A World without Farmer?

Food Production, Inclusive Development and Ecology:

Historical Evidences for a New Deal (1961-2007)

Bruno DORIN[1*], Jean-Charles HOURCADE[2], Michel BENOIT-CATTIN[3]

Conference of the International Society for Ecological Economics

Rio de Janeiro, 16-19 June 2012

[1] CIRAD, UMR Cired, TA C56/15, 73 rue J.F. Breton, F-34398 Montpellier, France

[*] Corresponding author. Tel: +33 4 67 61 75 82; Fax: +33 4 67 61 44 15

E-mail address: bruno.dorin@cirad.fr

URL: http//www.cirad.fr

[2] CIRED-CNRS, 45 bis avenue de la Belle Gabrielle, F-94736 Nogent sur Marne, France

[3] CIRAD, UMR MOISA, TA C56/15, 73 rue J.F. Breton, Montpellier, Montpellier, F-34398, France

Abstract

This paper questions the perspective of a “world without agriculture” which underpins the economic paradigm of “structural transformation” and “modern growth”. It does so by recomposing worldwide land and labour productivity trends in caloric terms from 1961 to 2007 and by providing an heuristic model showing that the “Lewis Path” to prosperity is only one out of four possible pathways. It shows that more than half of the world population is rather embarked in a “Lewis Trap” where farmers are increasingly numerous and relatively poorer. It highlights how land scarcity and insufficient job opportunities outside agriculture prevent them to increase their labour productivity and incomes with motorized machineries. The emerging paradigm of “ecological intensification” might contribute to overcome the current deadlocks by redirecting worldwide R&D towards small-scale knowledge-intensive and context-specific agricultures overlapping the manufacture and service sectors.

Keywords

Agriculture, Productivity, Development, Structural transformation, Poverty, Ecology

1. Introduction

The 2007-08 sharp increases in food prices led many agricultural economists to link the lack of interest in agriculture from both the academic and donor communities since the mid-1980s (Janvry, 2010) with the high concentration of poverty and under-nutrition in rural areas of Africa and Asia (Chen and Ravallion, 2007; FAO, 2009). They recommended to increase agricultural research and development (R&D) spending “to restore productivity growth” (Alston *et al.*, 2009) “so that agriculture can play its role as an engine of growth and poverty reduction and act as the longer-term pillar of the twin-track approach to fighting hunger” (FAO, 2009).

This role of agriculture as an engine of growth is a long standing question since the early stage of industrialization in almost all the traditions of economic thoughts, from the Physiocrats (Quesnay) to the Classical school (Ricardo). After the Second World War, it was a key dimension of the “structural transformation” paradigm (Chenery and Srinivasan, 1988), anchored in both historical experiences of “modern economic growth” (Kuznets, 1966) and dual-economy theories describing the interrelated structural changes between the “traditional” (agriculture) and “modern” (non-agriculture) sectors (Lewis, 1954). In these models, agriculture provides low-cost food, labour and savings to the process of urbanization and industrialization which, in turn, raises labour productivity in the rural economy, pulls up wages and gradually eliminates the worst dimensions of absolute poverty. Both cause and effect of economic growth, this “Lewis Path” should lead to a “world without agriculture” (Timmer, 1988, 2009): labour moves to the “modern sector” which facilitates development, economies grow, and the share of agriculture in total labour and in growth domestic product

(GDP) both decline to a level of 2-3% when converge productivity and incomes across sectors (Larson and Mundlak, 1997).

After the failure of the Maoist experience, this industrialist growth pattern was not really challenged until the Club of Rome in 1972 and the “ecological critique” (MEA, 2005 and others). The later underlines the limited carrying capacity of our planet and how the modernization of agriculture since the 1960’s (Green Revolution and so on) has disturbed many ecological services (nutrient cycling, soil formation, water purification, biodiversity…) because of its overuse of freshwater, fossil energy and other industrial inputs. It calls for actions to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. But it does not really address the question of how the present billion of very poor farmers concentrated in Asia and Africa can board the train without having to jump abruptly with their family members into urban slums.

This paper questions the future direction of technical change in the light of past agricultural developments. A novel consolidation of existing data first shows that world food productivity routes were contrasted since the 1960’s, some of them being in sharp contrast with the “Lewis Path”. We then show why a large part of the world can hardly follow this “Lewis Path” to prosperity and may fall permanently in a “Lewis Trap” if the direction of technical change continues to favour a “world without agriculture”. Finally, we sketch a R&D agenda which aims to avoid such rural poverty trap while reconciling some important FAO and MEA’s recommendations.

2. Caloric metric and taxonomy of agricultural patterns

After pioneering works such as those of Schultz (1953), Solow (1957) or Farell (1957) on productivity and its measurement, comparative research on the rate and direction of productivity growth in agriculture has gone through three stages according to Ruttan (2002).

(1) The measurement of partial productivity ratios such as output per worker and per hectare helped to identify wide differences among countries or world regions.

(2) With cross-country production functions and multifactor productivity estimates, Hayami and Ruttan showed that resource endowments (land and livestock), modern technical inputs (machinery and fertilizer) and human capital (including technical education) each accounted for around one-fourth of the differences in labour productivity between developed and less-developed countries. Since the economies of scale represented only 15 percent of the differences, they concluded that population pressure on land resources could be circumvented and the labour productivity increased by several multiples (up to the levels of Western Europe in the early 1960s) by investing in agricultural research, human capital and modern agricultural inputs.

(3) Studies testing the convergence of growth rates and levels of multifactor productivity mostly employ the Malmquist or frontier productivity approach. They generally indicate a widening productivity gap between developed and developing countries from the early 1960s to the early 1990s, and declining total factor productivity in developing countries (relative to the frontier countries) with less technical change against efficiency change.

In this paper, we come back to the early stage of this research line, building upon new estimates of production for representing land and labour productivities. We aggregate in kilocalories (kcal) all plant food harvested during a year (one crop or more), in almost all countries of the world and during a 47-year period (1961-2007). These new partial productivity estimates enlarge some published by Hayami et Ruttan (1985), Malassis et Padilla (1986) or Bairoch (1999). They cover a time period characterized by unprecedented productivity changes in agriculture.

Our graphical technique to summarize global trends in land and labour productivities differ from the one adopted by Hayami, Ruttan or Craig et al. (1997), but retain the same five dimensions: acreage of land per agricultural worker (here, x-axis), partial land productivity (y-axis), partial labour productivity (iso-curves), time (1961-2007) and space (countries or regions). Figure 1 shows two orthogonal directions between which labour productivity can be increased in agriculture: higher production per piece of land (with irrigation, fertilizers, etc.) and higher cultivated land per worker (with tractors, combine harvesters, etc.). These directions are subsequently called “intensification” and “motorization”.

The representation above is based on a simple identity that we label “TALA” for “Technology, Affluence and Labour productivity in Agriculture”, where Q denotes the production of plant food (kcal), A the acreage of cultivated land (ha) and L_a the workforce in agriculture (heads):

$$Q/A \bullet A/L_a = Q/L_a \qquad \text{(1) TALA}$$

In TALA, the increase in labour productivity (Q/L_a, in kcal/worker) is the product of the increase in “intensification” (higher Q/A, in kcal/ha) by the increase in “motorization” (higher A/L_a, in ha/worker).

If we insert the two left-side components of the TALA equation into a broader OTAWA identity (“Outcome, Technology, Affluence and Workforce in Agriculture”), we show how they co-evolve with the share of agricultural labour into total population (L_a/N) to contribute to the total per capita production (Q/N):

$$Q/N = Q/A \bullet A/L_a \bullet L_a/N \qquad (2)\ \text{OTAWA}$$

This identity describes the ex-post result of the interaction between parameters but is not a causal relationship treating the right-side parameters as independent variables. Utilized by Malassis and Padilla (1986), it allows for characterizing generic patterns of agricultural production in relation to socioeconomic conditions[1]. More specifically, it helps checking whether changes in agricultural per capita production and yields follow an “intensification” pathway all over the world, or whether there are significant differences in the two other terms. These terms are critical for characterizing the “growth engine” at play. They relate the affluence of land per worker and the “motorization” of agriculture to a central dynamic of the “Lewis Path” of “structural transformation”, i.e. the “discharging” (Sauvy, 1980) of labour from agriculture (L_a) to other sectors and the convergence of productivity and incomes across sectors.

To further explore this dynamic between sectors, it is necessary to come back to the conventional metric of labour productivity, namely the value-added in monetary terms (Y). The data are fully available from 1970 in constant 1990-US$ for the agricultural and non-agricultural sectors ($Y=Y_a+Y_{na}$). They are used to calculate the two following indicators:

---

[1] OTAWA identity is similar to the “IPAT identity” used in the environmental literature (Ehrlich and Holdren, 1972; Waggoner and Ausubel, 2002), where I (environmental impacts) = N (population size) • A (level of affluence) • T (level of technology), and the “Kaya identity” in the energy literature (from the name of the Japanese engineer Yoichi Kaya).

(i) the difference between the share of agriculture in total incomes and the share of farmers in total labour; because C.P. Timmer amply uses this difference, we name it by analogy the "Timer gap" (*TG*):

$$(Y_a/Y) - (L_a/L) \qquad \text{(3) Timer Gap } (TG)$$

(ii) the ratio of the above two shares that we name the "Timer ratio" (*TR*):

$$(Y_a/Y) \,/\, (L_a/L) \qquad \text{(4) Timer Ratio } (TR)$$

With "modern growth", *TG* is initially negative (the average income per worker in agriculture is below the national average) and is expected to narrow towards 0 with higher per-capita incomes, while *TR* is initially low (near 0) and increases towards 1 when *TG* gets closer to 0.

