewable resource serves as an input into an "enclave" export processing sector. López shows that improvements in the terms of trade increases the rate of open access resource extraction and real income to increase in the short-run, but inevitably permanent income falls in the long run.

accumulation, and thus no long-term take off into sustained growth once the frontier is closed. If during the frontier expansion phase the economy does manage to invest in capital accumulation as well as increased consumption and exports, then the initial boom period will coincide with increased growth. However, this growth path cannot be sustained. Once the frontier is "closed" and any reserves of land and natural resources available to an economy have been fully exploited or converted, some economic retrenchment is inevitable, and an economic bust will occur.

As indicated at the beginning of the section, agricultural land expansion is the most prevalent form of frontier expansion evident in developing countries today. If agricultural land expansion in these small open economies is associated with a "boom and bust" pattern of economic development, then there are two possible consequences. First, economies that have increased their agricultural land base significantly over the long run are likely to have lower levels of GDP per capita then economies that have tended to reduce their dependence on agricultural land expansion. For the latter countries, a shrinking agricultural land base may be evidence that tradable manufacturing and other dynamic sectors have become structurally more important in the economy relative to natural resource sectors and that agriculture itself has become a more capital-intensive, productive and innovative sector.[7] Second, for those countries that are dependent on agricultural land expansion, further increases in agricultural area will tend to produce only modest increases in GDP per capita. Beyond a certain point, additional increases in land expansion will be associated with lower GDP per capita, because of the "boom and bust" pattern of resource-dependent development described above.

[7] In the small open economy model of Brander and Taylor (1997), if the country specializes in the manufacturing good in the long run, it gains unambiguously from trade.

A fairly straightforward way of empirically verifying the above phenomena is to estimate a relationship between GDP per capita and some measure of long-run agricultural expansion. For example, if the latter indicator was some index, $"_{it}$, then the above hypotheses suggest that there may be a cubic relationship between per capita income, Y_{it}, and this indicator of long run agricultural land change:

$$Y_{it} = b_0 + b_1\alpha_{it} + b_2\alpha_{it}^2 + b_3\alpha_{it}^3 \quad .$$

Note that $b_0 > 0$, $b_1 < 0$, $b_2 > 0$, $b_3 < 0$ and $|b_1| > b_2$ would imply that i) countries with increased long run agricultural land area would have lower levels of per capita income than countries with decreased agricultural land area and ii) per capita income would tend to fluctuate with long run agricultural land expansion.

The above relationship was estimated through employing a panel analysis of tropical developing countries over 1961-94. Per capita income, Y_{it}, is again represented by gross domestic product (GDP) per capita in constant purchasing power parity (1987 \$). The indicator $"_{it}$ is an agricultural land long run change index, created by dividing the current (i.e. in year *t*) agricultural land area of a country by its land area in 1961.[8]

The results of the analysis for all tropical countries and for low and lower middle income countries (i.e. real per capita GDP less than \$3,500 over 1961-94) are shown in Table 1. For both regressions, the estimated coefficients are highly significant and also have the expected signs and relative magnitudes.[9] Thus the estimations provide some empirical evidence that

[8] The data used in this analysis is form the World Bank's *World Development Indicators*, and are available from the author upon request.

[9] Although only the preferred models are indicated in Table 1, the panel analysis was performed comparing OLS against one-way and two-way random and fixed effects models. Alternative versions of these models also employed White's robust correction of the covariance matrix to overcome unspecified heteroskedasticity. However, heteroskedasticity proved not to be a significant problem in both regressions. In the regression for all tropical developing countries, the F-test for the pooled model and Breusch-Pagan LM test were highly significant,

agricultural land expansion in developing countries conforms to a "boom and bust" pattern of economic development. This is seen more clearly when the regressions are used to project respective relationships between long run agricultural land expansion and GDP per capita, which are displayed in Figure 1.

As indicated in the figure, an increase in agricultural land expansion in the long run is clearly associated with a lower level of per capita income than decreasing agricultural land area. For all tropical countries, the turning point is a long run agricultural change index of 1.2. For lower income countries the turning point is 1.3. Although continued agricultural land expansion beyond these points does lead to a slight increase in GDP per capita, this impact is short-lived. For all tropical countries, per capita income starts to fall once the land area index reaches 2.3; for lower income countries this occurs sooner at an index of 1.9. Note as well that for lower income countries, there is very little increase in GDP per capita associated with expansion of land over the 1.3 to 1.9 range.

It is revealing to compare the projections in Figure 1 with the actual land use situation in 1994 for developing countries. For all countries in 1994, the average land expansion index was 1.18, and for lower income countries it was 1.17. Of the 35 countries in 1994 with per capita incomes less than $3,500, only six have not experienced some agricultural land expansion compared to the 1961 base year.[10] Only eleven lower income countries are in the 1.3 to 1.9 range of agricultural land expansion, where continued expansion is associated with slightly

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suggesting rejection of the OLS model due to the presence of individual effects. The Hausman test was significant only at the 10% level, suggesting that random effects specification is preferred to the fixed effects model. The one-way model tended to outperform the two-way effects model. In the regression for lower income countries, the F-test for the pooled model, the LM test and the Hausman test were all highly significant, suggesting that the fixed effects model is preferred. The two-way model tended to outperform the one-way effects model.

[10] The six countries are Grenada (with a long run agricultural land change index of 0.684), Jamaica (0.893), Bolivia (0.961), Bangladesh (0.981), Mauritania (0.998) and the Maldives (1.000).

higher levels of GDP per capita.[11] One country (Fiji) has already passed the turning point of 1.9 where further agricultural land expansion corresponds with lower levels of GDP per capita. Thus it is fair to say that, for the vast majority of lower income countries, further agricultural land expansion is likely to be associated with lower levels of GDP per capita.

