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Adaptation to land constraints: Is Africa different?

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ABSTRACT

Since the seminal works of Malthus and Boserup, scientists have long debated the impact of population growth and land constraints on the wellbeing of rural people. Today these concerns are particularly relevant to Africa, with its rapid population growth, very small farms, and chronic food insecurity. In this paper we examine adaptation to falling land-labor ratios using a comprehensive theoretical framework in which households faced with binding land constraints can respond in three ways: intensifying agricultural production, diversifying out of agriculture, and reducing fertility rates. Using cross-country data and drawing upon the existing literature, we reach three conclusions. First, population density is associated with reduced fallows and more intensive use of land but not fertilizer use or irrigation, indicating major challenges in achieving sustainable intensification or agricultural productivity growth. Second, there is little evidence of successful non-farm diversification in response to land pressures in Africa from domestic or international income sources. Third, rural Africans in land constrained countries desire smaller families, but have thus far benefited little from family planning policies. These findings underscore the need for a coordinated multi-sectoral approach to sustainably reduce poverty in the region.

> *"The potential problems of declining labor productivity and environmental degradation are not problems of levels of population densities. Given sufficient time, it is likely that a combination of farmer inventions, savings, and the development of research institutions... will be able to accommodate much more than the current population in most countries... However, if all of these changes are required quickly and simultaneously because of rapid population growth rates, they may emerge at too slow a pace to prevent a decline in human welfare."*
>
> [p. 51 of Pingali and Binswanger (1988)]

Introduction

Since the pioneering work of Malthus (1798), the relationship between demography and agricultural development has been the subject of important research in a number of literatures. Following Boserup (1965), the literature in the 1980s and early 1990s focused on testing the important prediction that rising population density in rural areas induces farmers to intensify agricultural production (Binswanger and McIntire, 1987; Binswanger and Rosenzweig, 1986; Lele and Stone, 1989; Pingali et al., 1987; Pingali and Binswanger, 1988; Ruthenberg, 1980; Turner et al., 1993). In the 1990s research in this area gradually shifted to assessing the implications of rural population growth for natural resource degradation (Bilsborrow, 1992; Carswell, 1997; Clay and Reardon, 1998; Krautkraemer, 1994; Mortimore, 1993; Pingali, 1990; Scherr, 1999; Tiffen, 1995). And since the Green Revolution successes in Asia, there has emerged a more generic literature on intensification and technology adoption (Diao et al., 2008; Djurfeldt et al., 2005; Evenson, 2004; Evenson and Gollin, 2003a,b; Hazell, 2009; Johnson et al., 2003; Mosley, 2002), with population pressures being treated as an underlying theme.

Despite some important research on the linkages between demography, land availability and agricultural development, the recent development literature has rarely revisited or extended the theory and evidence that emerged in earlier decades. This knowledge gap persists despite renewed concerns that rapid rural population growth – particularly in sub-Saharan Africa (hereafter Africa or SSA) – could have potentially disastrous consequences on rural welfare and food security (Lipton, 2009, 2012). Indeed, it could be argued that population pressures pose a far more severe challenge for African agriculture than the related threat of adverse climate change. For while the magnitude and impacts of climate change remain very uncertain, rapid population growth in Africa will be inevitable for many decades to come, and in many large

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Table 1
Rural population patterns and trends, 2010. *Source*: Authors' construction from FAO (2012) data for the year 2010.

	#	Population density[a]	Rural population (millions)		
		2010	2010	2050	Change
Africa	41	117	505	810	305
High density Africa[b]	12	172	294	457	163
Low density Africa[b]	29	49	211	353	142
South Asia	7	528	1132	1120	−12
East Asia	9	199	975	524	−452
Middle East & North Africa	10	506	157	159	2
Eastern Europe, Central Asia	21	58	98	75	−22
Latin America	21	53	125	100	−24

[a] *Notes*: Rural population density is the estimated rural population divided by land devoted to arable land and permanent crops.
[b] High density Africa consists of countries with rural population densities in excess of 100 people per square kilometer. This includes Rwanda (420 people per sq. km), Burundi (339), Comoros (309), Malawi (209), Uganda (201), Ethiopia (194), DRC (187), Benin (152), Kenya (113), Gambia (108), Nigeria 106), and Sierra Leone (104).

African countries this growth is taking place against already constrained land resources.

Tables 1 and 2 motivate this concern. Table 1 reports estimates of rural population density (defined as the rural population relative to total crop land), and projections of rural population growth for the developing world.[1] While rural population density in Africa is still relatively low on average, twelve African countries constitute a high density group with rural population densities above 100 people per square kilometer. Moreover, this list includes Africa's three largest countries (Nigeria, Ethiopia and the Democratic Republic of Congo),[2] and a number of other large African countries (Uganda, Kenya, Malawi), which collectively amount to 58% of sub-Saharan Africa's rural population. 2 reports both FAOSTAT and census/survey data showing that farm sizes in these high density countries declined sharply from the 1970s to the 2000s. Evidence on declining farm size for a number of specific African countries over the same period is presented in Jayne et al. (2003). The census/survey data suggest that over this 30-year period the average landholding in high density Africa declined from about 2 hectares to 1.2 hectares, on average, but stayed the same in low density Africa. On top of this trend of declining farm sizes in high density Africa, the rural populations of these countries are expected to increase by a further 163 million people in the next 40 years (Table 1).[3] Low density rural Africa will also face a substantial surge in its rural population of some 142 million people, but in theory could cope with this pressure through land expansion.[4] And in stark contrast to Africa, rural populations in the rest of the developing world are actually expected to have declined by 2050.

The retrospective and prospective statistics in Tables 1 and 2 point to what is potentially a very disturbing scenario: rapid population growth taking place amidst already declining land endowments in high-density African countries, which are already typified by severe rural poverty. Faced with that pressure, it is surely crucial to ask whether and how rural Africans are adapting to rising land constraints, and to consider the potential implications for Africa's development strategies, which may be wide ranging and multisectoral.

To address these questions, we first integrate prior strands of the literature into a single framework that identifies the distinct means by which rural people (and their governments) may adapt to or mitigate emerging pressures on agricultural land (Section 'Theoretical and methodological frameworks'). Our starting point is an agrarian economy with farm income per capita as the key welfare variable. A simple disaggregation of farm income per capita demonstrates three possible means of responding to rapid rural population growth under binding land constraints[5]: (1) growth in the value of farm output per hectare (agricultural intensification); (2) exits from the farm sector to rural nonfarm, urban or overseas labor markets; and (3) reductions in rural fertility rates. Of note is that the vast majority of the existing literature on population pressures has focused on the need to transition from land expansion to land intensification, with fertility reductions and nonfarm diversification being largely the subject of very separate literatures on demography, the rural nonfarm economy and migration.

Empirically, we focus on the big picture by examining cross-country patterns and trends in available data. We also conduct cross-country tests of the strength of responses to changes in population density, occasionally augmenting our own analysis with findings from the existing literature. While cross-country analysis has well known limitations – particularly causal identification (Durlauf et al., 2005) – a multi-country empirical analysis has the potential scope to add external validity to some of the country-specific conclusions generated in the more detailed case studies contained in this special issue, and in the existing literature (e.g. Pender et al., 2006), or to identify new stylized facts worthy of further research (Pritchett, 2001). To these ends, Sections 'Agricultural intensification', 'Nonfarm diversification', and 'Reducing rural fertility rates' explore the three different means of responding to land constraints using an unusually large and rich set of data on rural demography and farm sizes, agricultural inputs and production, rural fertility rates and income diversification indicators. The strengths and weaknesses of our data and techniques are discussed in more detail in Appendix A.

While a more detailed summary of our results is provided in our concluding section (Section 'Conclusions'), we note here the study's three main conclusions.

[1] We will discuss our operational definitions of population density further below, but we note here that if we want density measures that are good proxies for "land pressures", then using total land area or even total agricultural area (including livestock grazing area) is not very desirable. Much non-agricultural or livestock area is very sparsely populated, meaning that countries with populations heavily clustered in cropping areas but with extensive non-crop areas would appear land abundant. Egypt – with 100% of its cropland irrigated, and almost all of the non-cropland area being desert – is an extreme example, but Ethiopia, Kenya and other African countries share this characteristic of population clustering in areas of good cropping potential.

[2] Data for the Democratic Republic of Congo (DRC) are notoriously sketchy, and it is indeed surprising that farm sizes and land per capita are so small in such a land abundant country. We therefore consider the DRC a very borderline case. On the other hand there are counties like Madagascar which the FAO data suggests is land abundant, despite average farm sizes of under 1 hectare. Thus the classification of high and low density does indeed depend on which indicator or data source is used.

[3] These estimates may be conservative for several reasons. First, they assume a size reduction in fertility rates, which has thus far been sluggish in much of Africa, particularly the DRC. Second, they assume reasonably rapid urbanization, which is often exaggerated in Africa (Potts, 2012).

[4] See Chamberlain et al. (2014) for more analysis of the constraints land expansion.

[5] A companion paper in this special consider the scope for land expansion and rural-to-rural migration. See Chamberlain et al. (2013).

Table 2
Alternative indicators of land endowments in developing regions, 1970s and 2000s. *Sources*: Hectares per capita are derived from FAO (2012) population and crop land estimates, where crop land is arable land plus permanent crop land. Hectares per holder are principally drawn from FAO World Census of Agriculture data from 1996 to 2005 and augmented by the authors with results from various household surveys (mostly for 2005–2010). Gini coefficients of land inequality are calculated by the authors from these sources.

Region	Period	Hectares per ag. worker (FAO)	Hectares per rural capita (FAO)	Hectares per holding (surveys)	Farmland Gini coef. (Gini, 0–1)[a]
Africa – high density[b]	1970s	0.84	0.35	1.99	
($n = 5$)	2000s	0.58	0.25	1.23	0.46
Africa – low density[b]	1970s	1.65	0.64	2.65	
($n = 11$)	2000s	1.37	0.53	2.82	0.53
South Asia	1970s	0.78	0.22	2.01	
($n = 5$)	2000s	0.55	0.15	1.19	0.53
China & S.E. Asia	1970s	0.80	0.30	2.08	
($n = 4$)	2000s	0.68	0.28	1.58	0.55
Middle East	1970s	5.52	1.02	9.86	
($n = 6$)	2000s	7.44	0.83	5.62	0.65
North Africa	1970s	3.60	0.74	6.90	
($n = 4$)	2000s	3.10	0.72	6.35	0.61
Central America	1970s	2.13	0.57	28.78	
($n = 7$)	2000s	2.44	0.56	14.83	0.76
South America	1970s	5.67	1.77	112.59	
($n = 9$)	2000s	5.42	2.43	140.86	0.85

[a] *Notes:* Farm inequality refers to Gini coefficient of land holdings, but since fewer observations were available for this indicator so we simply report an average over time.
[b] "Africa-low density" includes Botswana, Cote d'Ivoire, Ghana, Madagascar, Mali, Senegal, Sierra Leone, Tanzania, Togo and Zambia. "Africa-high density" includes Ethiopia, Kenya, Malawi, Rwanda and Uganda.

