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Land expansion and growth in low- and middle-income countries*

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Over past decades, low and middle-income countries have experienced considerable expansion of agricultural land, yet this effect on growth has not been examined The following paper shows that the Solow-Swan growth model can be extended to the case whereby arable land is expanding, as originally suggested by Solow (1956). This extension indicates that land expansion boosts growth, and this effect increases with the relative share of land in income. An empirical analysis over 1990–2018 for 138 low and middle-income countries supports this finding. The growth impact of land expansion over 1990–2018 varied significantly across the sample of countries depending on how much income was derived from land. This result explains why countries dependent on agriculture have engaged in extensive land expansion: it boosts overall growth. However, these growth benefits must be weighed against the considerable environmental costs of converting forests and other natural habitat to more agricultural land, such as increased carbon emissions, loss of ecosystem services and biodiversity, risk of disease, and impacts on local livelihoods.

Key words: agricultural land, developing countries, growth, land expansion, low and middle-income countries, Solow-Swan model.

1. Introduction

A well-known prediction of the growth model of Solow (1956) and Swan (1956) is that, if land is treated as a fixed factor of production, the negative impact of population growth on the growth rate of income per capita depends on the relative importance of agriculture in the economy (Nordhaus 1992; Gylfason and Zoega 2006; Karras 2010). However, treating land as a fixed factor ignores an important stylized fact of land use in most low- and middle-income countries. Over the past several decades, agricultural area and especially cropland have continued to expand (Gibbs *et al.* 1990; Leblois *et al.* 2000; Lambin and Meyfroidt 2011; Hosonuma *et al.* 2012; Laurence *et al.* 2014; Meyfroidt *et al.* 2014; Busch and Ferretti-Gallon 2017; Carrasco *et al.* 2017; UNCCD 2017). As shown here, modifying the basic Solow-Swan

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growth model to account for this stylized fact has additional implications for the long-run balanced growth conditions of the model. These implications can be tested empirically.

Swan (1956) explicitly included land as a fixed factor in his original growth model, because it was essential for him to show explicitly how neoclassical and classical approaches to growth differ. Thus, as argued by Dimand and Spencer (2009, p.116), 'Swan considers the role of technical progress in a classical setting in which there are diminishing returns because of a fixed supply of a third factor, land'. In contrast, for Solow (1956, p. 67), 'there is no scarce nonaugmentable resource like land' in his growth model, because the 'scarce-land case would lead to decreasing returns to scale in capital and labour and the model would become more Ricardian'. Instead, Solow wanted to construct a growth model based solely on neoclassical foundations, and this requires an aggregate production with constant returns to scale. Yet, as pointed out by Toye (2009), Solow clearly acknowledged that his model could be adopted for land-abundant low- and middle-income countries, and he alluded to this possibility by suggesting: 'Not all "underdeveloped" countries are areas of land shortage. Ethiopia is a counterexample. One can imagine the theory as applying as long as arable land can be hacked out of the wilderness at essentially a constant cost' (Solow 1956, p. 67, n. 2).

The following paper shows that the Solow-Swan growth model can indeed be extended to the case whereby arable land is 'hacked out of the wilderness' as envisioned by Solow. Moreover, this extension has two important predictions for the balanced growth path. First, the main result from the model with fixed land still holds: An increase in population growth reduces long-run growth, and this effect depends on the relative share of land in aggregate income. However, land expansion has an additional impact. First, it clearly boosts growth, and second, this effect increases with the relative share of land in income. Both predictions are tested empirically for a cross-section of 138 low- and middle-income countries over the period 1990 to 2018. The results suggest strong support for both predictions of the extended growth model. In particular, for low- and middle-income countries, agricultural land expansion over 1990–2018 boosts growth, and this effect on growth due to land expansion is augmented by a country's share of agricultural land in income. This result explains why many low- and middle-income countries engage in extensive agricultural land expansion: their economies still depend on agriculture and other primary product activities, and consequently, land expansion spurs more growth.