A Model of Frontier Expansion in a Small Open Economy

The previous section has explored evidence, particularly with the example of agricultural land expansion, that frontier-based development in developing countries may generate a boom and bust pattern in a small open economy. It was suggested that the key to this phenomenon is that the small open economy faces a trade off between allocating the production from additional frontier resources either to increase domestic consumption and exports (in exchange for imported consumption), or alternatively for capital accumulation. The rest of this paper focuses on illustrating the impacts of frontier-based development further through the following model of a small open economy.

The economy is assumed to comprise two sectors, an "established" or "mainstay" sector and a "frontier" sector. The latter comprises all economic activities, such as agriculture, forestry, ranching, mining or any other basic extractive industries that are dependent on the exploitation or conversion of "newly acquired" resources available on an open, but ultimately limited, "frontier". Although clearly heterogeneous, these available "frontier resources" will be viewed in the following model as an aggregate, homogeneous stock, which we can also refer to broadly

[11] The eleven countries are Sri Lanka (with a long run agricultural land change index of 1.348), Burundi (1.397), Rwanda (1.403), Papua New Guinea (1.432), Nicaragua (1.454), Uganda (1.478), the Philippines (1.511), Vanuatu (1.610), Paraguay (1.663), Belize (1.671) and Guatemala (1.705).

as "land". Equally, the extractive activities and economic uses of these resources will be aggregated into a single sectoral output.

Thus at time $t = 0$, the frontier sector of the economy is assumed to be endowed with a given stock of accessible natural resources, F_0, which acts as a "reserve" that can be potentially tapped through the current rate of conversion, N. The output produced through converting or exploiting these frontier "reserves" in turn contributes to domestic consumption and the flow of exports, or alternatively augments the existing capital stock, in the economy. Hence, in the following model, the process of "frontier expansion" is essentially marked by the continual use and depletion of the fixed stock of frontier land resources, F_0.

To sharpen the analysis, we will not include explicitly a cost of frontier resource conversion but postulate that the existence of institutional, geographical and economic constraints limits the maximum amount of frontier exploitation at any time t to $\overline{N}$. There are two reasons for assuming that such constraints limit the extent of frontier resource conversion or depletion. First, any frontier resources are located far from population centers, and thus the rate at which these resources may be profitably converted or exploited may be constrained by distance to market and accessibility. For example, recent studies of tropical deforestation indicate that remoteness from urban areas and the lack of roads in frontier areas limit forestland conversion to agriculture (Cropper *et al.* 1999; Chomitz and Gray 1996; Nelson and Hellerstein 1996). Second, recent studies have also explored the impact on tropical land conversion of institutional factors, such as land use conflict, security of ownership or property rights, political stability, and the "rule of law" (e.g. Alston *et al.* 2000; Barbier 2002; Deacon 1994, 1999; Godoy *et al.* 1998). For example, empirical work by Deacon (1994 and 1999) suggests that formal and informal institutions that reduce ownership risk or establish the "rule of law" would constrain the extent of tropical forestland conversion.

Over a finite planning horizon, T, it follows that

$$F_0 \geq \int_0^T N\,dt, \quad 0 \leq N \leq \overline{N}, \quad F_0 = F(0) \tag{1}$$

where $\overline{N}$ is the maximum rate of frontier exploitation or conversion at any time t.

We will also assume that the other input used in frontier economic activities is labor, L^A. Thus aggregate output, A, from economic activities in the frontier sector can be denoted by the production relationship $A = A(N,L^A)$, which is assumed to be homogeneous of degree one and can be written in the following intensive form

$$a = a(n), \;\; a'(n) > 0, \;\; a'(0) = \alpha \tag{2}$$

where $a = A/L^A$ and $n = N/L^A$ and $a''(n) = 0$.

The second sector of the economy is the “mainstay” or “metropolis” sector. It contains all economic activities, industrial and agricultural, that are not directly dependent on the exploitation of frontier resources. Instead, production in this sector is a function of labor, L^M, and the stock of accumulated capital in the economy, K, which includes settled (i.e. non-frontier) agricultural land. Thus aggregate production in the mainstay sector can be denoted as $M = M(K,L^M)$, which if linearly homogenous can be written as

$$m = m(k), \quad m' > 0, m'' < 0 \tag{3}$$

where $m = M/L^M$ and $k = K/L^M$.

Aggregate labor supply, L, in the economy is therefore allocated to both sectors and is also assumed to growing at the exogenous rate, θ, i.e.

$$L = L^A + L^M, \quad L = L_0 e^{\theta t} = e^{\theta t}. \tag{4}$$

We make the standard assumption that the initial stock of labor, L_0, is normalized to one. Also, it will be assumed that if the total labor supply is growing exogenously at the rate θ, so will the labor allocated to the frontier and mainstay sectors, L^A and L^M, respectively.

Utilizing the relationship $N = nL_0^A e^{\theta t}$, condition (1) can be re-written as

$$F_0 \geq \int_0^T nL_0^A e^{\theta t}\, dt, \quad 0 \leq n \leq \bar{n}, \quad F_0 = F(0) \tag{5}$$

where $\bar{n}$ is the maximum per capita amount of frontier resource conversion that can occur at any time t. Since from (4) frontier labor supply grows exogenously, the maximum conversion rate, $\bar{n}$, must decline over time.[12]

Per capita output from either the frontier or mainstay sectors may be used for domestic consumption, c, or exported, x. To focus the analysis, we will treat domestic consumption and exports from the mainstay and frontier sectors respectively as homogeneous commodities. Let $q = c + x$ be defined as aggregate consumption, both domestic and foreign, of the economy's total output. Assuming that at any time t frontier resource conversion that is not either consumed domestically or exported augments the economy's capital stock, then it follows that per capita capital accumulation in the economy is governed by

$$\dot{k} = m(k) + a(n) - (\omega + \theta)k - q, \quad k_0 = k(0), \tag{6}$$

where ω is the rate of capital depreciation (see Appendix).