First, the theories of agricultural intensification developed by Boserup, Binswanger and others certainly receive very strong support from the data for both African and non-African samples, but with several important exceptions. One of those is the lower responsiveness of fertilizer use to land constraints in Africa. An existing literature links this to a vicious circle of over-exploitation of land, a resultant process of nutrient mining and loss of soil organic matter, and further reductions in the returns to fertilizer use. A second exception is Africa's much lower use of – and potential for – irrigation. Irrigation was clearly an essential component of Asian countries being able to feed themselves and reduce poverty. The true potential for irrigation in Africa is still unclear, but irrigation expansion in Africa will not be the "low hanging fruit" that it was in Asia. Africa's low use of irrigation also partially explains its weak response of fertilizer intensification to rising population density. Third, Africa's greater diversity of crops, its proliferation of small countries, and its historic underinvestment in crop research, would all predict a more sluggish process of research, development and adoption of improved seed varieties. These unique characteristics all suggest that, without fundamental changes in the thrust of agricultural policies, Africa has much less scope for sustained and sustainable smallholder-led agricultural intensification than Asia, and that increasingly binding land constraints will be a major drag to poverty reduction in the region, in the absence of non-farm income drivers.

Yet our second finding of note is that nonfarm income drivers are equally sluggish in Africa. Some high density countries have large rural nonfarm sectors, but many do not. All African countries have weak manufacturing bases, and are heavily reliant on job creation in low-return services activities. And while international remittances data are patchy, it also appears that African countries have not been as successful at tapping into overseas labor markets as Asian countries.

Finally, we find novel evidence that desired fertility rates in rural areas decline in response to higher rates of population density, but achieved fertility rates do not. In other words, high density countries in Africa face large gaps in unmet contraception needs, suggesting that family planning policies would be more efficacious in these countries than in more land abundant regions. While some land constrained African countries are more aggressively pursuing family planning policies (for example, Ethiopia), the importance of these policies, and complementary policies targeted at increasing women's education and empowerment, is under-emphasized in most policy discussions, as are the lessons from Asia's far more successful attempts to reduce fertility rates.

These pessimistic conclusions clearly raise cause for concern. Many of these findings obviously link to existing concerns in several different literatures, though rarely do previous studies piece these different dimensions of the problem together. Rarer still is explicit acknowledgement of the severity of land constraints in policy discussions and processes in Africa, a region that is too often labeled as land abundant. The most land-constrained countries in Africa face a daunting combination of continued population pressure, limited scope for agricultural intensification, and a sluggish industrialization process (Headey et al., 2010). Policymakers in Africa urgently need to think through the most effective ways of addressing these problems, and thereby catalyzing a more successful economic transformation.

Theoretical and methodological frameworks

As a departure point for understanding the relationship between rural population density and household welfare, we consider rural income per capita adopted as the welfare maximand of principal interest (we drop country and time period subscripts for the sake of simplicity). Aggregate income (Y) in a rural economy can be derived from either farm income (subscript f) or nonfarm income (subscript nf):

$$Y \equiv Y_f + Y_{nf} \tag{1}$$

In per capita terms (where N refers to the rural population), income is the sum of the shares of labor in the farm and nonfarm sector multiplied by each sector's labor productivity.

$$\frac{Y}{N} \equiv \theta_f Y_f + (1-\theta_f)y_{nf}, \text{where } \theta_f = \frac{N_f}{N},\ y_f = \frac{y_f}{N_f} \text{and } y_{nf} = \frac{y_{nf}}{N_{nf}} \tag{2}$$

In autarkic subsistence economies (the subject of Malthus' and Boserup's analyses) the nonfarm sector is non-existent, such that $\theta_f = 1$ and all rural income is farm income (we will return to the nonfarm sector below). Farm income per capita can then be decomposed into the product of farm income per hectares of land, and per capita land endowments (L):

$$\frac{Y_f}{N} \equiv \frac{Y_f}{L} \cdot \frac{L}{N} \tag{3}$$

Taking the log and first differences, we observe that growth in agricultural output per capita is the sum of growth in income per hectare and growth in per capita land endowments.

$$\Delta \ln \frac{Y_f}{N} \equiv \Delta \ln \frac{Y_f}{L} + \Delta \ln \frac{L}{N} \tag{4}$$

Since the land to population ratio is the reciprocal of agricultural population density (d), growth in farm income can also be expressed as growth in value per hectare less growth in agricultural population density:

$$\Delta \ln \frac{Y_f}{N} \equiv \ln \frac{Y_f}{L} - \Delta \ln d \tag{5}$$

An alternative disaggregation shows that changes in average farm income are the sum of changes in output per hectare and changes in farm land, less agricultural population growth.

$$\Delta \ln \frac{Y_f}{N} \equiv \Delta \ln \frac{Y_f}{L} - \Delta \ln L - \Delta \ln N \tag{6}$$

Re-introducing a nonfarm sector, agricultural population growth will be the sum of the percentage change in the net birth rate (b, birth rates less death rates) and the net migration rate out of agriculture, which is θ_f:

$$\Delta \ln N \equiv \Delta \ln b + \Delta \ln \theta_f \tag{7}$$

Substituting (7) into (6) we obtain the following key identity:

$$\Delta \ln \frac{Y_f}{N} \equiv \Delta \ln \frac{Y_f}{L} + \Delta \ln L - \Delta \ln b - \Delta \ln \theta_f \tag{8}$$

Whilst purely a decomposition, this identity is nevertheless instructive insofar as it provides a description of the four possible means of adapting to or mitigating agricultural land pressures:

(1) Land expansion ($\Delta \ln L$).
(2) Agricultural intensification, defined here as increases in agricultural output (value) per hectare $\left(\Delta \ln \frac{Y_f}{L}\right)$.
(3) Reducing rural fertility rates ($\Delta \ln b$).
(4) Diversification into nonfarm sectors ($\Delta \ln \theta_f$), be it local, urban or international.

It should also be apparent that different and often competing theories of rural development are embedded in these equations. For example, in Malthus' theory, population growth and value per hectare are exogenous, and land is in fixed supply. These assumptions predict a decline in farm income per capita as the rural population expands, until induced higher mortality rates check population growth. In Boserup's hypothesis, however, agricultural intensity is itself a function of land constraints. If ε_d is the elasticity of agricultural value per hectare with respect to population density, then Eq. (5) can be expressed as:

$$\Delta \ln \frac{Y_f}{N} = (\varepsilon_d - 1) \Delta \ln d \tag{9}$$

Thus the impact of population density on farm income per capita could be negative ($\varepsilon_d < 1$), zero ($\varepsilon_d = 1$), or conceivably even positive ($\varepsilon_d > 1$). This magnitude clearly matters. If ε_d is zero or close to zero, then Eq. (9) implies that net farm income per capita declines almost proportionately to the decline in land per capita. If ε_d is closer to 1, on the other hand, then the agricultural intensification response to declining farm sizes may be strong enough almost fully offset the loss of farming land. More generally, there may be other factors exogenously raising agricultural output per hectare, such as farm policies, and improved infrastructure and market access conditions. And insofar as shrinking land-labor ratios reduce farm labor requirements, we would also expect reductions in desired fertility rates and increased demand for nonfarm labor employment. In effect then, each of the right hand side terms in Eq. (8) could be a function of existing population density, which is what much of this paper is focused on testing.

Finally, several other theories of development could be embodied in this framework. The literature on Asia's Green Revolution's emphasized policy-induced technical change as an antidote to rising land constraint and a complement to Boserupian intensification. A large literature on structural transformation, beginning with Lewis (1954), emphasizes industrialization as an escape from rural poverty, especially in surplus labor conditions.

The theoretical framework above suggests that various adaptive behaviors may be causally affected by land pressures, measured above as agricultural land per capita or its inverse, agricultural population density. Whilst there is a substantial literature exploring some of these relationships – particularly the relationship between land pressures and agricultural intensification – there are some significant (and under-discussed) methodological challenges to estimating the impact of land pressures on agricultural intensification and other adaptive behaviors.[6]

In terms of data, many of the variables referred to in the equations above are difficult to measure. Appendix Table A1 outlines our attempts to measure some of the adaptations to population density, as well as relevant control variables. Consistent with the equations above we measure population density as the agricultural population (those saying they rely primarily on agricultural income) relative to total cropland. One might argue that potentially arable cropland should be used in the denominator, but measurement of this is hardly straightforward, particularly the measurement of land with economic potential for cropping (Young, 1999; Chamberlain et al. 2014). In Africa these are particularly important issues. For example, while we know that there are immense tracts of land in the DRC and Madagascar with some potential for cropping, farm census data of the type shown in Table 2 suggest that average farm holdings in these countries are below 1 hectare, suggesting that farmers in these countries do face constraints on land expansion, even if these constraints are not purely physical.

In econometric terms, there are a number of reasons why endogeneity issues might pervade any attempts to explore the relationships examined above. For example, population density and agricultural intensification are clearly simultaneously influenced by agroecological potential, access to markets and other policies. Similarly, serial correlation in time series variables can create important estimation problems. A disadvantage of the cross-country data used herein is that there are serious challenges to identifying strictly causal relationships. Data constraints leave us with small samples and very few indicators of key policy variables that we would ideally want to control for. And there are also no obvious instruments for changes in rural population density, since it is difficult to find reported indicators that influence population growth but are unlikely to influence farming practices or nonfarm diversification.