We can make a heuristic use of *TR* equation to characterize the conditions of structural transformation towards a "world without agriculture" (the "Lewis Path"), and what other pathways are followed when these conditions are not met. We do so by crossbreeding two derivatives with respect to time.

(iii) The derivative of *TR* (Equation 6), with $\theta = Y/L$ and $\theta_a = Y_a/L_a$, shows that *TR* growth rate is positive and converges towards 1 only when the agricultural labour productivity θ_a grows faster than the average labour productivity θ.

$$ln(TR) = ln(Y_a) - ln(Y) - ln(L_a) + ln(L) = ln(\theta_a) - ln(\theta) \qquad (5)$$

$$\dot{T}R / TR = \dot{\theta}_a / \theta_a - \dot{\theta} / \theta \qquad (6)$$

(iv) The derivative of θ_a (Equation 8) shows that the number of agricultural workers decreases only when the agricultural labour productivity θ_a grows faster than the agricultural product Y_a.

$$ln(\theta_a) = ln(Y_a/L_a) \Leftrightarrow ln(L_a) = ln(Y_a) - ln(\theta_a) \qquad (7)$$

$$\dot{L}_a / L_a = \dot{Y}_a / Y_a - \dot{\theta}_a / \theta_a \qquad (8)$$

These results are interesting not to only confirm intuition. They show out that according to the sign of *TR* and L_a growth rates, three other pathways than the "Lewis Path" can be identified and characterized according to the relative growths of Y_a, θ_a and θ (Table 1).

(a) In pathway A, the "Lewis Path" leading to a "world without agriculture", agricultural workforce decreases (negative L_a growth rate) and farm and nonfarm labour incomes converge (*TR* tends towards 1) because agricultural labour productivity (θ_a), boosted by motorized equipments in the current technological pattern, grows faster than the demand for agricultural products (Y_a) and the labour productivity in non-agricultural sectors (θ_{na}).

(b) In pathway B, the number of farmers decreases as in A, but the income gap with other workers increases (negative *TR* growth rate). This is a "Farmer-Excluding" growth since farmers become fewer and poorer. Like in the Soviet Union during the anti-Koulak campaigns in the 1930s, economic revenues per farmer (θ_a) grow slower than the average, and the agricultural surplus is transferred to other sectors at risk of famines in a predominantly rural economy.

(c) Pathway C is "Farmer-Inclusive" since their number increases and their incomes converge to the nonfarm ones. One can imagine here an agricultural product (Y_a) that grows rapidly due to growing domestic demand or agricultural exports, which pulls farmers wealth up (θ_a) relative to the rest of the active population whose own income growth is rather low (θ_{na}), possibly nil or even negative (growing urban poverty).

(d) In pathway D, both agricultural workforce and its income gap with other sectors increase. It is the extreme opposite of the Lewis Path and we name it "Lewis Trap" because unless new lands are available for cultivation, the average acreage per farmer decreases (more and more farmers on the same piece of land) along with the opportunity to boost their individual productivity with motorization. Farmers are more numerous and poorer since they can't increase their productivity (θ_a) faster than the food demand (Y_a)[2] and the labour productivity gains in non-agricultural sectors (θ_{na}).

Let us now examine which of these pathways have been followed in the past and which part of the humanity is actually in a "Lewis Path".

3. Empirical evidences: Lewis Path versus Lewis Trap

3.1. Productivity estimates with a calorie metric

Obtaining comparable measures of real agricultural output for a wide range of countries and time periods requires considerable care. Most studies built indexes based on a basket of agricultural products whose production in monetary value is deflated by general price inflation in order to capture real production changes over time (Craig et al., 1997). This technique is a way of getting time series of "real agricultural output" but faces well-known difficulties, such as structural changes over time in the composition of the output basket, absence of detailed data on local prices, PPP versus real exchange rates dilemma.

[2] which include their own demand for food

In order to trace in physical terms national overall agricultural productions and partial productivities of land and labour, we aggregated national tonnages of crop outputs through a common metric, the calorie, in a similar way the ton oil equivalent (toe) is used to build energy balances. We did that in three steps.

(a) Checking and merging of five international statistical series: “Commodity Balances”[3], “Land”[4], “Population”[5] and “Machinery”[6] from FAO (2010) over 47 years (1961-2007) and, for our cross-sector study, “Value Added by economic activity”[7] from UNSTAT (2010) over 38 years (1970-2007) – Many islands or micro-states had to be removed because of missing or inconsistent data, and, for the same reason, Afghanistan, Iraq, Oman, Papua New Guinea and Somalia. Our final database, however, covers 98% of the world population (2000) and of the world land area (Antarctica excluded).

(b) Conversion and aggregation into calories of all harvested edible plant biomass – Our aggregated index of plant food productions in calories writes $Q_r = \sum_i (q_{ir}c_i)$, where r is a country or region, i a plant biomass edible in its primary form (cereal, oilseed, root, fruit, etc., regardless its final use as food, feed, seed or other)[8], q its volume of production in metric tonnes, and c its food caloric content (kcal per tonne) according to the FAO (2001) or the USDA (2006)[9]. The regions considered in this study are six or eight: Sub-Saharan Africa (SSA), Middle East and North Africa (MENA), Latin America and the Caribbean (LAC),

[3] of which agricultural production in tonnes
[4] of which “Arable land” (annual crops) and “Permanent crops” (perennial crops); we named “cultivated area” the sum of the two land surfaces
[5] of which “total population”, “urban population”, “agricultural population”, “total economically active population” and “total economically active population in agriculture”
[6] of which “agricultural tractors in use”
[7] of which “Total value added” and “Value added from agriculture, hunting, forestry, fishing” at constant 1990 prices in US dollars (USD)
[8] 55 product lines of the FAO’s Commodity Balances: Wheat, rice & other grains of cereals; Beans, peas & other pulses; Cassava, potatoes & other roots or tubers; Tomatoes, onions & other vegetables; Apple, oranges & other fruit; Soya bean, cottonseeds, olives & other oilseeds or tree nuts; Sugars & molasses; Cocoa, coffee & tea; Pepper, cloves & other spices
[9] for details on calculations and general checking of the estimates, see Dorin (2011)

developing Asia (ASIA) of South Asia (sASIA) and East Asia (eASIA), Transition Countries (TRAN) and, finally, industrialized countries of 1990-OECD[10] (OECD) in Eurasia (eOECD) and in north America and Oceania (aOECD) (Figure 2).

(c) Estimation of partial land and labour productivities – Regional productions Q_r were divided by, respectively, corresponding FAO's net areas under annual and permanent crops (A), and FAO's "economically active populations in agriculture" (L_a). Since the FAO uses new ILO[11] estimates that starts from 1980 only (5th edition, revision 2008), we inferred 1961-1979 active populations from the updated 1980 values and the 1961-1980 annual growth rates calculated with earlier estimates[12]. These labour statistics include male and female workers involved in agriculture, forestry and fisheries, and therefore do not only count people producing plant food. Similarly, cultivated lands include some other agricultural production than edible biomass, such as fibres, rubber, tobacco or fodders. These biases tend to underestimate land and labour productivities, especially in countries producing relatively more non-food biomass or more animal products than the average[13].

3.2. A striking heterogeneity of productivity pathways

Our results can be synthesised in a five-dimension graph which shows the specific path (1961-2007) of each region according to the average land availability per farmer (x-axis) and the ability to increase land (y-axis) and labour (isocurves) productivities.

[10] Organisation for Economic Co-operation and Development as in 1990
[11] International Labour Organisation, Geneva
[12] "Population-Estimates 2004 rev." as released by the FAO in 2008. With these previous estimates, our world active population in agriculture reached 1,058,355 thousands people in 1980 (841,.922 in 1961 and 1,308,611 in 2000) while it reaches only 948,580 with the latest estimates (760,656 in 1961 and 1,217,540 in 2000).
[13] It is tricky to include animal products in the calculations (about 10% of the total world production of food calories) since their production rely on *(i)* domestic plant foods (already taken into account in our calculations) and imported ones (such as oilcakes), *(ii)* large but very poorly known surfaces of permanent grazing areas (pastures, savannah, shrubs, etc.)

Figure 3a shows two striking points:

(i) a fantastic growth of labour productivity in industrialized countries due to motorization and concomitant opportunities for many workers to migrate outside the farm sector;

(ii) despite such growth, a world average food productivity path that remains rather close to that of Asia, based above all on a yield boost with extremely low labour productivity and a declining availability of land per farmer.

Figure 3b shows the same results with a log-scale for x-axis and the partition of two regions (OECD and ASIA) into two subsets, while Figure 3c projects all countries without grouping them into regions. These last two figures show two other striking points:

(iii) the very special position of USA, Canada and Australia compared with that of other countries;

(iv) a critical interval, between 2 and 3 ha per farmer, below which the affluence of land usually decreases and above which it usually raises.

The following section details these results to show how the global increase in food production is based on contrasting regional dynamics.

3.3. Contrasting regional development paths

(a) Global performances

In 47 years, the world[14] production of food calories of plant origin increased by 186%, from less than 12 Tera kcal a day in 1961 to over 33 in 2007 (Figure 4a). As the human population has slightly more than doubled during the same period (+116%), the world average daily

[14] In this paper, "world" means the total of our Agribiom countries (Figure 2).

availability of plant food per capita was enhanced by 1240 kcal in five decades to reach 5,070 in 2007, but with large regional differences (Figure 4b). This growth was achieved through:

- 153 millions additional hectares of cultivated area (+11%) (Figure 5a) and a 156% increase in their daily productivity (from 8,620 kcal/ha in 1961 to 22,110 in 2007)[15],
- 514 millions additional agricultural workers (+68%) (Figure 6a) and a 70% increase in their daily productivity (from 15,320 to 26,095 kcal/worker).