In exchange for its exports, the economy imports a consumption good, z. As the country is a small open economy, the terms of trade are fixed and defined as $p = p^x/p^z$. Thus the balance of trade condition for the economy is

[12] Technically, $\bar{n}$, should be subscripted to indicated that it changes over time with the growth in L_A; to simplify notation, this convention is dropped.

$$px = z \tag{7}$$

Finally, all consumers in the economy share identical preferences over the finite time horizon [0, *T*] given by

$$W = \int_0^T [\beta \log(c) + \log(z)] e^{-\rho t} dt + \psi_T k(T) e^{-\rho T}, \ \ \rho = \delta - \theta, \ \beta > 0, \tag{8}$$

where δ is the discount rate and ψ_T is the scrap value of the terminal capital stock, $k(T)$.

Maximization of *W* over finite time *T* leads to the following Hamiltonian

$$H = [\beta \log(q - x) + \log(px)] e^{-\rho t} + \lambda [m(k) + \alpha n - (\omega + \theta) k - q] - \mu n L_0^A e^{\theta t} \tag{9}$$

which is maximized with respect to aggregate per capita consumption, *q*, exports, *x*, and frontier resource exploitation, *n*. The resulting first-order conditions are

$$e^{-\rho t} \frac{\beta}{c} = \lambda \tag{10}$$

$$\frac{\beta}{c} = \frac{p}{z} \quad \text{or} \quad \frac{c}{\beta} = \frac{z}{p} = x \tag{11}$$

$$\lambda a'(n) - \mu L_0^A e^{\theta t} \begin{matrix} < \\ = \\ > \end{matrix} 0 \ \Rightarrow \ \begin{matrix} n = 0 \\ 0 < n < \bar{n} \\ n = \bar{n} \end{matrix} \tag{12}$$

$$\dot{\lambda} = \lambda [(\rho + \omega + \theta) - m'(k)], \ \ \lambda(T) = \psi_T e^{-\rho T} \tag{13}$$

$$\dot{\mu} = 0, \ \mu \geq 0, \ F_0 - \int_0^T L_0^A n e^{\theta t} dt \geq 0, \ \mu \left[F_0 - \int_0^T L_0^A n e^{\theta t} dt \right] = 0 \tag{14}$$

plus the equation of motion (6). Equation (10) is the usual condition requiring that the discounted marginal utility of consumption equals the shadow price of capital. Equation (11) is the open economy equilibrium condition, which indicates that the relative marginal value of domestic to imported consumption must equal the terms of trade, *p*. Condition (12) governs the optimal frontier resource conversion, *n*. If the value marginal product of frontier resource exploitation, $\lambda a'(n)$, exceeds the marginal (shadow) costs of any conversion, $\mu L_0^A e^{\theta t}$, then per capita resource conversion will be at the maximum rate, $\bar{n}$. If the costs of conversion are greater than the marginal benefits, then no frontier resource exploitation will occur. When benefits equal cost, then conversion is at the rate n where $0 < n < \bar{n}$. Equation (13) determines the change over time in the value of the capital stock of the economy. This value will grow if the marginal productivity of capital per worker in the mainstay sector, $m'(k)$, is less than the effective discount rate plus any capital depreciation and population growth, $\rho + \omega + \theta$. In addition, the terminal value of the capital stock, $\lambda(T)$, combined with (10), (11) and (12) will determine the final levels of per capita domestic consumption plus exports, $c(T) + x(T)$, in the economy.

Finally, condition (14) states that the marginal value, μ, of the fixed stock of frontier resources, F_0, is essentially unchanging over the planning horizon. Instead, whether the scarcity value of frontier resources is positive or zero depends on whether the available stock of frontier resources, F_0, is completely exhausted through conversion, n, by terminal time, T. Combined with the other first-order conditions, (14) proves to be important in characterizing the optimal "frontier expansion" path of the economy.

For example, suppose that by the end of the planning horizon at time T the stock of frontier resources is not completely exhausted through "frontier expansion", i.e. $F_0 > \int_0^T L_0^A n e^{\theta t} dt$ over [0, T] such that $F(T) > 0$. From (14) it follows that $\mu = 0$. The unlimited availability of frontier resources to the economy over the entire planning period means that these reserves have no scarcity value. However, from (10), the marginal value of accumulated capital in the economy is always positive ($\lambda > 0$). As a consequence, in (12) the value marginal product of frontier resource exploitation, λα, will exceed the costs of conversion, and thus the economy will convert frontier resources at the maximum per capita rate, $\bar{n}$, throughout [0, T].

Alternatively, suppose that $F_0 = \int_0^T L_0^A n e^{\theta t} dt$ so that frontier resources are exhausted at least by the end of the time horizon, T, if not at some time $t^F < T$. These resources now have positive scarcity value, $\mu > 0$, throughout the planning period. This in turn implies that optimal paths of frontier expansion may have either an interior solution for frontier resource conversion, $0 < n < \bar{n}$, or corner solutions, $n = \bar{n}$ and $n = 0$. Since these paths have interesting and differing economic implications, we will focus mainly on them. Thus the rest of the paper will consider only the case where frontier expansion and resource conversion comes to an end some time during the planning horizon of the open economy.