The outline of the paper is as follows. The next section summarizes briefly the evidence of continuing agricultural land expansion in low- and middle-income countries. Then, the well-known extension of the Solow-Swan growth model for fixed land is developed. This is followed with extending the model further to allow for land expansion at constant cost, as suggested by Solow (1956). The two predictions for balanced growth are then tested empirically for 138 low- and middle-income countries over 1980–2018, and a number of robustness checks are performed. Based on these empirical results, the paper shows explicitly how the share of land in income influences the impact of agricultural land expansion on growth in developing countries. The concluding section discusses further the implications of the analysis for low- and middle-income countries.

2. Agricultural land use trends

Over the period 1970–2016, agricultural land area in low- and middle-income countries increased by 16% (see Figure 1). However, the trend varies considerably across regions. In East Asia and Pacific, agricultural land use has expanded by 21%, in Sub-Saharan Africa by 15%, and in Latin America and the Caribbean by 6%.

The demand for new agricultural land among most low- and middle-income countries shows little sign of abating. Developing countries are expected to require anywhere from 0.9 to 1.35 million km^2 of new cropland by 2030, and will also need new land for biofuel crops, grazing pasture and industrial forestry, and also to replace land lost to degradation (Lambin and Meyfroidt 2011; Laurence *et al*. 2014; UNCCD 2017). From 2010 to 2050, global expansion of agricultural land for crops, biofuels and pasture is expected to increase by 4.2 million km^2, almost all of it occurring in developing regions such as Sub-Saharan Africa, Central and South America, South Asia and Southeast Asia (UNCCD 2017).

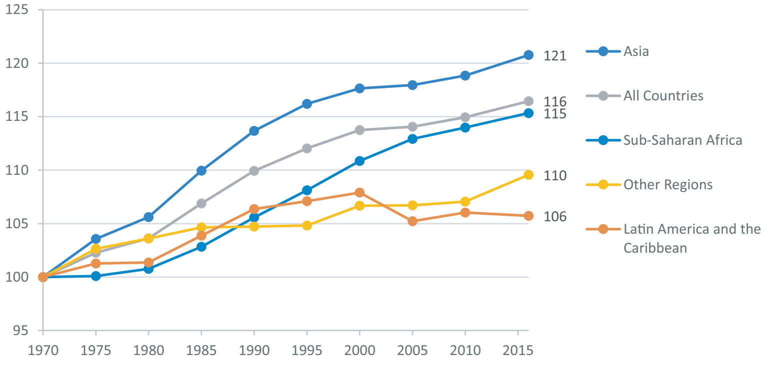

Figure 1 Long-run Agricultural Land Use in Developing Regions, 1970–2016. Note: Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures. The 1970–2016 agricultural land trends depicted in this figure are for 115 low- and middle-income countries, which have 2019 GNI per capita of $12,375 or less. Asia refers to 22 low- and middle-income countries from East Asia and Pacific and 8 countries from South Asia. Sub-Saharan Africa refers to 43 low- and middle-income countries from Sub-Saharan Africa. Latin America and the Caribbean refers to 25 countries from Latin America and the Caribbean. Other Regions refer to 13 low- and middle-income countries from Middle East & North Africa and 4 countries from Europe and Central Asia. Source: World Bank, World Development Indicators, https://databank.worldbank.org/source/world-development-indicators Accessed 19 August 2019. [Colour figure can be viewed at wileyonlinelibrary.com]

Consequently, the trend of substantial expansion of the agricultural land base in low- and middle-income economies through the conversion of forests, wetlands and other natural habitat is expected to continue in coming decades (Gibbs *et al.* 1990; Leblois *et al.* 2000; Lambin and Meyfroidt 2011; Hosonuma *et al.* 2012; Laurence *et al.* 2014; Meyfroidt *et al.* 2014; Busch and Ferretti-Gallon 2017; Carrasco *et al.* 2017).