The empirical results in this paper therefore only make for suggestive causal inferences. Where possible we try to account for obvious biases (for example, removing fixed effects through first

[6] Previous analyses of Boserupian intensification tended to use cross-sectional correlations between population densities and farming systems to draw strong inferences, without explicitly recognizing the various challenges to drawing causal inferences.

differencing), but we fully acknowledge that many of the identified relationships discussed below warrant further empirical testing. More rigorous tests are indeed conducted in many of the country case studies in this special issue. Others warrant future research.

Agricultural intensification

Boserup (1965) is regarded as the original proponent of the idea that as rural population density increases and land constraints become binding, farming households gradually switch from an extensive production system (where land is continually expanded or infrequently rotated) to more intensive systems in which the diminished availability of land is substituted by other inputs. At early stages of this evolution, intensification may simply involve a reduction in the period in which land is left fallow. As fallow land is increasingly exhausted, however, the substitution to non-land inputs accelerates, including substitutions of labor effort, fertilizers (initially organic, and then chemical), pesticides/herbicides, traction (animal, and then machine), land structures (e.g. terraces), increased use of water control techniques (irrigation), and increased cropping intensity. While Boserup's theory was the most well developed and extensive statement of the evolution of farming systems at that time, it is also worth noting that 140 years earlier von Thünen (1826) derived a related hypothesis that proximity to markets (towns and cities) also induces a switch to higher value commodities, in order to increase the value per hectare, which could also be regarded as a form of intensification.[7]

In the 1980s, Binswanger, Pingali and others extended the theoretical and empirical analysis of agricultural intensification (Binswanger and McIntire, 1987; Binswanger and Rosenzweig, 1986; Lele and Stone, 1989; Pingali et al., 1987; Pingali and Binswanger, 1988; Ruthenberg, 1980; Ruttan and Hayami, 1984; Ruttan and Thirtle, 1989).[8] While the insights from this literature are vast, we emphasize three important hypotheses.

First, while the Boserupian intensification process generally holds, "material" determinants (i.e. agroecological factors) can substantially influence the form and speed of intensification. Animal traction may be a highly effective substitution for labor effort in many areas, but may be inhibited by the disease environment (e.g. Tsetse fly) in other areas. In some countries we also observe high degrees of cereal intensification (e.g. Bangladesh), but in other regions high density areas specialize in cash crops (e.g. coffee in the East African highlands).

Second, access to both domestic and foreign markets can drive agricultural intensification even in the absence of greater population density (in effect, an extension of von Thünen's hypothesis). That said, market access may influence the form of intensification, and may also interact with agroecological conditions. For example, proximity to cities may encourage the production of high value perishable commodities, but non-perishable cash crops can be grown in conditions of relatively poor market access.

Third, there is no guarantee that rapid population growth – of the kind seen in developing regions over the last century or so – will automatically induce agricultural intensification. Subsequent research raised analogous concerns about the impact of rapid population growth on environmental sustainability of agricultural production, or "involution" instead of evolution **(Bilsborrow, 1992; Carswell, 1997; Clay and Reardon, 1998; Krautkraemer, 1994; Lele and Stone, 1989; Mortimore, 1993; Pingali, 1990; Sanchez, 1998, 2002; Scherr, 1999; Tiffen, 1995). In this regard, policy-induced intensification may be an important means of "nudging" endogenous Boserupian intensification, especially in high density areas where there is latent demand for more intensive technologies (Binswanger and Pingali (1988). Johnson (2000), Djurfeldt et al. (2005) and Binswanger and Deininger (1997) all suggest that rising population density may itself induce policy responses. Rising population densities not only create scope for large-scale food crises, they also lower the transaction costs of form effective rural lobby groups.

Given these caveats and nuances, what do international data tell us about the intensification paths of small-farm developing countries? In Tables 3–5, and Figs. 1 and 2, we explore trends in various intensification indicators for the three regions with pervasively small farm sizes, as demonstrated in Table 2: sub-Saharan Africa (high and low density), South Asia and East Asia. The indicators of intensification we use are all derived from FAO (2012) data, and are described in more detail in Appendix Table A1. Some of these indicators are standard (cereal yields, crop and agricultural output per hectare, fertilizer (nitrogen) use per hectare), but others deserve further explanation. For example, in line with Boserupian literature we constructed a basic indicator of cereal cropping intensity. The numerator of this ratio is cereal area harvested in a given year (potentially multiple times), while the denominator is temporary crop area harvested at least once in the last five years. This indicator is therefore a close approximation of Ruthenberg's (1980) R-index.[9] We also focus on non-land capital per hectare as an aggregate measure of intensification, as well as cattle/oxen per hectare. The latter is discussed extensively as an intensification indicator in Binswanger and Pingali (1988). We also consider both high value non-cereal crops (e.g. coffee) and non-cereal staples, such as cassava, as a potentially important form of intensification. Finally, we measure our latent variables, "land constraints", with the agricultural population per square kilometer of agricultural land.[10] In terms of analytics we focus on longer run trends in these indicators, but we also run somewhat more formal econometric tests to derive point estimates of the elasticities between population density and these intensification indicators. These tests rely on first differenced estimates of 10 year changes in intensification against 10-year changes in population density. We also note that a much broader array of tests is available upon request.

We begin by focusing in Fig. 1, which shows LOWESS predicts of the gradients between crop output (or value) per hectare and agricultural population density in 1977 and 2007, for African and Asian sub-samples. Crop output per hectare is important as perhaps the most comprehensive indicator of intensification, and one that is welfare-relevant in that it is a strong predictor of household income, holding farm sizes and rural nonfarm income constant. The figure demonstrates several striking stylized facts. First, we again observe that Asia has a much broader range of population

[7] Moreover, both Boserup and von Thünen focused considerable attention on the increasing value of land (and formalization of land markets) as population density or proximity to markets increases. However, that implication is not directly testable with the cross-country data used here.

[8] The induced innovation hypothesis of Ruttan and Hayami (1984) can also be thought of as a more general theory of farmers' adaptation to changing endowments.

[9] In principal we should measure cereal area harvested multiple times to cereal area harvested at least once in the last 5 years. This was not possible for the bulk of our sample, but correlations between the two indicators for subsamples were very high (in excess of 0.9). Even so, the indicator is surely measured with substantial error, though the broad patterns across countries are plausible.

[10] We considered alternative indicators of land constraints, but all seemed to suffer from more serious flaws that this indicator. For example, one could measure the rural population per area of land, but this might include nonfarm populations that have little interest in farming. As it happens the rural and agricultural population densities are very highly correlated anyway. Or one could use alternative measures of land in the denominator, such as cropland land (but this may exclude pastoral areas that are potentially usable for cropping) or potentially cultivable land (but this indicator seems very weakly correlated with average farm size data from censuses and surveys). None of these indicators are ideal, and we did explore sensitivity to some of our econometric results. In general we obtain similar point estimates when using these different indicators of land constraints, but the standard errors are sometimes inflated to the point of rendering the elasticities insignificantly different from zero.

Table 3
Trends in various indicators of agricultural intensification for four small-farm developing regions: 1977–2007. *Source*: All variables are constructed from FAO (2012) data.

	Indicators[b]>	Ag. Pop. density (per km²)	Cropping intensity (%)	Cereal yields (Hg/Ha)	Total crop value per Ha ($)	Cattle & oxen per 1000 Ha	Non-cereal output share (%)	Irrigated cropland (%)	Nitrogen (kg) per Ha	Non-land capital ($) per Ha
East & South	1977	242.4	97.4	13917	661.2	463.3	43.6	10.9	23.0	1.6
East Asia	2007	205.0	116.8	29622	1348.4	623.9	50.4	19.3	94.3	2.5
	Change (%)	*−15.4*	*19.9*	*112.8*	*103.9*	*34.7*	*15.6*	*76.6*	*309.3*	*61.7*
South Asia	1977	358.1	100.7	12645	572.7	1645.1	40.6	23.2	21.5	2.4
	2007	489.9	116.5	23452	1227.5	1965.8	44.7	43.0	82.8	3.2
	Change (%)	*36.8*	*15.7*	*85.5*	*114.3*	*19.5*	*10.1*	*85.0*	*285.3*	*33.4*
Africa	1977	123.4	62.0	10614	398.3	324.0	55.9	0.2	2.0	0.9
Higher density[a]	2007	180.8	77.8	13500	575.3	481.2	50.0	0.5	6.3	1.3
	Change (%)	*46.4*	*25.4*	*27.2*	*44.4*	*48.5*	*−10.6*	*111.0*	*221.0*	*39.7*
Africa	1977	32.6	55.8	7758	320.4	164.6	53.2	0.3	3.8	1.3
Low density	2007	40.6	61.7	10084	441.1	258.9	52.3	0.5	4.7	1.6
	Change (%)	*24.5*	*10.6*	*30.0*	*37.7*	*57.3*	*−1.7*	*64.8*	*24.9*	*23.6*

Notes: Statistics reported are the mean values across the set of countries in a given group.
[a] High density countries includes Benin, Burundi, The Democratic Republic of Congo, Ethiopia, The Gambia, Kenya, Malawi, Nigeria, Rwanda, Togo, Sierra Leone and Uganda. All have population densities exceeding 100 people per square km in 2007.
[b] All variables are described in the text.

Table 4
Sources of intensification in Africa and Asia from the 1970s to the 2000s.