As a combined effect of these evolutions, the world average number of persons nourished by a farmer has increased from 4.0 to 5.2 (+29%) despite a puzzling decrease in the average cultivated area per agricultural worker, from 1.8 to 1.2 ha.

(b) Highest land productivity in Asia

Figure 5b displays the regional plant food productions per cultivated hectare. It shows continuous growths (except for transition countries) but growing discrepancy between regions, from one to two in the early 1960s (5,100 to 10,400 kcal a day) to one to three in 2007 (10,300 to 31,400 kcal a day). Since the mid-1980s onwards, land productivity in food calories has become the highest in Asia[16] where investments in infrastructure, education, credit, irrigation, fertilizers, high-yielding varieties and price-regulations helped to boost both crop intensity (number of crops per year on the same plot) and individual crop yields (mainly those of wheat, rice, sugarcane and oil palm). For industrialized countries, many reasons can explain their apparent yield deceleration since the mid-1980s: lower incentives for caloric foodstuffs, increasing prices of fossil energies and other agricultural inputs such as fertilizers and water, soil or biodiversity erosion, environmental regulations, etc. By contrast, land productivity is accelerating in Latin America where sugarcane and oilseeds crops have

[15] This leads us to estimate that 90% of the world plant food production growth was based on an increase in land productivity and not land extension, with of course regional specificities (just about 65% in Sub-Saharan Africa and Latin America for example): see Table 3 ([5]/[3]).

[16] Above 40,000 kcal/ha in 2007 in Malaysia (62,200), China (46,100), Bangladesh (42,500) and Vietnam (41,500), but also in European countries such as Belgium (56,800), Germany (44,600), the Netherlands (41,400) and the United Kingdom (40,100).

increased dramatically for food and non-food uses (feed and biofuels), closing the gap with industrialized countries during the 2000s. The land productivity in MENA has been multiplied by three which is the highest growth rate after Asia, whereas it was by two only in Sub-Saharan Africa where the Green Revolution has been less supported than elsewhere.

(c) A labour productivity boom in industrialized countries

In contrast with the land productivity indicator, the production of food calories per worker increased far more quickly in industrialized countries than in non-industrialized ones. In 2007, it reached a daily average of almost 670,000 kcal (1,992,000 in Canada, 1,908,000 in USA, 1,118,000 in France, 1,107,000 in Denmark) whereas it remained below 120,000 kcal in all other regions, and even below 14,000 in Asia and Sub-Saharan Africa (Figure 6b). This "agricultural divide" is due to motorized machineries (see the "number of tractors" per agricultural worker in Figure 6c) and higher consumption of fossil fuel (Giampietro et al., 2011). These results go along with huge differences in incomes[17]: almost 120 US$ a day in 2007 for an industrialized farmer whereas it is below 2 $ in Sub-Saharan Africa and Asia (3.9 US$ on world average). In the latter two regions, the labour productivity is about the same in 2007 despite large differences in land productivities. The average availability in land per worker explains this apparent paradox (it is 2.6 times lower in Asia than in Saharan Africa) even if it decreased in both regions during the period.

(d) Opposite trends in land per farmer

The average net-cultivated areas per agricultural worker (x-axis of Figure 3a) shows a striking divergence between two groups of regions:

[17] Average agricultural value-added per farmer in constant 1990-US$. This income has to pay for human work but also fixed assets if any (land, draft animals, buildings, equipments…).

- a constant rise in industrialized countries, transition countries and Latin America, up to respectively 26.6 ha, 9.9 ha and 4.0 ha in 2007[18];

- a decrease everywhere else, down to 2.5 ha in MENA, 1.15 ha in Sub-Saharan Africa and 0.45 ha in Asia.

By definition, these evolutions combine evolutions of net-cultivated land (Figure 5a) and of active population (Figure 6a). The cultivated land has decreased in transition and industrialized countries (–64 Mha in total over 47 years) but expanded in other regions (+217 Mha), especially in Latin America and Sub-Saharan Africa (Table 3) at the expense of two carbon and biodiversity pools, forests or permanent pastures[19]. The agricultural active population has also decreased in transition and industrialized countries (–64 Mcap.) and expanded elsewhere (+594 Mcap.) except in Latin America since 2000. It has even doubled or more in Asia (+91%) and Sub-Saharan Africa (+150%). The latter two regions now gather 91% of the world farmers (77% in 1961) who represent 60% of the regional workforce (80% in 1961). This share is much lower elsewhere (Figure 6d).

3.4. Growing divergences: a silent bifurcation

Some decades ago, Hayami and Ruttan delimited three “growth paths” (Ruttan, 2002: 10-11): *(i)* in the “land-abundant path” where stand industrialized and transition countries according to our growth estimates (Table 3), output per worker (column [8]) rises more rapidly than output per hectare (column [5]);

---

[18] This average cultivated area per worker do not account for disparities within a region or a country, which can be large. E.g.: according to USDA, there are 2.2 millions farms in the USA in 2010; their average size is 169 ha, but 56% of them have an average size of 34 ha and cultivate only 11% of the land whereas 10% of them have an average size close to 800 ha and crop nearly half of the cultivated land. Similarly, in many Latin-American coexist a formal sector with few large-scale capital-intensive enterprises adopting labour-saving technologies, and an informal sector with numerous small-scale, labour-intensive enterprises based on low wages.

[19] Between 1961 and 2007, the world area under pasture increased by 278 Mha (+9%), with +135 Mha in ASIA (+32%), +77 Mha in MENA (+32%) and +85 Mha in LAC (+19%).

(ii) in the "intermediate growth path" where are Latin America and MENA, output per worker and per hectare grows at a somewhat comparable rates;

(iii) in the "land-constrained path" where fall Sub-Saharan Africa and Asia, output per hectare rises faster than output per worker.

It is indeed the abundance of land that first explains the labour productivity growth in agriculture. In the first group however ("land-abundant path"), high and growing affluence of land per farmer (A/L_a) is not explained by an extension of the cultivated land (A) much faster than elsewhere (columns [1]) but rather by a massive decrease in the number of farmers (column [7]). This emigration began much before our study period but was sustained by the development of heavy motorized equipments in the second half of the twentieth century. Such "labour-saving" and "energy-intensive" path did not occur elsewhere – or with delay and at a much slower pace – which enlarged gaps similar to the ones that Pomeranz (2000) has traced back to 1750.

Rural exodus and motorization increase the abundance of land per farmer, their labour productivity and the convergence of their incomes toward those of other workers. It is the "structural transformation". Figure 7a and Figure 7b clearly show the equal importance in this transformation of the GDP growth per capita and of the land growth per farmer. The indicators of a "world without agriculture" (y-axis) follow indeed very similar trends, be they plotted against the national average GDP per capita (x-axis) like in C.P. Timmer (2009: 7) or against the national average acreage per farmer.

Before 1970, the land affluence per farmer was below 5 ha in industrialized Eurasia, transition countries and Latin America. It was much lower than in North America and Oceania but within or above the critical interval of 2-3 ha mentioned before, and their *TG* value (Equation 3) rose well above –10% in 2007 (Figure 7c). The MENA region followed them with the most spectacular change of *TG* value observed between 1970 and 2007, from –43% to –15%, while its land affluence stayed within the critical interval throughout the period. However, MENA also became meantime a massive importer of food thanks partly to its export of oil, whereas OECD and Latin American countries became growing net food exporters (Dorin, 2011: 64).

On the other hand, all regions having an affluence of land below 2 ha per farmer remained stuck below a *TG* value of –35% in 2007, a value which is also the 2007 average of the whole world due to the demographic importance of these regions (Asia and Sub-Saharan Africa). The Asian one even shows a declining *TG* value, i.e. a growing income gap between agricultural workers and the others. Do these regions – in particular – have a chance to follow the road to prosperity marked out by Lewis in theory, by industrialized countries in practice? In these industrialized countries, the agricultural share in total employment is now below 3% (13% in 1970) while their GDP per capita is at least 7 times higher than elsewhere (less than 6 in 1970).

4. Changing utopia for another?

Table 4 sumps up above results and characterizes agricultural transformation pathways followed by the main world regions over 1970-2007[20]. It shows that the Lewis's road of "structural transformation" was followed only by industrialized and transition countries[21]. Latin America and Africa followed a "Farmer-Inclusive" path with an increasing number of farmers and a narrowing gap between farm and non-farm incomes, while Asia (more than half of the world population) is embarked in a "Lewis Trap". The question though is under what conditions Africa and Latin America can avoid falling in this trap and Asia go out from it.

Long-term scenarios apt to respond this question should integrate various conjectures about the future of the economic globalisation process, the links between ageing and saving behaviours, productivity trends in farm and non-farm sectors, dynamics of markets like energy, land and real estates, etc. They are not currently available.

In their absence however, it is possible to use the "simple mathematics" of Timmer (2009: 10) to show out the fundamental parameters at play in shifting from a "Lewis Trap" to a "Lewis Path". The labour productivity growth in the non-agricultural sector is one of them. If it remains constant (for example), labour can move from agriculture to non-agriculture as fast as the non-agricultural sector grows. This is the "fast track" of the "Lewis Path". Conversely, if

[20] Note that similar growth rates of labour productivity in agriculture are obtained despite the change of metric, from per-worker production of plant calories (Table 3, column 8) to per-worker value-added in 1990-US$ (Table 4, column 7). One exception is East Asia where high value-added productions such as meat grew faster than the plant food productions. Results of Table 3 over 1970-2007: 3.90% (aOECD, *vs*. 3.69% in 1990-US$), 4.77% (eOECD, *vs*. 4.36%), 2.61% (TRAN, *vs*. 3.07%), 2.98% (LAC, *vs*. 2.73%), 2.11% (MENA, *vs*. 2.40%), 0.51% (SSA, *vs*. 1.01%), 1.13% (sASIA, *vs*. 1.25%), 1.55% (eASIA, *vs*. 3.00%).