We begin with the conditions for an interior solution to the choice of frontier resource conversion, $0 < n < \bar{n}$:

According to (12), an interior solution for n requires that the benefits of frontier exploitation equal the cost. This condition can be re-written as

$$\lambda = \frac{\mu L_0^A e^{\theta t}}{a'(n)} \quad \text{and} \quad \dot{\lambda} = \theta\lambda \tag{15}$$

given that μ is constant. Substituting (15) into (13) yields

$$\theta\lambda = \lambda[(\rho + \omega + \theta) - m'(k)] \quad \text{or} \quad m'(k_1) = \rho + \omega. \tag{16}$$

The latter expression implies that the per capita capital stock remains constant at some value, k_1, and therefore $dk/dt = 0$ in (6). This result indicates that, if it is optimal for the economy convert frontier resources but at a rate less than the maximum level, $\bar{n}$, then frontier expansion will be only sufficient to maintain the per capita stock of capital.

Using (15) in (10) and differentiating yields

$$-\frac{\beta\dot{c}}{c^2} = e^{\rho t}\left[\dot{\lambda} + \rho\lambda\right] \quad \text{or} \quad \dot{c} = -c\left[\theta + \rho\right] < 0 \tag{17}$$

and from (11)

$$\dot{x} = \frac{\dot{z}}{p} = \frac{\dot{c}}{\beta} < 0 \quad \text{and} \quad \dot{q} = \dot{c} + \dot{x} = \left[1 + \frac{1}{\beta}\right]\dot{c} < 0\,. \tag{18}$$

If the economy follows the interior solution for its frontier expansion path, then per capita domestic consumption, exports and imports will decline over time. From (6), a further implication of aggregate consumption, q, falling over time is that the rate of frontier resource conversion, n, must also be declining.

Clearly, a frontier expansion path that leads to declining per capita domestic consumption and exports is not very desirable. Although it is possible for the economy to choose alternative frontier expansion paths that have positive rather than negative impacts on overall economic development, at least over some initial time period [0, t], it is fairly straightforward to demonstrate that such optimal paths are inconsistent with the interior solution for resource conversion outlined above.

From conditions (10), (11) and (13), positive growth in per capita domestic consumption and exports in the economy requires

$$\dot{q} = \dot{c} + \dot{x} = c\left(1 + \frac{1}{\beta}\right)\left[m'(k) - (\rho + \omega + \theta)\right] > 0, \quad \text{if} \quad m'(k) - (\rho + \omega + \theta) > 0\,. \tag{19}$$

Economic growth will occur if the marginal productivity of capital per worker in the mainstay sector, $m'(k)$, exceeds the effective discount rate plus any capital depreciation and population growth, $\rho + \omega + \theta$. However, equation (13) indicates that the latter condition also implies that the value of the capital stock, λ, must be declining over time. If this is the case, (15) and (16) are no longer valid as they are based on condition (12) set to zero, which in turn requires λ to be positive and growing at the rate θ. Thus the interior solution for frontier resource conversion, $0 < n < \bar{n}$, is not consistent with an optimal path of the economy that leads to growth in per capita domestic consumption and exports.

With any interior solutions for resource conversion ruled out, then $n = 0$ and $n = \bar{n}$ are the only two remaining choices, if the economy wants to be on an optimal frontier expansion path that is also compatible with growth. As (10) and (19) imply that the value of the capital stock is positive but declining over time, then the optimal policy is for the economy to choose $n = \bar{n}$ first, such that $\lambda > \frac{\mu L_0^A e^{\theta t}}{a'(n)} > 0$, to ensure that growth can at least occur for some until initial time interval [0, t]. However, by choosing the maximum frontier resource extraction rate over this initial period, the economy will also ensure that F_0 is exhausted at some future time, $t^F < T$, well before the end of the planning horizon. Once frontier expansion comes to an end, the economy will of course have to stop resource conversion, $n = 0$, for the remaining time in the planning period $[t^F, T]$. Thus one possibility for the economy is to pursue maximum frontier expansion until all new reserves are exhausted, and then make do with $n = 0$ until the end of the time horizon.[13]

Note that the rate of capital accumulation will also differ, as the economy switches from maximum frontier resource conversion to none at all

$$\dot{k} = m(k) + a(\bar{n}) - (\omega + \theta)k - q, \quad n = \bar{n} \tag{20}$$

$$\dot{k} = m(k) - (\omega + \theta)k - q, \quad n = 0\,. \tag{21}$$

[13] Note that it is never optimal to halt resource extraction, $n = 0$, as long as there is some frontier stock remaining, $F(t) > 0$. From (10) and (12), $n = 0$ implies that $0 < \lambda < \frac{\mu e^{(\theta-\alpha)t}}{a'(n)}$; i.e. μ is unambiguously positive. However, from (14), $n = 0$ also requires $\mu F_0 = 0$ and $\mu \geq 0$. Together, these conditions imply that the zero extraction policy is only optimal once the frontier resource stock is completely exhausted, i.e. when $F_0 = 0$.

The final dynamic equation of the economy can be found by using (19) and the fact that $c = \frac{\beta}{p} z = \beta x$

$$\dot{q} = \dot{c} + \dot{x} = c\left(1 + \frac{1}{\beta}\right)\left[m'(k) - (\rho + \omega + \theta)\right]. \tag{22}$$

Equations (20)-(22) can be solved to yield two $\dot{k} = 0$ isoclines and a single $\dot{q} = 0$ isocline. These isoclines can be depicted diagrammatically in (k, q) space (see Figure 2). From (22), $\dot{q} = 0$ if $m'(k) = \rho + \omega + \theta$, which means that this locus is a vertical line defined at some $k = k^*$ that satisfies this condition. From (20) and (21), the $\dot{k} = 0$ isocline corresponding to $n = \bar{n}$ will be $a(\bar{n})$ distance higher than the $\dot{k} = 0$ isocline for $n = 0$. Finally, it is fairly straightforward to demonstrate that the directionals corresponding to these isoclines are $d\dot{k}/dq < 0$ and $d\dot{q}/dk < 0$.[14]

Optimal Frontier Expansion Paths

To summarize, the open economy can pursue three general types of paths: an interior solution path, a path of maximum frontier expansion until the frontier is "closed", and a "stop-go" path alternating between maximum frontier expansion and temporary halts to resource conversion and exploitation.