3. Growth and fixed land

Assume that aggregate production function of the economy is given by the Cobb-Douglas specification

$$Y(t) = K(t)^{\alpha} X^{\beta} [A(t)L(t)]^{1-\alpha-\beta}, \tag{1}$$

where Y is real aggregate output, A is the Harrod-neutral level of technology, K is the capital stock, X is the stock of land (assumed fixed), L is labor, and $0 < \alpha, \beta < 1$. Exogenous growth rates for A and L are given by $\dot{A}/A = \lambda$ and $\dot{L}/L = n$, where a dot over a variable indicates a time derivative.
Given a constant savings rate $0 < S < 1$ and depreciation rate $0<\delta<1$, capital grows over time according to

$$\frac{\dot{K}}{K} = s\frac{Y}{K} - \delta, \tag{2}$$

where time arguments have been omitted for simplicity. Along a balanced growth path, the capital-output ratio K/Y must be constant, which (2) implies $\dot{Y}/Y = \dot{K}/K$. Using this result in (1), the balanced growth rate for per capita output $Y = Y/L$ is

$$g = \frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \sigma\lambda - \frac{\beta n}{(1-\alpha)}, \quad \sigma = \frac{1-\alpha-\beta}{1-\alpha}. \tag{3}$$

An increase in population growth reduces long-run growth in output per capita $dg/dn<0$, and this effect depends on the relative share of land in income, that is $\partial|dg/dn|/\partial\beta>0$That is, the growth-reducing effect of population growth is larger if the relative share of land in income is greater rather than smaller.

4. Growth and agricultural land expansion

We now introduce the extension suggested by Solow (1956, p. 67, n. 2), who proposed that his growth model could apply to developing countries ‘as long as arable land can be hacked out of the wilderness at essentially a constant cost’. We therefore assume that land expansion occurs at the rate γ but comes at a cost ϵ to economic production. That is, new sources of agricultural land are available for use in production, but a proportion of aggregate output Y is sacrificed to devote resources to bring this land into production.

It follows that land expansion is governed by

$$\frac{\dot{X}}{X} = \gamma, \tag{4}$$

and capital accumulation occurs according to

$$\frac{\dot{K}}{K} = (s - \varepsilon)\frac{Y}{K} - \delta. \tag{5}$$

The allocation of output ϵ for land expansion lowers effective savings and thus the rate of capital accumulation. However, the balance growth condition $\dot{Y}/Y = \dot{K}/K$ still holds.

Along the balanced growth path, the long-run growth rate for per capita income is

$$g = \frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \sigma\lambda - \frac{\beta(n-\gamma)}{(1-\alpha)}, \quad \sigma = \frac{1-\alpha-\beta}{1-\alpha}. \tag{6}$$

Two predictions emerge from equation (6). First, the main result from the model with fixed land still holds: An increase in population growth reduces long-run growth, and this effect depends on the relative share of land in income β. However, land expansion $\dot{X}/X = \gamma$ has an additional impact. First, it clearly boosts growth, that is $dg/d\gamma > 0$, and second, this effect increases with the relative share of land in income, that is $\partial|dg/d\gamma|/\partial\beta > 0$.

Figure 2 illustrates the effects of land expansion on growth in per capita income. The figure is drawn for an economy for which expansion occurs at the rate $0 \leq \gamma \leq n$. Growth is clearly lowest when land is fixed and rises at the rate $\beta/1-\sigma$ as additional expansion occurs. When land expansion cancels out the negative drag of population growth, per capita income growth reaches its highest level $\sigma\lambda$.

As Figure 2 indicates, the rate of increase in growth due to land expansion depends on the share of agricultural land in income β. That is, as agriculture is fairly important to this economy, i.e β is relatively large, more land expansion will cause a large increase in the balanced growth rate g.