[21] 15 countries in 2007 out of 154 in our sample have less then 3% of their workforce employed in agriculture: Belgium, Canada, Denmark, France, Germany, Israel, Japan, Kuwait, Lebanon, Luxembourg, Slovenia, Sweden, The Netherlands, United kingdom, USA. Except for Kuwait, UK and USA, all of them had a percentage above 6% in 1980. In 2007, a "world without agriculture" (3% share of total employment) would mean 93 millions farmers producing each 358000 kcal/day on 16 ha (39, 302000 and 35 respectively in 1961).

the non-agricultural labour productivity grows at the same rate than the sector itself, the latter cannot absorb any new workers and the rural labour is forced to remain in agriculture or to be jobless.

With Timmer's arithmetic, let us conduct a simple heuristic exercise projecting India in 2050 thought a baseline scenario and two variants of non-agricultural labour productivity growth. These scenarios share common assumptions on population growth, land surfaces and GDP growth (Table 5). Population assumptions (total and active) are derived from FAO (2010) and capture the expected "demographic dividend"[22]. Assumptions on GDP are those of Shukla and Dhar (2011)'s baseline scenario for India (2005-2050) relying on a computable general equilibrium: an average growth of 7.3%[23] per annum (p.a.) with 2.6% from agriculture and 7.7% for all other sectors.

The overall growth gives an average GDP growth per worker of 6.2% p.a. leading to 67 US$ per day in 2050. By sector, it is 3.0% for farm activities and 5.4% for non-farm activities in Shukla and Dhar's baseline scenario[24]. When the overall growth of labour productivity ($\ln \theta$ = 6.2%) is higher than the agricultural one ($\ln \theta_a$ = 3.0%) and when the latter is higher than the growth of the agricultural outputs ($\ln Y_a$ = 2.6%), it indicates a "Farmer-Excluding" path according to our typology (Table 1). Farmers are fewer (their share in the workforce fall to 30%) but relatively poorer; they earn on average 17 times less than non-agricultural workers (TR = 0.1) whereas it was a little more than 6 in 2007 (TR = 0.29) (Table 5).

[22] Rise in the rate of per capita economic growth due to a rising share of working age people in a population.
[23] assumption lying between the 2000-2007 growth rate (5.6%) and very optimistic projections (e.g. 8.5% over 2007-2050 from Hawksworth and Cookson, 2008)
[24] The average growth (6.2%) is higher than 5.4% and 3.0% because each worker passing from agriculture to non-agriculture yields an incremental 2.4% productivity growth rate.

From this baseline, we test the sensibility of above results to two different assumptions regarding the labour productivity growth rate in non-agricultural activities (scenarios 1 and 2), all things being equal. In scenario 1, the rate passes from 5.4% to 5.8% p.a. Table 5 shows that India then falls in a “Lewis Trap” (ln θ_a < ln Y_a). Compared to 2007, farmers are relatively poorer (*TR* = 0.1) but also more numerous (still 40% of the workfoce in 2050). Because of higher labour productivity growth in the non-agricultural sector, the labour demand of this sector is lower at constant output and cannot absorb as much agricultural population as in the baseline scenario. 575 million people (farmers with their family members) lives alongside much richer urban dwellers (about 1 billion people) and the average available land falls to 0.58 ha per agricultural worker (0.66 in 2007). Such a disparity would put the growth catch-up in India at risk of being disrupted by severe social and political crises, a typical danger for high-performing Asian economies pinpointed by Hayami and Godo (2004).

In scenario 2, we calculate the average labour productivity growth of non-farm workers needed to reach “an India without agriculture” in 2050 after a fast Lewis Path. This rate, 4.6% p.a., is much lower than in the baseline (5.4%). A likely unrealistic labour productivity growth rate of 9.3% in agriculture has thus to be assumed to achieve the convergence of incomes (*TR* = 1) to 67 US$ per worker and 30 US$ per capita after four decades of unprecedented rural drift.

The limitation of these numerical experiments is that a higher (lower) labour productivity could lead to a higher (lower) GDP and a higher (lower) absorbing capacity[25]. But this

[25] In the absence of model endogenizing in a credible way labour productivities in India, final and external demand and the competitiveness of Indian production in 2050, one can simply note that a higher GDP is unlikely because our baseline scenario is perhaps already too optimistic. An average annual growth rate of 7.3% over nearly a half-century would already be very exceptional for a large country and would likely confront constraints in the pace of construction of the underlying infrastructures. Over 1970-2007 (37 years), we found only China above such a rate, with 8.5% (rate measured with total

limitation is unessential to show out that, in India as elsewhere, the future of agriculture is not determined by the only specific parameters of the sector. Hence, the Lewis Path depends on a "fine tuning" between the growth rate of outputs and the labour productivities in the farm and non-farm sectors. The uncertainty surrounding such a "fine tuning" seems much higher than in the past, even in the long run, for reasons discussed below.

The Lewis' structural transformation is likely to span generations but Timmer (2009) first shows that over the past 50 years, the turning point where the divergence turns to convergence has been reached at later and later stages in the economic transformation of successful growth performers, "perhaps suggesting that industry is becoming less and less able to absorb labour" (Binswanger-Mkhize et al., 2010). There are two reasons to think that such a trend will continue in the future. Firstly, although gains in industrial labour productivity through economies of scale and motorization/automation almost saturate in OECD countries, they will develop elsewhere. Secondly, this trend might co-exist with a slower increase of industrial production due to increasing cost of oil and other non-renewable raw materials, strengthening of environment-friendly regulations, market saturation in industrialized countries, slower increase of wages in developed economies not fully compensated by an increase of incomes in developing countries. The overall result might be the co-existence in urban areas of highly skilled and highly paid labour with high labour intensive and low wages services, but this amounts to transfer to cities the social fragmentation problem[26].

The increasing difficulties to follow a Lewis Path are confirmed by the end point of scenario 2. More than 80% of the population (1.3 billion people out of 1.6) lives in cities whose density reaches 55,000 inhabitants per km^2 (Table 5) while in 2010, it was 35,000 in Dhaka

value-added in 1990-US$ from Unstat, 2010). It was followed by countries only in Asia: Malaysia (7.1%), South Korea (6.5%), Thailand (6.2%), Vietnam (6.1%) and Indonesia (6.0%).

[26] The "Farmer-Inclusive" growth of Latin America and Africa?

(Bangladesh) and 27,100 in Mumbai (India), the two current densest cities in the world (Demographia, 2011). Such a mega-urbanization is a challenge ever faced in history. In Europe, the Lewis Path was instead facilitated by the emigration of 60 million people to the "New Worlds" (35 million to the USA alone) between 1850 and 1930 (Losch et al., 2011). Such large open spaces for exporting labour surpluses do not exist anymore.

The end point of scenario 2 also shows that in rural areas, the available land per farmer is bounded to 10 ha. The figure is much lower with a lower mega-urbanization. There is thus no perspective of boosting farm labour productivity through large-scale motorization as in OECD countries where the average land acreage per farmer was 27 ha in 2007. Indian farmers may try to overcome this barrier by increasing the land productivity with more external inputs (fertilizers, pesticides, fuels, seeds, water) but the marginal productivity of these inputs decreases and the negative externalities of their intensive use are already high (natural resource depletion, biodiversity loss, global greenhouse gases, animal and human health problems) (Dorin and Landy, 2009). They may increase the efficiency of their use but their ever-increasing price may wipe off all efforts. They may get better prices for their products on international markets but they can hardly compete with the large-scale and well-organized agro-industries that emerged during the past century. Since they cannot migrate enough to already crowded urban shantytowns, they may actually stay with a business whose natural capital declines (soil, biodiversity, safe water) while their own capabilities are diminished due to poverty (nutrition, health, education). This is the Lewis trap.

The contradictions to which a Lewis Path leads are not specific to the Indian example but the latter helps to highlight them. Bifurcating towards an alternative pathway requires an overall redirection of R&D where genetically modified organisms (GMO) are far to be the master piece as many believe it. GMO may help to save some inputs like nitrogen, water or pesticide but they increase the cost of seed and will not solve the labour absorption problem we have just demonstrated the critical importance.

The problem is to increase total agricultural production (Q) and farmers' wealth (θ_a) without downsizing in large proportion their number (L_a) and without jeopardizing natural resources. It can be written as follows, where Y_{na}^{a} is the cost of non-agricultural inputs (chemical fertilizers, pesticides, irrigation, etc.) and p the price paid to farmers for their production:

$$\theta_a = (pQ - Y_{na}^{a}) / L_a \tag{9}$$

Over the past decades, R&D focused on few monocultures whose production Q increased with higher Y_{na}^{a} and environmental costs (Foley et al., 2005) while their price p decreased, making the equation really profitable (θ_a) only when farmers were fewer (L_a) with larger acreages. Revising and enlarging such a selective R&D requires finding an alternative to input-dependent and ecologically simplified food production systems to increase Q.

This alternative resembles the agenda of the "agro-ecological perspective" (Altieri, 1999) or "agro-ecological matrix" (Perfecto and Vandermeer, 2010) that can also be called "ecological intensification":

(1) diverse agro-ecological systems exploiting best biological synergies between numerous plant and animal species above and below the ground might not only be much more productive (Q) than conventional modern agriculture but also much more resistant and resilient to natural and economic chocks;

(2) inputs Y_{na}^{a} can be saved which lowers environmental and production costs;

(3) price p to producers could be increased if farmers provide more diversified diets and tasty nutritious food to rural and urban households, other goods such as fuels, fibres, drugs and building materials, and are paid for ecosystem services of local and global importance (safe water, carbon and biodiversity pool, soil fertility, nutrients recycling, pollination, diseases and flood control, climate mitigation/adaptation);

(4) labour intensity (L_a) could be high because the ecological intensification requires more dedicated human abilities than capital to detect and exploit biological synergies on heterogeneous land quality and variable weather conditions.