Period	(1) Crop intensity (%)	(2) Crop yields	(3) Output per Ha	Period	(1) Crop intensity (%)	(2) Crop yields	(3) Output per Ha
Democratic Republic of Congo				*Bangladesh*			
1970s	59.1	607	359	1970s	131.9	569	751
2000s	77.0	584	450	2000s	153.9	1125	1731
Change (%)	*30.3*	*−3.7*	*25.5*	*Change (%)*	*16.7*	*97.5*	*130.5*
Ethiopia				*China*			
1970s	53.2	291	155	1970s	137.2	693	951
2000s	89.7	421	378	2000s	109.3	2099	2294
Change (%)	*68.7*	*44.7*	*144.0*	*Change (%)*	*−20.3*	*202.8*	*141.2*
Kenya				*India*			
1970s	60.9	356	217	1970s	97.0	397	385
2000s	71.7	354	254	2000s	102.2	804	822
Change (%)	*17.7*	*−0.5*	*17.1*	*Change (%)*	*5.4*	*102.5*	*113.4*
Madagascar				*Indonesia*			
1970s	69.4	783	543	1970s	65.5	812	532
2000s	73.2	854	625	2000s	67.6	1617	1093
Change (%)	*5.5*	*9.1*	*15.0*	*Change (%)*	*3.1*	*99.3*	*105.5*
Malawi				*Nepal*			
1970s	96.7	348	337	1970s	119.8	435	521
2000s	99.4	635	631	2000s	175.1	745	1304
Change (%)	*2.8*	*82.4*	*87.4*	*Change (%)*	*46.2*	*71.3*	*150.4*
Nigeria				*Pakistan*			
1970s	74.8	412	308	1970s	82.2	415	341
2000s	109.0	727	792	2000s	100.0	766	766
Change (%)	*45.7*	*76.5*	*157.2*	*Change (%)*	*21.7*	*84.6*	*124.6*
Rwanda				*Philippines*			
1970s	91.2	847	772	1970s	121.0	675	817
2000s	114.3	835	955	2000s	117.9	1187	1399
Change (%)	*25.4*	*−1.4*	*23.7*	*Change (%)*	*−2.5*	*75.8*	*71.3*
Uganda				*Thailand*			
1970s	63.4	670	425	1970s	70.7	766	541
2000s	81.4	691	563	2000s	79.8	1519	1213
Change (%)	*28.3*	*3.2*	*32.4*	*Change (%)*	*12.9*	*98.4*	*124.0*
Africa (average of 8 countries above)				*Asia (average of 8 countries above)*			
1970s	71.1	539	389	1970s	103.2	595	605
2000s	89.5	638	581	2000s	113.2	1233	1328
Change (%)	28.0	26.3	62.8	*Change (%)*	10.4	104.0	120.1

Notes: (1) Crop intensity is area harvested multiple times in a year relative to area harvested at least once or under temporary fallow. (2) "Yields" is output per area harvested. (3) Output per ha is the product of (1) and (2). See text for details.

densities relative to Africa, although plenty of Asian and African countries have similar densities. Second, there is a relatively gentle positive gradient between population density and crop output per hectare, which is at least consistent with the Boserup hypothesis. Third, Asia's gradient has shifted in a parallel fashion upwards over 1977–2007. The size of the shift is just under 700 dollars per hectare, which is an approximate doubling of existing output in 1977. Fourth, Africa's gradient has scarcely shifted at all over 1977–2007.

Table 5
First difference estimates of the elasticities of intensification variables with respect to agricultural population density in Africa and Asia. *Sources*: Author's estimates from FAO (2012) data.

Regression no. Dependent variables	R1 Non-land capital per hectare	R2 Cattle/oxen per hectare	R3 Nitrogen per hectare	R4 Cereal output per hectare (yields)	R5 Crop intensity (%)	R6 Non-cereal output per hectare ($)	R7 Total ag. output ($) per hectare
African sample							
Δln density	0.20*	0.38*	0.71	−0.13	0.51*	0.50**	0.46**
	(0.11)	(0.21)	(1.15)	(0.25)	(0.30)	(0.20)	(0.19)
# obs.	94	127	108	127	127	127	127
R-squared	0.05	0.11	0.14	0.01	0.04	0.07	0.06
Asian sample							
Δln density	0.34	0.75***	0.74*	0.53**	0.45***	0.13	0.37*
	(0.21)	(0.27)	(0.41)	(0.23)	(0.16)	(0.31)	(0.21)
# obs.	42	56	51	56	56	56	56
R-squared	0.10	0.23	0.56	0.12	0.29	0.12	0.13

Standard errors are in parentheses. These are robust regressions of the percentage change in the intensification variables against the percentage change in agricultural population density, with period effects, which are omitted for the sake of brevity. Data are structured as 10-year intervals from 1977 to 2007. See Table A1 for definitions of variables.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Together these facts would imply that while Boserupian intensification is important in the long run (as indicated by the positive gradients), short run changes in intensification mostly come about from more exogenous drivers.

In Table 3 we turn to a broader range of intensification indicators and report levels and trends for the small-farm regions discussed in Table 2. The first column reiterates the finding from Table 2 that South Asia has much higher population densities than high-density Africa, but high-density Africa's population density has nearly caught up to East and South-East Asia. In the second column we report trends in the indicator of cereal cropping intensity. We find that cropping intensity in the average high-density African country has increased more rapidly than any other regional grouping over 1977–2007, by about 25%. In 2007 average crop intensity in this group was about 78%, compared to 117% in the two Asian regions. The next column shows that growth in cereal yields has been much lower in both high and low density Africa, growing by a paltry 30% from 1977 to 2007, compared to the approximate doubling of yields in Asia. Total value per hectare grew slightly quicker than cereal yields in Africa, but still far slower than Asia. Consistent with the sluggish growth in output, input growth was also slow with the exception of cattle/oxen per hectare. Most strikingly, there was scarcely any sizeable expansion in irrigated area or nitrogen application per hectare. And in contrast to Asia it appears that the contribution of non-cereal crops to total output actually declined somewhat in high density African countries.

The sluggish development of African agriculture is, of course, a familiar result in the agricultural development literature, although it is less often discussed in the context of Boserup's theory. In Table 4 we therefore explore Boserup's hypothesis more deeply by focusing on trends in cropping intensity, and its contribution to overall intensification, defined as crop output per hectare. Crop output (Y_c) per hectare of arable and permanent cropland (L) is the product of crop intensity (the ratio of area harvested, H, to arable and permanent cropland, L) and "yields", where the latter is defined as the value of crop output (again Y_c) per area harvested:

$$\frac{Y_c}{L} \equiv \frac{H}{L} \cdot \frac{Y_c}{H} \tag{10}$$

This identity allows us to decompose growth in crop output per hectare into growth in cropping area and growth in yields, which we do for selected high density countries in Africa and Asia from the 1970s to the 2000s (Table 4). The main result from Table 4 is that increased cropping intensity appears to have driven about half of the growth in crop output per hectare in high density African countries. The contribution of increased cropping intensity to overall intensification is particularly striking for Ethiopia, Nigeria, and Congo (DRC). In these three most populous countries in Africa increased cropping intensity seems to have been the main driver of growth in output per hectare. In several other high density countries one possible explanation of the lower contribution of cropping intensity may be that initial levels were already high. The data suggest that Malawi and Rwanda had cropping intensities of close to unity even in the 1970s. And of course, for all these countries there is scarcely much contribution of yields to increased output per hectare.

This is a total contrast to the Asian countries in Table 4. In these eight countries increased cropping intensity explains just 10% of the total increase in output per hectare, with growth in yields explaining the other 90%. Moreover, even in those countries where there were reasonably sizeable contributions from cropping intensity, these increases appear to be explained by expansion of irrigation, as well as the development of high yielding varieties that permitted multiple cropping (Bangladesh being a case in point). Even so, in no Asian country did increased cropping intensity contribute more than a mere fraction to growth in total crop output per hectare.[11]

In Fig. 1 we link another worrying dimension to this kind of intensification path, namely the very low levels and low growth rates of chemical fertilizer application. Fig. 1 plots nitrogen application per hectare against cropping intensity for selected African and Asian countries from the 1970s to 2009. In the three Asian countries examined cropping intensity in 2009 is well above 80%, but growth in cropping intensity was accommodated by expanded nitrogen application. In contrast, African countries increased their cropping intensity without applying more nutrients. This is consistent with a literature linking population growth to nutrient mining and loss of organic matter in Africa (Drechsel et al., 2001; Stoorvogel et al., 1993; Tittonell and Giller, 2013; Marenya and Barrett, 2009). This in turn is thought to create a vicious circle, since land degradation could further constrain the returns to

[11] A caveat that warrants reiteration is that the FAO land and production estimates are clearly measured with substantial error. The quality of national statistical systems is particularly weak in Africa, and largely dysfunctional in countries like the DRC. The estimates in Table 4 are therefore quite speculative, and the more so for the African sample.

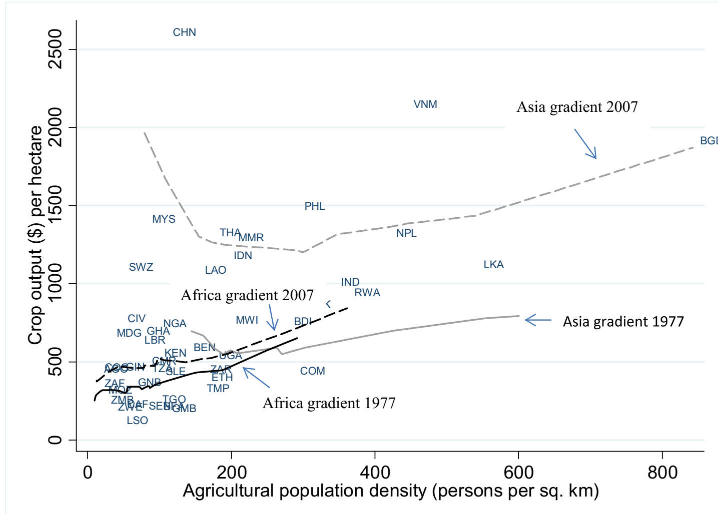

Fig. 1. Crop output ($) per hectare and population density in African and Asian samples, 1977 and 2007*. *Notes*: The fitted curves are based on Lowess regressions. *The scatterplot refers to 2007 observations only. The three letter codes are World Bank country codes. See: <http://wits.worldbank.org/WITS/wits/WITSHELP/Content/Codes/Country_Codes.htm>. *Sources*: Both indicators are derived by the authors from FAO (2012) data. Crop output is measured in 2005 international dollars. Agricultural population density is the number of people primarily dependent on agriculture per square kilometer of agricultural land.