However, as shown in Figure 3, if the economy maintains the same level of land expansion (i.e. $\gamma = \gamma^*$) but becomes less dependent on agriculture (i.e, β falls), it will experience a higher level of growth. On the one hand, with a smaller β, the positive effect of land expansion on growth is reduced; on the other, a decline in β will boost growth through offsetting the adverse impact of population growth n. As the dotted lines in Figure 3 indicate, if the rate of

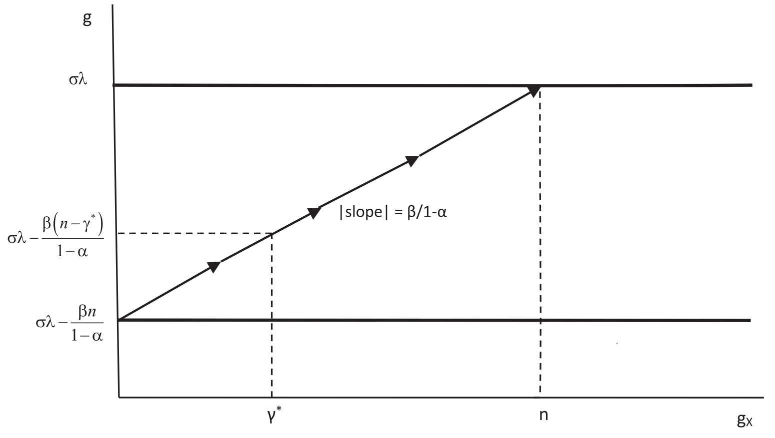

Figure 2 Land expansion and growth.

land expansion γ^* is unchanged, the latter effects dominate and overall growth will increase in the economy.

5. Empirical strategy

The two predictions of equation (6) from the extended Solow-Swan growth model can be tested empirically for 138 low- and middle-income countries over the period 1990 to 2018. As the predictions imply that both population growth n and land expansion γ impact long-run growth through their interactions with the relative share of land in income β, the basic model to be estimated is

$$g(i) = \theta_0 + \theta_1 \beta(i) n(i) + \theta_2 \beta(i) \gamma(i) + z'(i)\theta_z + v(i), \quad (7)$$

for $i = 1, \ldots, N$ countries. Long-run growth g is the annual average growth in GDP per capita (PPP constant 2011 \$) over 1990 to 2018, n is the average

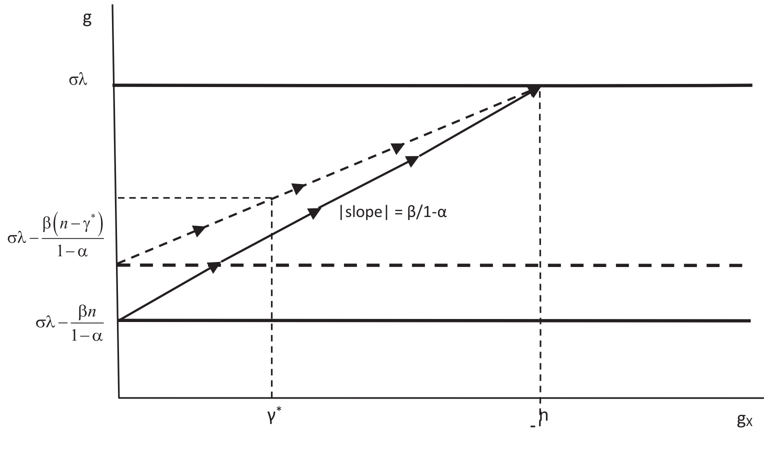

Figure 3 The effects of a fall in β.

population growth rate over 1990–2018, γ is average land expansion over 1990 to 2016, and β is represented by agriculture, forestry and fishing valued added as a share of GDP averaged over 1990–2018. The main purpose of estimating equation (7) is to test the null hypothesis that land expansion γ affects long-run growth through its interactions with the relative share of land in income β, that is whether the coefficient θ_2 is significantly different from zero.

The vector z consists of other standard variables that explain differences in long-run growth across countries based on the standard empirical neoclassical growth framework for conditional convergence (Barro and Sala-I-Martin 2004). This approach relates the real per capita growth rate over a given period to an initial level of per capita real gross domestic product (GDP), plus a variety of control variables representing international openness, governance, and prevailing capital endowments and structural differences among economies. Here, we adopt two sets of controls. The first follows Karras (2010), who tests the prediction of the Solow model with fixed land by including two controls: the initial level of income (e.g. 1990 GDP per capita in this analysis) and the investment rate (e.g. gross fixed capital formation, % GDP). The second set includes additional controls relevant to testing cross-country growth across developing countries, such as trade openness (trade, % of GDP), structural dependence on land and natural resources (primary products, % of total exports), and institutional quality and its interaction with resource dependency (Mehlum *et al.* 2006; van der Ploeg 2011; Barbier 2019). In addition, a dummy variable for Sub-Saharan African countries is included to account for the structural difference of this region, which includes predominantly low-income and agricultural-dependent economies (Diao *et al.* 2010; Dercon and Gollin 2014).