Figure 2 depicts four trajectories that represent the first two types of possible frontier expansion paths available to the economy. Although there are two saddlepoint equilibria resulting from the intersection of the with the $\dot{q} = 0$ vertical locus defined at $k = k^*$, neither of these equilibria is attainable by any of the frontier expansion paths in finite time.

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[14] From (20) and (21), $\frac{d\dot{k}}{dq} = -1 < 0$. From (22), $\frac{d\dot{q}}{dk} = c\left(1 + \frac{1}{\beta}\right)m''(k) < 0$.

For example, the frontier expansion path defined by the interior solution, $0 < n < \bar{n}$, is the trajectory labeled *AB*. However, as is clear from (16)-(18), the economy can only be on this trajectory if it has already attained the per capita capital stock, k_1, which then remains constant over time. This path must always be the right of k^*, since from (16) $m'(k_1) = \rho + \omega$ whereas from (22) the $\dot{q} = 0$ isocline is always defined at $m'(k^*) = \rho + \omega + \theta$. In addition, exports and consumption per capita, $q = c + x$, are always declining along this optimal path. Moreover, this trajectory is only feasible between the two parallel $\dot{k} = 0$ isoclines.[15]

As noted above, a more likely scenario is for the economy to choose an optimal frontier expansion path that is also compatible with growth, at least for some until initial time interval [0, *t*]. In this case, the optimal policy is for the economy to choose the maximum rate of frontier resource conversion, $n = \bar{n}$ at the outset. If the economy is able to maintain maximum frontier expansion until the resources are exhausted, then it will persist with this policy until the frontier is "closed". Assuming that the economy starts at a given initial level of capital stock, $k_0 < k^*$, there are nevertheless several possible paths that the economy might follow, depending on the length of the planning period $[0,T]$, the available stock of frontier resources, F_0, and the terminal value of the capital stock, $\lambda(T)$. Three representative paths are depicted in Figure 2, and labeled I-III.

Trajectory I illustrates the case where $\lambda(T)$ is low such that terminal per capita consumption and exports are relatively high, $q(T_2)$. Along this trajectory, the economy will pursue maximum frontier resource conversion, $n = \bar{n}$, until F_0 is exhausted. Once frontier

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[15] From (20), at point *A*, on the $\dot{k} = 0$ isocline corresponding to $n = \bar{n}$, $q = m(k_1) + a(\bar{n}) - (\omega + \theta)k_1$. Since q can only increase if $n > \bar{n}$, which is impossible by definition, then any points above are infeasible for the trajectory defined by the interior solution to the problem. Equally, (21) rules out the possibility of points below point *B* as being attainable for the interior solution, since at this point $q = m(k_1) - (\omega + \theta)k_1$ and $n < 0$ is not a feasible outcome.

expansion ends, at point C, the economy will no longer utilize frontier resources, $n = 0$, until reaching terminal point, $q(T_2)$. Although during the initial frontier expansion phase, exports and consumption grow rapidly, per capita capital accumulation occurs only modestly. Once this phase ends and the frontier is "closed", c and x continue to expand but k starts declining, and at the end of the planning period may be less than k_0. Note that if the total amount of frontier resources available to the economy is larger, then the frontier expansion phase will last longer and thus the switch to $n = 0$ would come later than depicted. The result will be that k will decline less, and at terminal time could equal or exceed k_0.

Both trajectories II and III illustrate the case where $\lambda(T)$ is relatively high so that terminal c and x are low. The result in both cases is a "boom and bust" path for the economy.

Trajectory II is representative of an economy with a larger frontier and/or time horizon. The initial phase of maximum frontier expansion, $n = \bar{n}$, coincides with the economic "boom" period in consumption, exports and capital accumulation. However, even during this phase of frontier resource exploitation, c and x begin to decline. Frontier expansion eventually leads mainly to increases in the stock of capital person. However, once the economy accumulates k_1 amount of capital, there is no incentive to increase it further, as this would result in a decline in net production, $m(k) - (\omega+\theta)k$, from the mainstay sector. Thus once k_1 is reached, the economy will follow along the segment DE of the interior solution path. The rate of frontier resource exploitation will be adjusted to $0 < n < \bar{n}$, and per capita consumption and exports will fall. At point E, frontier resources are exhausted, and since $n = 0$, the economy will depend solely on the mainstay sector until terminal point $q(T_1)$ is reached. During this last phase of trajectory II, c and x will continue to decline. Capital per person will also fall initially and then recover, but will not exceed k_1 at terminal time.

Trajectory III may be the more typical outcome if an economy has a smaller frontier stock and/or a shorter time horizon. The initial phase of maximum frontier expansion, $n = \bar{n}$, also coincides with the economic "boom" period in *c*, *x* and *k*. However, once frontier exploitation ends at point *F*, then a "bust" phase ensues. Although per capita exports and consumption continue to decline until the end of the planning period, additional capital accumulation will eventually occur. The final level of capital person will be between k^* and k_1.