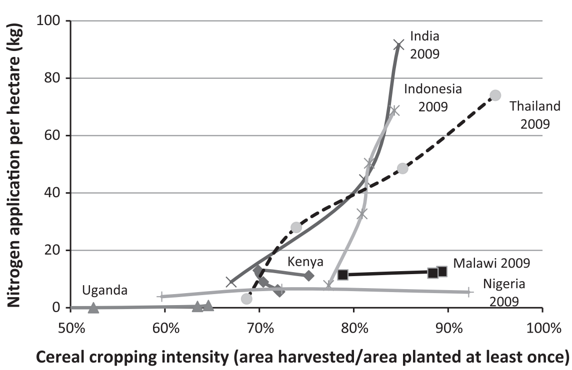

Fig. 2. Cereal cropping intensity and fertilizer application. *Notes*: Cereal cropping intensity is the ratio of area harvested (potentially several times) to the sum of area cropped at least once plus area under temporary fallow. *Source*: Author's estimates from FAOSTAT (2013) data.

fertilizer application and improved seeds, especially in the absence of interventions to improve organic soil matter (Jayne and Rashid, 2013; Marenya and Barrett, 2009).[12]

In Table 5 we present somewhat more formal tests of intensification responses to rising population growth for small-farm countries in Africa and Asia. The results are based on first differenced models in which we regress the first difference of the log of various intensification variables against the log of the first difference of agricultural population density, separately for Asian and African samples.[13] The estimated parameters are therefore scale-free elasticities that allow comparison across the different intensification indicators. The data are structured as five decades for the years 1967, 1977, 1987, 1997 and 2007, though several of the variables are measured for shorter time periods.[14] We also reemphasize the caveats outlined in the previous section regarding causal inference. In addition, the combination of small sample sizes, measurement error and specification errors does not permit us to estimate these elasticities with much precision. So our conclusions from Table 5 must obviously be very cautious, and they clearly need to be backed up by more rigorous and in-depth case studies, such as those presented in this special issue (Headey et al., 2014; Chamberlin et al., 2014; Ricker-Gilbert et al., 2014; Muyanga and Jayne, 2014).

Bearing these caveats in mind, what do these regressions tell us about intensification paths in Africa and Asia? Strikingly, most intensification variables seem significantly responsive to increases in agricultural population density, though the point estimates differ in magnitude across the regressions, and between the African and Asian samples. Non-land capital per hectare is about as responsive in Africa as Asia. In contrast to Table 3, cattle/oxen per hectare looks somewhat more responsive to land pressures in Asia than Africa. But consistent with Table 3, nitrogen per hectare is only significantly responsive to increasing population density in the Asian sample. The point estimate for Africa is similar in magnitude, but the much larger standard error likely reflects the problems that almost all African countries have had in consistently increasing fertilizer use. In Asia cereal yields appear to be highly responsive to increasing population density, but in Africa this is not the case, at least at the national level.[15] In contrast to yields, cereal cropping intensity appears equally responsive in Africa as Asia. In Africa non-cereal crop output per hectare rises significantly with population density, whereas there is much less effect in Asia. However, the data are not disaggregated enough to tell us which types of crops drive this effect in Africa. In much of the high density East African highlands there are indeed strong forms of non-cereal intensification in terms of cash crops like coffee and tea, but also staples like bananas, cassava and enset. Finally, agricultural output per hectare appears to be equally responsive in Africa and Asia, with

[12] Another major explanation of low fertilizer uptake in Africa is its high cost relative to most other regions. In our data set, for example, we found a very close inverse correlation between distance to ports and fertilizer use, consistent with domestic transport costs being an important constraint on demand.

[13] We also ran regressions in a pooled sample that used interaction terms with African dummy variables. As expected given the size of the standard errors, the density elasticities are never significantly different between Asia and Africa, with the exception of cereal yields, for which we find that Africa has lower elasticities at the 10% level.

[14] We do this chiefly because the annual data reported on FAOSTAT is somewhat illusory since most of the variables are not, in fact, measured annually (e.g. population density). And while we use quite a large sample of developing countries, we exclude small countries (less than 400,000 people in 1990), and also hyper-arid countries, unless they have 5% or more of their crop land irrigated.

[15] In some of the case studies in this special issue there is some evidence that yields are much higher in high density areas, although these results are based on cross-sectional variation rather than changes in density over time.

point estimates of 0.46 in Africa and 0.37 in Asia. This suggests that as farm sizes shrink by 1%, farm income per capita shrinks by more than half, implying serious welfare losses unless more densely populated regions can derive more income from nonfarm activities, which is the question we turn to in the next section.

But before turning to that question, let us first summarize some salient differences between Africa's intensification path and Asia's. Our principal conclusion is that high density countries in Africa have largely intensified via traditional technologies: by increasing cropping intensity (and presumably unobservable labor inputs), by using more cattle/oxen, and by increasing production of non-cereals. The last of these claims is somewhat speculative, but we do know that higher density areas rely more on perennial staples like cassava, bananas and enset, in addition to traditional cash crops such as coffee and tea (Headey et al., 2014; Jayne and Muyanga, 2013). However, the low adoption of modern technologies such as fertilizers and seeds is well documented, as are the links between population growth and nutrient mining in Africa. And while there are uncertainties about the extent to which African countries have real economic potential to scale up irrigation (see You et al., 2012, for example), there are at least good grounds to conclude that irrigation will not be the low hanging fruit it was in many Asian countries. Particularly disturbing is that much of the densely populated East African highlands have relatively little potential for large scale irrigation. Lower rates of irrigation in Africa will, in turn, imply lower returns to improved seed and fertilizer packages relative to Asia, and make further increases in cropping intensity much more difficult, and potentially unsustainable over the long run.

A third difference between Asia and Africa that we have only indirectly touched upon is the sheer diversity of agricultural production in Africa. Agroecologically, Africa has diverse soils and climate (Voortman et al., 2000), both across countries, and within the larger countries. Production-wise, cereals account for a smaller share of agricultural production in Africa and there is more diversity within cereals (maize, wheat, rice, sorghum, millet) relative to rice-dominated Asia. In addition to this inherent agricultural diversity, the large number of relatively small countries in Africa, along with chronic underinvestment in agricultural research and development (Pardey et al., 2006) as well as infrastructure (Foster, 2008), has led to the sluggish development and uptake of improved seeds (Evenson and Gollin, 2003a,b). As Mellor argues in this issue, Africa actually needs more R&D and infrastructure investment than Asia precisely because of this diversity, but it has received, and itself invested, far less.

These are obviously quite pessimistic conclusions that temper the optimism around Africa's recent resurgence in agriculture. The institutional and macroeconomic environment has improved across the board in Africa relative to the 1970s and 1980s, but in and only a few cases have these generic improvements been accompanied by increased public investment in agriculture. With high and rapidly rising population densities in much of the continent, African governments clearly need more and better investment to shift their production systems onto more sustainable intensification paths.

Nonfarm diversification

Whilst the work of Boserup and others has demonstrated the importance of agricultural intensification as an important response to population density, that literature devoted very little attention to diversification out of agriculture as an alternative means of adaptation. This omission is potentially an important one: if there are limits to agricultural intensification, then could nonfarm employment and migration provide an escape route for densely populated areas? In this section we look at a mix of fresh and existing evidence on the extent to which land pressures induces three means of diversifying out of agriculture: the rural nonfarm economy, the domestic urban economy, and overseas migration. Unfortunately, both cross-country data and standard household surveys are poorly suited to studying these forms of "migration", particularly because of self-selection issues (de Brauw and Carletto, 2008). Hence, the analysis of this section is quite exploratory.

The rural non-farm economy

During the 1970s and 1980s economists increasingly realized that rural nonfarm income and employment shares in developing countries are large, and in some contexts even exceed agricultural employment and income shares. This cognizance consequently led to quite a large literature on the rural nonfarm economy (RNFE), particularly on the drivers and constraints to RNFE growth. The literature generally cites a number factors underlying RNFE expansion, including agricultural productivity growth triggering demand and supply multipliers (Mellor, 1976; Haggblade et al., 1989), industry-led growth (Foster and Rosenzweig, 2004; Ghani et al., 2012), and expansion in education and infrastructure (roads, electricity). Nevertheless, some of the literature has referred to population density (and a related factor, road density) as a close correlate of rural nonfarm activity, while much of the microeconomic literature on the RNFE has identified farm sizes as a correlate of RNFE activity. As an example of the latter, Pender et al. (2006) argue that the favorable market access and high agricultural potential of densely populated areas in the central Kenya and Ugandan highlands involves a virtuous circle of farm and nonfarm activities supporting each other, whereas other studies find that low road density and poor access to major urban centers is associated with low RNFE shares. Similarly, studies from South Asia have found that population and road density are closely associated with rural nonfarm employment shares (Haggblade et al., 2007; Headey et al., 2011). Household surveys often also show that farm sizes have a U-shaped relationship with RNFE activity, with small farmers or landless people appearing to be pushed into the RNFE, while the largest farmers use the RNFE for positive income diversification (Haggblade et al., 2007). This would imply that shrinking farm sizes and emerging landlessness would result in greatly increased demand for RNFE activities. Nevertheless the general equilibrium welfare implications of this push are unclear: unaccompanied by increased labor demand, the greater supply of RNFE activity would be expected to either reduce wages or create unemployment. Consistent with this, many of the country case studies from this special issue find a significant negative relationship between local population density and village wages.

As we noted above, a major obstacle to identifying these relationships is that measuring RNF employment or income in a consistent way across countries is particularly problematic. In an effort to overcome these issues we use primary employment data from the rural components of the Demographic Health Surveys (DHS), following Headey et al. (2010). Though the data are simplistic in focusing on primary occupations only, the DHS are advantageous in this regard because they are highly homogenous in their use of survey instruments and basic survey design. Descriptive data from this source is presented in Table 5 for men and women in low and high density SSA countries, and in selected non-SSA countries. While the DHS follow a common methodology, we do note some problems with the data. For women, we observe some sensitivity as to whether women (or survey enumerators) classify themselves as working in sales/services (a nonfarm activity) or in agriculture or domestic work (farm activities).[16] For men, an

[16] Specifically, for different DHS rounds in the same country we observed some jumpiness in the data for RNFE employment shares seemingly pertaining to reclassifications between domestic workers and sales workers. It may be the result of women working part time or seasonally in sales work, such as roadside vending.

Table 6
Rural nonfarm employment shares for men and women in the 2000s. *Sources*: All data are calculated from the DHS (2012). n.a. means not available.

High density Africa			Low density Africa			Other LDCs		
Country	Women	Men	Country	Women	Men	Country	Women	Men
Benin	50.4	23.7	Burkina Faso	12.9	8.1	Bangladesh	53.4	44.5
Congo (DRC)	14.0	23.5	Chad	13.7	9.6	Bolivia	71.4	25.9
Ethiopia	34.3	9.7	Cote d'Ivoire	31.7	22.1	Cambodia	36.0	n.a.
Kenya	47.1	37.3	Ghana	50.1	26.6	Egypt	69.4	n.a.
Madagascar	17.8	15.3	Mali	44.6	16.0	Guatemala	79.1	n.a.
Malawi	41.5	36.0	Mozambique	5.2	23.0	Haiti	24.0	19.0
Nigeria	65.5	37.0	Niger	60.2	35.8	India	22.4	n.a.
Rwanda	7.3	14.2	Senegal	63.7	37.1	Indonesia	59.2	39.5
Sierra Leone	25.2	20.1	Tanzania	7.2	10.5	Nepal	90.5	34.2
Uganda	15.5	20.3	Zambia	30.1	19.5	Philippines	16.2	42.6

unemployment category presents some problems for selected countries, particularly Nigeria. And of course, income shares would be preferable to employment shares.