All data are from the World Bank's World Development Indicators, with the exception of institutional and governance variables included in z. These are obtained from the World Bank's Worldwide Governance Indicators.

The empirical strategy involved estimating the basic model of equation (7) but without controls z. Variants of the basic model were also estimated with and without interaction terms and with and without population growth n and land expansion γ as independent variables. The two different sets of controls were then added to determine the most robust version of the model. Robustness checks were also performed, including endogeneity and weak instrument tests for land expansion as an independent variable. Each test failed to reject either the null hypothesis of exogeneity or of weak instruments.

6. Estimated results

Models 1–3 in Table 1 show the estimations of (7) with and without controls z. In all versions of the model, the null hypothesis that land expansion γ impacts long-run growth through its interactions with the relative share of land in income β cannot be rejected. The coefficient for θ_2 is significant and positive, ranging from 0.2 to 0.3 across all three versions. The preferred estimation is Model 3 with the full range of controls z, which with the exception of a measure of openness (trade as % of GDP), have significant coefficients with the expected signs.

As the extended Solow-Swan model suggests, land expansion boosts growth across low- and middle-income economies, and this impact is magnified by the dependence of an economy on land for income. The marginal effects (evaluated at the median β) confirm that land expansion increases average annual growth in per capita income for 1990–2018 across the sample of countries. A 1% increase in land expansion boosts growth by 0.31–0.45%.

Of all the alternative versions of the basic model tested, only one has a significant coefficient for land expansion. This model includes population growth interacted with the share of land in income β, but agricultural land expansion appears on its own as an independent variable:

$$g(i) = \theta_0 + \theta_1 \beta(i) n(i) + \theta_2 \gamma(i) + z'(i)\theta_z + v(i). \tag{8}$$

In effect, this model tests the alternative null hypothesis that agricultural land expansion γ impacts long-run growth directly, and this effect is not influenced by a country's share of land in income β.

Models 4–6 of Table 2 display the results of estimating equation (8) with and without controls z. However, only in Model 6 is the coefficient θ_2 significant and at the 10% level. Thus, the alternative null hypothesis that agricultural land expansion directly impacts growth can be rejected by two of the models estimating equation (8) and is only weakly supported by Model 6 with the full complement of controls z. In the latter model, a 1% increase in land expansion raises growth by 0.34%.

To summarize, these preliminary results confirm the basic prediction of the extended Solow-Swan model that agricultural land expansion boosts long-run growth across low- and middle-income countries and that this effect increases with the relative share of land in income. Model 3 is the most robust regression of this relationship, and the predicted results of the model are depicted in Figure 4.

7. Robustness checks

Various robustness checks were performed on the regressions analysis. Skewness and kurtosis tests for normality detected the presence of heteroscedasticity, which were confirmed through Breusch-Pagan and Cook-Wiesberg tests. Although the hypothesis of homoscedasticity could not be rejected for Model 1 it is rejected for Models 2–6. Consequently, all six models were estimated with robust regression using White's heteroscedasticity consistent covariance matrix estimator, and the coefficient t-tests reported in Tables 1 and 2 are based on robust standard errors.