Conclusion

This paper has followed in the tradition of "endogenous frontier" models of economic development that have been employed to explain the opening of primary products trade and export-led growth in previously unexploited regions and countries in the nineteenth and early twentieth centuries (di Tella 1982; Findlay 1995; Findlay and Lundahl 1994; Hansen 1979). However, rather than focusing on historical patterns of economic development in economies with surplus land and natural resources, the purpose of this paper has been to analyze the process of frontier expansion and economic development in a present-day, resource-trade dependent developing economy. The results of this analysis have demonstrated that frontier expansion may have important implications for the long-run growth path of such a small open economy. First, faced with an abundant supply of frontier resources, the economy is most likely to choose to exploit these resources at the maximum feasible rate possible in order to ensure at least an initial period of economic growth. However, it also appears inevitable that frontier expansion will lead to some form of "boom and bust" pattern of long-run development. If the economy is able to sustain the maximum rate of conversion until the frontier closes, or until it reaches maximum capital stock k_1, then the economic "bust" will be confined to the final stages of the optimal path.

Of course, for an economy with relatively small frontier reserves or a short time horizon, the initial "boom" period could be short-lived. This will be particularly the case if exploitation of frontier reserves leads mainly to increased domestic and imported consumption.

If a "boom and bust" pattern is inherent to frontier-based economic development in a small open economy, then this has important implications for understanding the empirical evidence as to why resource-abundant developing countries display lower than expected long-run rates of growth. Previous explanations have suggested that slower growth in these economies may be due to the economic distortions precipitated by a "resource boom", possibly as the result of commodity price rises or trade liberalization, which shifts resources from a dynamic sector such as manufacturing to the primary sector (Matsuyama 1992; Sachs and Warner 1995). Other theories have suggested that opening up trade for a developing economy dependent on open access resource exploitation will reduce welfare in that economy (Brander and Taylor 1997 and 1998). In contrast, the model of this paper suggests that frontier expansion itself may result in a "boom and bust" path for a small open economy, even if its terms of trade or commodity prices remain unchanged or if institutional, geographical and other constraints limit the amount of resource extraction and conversion that would otherwise occur under pure open access conditions.

Appendix

Let $p^A/p^M = p^A$ be the relative price of the frontier good, if the price of the mainstay good is the numeraire. Denoting profits in the frontier sector as $\pi^A = L^A\left[p^A a(n) - w - w^N n\right]$, equilibrium frontier production requires

$$\frac{d\pi^A}{dn} = L^A\left[p^A a'(n) - w^N\right] = 0 \quad \text{or} \quad p^A a'(n) = w^N$$

$$\frac{d\pi^A}{dL^A} = p^A a(n) - w - w^N n - \left[p^A a'(n)n + w^N n\right] = 0 \quad \text{or} \quad p^A\left[a(n) - a'(n)n\right] = w,$$

where w^N is the real rental price (in terms of p^M) of converted or extracted frontier resources, i.e. the "land" input into frontier economic activities, and w is the real market wage. The above two expressions indicate that the value marginal products of land and labor in the frontier sector must equal their respective input prices.

Perfect competition and free mobility of labor between the frontier and mainstay sectors also results in the following equilibrium condition for the latter sector

$$m(k) - m'(k)k = w.$$

The zero profit condition for the mainstay sector yields

$$\pi^M = L^M\left[m(k) - w - (r+\omega)k\right] = 0$$

$$\frac{d\pi^M}{dk} = L^M\left[m'(k) - (r+\omega)\right] = 0 \quad \text{or} \quad m'(k) = r + \omega,$$

where r is the real price of capital and ω is the rate of depreciation.

Let us assume that households in the mainstay sector not only sell their labor to produce the mainstay good but also own the capital used in this sector. Denoting c^M as the per capita consumption of these households and θ as population growth, it follows that per capita accumulation by mainstay households is governed by the following budget constraint

$$\dot{k} = rk + w - \theta k - c^M = m(k) - (\omega + \theta)k - c^M ,$$

after using the expressions above to substitute for *w* and *r*.

Households in the frontier sector sell their labor to produce the frontier good and own the resource or converted "land" input. However, all their income is consumed. Denoting c^A as the per capita consumption of these households, their budget constraint is

$$c^A = w + w^N n = p^A a(n),$$

after using the expressions above to substitute for *w* and w^N.

Aggregate per capita domestic consumption, *c,* in terms of the numeraire mainstay price, is therefore

$$c = c^M + \frac{c^A}{p^A}.$$

Combining the last three expressions, and making use of the fact that actual domestic consumption is actually aggregate consumption less exports, $c = q - x$, yields

$$\dot{k} = m(k) - (\omega + \theta)k + a(n) - (c + x) = m(k) + a(n) - (\omega + \theta)k - q .$$

References

Alston, L. J., G.D. Libecap, and B. Mueller. 2000. "Land Reform Policies, The Sources Of Violent Conflict, And Implications For Deforestation In The Brazilian Amazon." *Journal of Environmental Economics and Management* 39(2):162-188.

Barbier, E.B. 2002. "Institutional Constraints and Deforestation: An Application to Mexico." *Economic Inquiry*, forthcoming.

Billington, R.A. 1966. *America's Frontier Heritage.* Holt, Reinhart and Winston, New York.

Brander, James A. and M. Scott Taylor. 1997. "International Trade and Open-Access Renewable Resources: The Small Open Economy." *Canadian Journal of Economics* 30(3):526-552.

Brander, James A. and M. Scott Taylor. 1998. "Open Access Renewable Resources: Trade and Trade Policy in a Two-Country Model." *Journal of International Economics* 44:181-209.

Chambers, E.J. and D.F. Gordon. 1966. "Primary Products and Economic Growth: An Empirical Measurement." *Journal of Political Economy* 74(4): 315-332.

Chomitz, K. M. and D.P. Gray. 1996. "Roads, Land Markets and Deforestation: A Spatial Model of Land Use in Belize." *The World Bank Economic Review* 10(3):487-512.