The efficiency and economic viability of such an alternative pathway would be reinforced if land access and competition policies become more effective[27]. Agriculture is indeed normally subject to diseconomies of scale. The "inverse size-productivity relation" in agriculture is an old issue rose by Amartya Sen (Sen, 1964; Rudra and Sen, 1980) and the "small vs. large farms" microeconomic debate is not old dated (Wiggins et al., 2010) because many empirical data from all over the world continue to show that large farms dependent on hired managers and workers are less productive and less profitable per hectare than small farms operated primarily with family labour. Lower transaction costs of large-scale operations (information, credit, inputs, marketing…) are indeed usually offset by greater incentives of family members to work hard, by special institutional arrangements (such as cooperative or contract farming) and by the premium obtained from closer management and supervision of farm operations (Binswanger-Mkhize et al., 2010).

[27] A small number of farmers and related upstream and downstream agro-industries with good education and communication usually constitute powerful lobbies that national and international policymakers can hardly resist. These lobbies tend to increase the costly "protection problem" of agriculture in high-income economies (Schultz, 1953; Hayami and Godo, 2004) and a worldwide concentration of firms into few agro-food complexes with oligopolistic positions that limit competition and control both prices and technical innovations.

Actually no doubt that the conventional way of modernization agriculture can continue to expand especially in places where marginal productivity of external “modern inputs” (lab-seeds, petrochemical fertilizers, irrigation, pesticides…) is still very high, such in sub-Saharan Africa. But in Africa like in Latin America, population will continue to rise significantly and the absorption capacity of urban areas may not be sufficient to avoid urban chaos or a bifurcation toward a Lewis Trap. It is in this sense that what we just described above might be viewed as a workable and necessary alternative utopia to agro-industrial farming.

5. Conclusion

This paper intends to provide material for questioning the perspective of a “world without agriculture” which is embedded in the “structural transformation” paradigm of “modern growth”. It does so by recomposing worldwide productivity trends in caloric terms from 1961 to 2007 and by providing an heuristic model showing that the “Lewis Path” that leads to a “world without agriculture” is only one out of four possible pathways.

The numerical analyses shows that the Lewis Path is followed by industrialized and transition countries only. Latin America and Africa follows a “Farmer-Inclusive” path with an increasing number of farmers but a narrowing gap between their incomes and those of other workers, while Asia (more than half of the world population) is embarked in a “Lewis Trap” where farmers are increasingly numerous and poorer compared to other workers and most other farmers in the world.

The shift from a Lewis Trap to a Lewis Path may not be a question of time because we also bring two other evidences: *(i)* large-scale motorization (currently almost inexistent in Asia) rather than yield per hectare (very high in Asia) was up to now in the world the main driver for boosting agricultural labour productivity and the convergence of incomes across sectors, *(ii)* motorization cannot be large-scale in a country like India.

A Lewis Path in Asia is obviously challenging and cannot be commensurate with the one faced by industrialized countries in the past. In a country like France, the Lewis's structural transformation began long ago, was eased by labour-intensive industry and labour emigration outside Europe until World War II, and was then completed by policies encouraging a "modern agriculture" (Servolin, 1989) with no more "peasants" (Gervais et al., 1965; Mendras, 1967) but heavy-motorized "agriculturalists" until reaching a "world without agriculture" in the early 21st century (3% of the workforce and of the GDP).

Such an experience cannot be replicated in Asia for at least two reasons:

(i) in France, the cultivated acreage per worker could rise from 5 to 30 ha over 1961-2007 (from 37 to 63 in USA, 61 to 151 in Canada) whereas in India, it decreases from 1.2 to 0.7 ha and is bounded to 10 ha in a Lewis Path scenario;

(ii) today, the most dense French city is Paris with 3,400 inhabitant/km² whereas it already reaches 27,100 in Mumbai (Demographia, 2011) and should be 55,000 for all Indian cities in the Lewis Path scenario for 2050.

The utopia of a few large-scale farmers and agro-industries feeding the bulk of humankind in huge megacities can hardly be that of Asia. This utopia played an historical role in some parts of the world but it is now time to envisage a more inclusive "structural transformation" based on a mosaic of agro-ecological systems. The agro-ecological matrix seems indeed more likely to provide decent incomes and livelihoods to a multitude through *(i)* a more efficient manufacture of diverse tasty nutritious food, fibres, energy, drugs, fertilizers, building materials and safe water for both rural and urban dwellers, *(ii)* a more efficient provision of many ecological and social services that humankind is now looking for at local and global scales.

It is time to do so not only in Asia but also in Africa and Latin America to avoid unexpected bifurcations towards a Lewis Trap or growing poverty and violence in cities, as well as in industrialized countries which now experience the ecological and social limits of large-scale intensive monocultures (or breeding) in almost empty rural areas.

This small-scale knowledge-intensive and context-specific agriculture embedded in manufacture and service sectors has to be largely invented. It calls for a new R&D paradigm whose "payoffs will only happen if the effort is sufficiently massive, concerted, and sustained" (Janvry, 2010). The consensus in favour of the effort of which we speak is fortunately enlarging and many try to precise its contents and expected benefits (UNEP, 2011). It should involve economists wondering if we can expect a "perfect storm" in the future (Hertel, 2011) since their modelling tools should help to answer two pending big questions: *(1)* how our societies and their institutions get organized to promote and remunerate properly collective and public goods provided by agriculture? *(2)* how this new agriculture and rural organization can emerge and coexist with large-size agro-industries that now feed a growing portion of humankind?

References

Alston, J.M., Beddow, J.M., Pardey, P.G., 2009. Agricultural Research, Productivity, and Food Prices in the Long Run. Science 325, 1209-1210.

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. Agriculture Ecosystems & Environment 74, 19-31.

Bairoch, P., 1999. L'agriculture des pays développés. 1800 à nos jours. Production - Productivité - Rendement. Economica, Paris.

Binswanger-Mkhize, H.P., McCalla, A.F., Patel, P., 2010. Structural Transformation and African Agriculture. Global Journal of Emerging Market Economies 2, 113-152.

Chen, S., Ravallion, M., 2007. Absolute poverty measures for the developing world, 1981-2004. Proceedings of the National Academy of Sciences of the United States of America 104, 16757-16762.

Chenery, H., Srinivasan, T.N., 1988. Handbook of Development Economics, Volume 1, Part 2: Structural Transformation. Elsevier, Eastbourne, pp. 197-465.

Craig, B.J., Pardey, P.G., Roseboom, J., 1997. International productivity patterns: Accounting for input quality, infrastructure, and research. American Journal of Agricultural Economics 79, 1064-1076.

Demographia, 2011. Demographia World Urban Area (World Agglomerations). 7th Annual Edition. Demographia, p. 100.

Dorin, B., 2011. "Agribiom" (chapter 2) and "The world food economy" (chapter 3), in: Paillard, S., Treyer, S., Dorin, B. (Eds.), Agrimonde : Scenarios and Challenges for Feeding the World in 2050. Quae, Versailles, pp. 25-65.

Dorin, B., Landy, F., 2009. Agriculture and Food in India. A Half-Century Review, From Independance to Globalization. Manohar-Quae-CSH, New Delhi.

Ehrlich, P., Holdren, J., 1972. Review of the Closing Circle. Environment, 24-39.

FAO, 2001. Food Balance Sheets. A Handbook. Food and Agricultural Organization of the United Nations, Rome.

FAO, 2009. The State of Food Insecurity in the World. Economic crises, impacts and lessons learned. Food and Agricultural Organization of the United Nations, Rome, p. 61.

FAO, 2010. FAOSTAT, Internet web portal and database. Food and Agricultural Organization of the United Nations, Rome.

Farrell, M.J., 1957. The Measurement of Productive Efficiency. Journal of the Royal Statistical Society 120, 253-281.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570-574.

Gervais, M., Servolin, C., Weil, J., 1965. Une France sans paysans. Seuil, Paris.

Giampietro, M., Arizpe, N., Ramos-Martin, J., 2011. Food Security and Fossil Energy Dependence: An International Comparison of the Use of Fossil Energy in Agriculture (1991-2003). Critical Reviews in Plant Sciences 30, 45-63.

Hawksworth, J., Cookson, G., 2008. The World in 2050. Beyond the BRICs: a broader look at emerging market growth prospects. PricewaterhouseCoopers, London, p. 34.

Hayami, Y., Godo, Y., 2004. The Three Agricultural Problems in the Disequilibrium of World Agriculture. Asian Journal of Agriculture and Development 1, 3-14.

Hayami, Y., Ruttan, V.W., 1985. Agricultural development: An international perspective. Johns Hopkins University Press, Baltimore, MD.

Hertel, T.W., 2011. The Global Supply and Demand for Agricultural Land in 2050: A Perfect Storm in the Making? American Journal of Agricultural Economics 93, 259-275.

Janvry, A.d., 2010. Agriculture for development: new paradigm and options for success. Agricultural Economics 41, 17-36.

Kuznets, S., 1966. Modern Economic Growth: Rate, Structure and Spread. Yale University Press, New Haven and London.

Larson, D., Mundlak, Y., 1997. On the intersectoral migration of agricultural labor. Economic Development and Cultural Change 45, 295-319.