Interestingly, we observe no systematic cross-sectional relationships between RNF employment shares and population density. Less than 10% of women in Rwanda and Burundi and less than 10% of men in Ethiopia primarily work in the RNFE. However, other large and reasonably densely populated African countries like Nigeria, Malawi and Kenya have much larger RNFE shares. Moreover, the correlation between male and female RNFE shares across countries is reasonably low (0.51) and in some countries RNF primary employment is more prevalent for women than men, suggesting we do indeed need to analyze these indicators separately. The pattern of results in Table 5 is consistent with many other survey-based cross-country estimates of RNFE activity, such as data reported in the country case studies, as well as Pender et al. (2006), Haggblade et al. (2007) and FAO (1998).

In Table 6 we test for a density-RNFE relationship more systematically with multivariate regressions. Data constraints again prevent us from using panel techniques, so our approach instead uses a pooled regression of the panel data, with roads, electricity, education and income per capita added as key control variables. We also specify interactions between rural population density and an Africa (SSA) dummy variable. In regressions 1 and 2 we see positive but insignificant coefficients for the non-Africa women's sample in both a parsimonious and a more expansive model, and negative interaction terms for the African women's sample. However, in regression 2 the net effect of population density on RNFE shares for women is not significantly different from zero. In regressions 3 and 4 there are no significant density effects for the men's sample in either the African or non-African samples. Hence, in these admittedly small samples, population density does not appear to have independent effects on RNFE shares.

In contrast, the control variables in the model do lend substantial support to the existing literature on the drivers of rural nonfarm growth. Depending on the gender sample and on whether or not agricultural output per worker is included (this variable is highly correlated with the other control variables), we see some significant, positive and reasonably large elasticities for education, road density, electricity, and agricultural output per worker. It would therefore appear that there is no endogenous process by which rising land constraints automatically generate rural nonfarm employment. Instead, it appears that there are specific drivers of RNFE activity, such as infrastructure, human capital or growth linkages from other sectors.

Migration to urban centers

Does urbanization offer a viable exit out of land-constrained African agricultural sectors? There is considerable debate about the potential for rural–urban migration to alleviate poverty reduction, but it is a debate poorly informed by rigorous evidence. Rural–urban welfare comparisons consistently show that urban areas are better off than rural areas in terms of poverty levels, malnutrition, and access to education and health services (Headey et al., 2010; Ravallion et al., 2007). Rare dynamic studies on migration in Africa also show that migration appears to be welfare-enhancing (Beegle et al., 2008; de Brauw et al., 2013). Studies from various continents also suggest that there may be systematic under-investment in migration (and rural education) because of both market failures (information asymmetries, risk aversion) and government policies that implicitly or explicitly inhibit migration (Bryan et al., 2012; Jensen and Miller, 2011; de Brauw et al., 2013).

However, these conclusions come with important caveats. First, there is substantial evidence that Africa's rapid urbanization is overstated by UN statistics (Potts, 2012), and that urban poverty reduction in Africa has been slower than elsewhere (Headey et al., 2010; Ravallion et al., 2007). Second, the empirical literature on migration and subsequent income growth in Africa seems confined to two studies (Beegle et al., 2008; de Brauw et al., 2013), neither of which can satisfactorily account for self-selection biases. Third, whether migration can be successfully scaled up depends on macroeconomic and general equilibrium factors. Africa's performance in manufacturing has been very poor, and manufacturing accounts for a paltry share of national employment. Instead, much of the employment in urban areas is in low skill-low return services sectors, leading to what Gollin et al. (2013) term "consumption cities" as opposed to "production cities".

Perhaps as a reflection of the more pessimistic general equilibrium constraints to job creation outside of agriculture, we also observe no empirical link between rural population density and urbanization in Africa. Nigeria and Kenya have densely populated rural areas and large urban population shares on the order of 50%, but Ethiopia, Uganda, Malawi and Rwanda remain highly rural, with urban population shares of 25% or less.[17] Although more urbanization in Africa is likely to be desirable (and that constraints to migration should be removed), it will be difficult to generate remunerative urban employment without a more successful industrialization process (Headey et al., 2010). Sluggish urban industrialization to date may be among the leading factors explaining the observed weak relationship between rural population density and non-farm income in Africa.

International migration

If domestic industrial or services growth is failing to create sufficient nonfarm employment, then overseas labor markets offer a

[17] We also tried to test these patterns somewhat more rigorously by regressing 10-year changes in urban population shares against initial population density and initial urbanization levels. In non-African samples higher initial densities seem to drive urban growth, but in Africa there is no systematic effect.

Table 7
Estimating elasticities between rural nonfarm employment indicators and rural population density for women and men. *Sources*: All variables worker are calculated from the DHS (2012), except rural population density and agricultural output per worker, which are calculated from the FAO (2012). See Table A1 for definitions of variables.

Regression no. Sample	R1 Women	R2 Women	R3 Women	R4 Men	R5 Men	R6 Men
Population density	0.47	0.09	0.15	−0.33	−0.32	−0.31
	(0.31)	(0.37)	(0.32)	(0.41)	(0.50)	(0.52)
Density * Africa	−0.19**	−0.22**	−0.15*	0.03	−0.02	−0.02
	(0.09)	(0.10)	(0.08)	(0.12)	(0.12)	(0.12)
Africa dummy	−0.25	0.10	0.04	−0.43	0.09	0.09
	(0.2)	(0.23)	(0.20)	(0.30)	(0.32)	(0.33)
Secondary educ. by gender		0.03	0.11		0.35***	0.35***
		(0.08)	(0.07)		(0.12)	(0.12)
Road density		0.14*	0.15**		0.17*	0.17*
		(0.07)	(0.06)		(0.09)	(0.10)
Electricity		0.20**	−0.07		0.09	0.09
		(0.08)	(0.09)		(0.08)	0.11)
Ag. output per worker, log			0.46***			0.01
			(0.12)			(0.16)
Number of observations	162	122	95	74	74	74
R-square	0.2	0.53	0.24	0.55	0.55	0.55

Standard errors are in parentheses. These are robust regressions with regional fixed effects, which are not reported for the sake of brevity.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

potentially important means of diversifying out of farm. Moreover, World Bank (2012) data show that remittances to developing countries grew by around 1600% from 1990 to 2010, and now constitute a much larger source of inward financial flows than foreign aid. But while remittances have been growing in some African countries, they generally remain much lower than in other regions. Senegal and Togo have remittance shares as high as the Philippines and Bangladesh (10% of GDP), and Kenya and Nigeria also have relatively large and fast-growing remittance earnings (5–6% of GDP), as does Uganda (4% of GDP). But in all other high-density African countries formal remittances remain below 2% of GDP (e.g. Ethiopia, Malawi and Rwanda). Admittedly, informal remittances constitute a significant caveat for these statistics, especially where there is taxation of remittances, underdeveloped financial services, or mistrust of governments.

In Table 7, however, we test for relationships between remittances and population density more systematically. We use regressions in both levels (log–log) and first differences, and in regressions 1 and 2 we use agricultural population density, whilst regressions 3 and 4 use rural population density (since in this case, the choice makes some difference). Apart from a full set of regional and time period dummies, the only control variable that we include is total population, since smaller countries are known to have higher remittance ratios.[18]

In all the regressions the elasticity of remittances with respect to population density in the non-Africa sample is highly significant, but the differenced regressions (which remove fixed effects) invariably show much larger elasticities than the levels regressions (as well as larger standard errors). In the levels regressions the elasticities vary between 0.25 and 0.31, while the elasticities derived from first differences are 0.97 for agricultural density and 1.17 for rural density (note the larger standard errors in both cases, however). Irrespective of magnitudes, the significance of these coefficients is encouraging for viewing access to international remittance earnings as an important response to rising land pressures, but the regressions in first differences suggest that the remittance-density elasticity in Africa is much lower than the rest of the sample. Moreover, remittances in African countries are much lower than other regions. In the regressions in levels, for example, we observe negative coefficients on all the African regional dummy variables, except Southern Africa, where remittances from South Africa are important. Thus, as with the results for rural nonfarm income and urbanization, there are some signs that African populations have not yet been able to exploit overseas labor market opportunities as well as Asian countries have.

Reducing rural fertility rates

Along with fixed agricultural technologies, the inexorable growth of rural populations in underdeveloped settings was a key assumption of Malthus' original model. Whilst Malthus himself subsequently retracted this assumption, very little research has explicitly advanced the idea that households might voluntarily reduce fertility rates in response to rising land pressures (Bilsborrow (1987) is an exception, as is Clay and Reardon's (1998) study of Rwanda).

Even so, the economic analysis of fertility decisions (Becker and Lewis, 1973; De Tray, 1973; McCabe and Rosenzweig, 1976; Rosenzweig, 1977) provides strong expectations that fertility reductions may be quite an important means of adapting to such pressures. These theories advanced the notion that fertility outcomes are largely a function of choice; namely rational appraisals of the costs and benefits of additional children. Benefits include consumption utility, the value of child labor, and informal old age insurance that grown-up children can provide in the absence of formal welfare systems. Amongst the costs, the majority of theoretical emphasis focuses on the opportunity costs of child-bearing and rearing that women incur, such as forgone education and wage incomes. A more demographic literature has largely accepted these tenets, but also argues that supply side failures nevertheless create gaps between desired and achieved fertility rates. Such failures include lack of contraceptive knowledge and access, and female empowerment (Kohler, 2012).

Given this general theoretic framework, the next question is how rising land pressures might influence the cost-benefit analysis of the demand for children, as well as the supply of family planning services. There are three important mechanisms that one would expect to link these processes. The first pertains to the child labor requirements of agricultural intensification. At one extreme, extensive pastoralist and agro-pastoralist systems have high demands for child labor and are therefore typically associated with very high desired fertility rates (Binswanger and McIntire, 1987; Randall,

[18] Note that although we tested other controls (such as infrastructure, passport costs and travel restrictions), but these were insignificant once the population variables were included.