Cipolla, C.M. 1976. *Before the Industrial Revolution: European Society and Economy, 1000-1700.* Metheun, London.

Cropper, M., C..Griffiths, and M. Mani. 1999. "Roads, Population Pressures, and Deforestation in Thailand, 1976-1989". *Land Economics* 75(1):58-73.

Deacon, R.T. 1994. "Deforestation and the Rule of Law in a Cross-Section of Countries." *Land Economics* 70(4):414-430.

Deacon, R. T. 1999. "Deforestation and Ownership: Evidence from Historical Accounts and Contemporary Data." *Land Economics* 75(3):341-359.

di Tella, G. 1982. "The Economics of the Frontier." In C.P. Kindleberger and G. di Tella, eds. *Economics in the Long View.* Macmillan, London, pp. 210-227.

Findlay, R. and M. Lundahl. 1994. "Natural Resources, 'Vent-for-Surplus', and the Staples Theory." In G. Meier, ed. *From Classical Economics to Development Economics: Essays in Honor of Hla Myint.* St. Martin's Press, New York, pp. 68-93.

Findlay, R. 1995. *Factor Proportions, Trade, and Growth.* MIT Press, Cambridge, Mass.

Fischer, Günther and Gerhard K. Heilig. 1997. "Population Momentum and the Demand on Land and Water Resources." *Philosophical Transactions of the Royal Society Series B* 352(1356):869-889.

Food and Agricultural Organization of the United Nations (FAO). 1997. *State of the World's Forests 1997.* Rome: FAO.

Food and Agricultural Organization of the United Nations (FAO). 1995. *World Agriculture:Towards 2010 – An FAO Study.* Rome and New York: FAO and John Wiley & Sons.

Hansen, B. 1979. "Colonial Economic Development with Unlimited Supply of Land: A Ricardian Case." *Economic Development and Cultural Change* 27:611-627.

Hennessy, A. 1978. *The Frontier in Latin American History.* University of New Mexico Press, Albuquerque.

López, Ramón. 1998. “Where Development Can or Cannot Go: The Role of Poverty-Environment Linkages.” In *Annual Bank Conference on Development Economics 1997*, eds, B. Pleskovic and J.E. Stiglitz. Washington DC: The World Bank, pp. 285-306.

López, Ramón. 1989. "Exchange Rate Determination in Natural Resource-Rich Economies." *Revista de Análisis Económico* 4(1):91-105.

Matsuyama, K. 1992. "Agricultural Productivity, Comparative Advantage, and Economic Growth." *Journal of Economic Theory* 58:317-334.

Pack, H. 1994. "Endogenous Growth Theory: Intellectual Appeal and Empirical Shortcomings." *Journal of Economic Perspectives* 8(1):55-72.

Myint, H. 1958. “The Classical Theory of International Trade and the Underdeveloped Countries.” *Economic Journal* 68:315-337.

Nelson, G.C. and D. Hellerstein. 1997. "Do Roads Cause Deforestation? Using Satellite Images in Econometric Analysis of Land Use." *American Journal of Agricultural Economics* 79(2):80-88.

North, D.C. and R.P. Thomas. 1973. *The Rise of the Western World: A New Economic History.* Cambridge University Press, Cambridge, UK.

Rodríguez, F. and J.D. Sachs. 1999. "Why Do Resource-Abundant Economies Grow More Slowly?" *Journal of Economic Growth* 4:277-303.

Sachs, J.D. and A.M. Warner. 1995. "Natural Resource Abundance and Economic Growth." *National Bureau of Economic Research Working Paper* No. 5398, December.

Sachs, J.D. and A.M. Warner. 1997. "Fundamental Sources of Long-Run Growth." *American Economic Review* 87(2):184-188.

Sachs, J.D. and A.M. Warner. 2001. "The Curse of Natural Resources." *European Economic Review* 45:827-838.

Savage, W.M. and S.I. Thompson. 1979. “The Comparative Study of the Frontier: An Introduction.” In W.M. Savage and S.I. Thompson, eds. *The Frontier, Volume II.* University of Oklahoma Press, Norman, pp. 3-24.

Smith, S. 1976. "An Extension of the Vent-for-Surplus Model in Relation to Long-Run Structural Change in Nigeria." *Oxford Economic Papers* 28(3):426-446.

Southey, C. 1978. "The Staples Thesis, Common Property and Homesteading." *Canadian Journal of Economics* 11(3):547-559.

Toynbee, A.J. 1978. *Mankind and Mother Earth*. Granada Publishing, London.

Turner, F.J. 1986. “The Significance of the Frontier in American History.” In F.J. Turner, *The Frontier in American History*. University of Arizona Press, Tucson, pp. 1-38.

Watkins, M.H. 1963. "A Staple Theory of Economic Growth." *The Canadian Journal of Economics and Political Science.* 29(2):141-158.

Webb, W.P. 1964. *The Great Frontier.* University of Nebraska Press, Lincoln.

Wieczynski, J. 1976. *The Russian Frontier: The Impact of Borderlands upon the Course of Early Russian History.* University of Virginia Press, Charlottesville.

Wolfskill, G. and S. Palmer. 1983. “Introduction.” In G. Wolfskill and S. Palmer, eds. *Essays on Frontiers in World History.* University of Texas Press, Austin, pp. 3-11.

World Bank. 1992. *World Development Report 1992*. The World Bank, Washington, DC.

World Bank. 1997. *Expanding the Measure of Wealth: Indicators of Environmentally Sustainable Development.* The World Bank, Washington DC.