Table 1 Basic regression results

Land expansion and growth in low and middle-income countries, 1990–2018 a/			
Basic model	$g(i) = \theta_0 + \theta_1\beta(i)n(i) + \theta_2\beta(i)\gamma(i) + z'(i)\theta_z + v(i)$		
Dependent variable	Annual average growth in GDP per capita, 1990–2018		
	Models		
	(1) $N = 117$	(2) $N = 113$	(3) $N = 108$
Explanatory variables			
Constant	2.63 (9.36)**	14.15 (4.92)**	17.67 (5.80)**
(Population growth)* (Agricultural value added, % GDP)	−0.02 (−3.56)**	−0.04 (−5.72)**	−0.03 (−3.90)**
(Agricultural land expansion)* (Agricultural value added, % GDP)	0.03 (2.21)*	0.02 (2.20)*	0.02 (2.17)*
Log 1990 GDP per capita		−1.56 (−5.06)**	−1.73 (−5.47)**
Gross fixed capital formation, % GDP		0.10 (4.33)**	0.08 (3.51)**
Trade (% of GDP)			−0.01 (−1.58)
Primary product exports, % total exports			−0.02 (−2.60)*
Institutional quality			1.69 (2.09)*
Primary product exports* Institutional quality			−0.02 (−1.98)*
Sub-Saharan Africa			−1.26 (−3.54)**
Marginal effects of agricultural land expansion	0.55	0.39	0.38
Evaluated at the mean of β =	18.48	18.61	18.04
Marginal effects of agricultural land expansion	0.45	0.33	0.31
Evaluated at the median of β =	15.19	15.55	14.97
R^2	0.10	0.54	0.60
F-test	6.34**	16.33**	12.96**
Tests of endogeneity (H0: $(\gamma_{1990–2016})*(\beta_{1990–2018})$ is exogenous)			
Durbin chi-squared	0.27	0.29	2.09
Wu-Hausman F-test	0.26	0.27	1.94
Robust score chi-squared	0.31	0.34	2.11

Note: All regressions use the robust estimator of variance to correct for possible heteroskedasticity. Low- and middle-income countries have 2019 GNI per capita of $12,375 or less, based on World Bank classification. Excludes all countries with agricultural land area < 500 over 1990–2016 and indadequate agricultural land or GDP data.
**$P < 0.01$, *$P < 0.05$, †$P < 0.10$.

Procedures were also performed to test the hypothesis that the main independent variable – average annual 1990–2016 land expansion – is exogenous. The key instrument employed is average annual land expansion

Table 2 Alternative regression results

Land expansion and growth in low- and middle-income countries, 1990–2018			
Alternative Specification	$g(i) = \theta_0 + \theta_1\beta(i)n(i) + \theta_2\gamma(i) + z'(i)\theta_z + \theta v(i)$		
Dependent variable	Annual average growth in GDP per capita, 1990–2018		
	Models		
	(4) $N = 117$	(5) $N = 113$	(6) $N = 108$
Explanatory variables			
Constant	2.60	14.31	17.79
	(9.18)**	(4.86)**	(5.70)**
(Population growth)*	−0.02	−0.04	−0.03
(Agricultural value added, % GDP)	(−3.43)**	(−5.79)**	(−3.75)**
Agricultural land expansion	0.44	0.23	0.34
	(1.52)	(0.98)	(1.72)†
Log 1990 GDP per capita		−1.27	−1.74
		(−4.97)**	(−5.36)**
Gross fixed capital formation,		0.10	0.07
% GDP		(4.21)**	(3.38)**
Trade (% of GDP)			−0.01
			(−1.56)
Primary product exports,			−0.02
% total exports			(−2.62)*
Institutional quality			1.83
			(2.24)*
Primary product exports*			−0.02
Institutional quality			(−2.05)*
Sub-Saharan Africa			−1.33
			(−3.83)**
R^2	0.08	0.52	0.59
F-test	5.95**	16.69**	12.22**
Tests of endogeneity (H0: $\gamma_{1990–2016}$ is exogenous)			
Durbin chi-squared	0.07	0.76	0.02
Wu-Hausman *F*-test	0.06	0.72	0.02
Robust score chi-squared	0.10	0.89	0.01

Note: All regressions use the robust estimator of variance to correct for possible heteroskedasticity. Low- and middle-income countries have 2019 GNI per capita of $12,375 or less, based on World Bank classification. Excludes all countries with agricultural land area < 500 over 1990–2016 and indadequate agricultural land or GDP data.
$^{**}P < 0.01$, $^{*}P < 0.05$, †$P < 0.10$.

from 1970 to 1990. As shown in Tables 1 and 2, several endogeneity tests for the six models fail to reject the null hypothesis of exogeneity. In addition, the six models were regressed replacing average annual land expansion 1990–2016 with annual land expansion 1970–1990. In all six regressions, the coefficient θ_2 is no longer significant. Finally, the Montiel-Pflueger robust weak instrument test was also performed on annual land expansion 1970–1990. The effective *F*-test cannot reject the null of weak instruments for the threshold critical value.