2008). At the other extreme the most intensive agricultural systems involve small farms and a relatively high degree of mechanization, in which child labor plays a minimal role. More ambiguous is the transition between these two extremes, since at early stages of intensification labor requirements are typically quite high, especially during peak seasons (Pingali et al., 1987). Moreover, labor market failures make family labor relatively productive in comparison to hired labor (Binswanger and Rosenzweig, 1986). Thus one might expect a non-linear relationship between agricultural intensification and fertility rates, with fertility rates only reducing substantially after farm sizes fall below a certain limit, or once labor-saving technologies are profitably adopted.

A second expectation is that female labor requirements change as population density increases. As we argue below, when farm sizes fall below a certain threshold it becomes profitable for households to allocate a portion of household labor to nonfarm activities. Whilst female participation in the wage labor force may vary for other reasons, rural nonfarm employment among women in developing countries is surprisingly high, and often linked with lower fertility rates (Schultz, 1997). The emergence of labor markets also tends to reduce fertility rates.

Finally, insofar as one would expect increased population density to be associated with greater access to fertility-reducing health, family planning and education services, then these supply-side factors may reduce both desired and achieved fertility rates. Female education is particularly strongly linked to fertility outcomes (Schultz, 1997), though family planning policies have also shown some efficacy (Kohler, 2012), but less so in Africa.

These considerations lead us to test whether various achieved and desired rural fertility rates respond to land pressures, and whether the size of the response is comparable to other well-known drivers of fertility rates, such as female education and household income. Our hypotheses are tested in a model in which rural fertility rates are a function of population density, female education, female nonfarm employment and rural incomes.[19]

In Fig. 3, however, we first plot rural fertility rates from the Demographic Health Surveys (DHS, 2012) against rural population density. The graph shows, at best, a very modest negative gradient, but a large intercept difference between the African and non-African predictions, with the former lying some two children above the non-African sample. The relationships are also heteroskedastic, suggesting that many other factors play a role in determining rural fertility rates.

In Fig. 4 we instead look at desired fertility rates, an indicator based on questions about optimal number of children, asked of women aged 20–34. Here the results are strikingly different, at least for the African sample. For while the relationship remains heteroskedastic, at the lowest levels of population density in Africa the predicted number of desired children is 6, but this drops substantially to just 4 children countries like Rwanda and Burundi. The difference between actual and desired fertility rates (Figs. 3 and 4) is defined in the demographic literature as "unmet contraception needs" for women, which we report in Fig. 5 for an African sub-sample. The slope is strikingly positive and steep.

These results suggest that higher rural population density may indeed reduce *desired* fertility rates, but that inadequate access to family planning services have thus far inhibited the achievement of those fertility reductions. In Table 9 we explore these issues in a multivariate setting by estimating log–log regressions both realized and desired fertility rates as the two dependent variables of interest. The regressions use regional fixed effects and a robust regressor to minimize the influence of outliers in what is

[19] Since population density may partly determine some of these control variables, we will also test more parsimonious models.

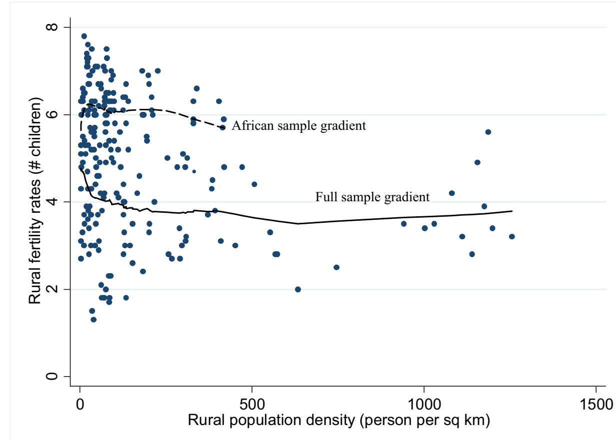

Fig. 3. Rural fertility rates and rural population density. *Notes*: The fitted curves are based on Lowess regressions. See Table A1 for definitions. *Sources*: Rural fertility rates are from the DHS (2012) and rural population density is from the FAO (2012).

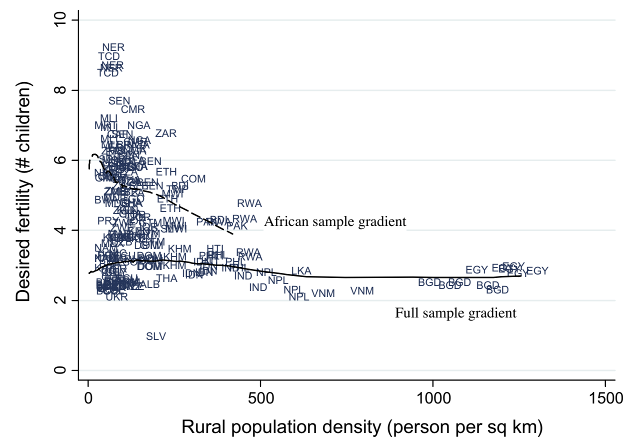

Fig. 4. Desired rural fertility rates and rural population density. *Notes*: The fitted curves are based on Lowess regressions. See Table A1 for definitions. *Sources*: Desired rural fertility rates are from the DHS (2012), and pertain to women aged 20–34. Rural population density is from the FAO (2012).

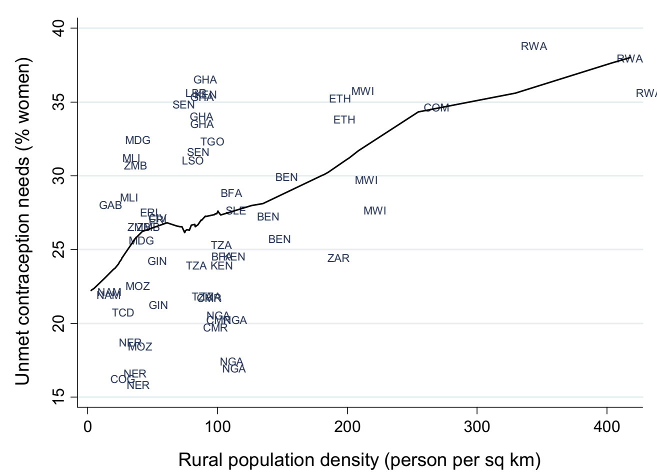

Fig. 5. Unmet contraception needs (% women) and rural population density in Africa. *Notes*: The fitted curves are based on Lowess regressions. *Sources*: Unmet contraception needs is sourced from the DHS (2012), and pertain to women aged 20–24. Rural population density is from the FAO (2012). Unmet contraception needs refers to who are fecund and sexually active but are not using any method of contraception, and report not wanting any more children or wanting to delay the birth of their next child.

Table 8
Elasticities between national remittance earnings (% GDP) and population density. *Sources*: Remittance data are from the World Bank (2012), while population density data are calculated from the FAO (2012). See Table A1 for definitions of variables.

Regression no.	1	2	3	4
Estimator	OLS	Robust	OLS	Robust
Structure	Levels (logs)	First difference	Levels (logs)	First difference
Density variable	Agricultural	Agricultural	Rural	Rural
Population density	0.25***	0.97**	0.31***	1.17***
	(0.07)	(0.47)	(0.07)	(0.43)
Population density * Africa	0.05	−0.94	0.04	−1.22**
	(0.08)	(0.71)	(0.08)	(0.57)
Total population	−0.24***	−1.31**	−0.23***	−0.82
	(0.04)	(0.6)	(0.04)	(0.51)
Lagged remittances		−0.21***		−0.24***
		(0.05)		(0.05)
Lagged population density		0.06		0.06
		(0.04)		(0.04)
West Africa dummy	−0.67*		−0.49	
	(0.36)		(0.36)	
Central Africa dummy	−1.55***		−1.40***	
	(0.4)		(0.4)	
East Africa dummy	−0.90**		−0.74*	
	(0.39)		(0.39)	
Southern Africa dummy	0.14		0.24	
	(0.35)		(0.36)	
1977–87 dummy	0.15		0.12	
	(0.17)		(0.17	
1987–97 dummy	0.33*	−0.09	0.28*	−0.06
	(0.17)	(0.12)	(0.16)	(0.12)
1997–2007 dummy	0.79***	0.19	0.72***	0.24*
	(0.16)	(0.13)	(0.16)	(0.13)
Number of observations	231	147	231	159
R-square	0.39	147	0.4	0.22

Standard errors are in parentheses. Note that the levels regressions include regional effects for all regions, but for the sake of brevity only African coefficients are reported.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Table 9
Estimating elasticities between rural fertility indicators and rural population density. *Sources*: Actual and desired rural fertility rates and female education are from the DHS (2012), and pertain to women aged 20–34. Rural population density is from the FAO (2012). See Table A1 for definitions.

Regression number	1	2	3	4
Dependent variable	Actual fertility	Actual fertility	Desired fertility	Desired fertility
Model	Linear	Log–log	Linear	Log–log
	b/se	b/se	b/se	b/se
Population density (per 100 m^2)	−0.14***	−0.09***	−0.11***	0.00
	(0.04)	(0.02)	(0.03)	(0.02)
Density * Africa	0.05	0.09***	−0.34***	−0.07***
	(0.10)	(0.03)	(0.10)	(0.02)
Female secondary education (%)	−0.02***	−0.05***	−0.01**	−0.08***
	(0.01)	(0.02)	(0.01)	(0.01)
Ag. output per worker, log	−0.58***	−0.13***	0.01	0.06***
	(0.13)	(0.03)	(0.12)	(0.02)
Africa dummy	1.25***	−0.15	2.13***	0.67***
	(0.3)	(0.15)	(0.29)	(0.12)
South Asia dummy	−0.32	−0.05	−0.43	−0.12**
	(0.34)	(0.08)	(0.33)	(0.06)
MENA dummy	1.15***	0.25***	−0.06	−0.05
	(0.41)	(0.09)	(0.40)	(0.07)
E. Europe, C. Asia	−0.24	−0.40***	−0.71*	−0.17**
	(0.42)	(0.10)	(0.41)	(0.07)
L. America, Caribbean	0.72**	0.11	−0.59**	−0.12**
	(0.31)	(0.08)	(0.30)	(0.06)
Muslim dummy	0.55***	0.07	0.84***	0.12***
	(0.20)	(0.05)	(0.20)	(0.04)
Number of observations	165	165	164	164
R-square	0.75	0.76	0.77	0.81

Standard errors are in parentheses. These are robust regressions.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

a relatively small sample,[20] but as above we always introduce interaction terms with an African dummy to test if adaptation processes are somehow different. We also estimate both linear models and log–log models.