Lewis, W.A., 1954. Economic Development with Unlimited Supplies of Labour. Manchester School of Economic and Socal Studies 22, 139-191.

Losch, B., Fréguin-Gresh, S., White, E., 2011. Rural Transformation and Late Developing Countries in a Globalizing World. A Comparative Analysis of Rural Change. World Bank, Washington D.C., p. 342.

Malassis, L., Padilla, M., 1986. Economie agro-alimentaire. L'économie mondiale (III). Cujas, Paris.

MEA, 2005. Ecosystems and Human Well-being: Synthesis. Millennium Ecosystem Assessment, World Resources Institute, Washington D.C., p. 155.

Mendras, H., 1967. La fin des paysans. S.E.D.E.I.S., Paris.

Perfecto, I., Vandermeer, J., 2010. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. Proceedings of the National Academy of Sciences of the United States of America 107, 5786-5791.

Pomeranz, K., 2000. The Great Divergence: China, Europe and the Making of the Modern World Economy. Princeton University Press, Princeton.

Rudra, A., Sen, A., 1980. Farm Size and Labour Use: Analysis and Policy. Economic & Political Weekly 15, 391-394.

Ruttan, V.W., 2002. Productivity growth in world agriculture: Sources and constraints. Journal of Economic Perspectives 16, 161-184.

Sauvy, A., 1980. La machine et le chômage. Dunod, Paris.

Schultz, T., 1953. Economic Organization of Agriculture. McGraw Hill, New York.

Sen, A., 1964. Size of Holdings and Productivity. Economic & Political Weekly.

Servolin, C., 1989. L'agriculture moderne. Seuil, Paris.

Shukla, P.R., Dhar, S., 2011. Climate agreements and India: aligning options and opportunities on a new track. International Environmental Agreements-Politics Law and Economics 11, 229-243.

Solow, R.M., 1957. Technical Change and the Aggregate Production Function. The Review of Economics and Statistics 39, 312-320.

Timmer, C.P., 1988. The agricultural transformation, in: Chenery, H., Srinivasan, T.N. (Eds.), Handbook of Development Economics. Elsevier Science Publishers, Amsterdam, pp. 275-331.

Timmer, C.P., 2009. A World without Agriculture. The Structural Transformation in Historical Perspective. The American Enterprise Institute, Washington D.C.

UNEP, 2011. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. United Nations Environment Programme.

UNSTAT, 2010. National Accounts Main Aggregate Database. United Nations, Statistical Division.

USDA, 2006. USDA National Nutrient Database for Standard Reference. Release 19. U.S. Department of Agriculture, Beltsville.

Waggoner, P.E., Ausubel, J.H., 2002. A framework for sustainability science: A renovated IPAT identity. Proceedings of the National Academy of Sciences of the United States of America 99, 7860-7865.
Wiggins, S., Kirsten, J., Llambi, L., 2010. The Future of Small Farms. World Development 38, 1341-1348.

Tables

Table 1. Typology of agricultural pathways

	$\dot{TR}/TR$ positive ($\dot{\theta}_a/\theta_a > \dot{\theta}/\theta$)	$\dot{TR}/TR$ negative ($\dot{\theta}_a/\theta_a < \dot{\theta}/\theta$)
$\dot{L}_a/L_a$ negative ($\dot{\theta}_a/\theta_a > \dot{Y}_a/Y_a$)	(A) Lewis Path $\dot{\theta}_a/\theta_a > \dot{Y}_a/Y_a, \dot{\theta}/\theta$	(B) Farmer-Excluding growth $\dot{\theta}/\theta > \dot{\theta}_a/\theta_a > \dot{Y}_a/Y_a$
$\dot{L}_a/L_a$ positive ($\dot{\theta}_a/\theta_a < \dot{Y}_a/Y_a$)	(C) Farmer-Inclusive growth $\dot{Y}_a/Y_a > \dot{\theta}_a/\theta_a > \dot{\theta}/\theta$	(D) Lewis Trap $\dot{\theta}_a/\theta_a < \dot{Y}_a/Y_a, \dot{\theta}/\theta$

Table 2. OTAWA/TALA regional values (2007)

	Land Mha [1]	Population Mcap. [2]	Production Gkcal.day^{-1} [3] [1]*[5], [2]*[7]*[8]	Outcome kcal.cap^{-1}.day^{-1} [4] [3]/[2], [5]x[6]x[7]	Technology kcal.ha^{-1}.day^{-1} [5]	Affluence ha.worker^{-1} [6]	Workforce worker.cap^{-1} [7]	Labour kcal.worker^{-1}.day^{-1} [8] [5]x[6]
aOECD	270	367	6,213	16,920	22,977	70,4	0,01	1,617,434
eOECD	89	578	2,818	4,874	31,586	9,2	0,02	291,241
TRAN	245	403	2,928	7,271	11,966	9,9	0,06	118,696
LAC	170	561	4,355	7,758	25,611	4,0	0,08	103,051
MENA	83	399	1,240	3,111	14,859	2,5	0,08	36,702
SSA	217	789	2,226	2,822	10,257	1,2	0,24	11,882
sASIA	204	1,544	4,399	2,849	21,562	0,6	0,22	13,198
eASIA	226	1,927	9,094	4,721	40,197	0,4	0,33	14,204
World	1,505	6,567	33,273	5,066	22,107	1.2	0.19	26,094

Table 3. OTAWA/TALA average regional annual growth rates (1961-2007)

	Land Mha [1]	Population Mcap. [2]	Production Gkcal.day^{-1} [3] [1]+[5], [2]+[7]+[8]	Outcome kcal.cap^{-1}.day^{-1} [4] [3]-[2], [5]+[6]+[7]	Technology kcal.ha^{-1}.day^{-1} [5]	Affluence ha.worker^{-1} [6]	Workforce worker.cap^{-1} [7]	Labour kcal.worker^{-1}.day^{-1} [8] [5]+[6]
aOECD	0.02%	1.11%	2.98%	1.85%	2.96%	1.18%	-2.22%	4.16%
eOECD	-0.42%	0.56%	1.38%	0.81%	1.79%	3.06%	-3.92%	4.92%
TRAN	-0.37%	0.51%	1.21%	0.69%	1.59%	1.72%	-2.54%	3.31%
LAC	1.11%	2.05%	3.49%	1.42%	2.36%	0.67%	-1.58%	3.04%
MENA	0.29%	2.50%	3.04%	0.52%	2.74%	-0.33%	-1.82%	2.40%
SSA	0.93%	2.72%	2.63%	-0.08%	1.69%	-1.06%	-0.68%	0.61%
sASIA	0.15%	2.14%	2.72%	0.56%	2.56%	-1.33%	-0.63%	1.20%
eASIA	0.56%	1.68%	3.34%	1.64%	2.79%	-0.82%	-0.29%	1.93%
World	0.23%	1.69%	2.36%	0.66%	2.12%	-0.88%	-0.55%	1.22%

Table 4. The structural transformation pathways (1970-2007)

	Population (heads)	Workforce (workers)		Economic growth (USD1990)		Labour productivity (USD1990/worker)		Timer gap/ratio		Pathway
	Total	Total	Agriculture	Total	Agriculture	Total	Agriculture	TG (Eq.3)	TR (Eq.4)	(Table 1)
aOECD	1.08%	1.62%	-0.89%	2.91%	2.76%	1.27%	3.69%	-7.85%	2.40%	Lewis Path
eOECD	0.47%	0.82%	-3.42%	2.74%	0.79%	1.90%	4.36%	-6.32%	2.42%	Lewis Path
TRAN	0.38%	0.38%	-1.96%	1.91%	1.07%	1.50%	3.07%	4.44%	1.67%	Lewis Path
LAC	1.89%	2.92%	0.30%	3.50%	3.03%	0.56%	2.73%	-4.01%	2.21%	FI growth
MENA	2.44%	3.00%	0.67%	4.10%	3.07%	1.08%	2.40%	-2.79%	1.36%	FI growth
SSA	2.75%	2.80%	2.05%	3.28%	3.09%	0.46%	1.01%	-0.98%	0.55%	FI growth
sASIA	2.13%	2.28%	1.49%	5.17%	2.76%	2.82%	1.25%	0.58%	-1.56%	Lewis Trap
eASIA	1.49%	2.07%	1.35%	7.61%	4.38%	5.44%	3.00%	0.47%	-2.31%	Lewis Trap
World	1.61%	1.95%	1.18%	3.10%	2.25%	1.13%	1.06%	-0.74%	-0.07%	Lewis Trap

Note: percentages are average regional annual growth rates between 1970 and 2007

Table 5. Scenarios of Lewis Trap and Path for India (2007-2050)

			1980-2007 Observed [1]	2007-2050 Baseline [2]	2007-2050 Lewis Trap [3]	2007-2050 Lewis Path [4]
Population	Total	Mcap	1,165	*1,615*	*1,615*	*1,615*
		annual growth	1.9%	*0.8%*	*0.8%*	*0.8%*
	Workforce	% population	40%	*45%*	*45%*	*45%*
Area	Cropped	Kha	170,000	*170,000*	*170,000*	*170,000*
	Cities	Kha	2,428	*2,428*	*2,428*	*2,428*
Growth (VA)	Total	annual growth	6.1%	7.3%	7.3%	7.3%
	- Agriculture	annual growth	3.0%	*2.6%*	*2.6%*	*2.6%*
	- Other	annual growth	7.2%	*7.7%*	*7.7%*	*7.7%*
	Total	USD_{1990}/cap.day	2.04	30.51	30.51	30.51
Labour productivity (VA/worker)	Total	annual growth	3.9%	6.2%	6.2%	6.2%
	- Agriculture	annual growth	1.6%	3.0%	2.3%	9.3%
	- Other	annual growth	3.7%	*5.4%*	*5.8%*	*4.6%*
Workforce	Total	annual growth	2.2%	1.1%	1.1%	1.1%
	- Agriculture	annual growth	1.4%	-0.4%	0.3%	-6.2%
	- Other	annual growth	3.4%	2.2%	1.8%	3.0%
	Total	Mcap	463	735	735	735
	- Agriculture	Mcap	259	217	295	17
	- Other	Mcap	204	517	440	718
Overview	Agriculture	% workforce	56%	30%	40%	2%
		% GDP (VA)	16%	2%	2%	2%
		Timer Ratio	0.3	0.1	0.1	1.0
		ha/farmer	0.66	0.78	0.58	10.11
	Cities	Mcap	340	947	795	1,337
		% population	29%	59%	49%	83%
		Kcap/km²	14	39	33	55