Table 1. Trends in Crop Production and Harvest Area in Developing Regions

Region	Crop Production				Harvested Land		
	1970-90 Contribution (%) of increases in:		1990-2010 Contribution (%) of increases in:		1990-2010 Contribution(%) of increases in:		1990-2010 Percentage of crop production from new land
	Yields	Harvested area	Yields	Harvested area	Arable land	Cropping intensity	
Sub-Saharan Africa	53	47	53	47	64	36	30
Near East and North Africa	73	27	71	29	31	69	8
East Asia[a]	59	41	61	39	82	18	34
South Asia	82	18	82	18	22	78	4
Latin America[b]	52	48	53	47	60	40	29
All developing countries	69	31	66	34	62	38	19

Notes: [a] Excludes China.
[b] Includes the Caribbean.

Source: FAO (1995).

Table 2. Demand for Cultivated Land in 2050 in Developing Regions

Region	Cultivated crop land in 1990 (1000 ha)	% of production increase from new land	Additional cultivated land required in 2050 (1000 ha)	% of new lands from forest and wetland conversion
Africa	252,583	29	241,703	61
Asia[a]	456,225	10	85,782	73
Latin America[b]	189,885	28	96,710	70
All developing countries	899,795	21	424,194	66

Notes: [a] Excludes China.
[b] Includes the Caribbean.

Source: Fischer and Heilig (1997).

Table 3. Panel Analysis of Per Capita Income and Long Run Agricultural Expansion, 1961-94

Dependent Variable: GDP per capita (PPP, constant 1987 $)[a] **Parameter Estimates:**[b]		
Explanatory Variables	**All Countries** (N = 1135)	**Lower Income Countries**[c] (N = 867)
Constant	14393.37	9560.07
	(23.69)**	(7.03)**
Long run agricultural land area change index (α_{it})[d]	-24293.31	-16645.71
	(-19.04)**	(-5.30)**
α_{it}^2	15217.53	11013.18
	(11.18)**	(4.58)**
α_{it}^3	-2896.32	-2330.33
	(-6.59)**	(-3.87)**
F-test for pooled model	168.01**	126.05**
Breusch-Pagan (LM) test	6576.23**	3614.50**
Hausman test	6.85	44.02**
Adjusted R^2	0.368	0.937
Preferred model	**One way random effects**	**Two way fixed effects**

Notes: [a] Mean for all countries over 1961-94 is $2,593, and for lower income countries $1,539. PPP is purchase power parity.
[b] t-ratios are indicated in parentheses.
[c] Countries with GDP per capita (PPP, constant 1987 $) less than $3,500 over 1961-94.
[d] Mean for all countries over 1961-94 is 1.150, and for lower income countries 1.149.
** Significant at 1% level, * significant at 5% level.

Figure 1. Projections of Agricultural Land Expansion and GDP per Capita in Tropical Countries, 1961-94

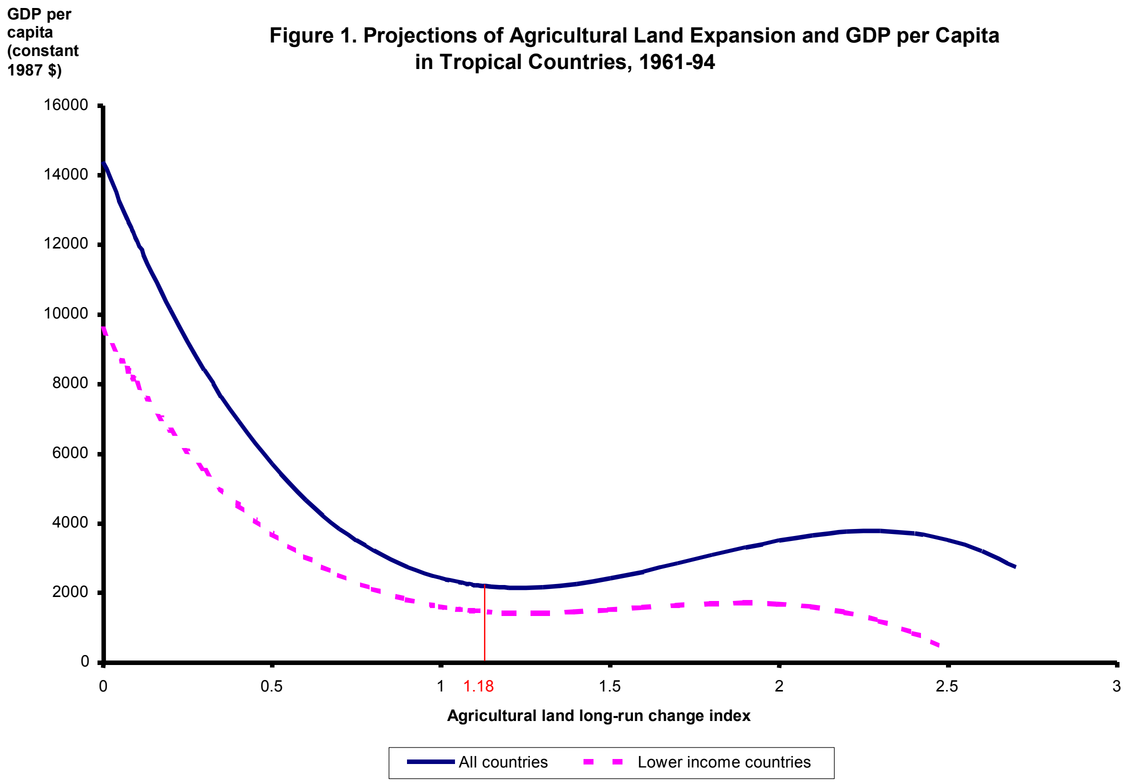

Figure 2. Frontier Expansion Paths for a Small Open Economy