In regressions 1 and 2 in Table 9 we regress actual fertility rates against our control variables. Although Fig. 2 did not give much suggestion of a significant negative gradient, the addition of control variables suggests that, in the non-African sample at least, higher population density is significantly associated with lower fertility rates. The marginal effect is fairly small, however. An increase of 100 people per square km is predicted to introduce a fertility reduction of 0.14 children (or in percentage terms, the elasticity is just −0.09). Moreover, population density seems unassociated with actual fertility rates in the African sample, consistent with Fig. 2.

In regressions 3 and 4 however, we see that higher population densities in Africa are quite strongly associated with lower desired fertility rates, and the marginal effect is quite large (consistent with Figs. 3 and 4). A 100 person increase in population density predicts a 0.45 child reduction in desired fertility in Africa. In percentage terms (regression 4) the elasticity appears fairly modest (−0.07). However, not only is the density elasticity highly significant, the results in Table 8 also suggest it is commensurate in size to other well-known determinants of fertility such as female education and income.[21]

These findings potentially strong policy implications inasmuch as they indicatively suggests that governments in high density African countries should consider focusing more resources on family planning, given the greater unmet demand for these services (by women at least) in land-constrained settings. The impact of family planning interventions in developing countries has been much disputed (see Kohler, 2012 for a review), though the economic benefits of reducing fertility rates are well established (Bloom et al., 2007; Bloom and Williamson, 1998). One source of pessimism with respect to family planning interventions is that they are likely to be ineffective when there is no latent demand for contraception. In the case of high density countries in Africa, however, our results suggest that there is indeed substantial demand for family planning services, at least among the female population.

Conclusions

This paper has explored the means and magnitudes by which rural populations, and their governments, adapt to rising land pressures, with a particular focus on whether Africa's adaptations to land pressures systematically differ from those of other developing regions, especially Asia. Whilst very much building on an existing literature, our approach has departed from that literature in two ways. First, our theoretical framework went beyond Boserupian intensification of agriculture to focus on fertility changes and "migration" into nonfarm sectors as two other potentially important means of responding to land constraints. Second, rather than using household or village survey data, we focused on cross-country evidence. While this ambitious approach comes with a number of caveats related to aggregation issues, measurement error, misspecification problems, and endogeneity biases, some reasonably firm conclusions can be drawn from our results (though many undoubtedly warrant more research). In this concluding section we briefly summarize these conclusions, and draw out some key policy implications of our findings.[22]

First, consistent with Boserup and others, we do find evidence that agricultural intensification is an important means of adapting to shrinking farm sizes, but that intensification can follow very different paths. For both Asia and Africa it is clear that higher density countries have more intensive agricultural systems irrespective of which period is examined. Yet over the period 1977–2007 we find very different intensification paths in these two regions. In Asia, yields grew rapidly, partly as a result of Green Revolution investments, but also in response to rising land constraints (Table 5). In Africa, we observe no response of yields to land constraints over the short run, nor any growth of modern inputs such as fertilizers or irrigation. Instead, we observe increased cropping intensity driving around half of the growth in total crop output per hectare. This would appear to be an unsustainable intensification path given the implied mining of nutrients, and the more limited prospects for low cost irrigation investments, at least in many high density African countries.

Second, while nonfarm employment is a potentially very important avenue for adapting to land constraints, its relationship with rural population density to date appears to be very weak. Our analysis of this issue was necessarily very exploratory given immense data constraints on each of the three forms of diversification we analyzed. Nevertheless, a quite consistent picture emerges from this qualified exploration of the available data: rural Africa is not doing well at diversifying out of agriculture, particularly those densely populated rural areas that are in greatest need of nonfarm diversification. Relative to their low density peers, high density African countries are no more likely to have high rural nonfarm employment shares, no more likely to experience faster urbanization, and no more likely to have larger remittance earnings.[23] Third, we found strong evidence that population density is strongly and negatively correlated with desired fertility rates (particularly in Africa), but not with achieved fertility outcomes. Though this result is, to the best of our knowledge, quite novel, it is nevertheless consistent both with economic theories of purposive fertility decisions, and with demographic theories that emphasize the importance of proactive family planning policies. From a policy perspective, the unmet demand for contraception in more densely populated areas suggests there is underinvestment in family planning in these countries. Whether this is really the case depends on the costs and benefits of family planning. With regard to benefits, lower fertility rates would gradually alleviate land pressures, but reduced fertility rates have also been linked to reductions in poverty and substantial improvements in maternal and child health and nutrition, and faster economic growth (Cleland et al., 2012; Eastwood and Lipton, 2004; Bloom and Williamson, 1998). On a more positive front, several high-density African countries have indeed scaled up family planning efforts in recent years – seemingly to some effect (Pörtner et al., 2012) – and several African leaders seem to have started prioritizing family planning in their development agendas (as well as related investments, such as female education).[24]

Finally, one implication of our findings is the need for some serious reappraisal of land issues in Africa. Standard agricultural

[20] This small sample and more limited time span of the DHS (most of which were conducted in the last 15 years or so) imply that estimating country fixed effects models may be unwise given that population density and other control variables will have changed very little over this period. When we did run fixed effects, the results were qualitatively similar (same signs), but the coefficients were implausibly large.

[21] These results are also highly robust to measuring desired fertility rates for different age groups and to different specifications.

[22] Further discussion of the policy implications of this paper and the other papers in the special issue can be found in the concluding article of the issue, by Jayne et al. (2014).

[23] Explaining these outcomes is well beyond the scope of this current paper, but we have at least made note of the usual suspects (lack of education and infrastructure, and the poor performance of the industrial sector).

[24] Indeed, the Prime Ministers of Rwanda and Ethiopia recently published an editorial in a special issue of *The Lancet* in which they place family planning initiatives as an important priority for their governments (Habumuremyi and Zenawi, 2012). On the other hand, President Museveni of Uganda called the country's population growth – which is the fastest in the world – "a great resource", and argues that development itself will suffice to reduce population growth, rather than vice versa.

Table A1
Definitions of key variables used in this study. *Sources*: Unmet contraception needs is sourced from the DHS (2012), and pertain to women aged 20–24. Rural population density is from the FAO (2012). Unmet contraception needs refers to who are fecund and sexually active but are not using any method of contraception, and report not wanting any more children or wanting to delay the birth of their next child.

Short variable name (sources)	Definition
FAO variables	
Agricultural population density	Population estimated to be primarily dependent upon agriculture divided by agricultural land, which is the sum of arable crops, permanent crops and permanent pastures
Rural population density	The population estimated to be rural divided by agricultural land
Rural population per hectare of suitable crop land (FAO, IIASA)	This is the rural population relative to the area estimated to possess some suitability for agricultural production
Agricultural output	Value of total agricultural production in 2005 international dollars, net of fee and seed inputs, divided by crop land
Crop output	Value of total crop production in 2005 international dollars, net of feed and seed inputs, divided by crop land
Cereal yields	Volume of cereal production in rice milled equivalent divided by total cereal area
Crop intensity	Area harvested to in a year (including multiple harvests) divided by temporary crop area harvested at least once in the last 5 years. Table 4 uses only cereal area in the numerator; Table 5 uses all crop area in the numerator
Non-cereal output	Value of non-cereal output (net of seeds) per hectare of crop land, in 2005 international dollars
Non-food output (%)	Value of non-food products as a percentage of total agricultural output (used to examine non-food cash crops)
Non-land capital	As above, but excluding land capital (which includes irrigation)
Cattle/oxen per hectare	Number of head of cattle, oxen and buffalo relative to total crop land. This is a proxy for animal traction & dairy
Nitrogen per ha	Nitrogen (kg of *N* nutrients) per hectare
Irrigation (%)	Percentage of crop land irrigated
Agric. output per worker	Value of total agricultural production in 2005 international dollars per agricultural worker
DHS variables	
Fertility rate (DHS)	This is the total fertility rate, or the average number of children born to a women over her lifespan
Desired fertility rate (DHS)	This is the number of children a woman aged 20–24 would ideally like to have over lifespan
Rural nonfarm employment share (DHS), men and women	This is the percent of men or women reporting nonfarm occupations as their primary form of employment. "Farm employment" includes domestic work, and the unemployed are excluded from the numerator and the denominator
Secondary education, by gender	The percentage of adult men and women have attended secondary school
Electricity (%)	Percentage of households reporting access to electricity
World Bank	
Remittances as% of GDP (WB)	Net remittances received as a% of GDP

Notes: Data sources are FAO (2012), FAO-IIASA (2009), DHS (2012), and World Bank (2012).

development strategies in Africa are heavily focused on other inputs (seeds, fertilizers, water), with very little emphasis on land issues outside of the literature on land governance (see Holden and Otsuka, and Deininger, both in this issue). Yet even setting aside possibilities for land expansion or redistribution, appropriate *rural* development strategies very much depend on what smallholders can achieve, *given* land and other resource constraints. In situations in which land constraints are binding, achieving much higher returns to household labor may require a coordinated agricultural intensification strategy and industrialization policy that induces rural–urban migration into productive non-farm sectors. This raises many questions. To what extent can yields and cropping intensity be increased on very small and mostly rainfed farms? Should policies instead focus more effort on high value crops and the value chains that support them? Or are their simply higher returns to getting young Africans out of agriculture, through education and other nonfarm investments?

These are issues that ought to be central to the appropriate design of development strategies and policy experiments in land constrained African countries. Yet if anything Africa's apparent land abundance at a continental scale appears to have fomented a neglect of the seriousness of land constraints in high density Africa, and the important consequences of these constraints for this region's development. Indeed, it is striking that in land-scarce South Asia the research and policy narratives are heavily focused on landlessness as a key dimension of poverty, while these terms are all but absent from most policy discussions in African countries, even in regions where many farms are inadequately small and landlessness already exists, is growing rapidly, or is likely to do so in the near future.

Appendix

See Table A1.

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