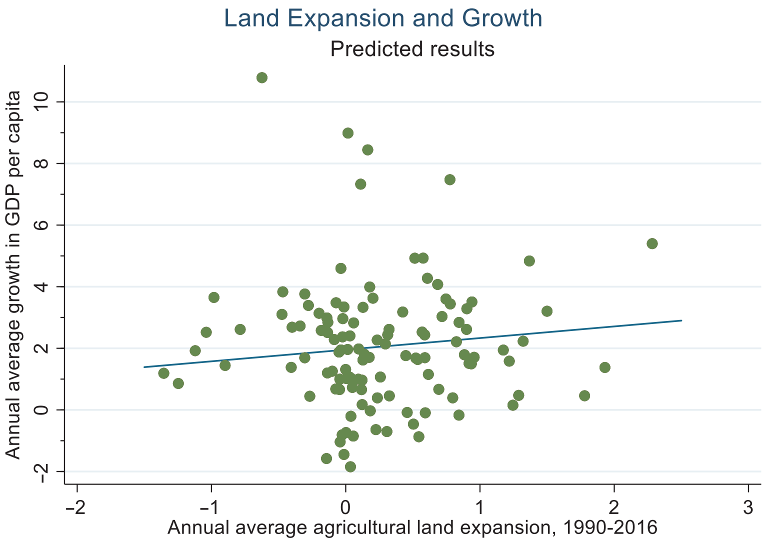

Figure 4 Graph of Predicted Results (Model 3). [Colour figure can be viewed at wileyonlinelibrary.com]

8. The effect of the share of land in income

An important prediction of the extended Solow-Swan growth model, and confirmed from the empirical analysis, is that the impact of agricultural land expansion on growth in low- and middle-income countries is augmented by the share of land in the income of a country. Based on the regression results from Models 3 and 6, Figure 5 illustrates this impact.

Model 6 indicates that a 1% increase in annual average land expansion over 1990–2016 increased annual average 1990–2018 growth of a low- and middle-income country by 0.34%, regardless of the contribution of land to income. In contrast, Model 3 shows that the growth impact of land expansion over 1990–2018 varied significantly across the sample of countries depending on how much income was derived from land. As shown in Figure 5, for a country such as Honduras with a share (15.2%) close to the median of the sample of countries, a 1% increase in annual land expansion yielded a 0.32% increase in annual average growth over 1990–2018. But for a country with a share one standard deviation above the median, such as Madagascar (26.9%), the effect of land expansion was to increase annual 1990–2018 growth by 0.56%. In contrast, for Mexico with a share (3.5%) one standard deviation below the median, annual long-run growth rose by only 0.07% with a 1% increase in annual land expansion.

As the example of Madagascar illustrates, these predictions have an important implications for poor countries that are highly reliant on land to generate income. Overall, low-income countries are more dependent on land and primary products as a share of GDP, and over 2000 to 2015, these