Notes: Values other than annual growth rates are those of the final year. Figures in italics are assumptions:
(a) population: polynomial function of the year derived from the 2000-2050 annual projections of FAO (2010) (r^2=0.999);
(b) workforce: polynomial function of the population derived from the 1961-2020 annual data of FAO (2010) (r^2=0.999);
(c) cropped area: fixed value of 170 Mha after 2000 (169.3 observed in 2007);
(d) urban area (cities): fixed value of 2,428 Kha after 2000, obtained by dividing the Indian urban population in 2007 (FAO, 2010) by an average density of 14,000 inhabitants per km^2 (13,767 circa 2006 for all Indian urban areas according to Demographia (2011), and 14,083 for urban areas over 500,000 inhabitants);
(e) urban population: urban population of 2007 + new population after 2007 – new agricultural population after 2007;
(f) agricultural population: agricultural workforce * β where β = ((population / workforce) – 0.25) as observed circa 2000;
(g) sectoral annual growth rates (agricultural and non-agricultural added values): scenario assumptions from which is derived the total annual growth rate
(h) labour productivity growth rate (agriculture or non-agriculture): scenario assumption from which is derived the other sector growth rate (non-agriculture or agriculture) in order to achieve the sectoral annual growth rates.

Figures

Figure 1. International comparison of agricultural land and labour productivities

(a) A traditional representation
Source: Craig el al. (1997: 1066)

(b) Our representation framework
of food productivity pathways

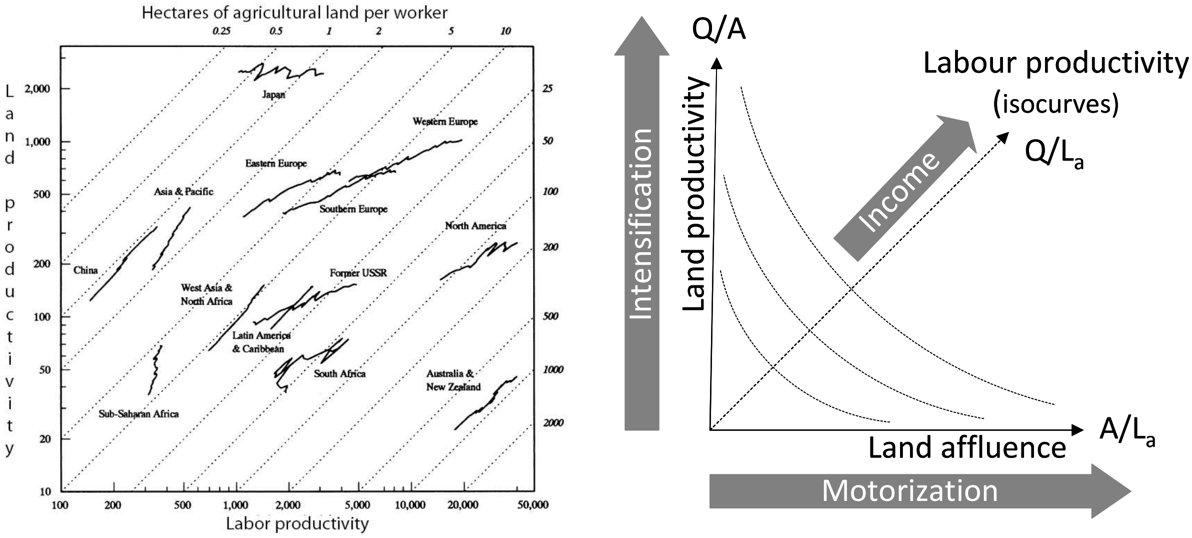


Figure 2. Map of the countries and regions used in this study
Cartographic source : Articque

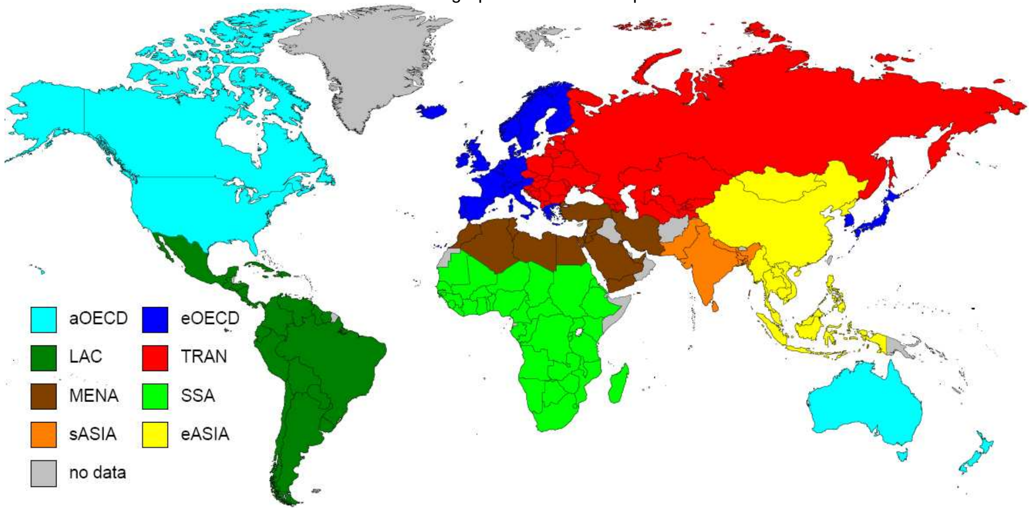


Figure 3. World food productivity pathways (1961-2007)

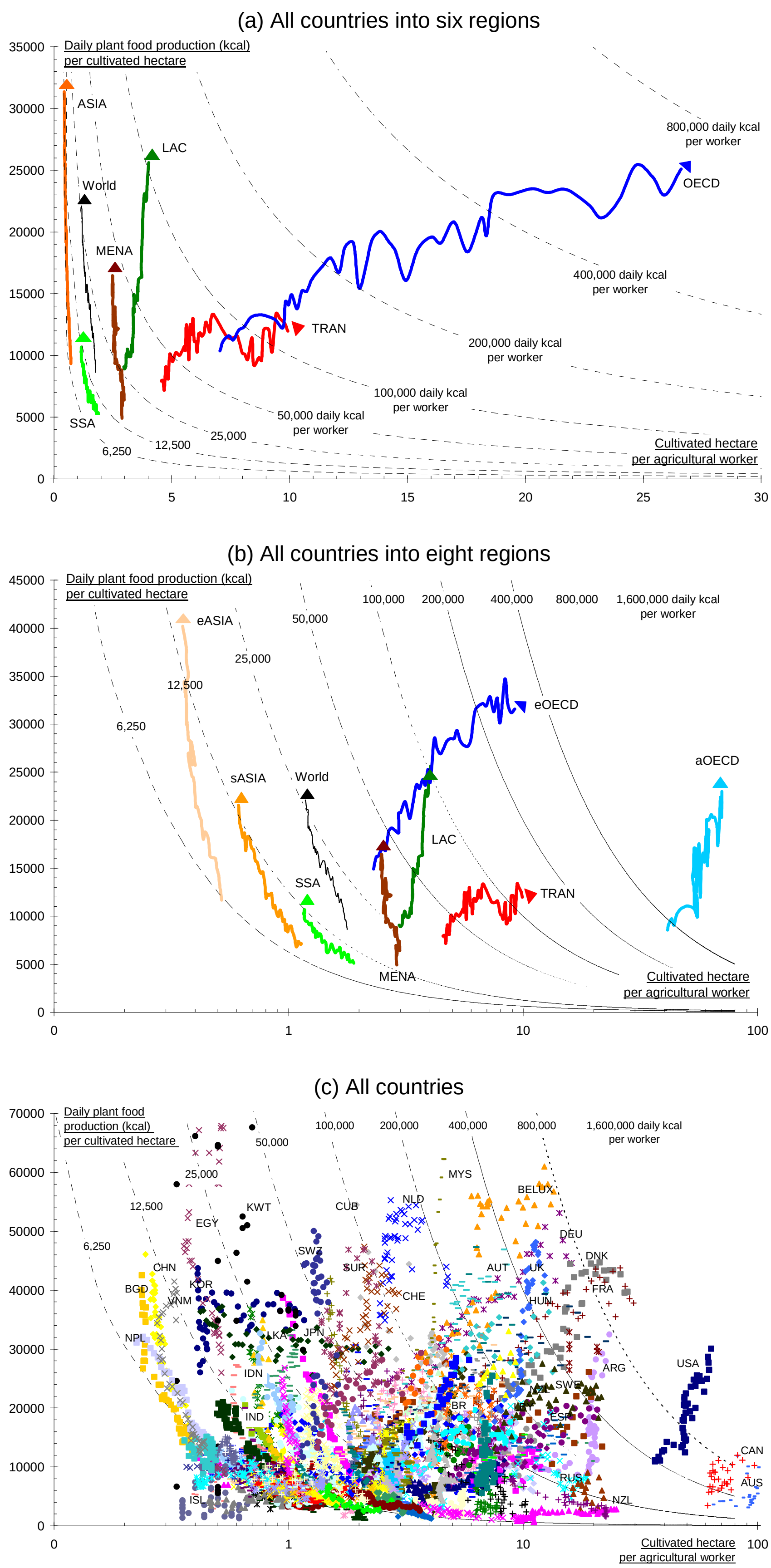
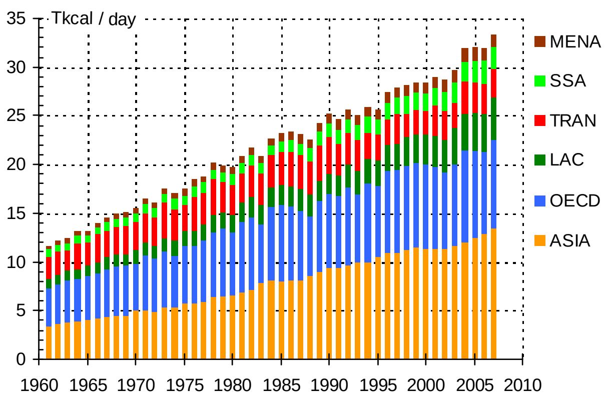