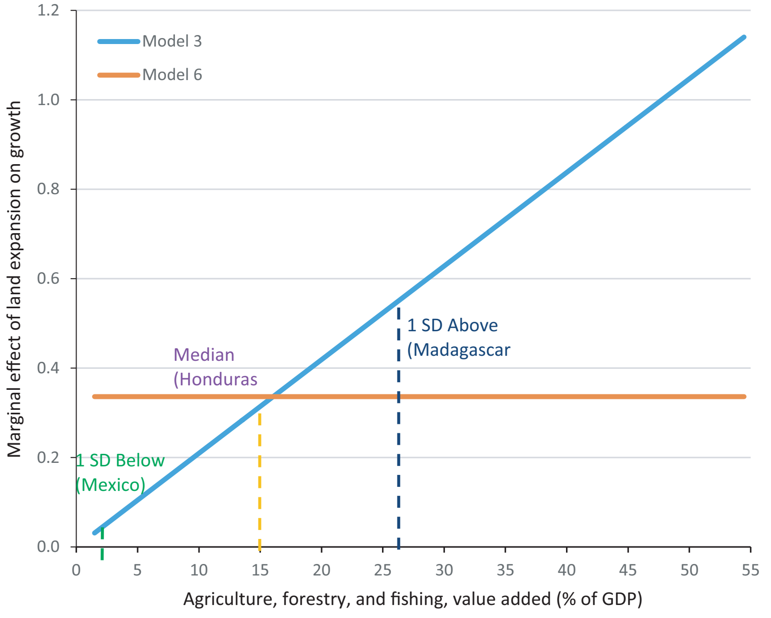

Figure 5 The effect of β. [Colour figure can be viewed at wileyonlinelibrary.com]

countries expanded land are by 10.3% compared to 4.4% on average across all developing countries. The predictions of this model explain why poorer economies engage in such extensive agricultural land expansion. These economies are highly dependent on agriculture and other primary product activities, and thus, increased land expansion generates more growth.

9. Conclusion

This paper has demonstrated that, for low- and middle-income countries, the Solow-Swan growth model should be extended to the case whereby arable land is 'hacked out of the wilderness' as envisioned by Solow (1956, p. 67, n. 2). Moreover, the extended model yields an important prediction that can be empirically tested: the impact of agricultural land expansion on growth in low- and middle-income countries is augmented by the share of land in the income of a country. An empirical analysis of this result was conducted for 138 low- and middle-income countries over the period 1990 to 2018. The outcomes of this analysis suggest that the basic prediction of the extended model is largely verified. Since 1990, for low- and middle-income countries, agricultural land expansion boosts growth, and the rate of increase in growth due to land expansion appears to depend on the share of land in income.

This result explains why many low- and middle-income countries engage in extensive agricultural land expansion: their economies still depend on agriculture and other primary product activities, and consequently, land expansion spurs more growth. Yet, these economic benefits of agricultural land expansion must be weighed against the significant environmental costs of converting additional forests and other ecosystems to agriculture. These costs include greater carbon emissions, loss of ecosystem services and biodiversity, and impacts on the livelihoods of many rural communities (Lambin and Meyfroidt 2011; Busch and Ferretti-Gallon 2017; Carrasco *et al*. 2017). In addition, evidence suggests that emerging infectious diseases, such as COVID-19, originate from wildlife species and that land-use change is an important pathway for the transmission of zoonotic diseases to humans (Faust *et al*. 2018; Zohdy *et al*. 2019; Johnson *et al*. 2020). Some of these environmental costs are borne locally, but many have much more important global impacts. A complete assessment of the benefits of agricultural land expansion for low- and middle-income countries should take into account these growing global and local environmental risks, and also explore possible mechanisms through which the international community could compensate developing countries to forego the benefits of agricultural land expansion to reduce global environmental costs.

Finally, although this paper demonstrates that the Solow-Swan growth model can indeed be extended to the case whereby arable land is ‘hacked out of the wilderness’ and that the resulting predictions are largely verified for developing countries over 1990–2018, the actual relationship between land conversion and growth may be more complicated in developing countries. One limitation of the Solow-Swan growth model is a closed economy model, and even though the empirical analysis allows for open economy influences through the use of control variables, an open-economy growth model with land conversion may lead to different predictions than the ones explored here. Equally, like all neoclassical growth models, the Solow-Swan model assumes exogenous technological change. If technological change is endogenous, and especially if it has a land-saving impact in agricultural-based economies, then the potential impact of land expansion on growth could be different than what is observed here. These are important areas for further research.

Data availability statement

The data that support the findings of this study are available in Projects at http://www.edwardbbarbier.com/. These data were derived from the following resources available in the public domain: https://databank.worldbank.org/reports.aspx?source=world-development-indicators.

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