Figure 4. Production of plant food (1961-2007)

(a) Production of plant food



(b) Production of plant food per inhabitant

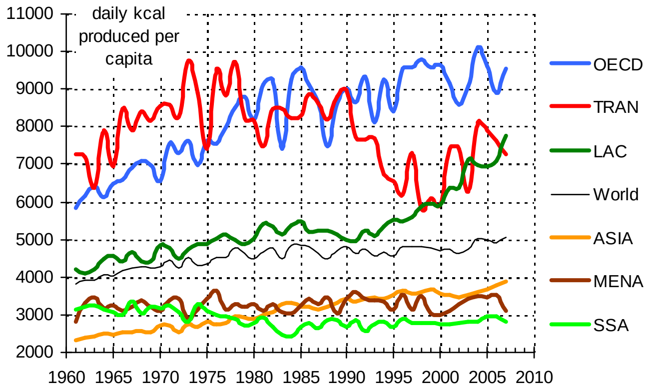
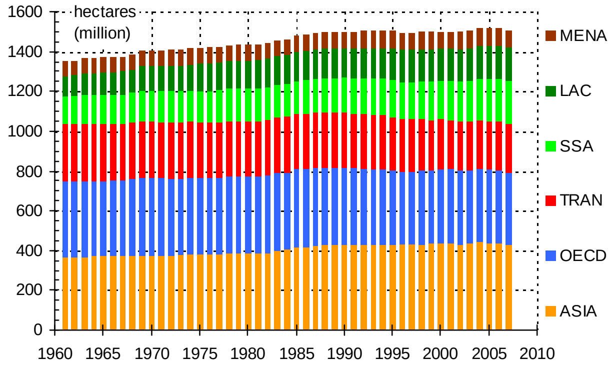


Figure 5. Land productivity (1961-2007)

(a) Cultivated areas



(b) Plant food production per cultivated hectare

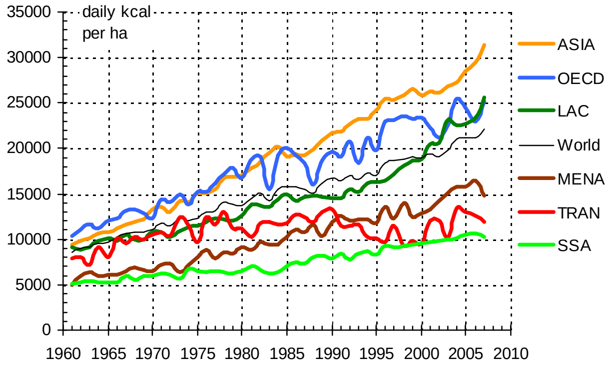
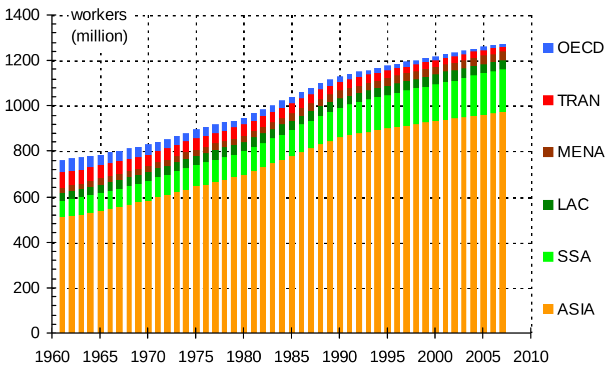
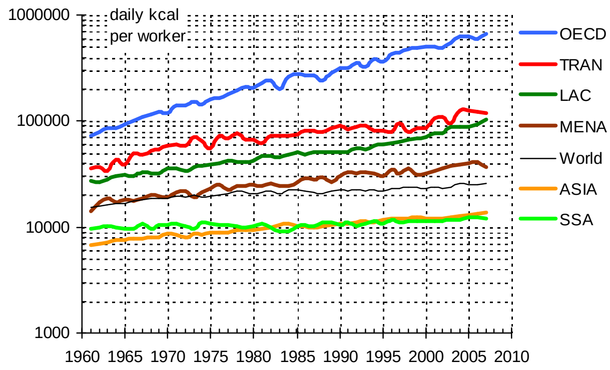


Figure 6. Labour productivity (1961-2007)

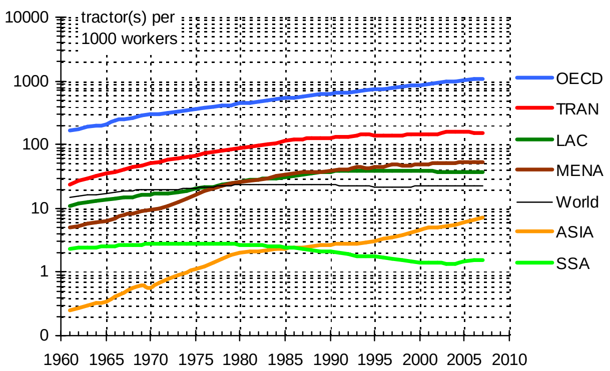
(a) Active Agricultural Workers



(b) Plant food production per worker



(c) Tractors per worker



(d) Agricultural workers in active population

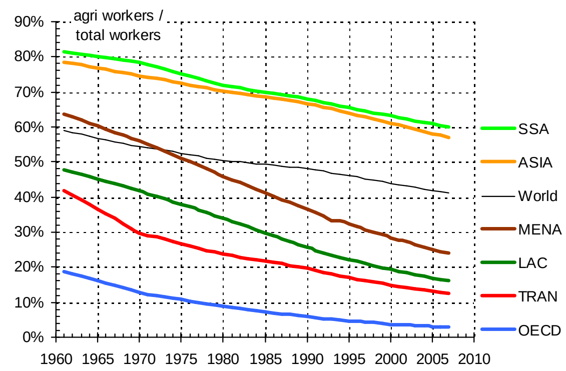
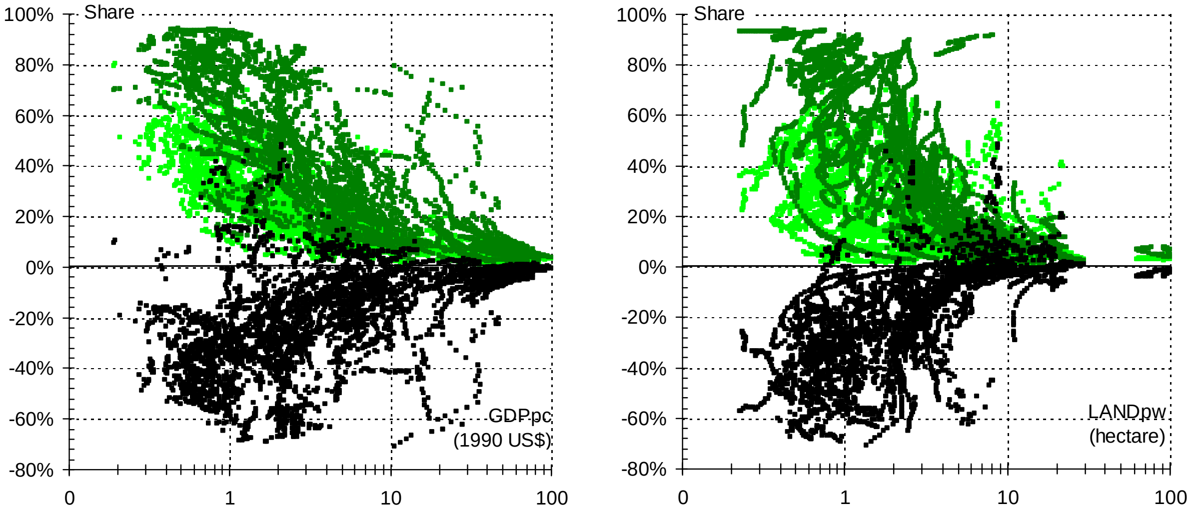


Figure 7. The structural transformation (1970-2007)

(a) Timmer and Akkus's representation (b) Another representation



Figures show all countries from 1970 to 2007 (5020 points without Kuwait and Iceland) and their respective:
■ share of agriculture in total value-added (light green points)
■ share of agriculture in total employment (dark green points)
■ agricultural value-added share minus agricultural employment share (black points): "Timer gap"
according to (a) average value-added per capita (GDPpc in 1990 US$ per day, values between [0.1-100.0])
or (b) average cultivated land per agricultural worker (LANDpw in hectare, values between [0.1-100.0])

(c) Regional pathways (all countries into eight regions)