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POPULATION PRESSURE AND AGRICULTURAL TECHNOLOGICAL CHANGE

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1. Introduction

1.1. Research area and question

One of the fundamental questions in rural development is what makes farmers change their technology. If we believe that the development of agriculture is a key element in economic development, then the study of agricultural technological change should be a central part of development economics as well.

Working in rural development in Thailand and Togo I noticed that two major factors made farmers interested in changing their technology: shortage of arable land and the demand for their products outside their extended family. Since demand is positively related to the population size we might combine these factors into one parameter of population pressure, expressed in Population Per Arable Land (PPAL). This parameter is very attractive because it is easily calculated and, as I will show later, most countries go through a monotonically increasing evolution of PPAL, which allows for comparisons over time and across countries.

1.2. Literature review

Ester Boserup (1965) postulated in her classic work that population pressure causes farmers to invent/adapt new technology. She defined population pressure as population per area, classified countries in groups according to this pressure and compared the agricultural technology between groups. In a later work Boserup (1981) refined her definition by excluding desert, arctic and steep mountainous areas. She shows how countries with high population densities have a more intensive agricultural technology. This hypothesis is supported with more detailed evidence by authors like Pingali, Bigor and Binswanger (1987). In short, the hypothesis states that farmers will adapt to a higher population pressure by changing their technology from extensive systems such as hunting and gathering or forest fallow, towards more intensive systems by shortening and eventually eliminating fallow. This elimination of fallow is compensated for by incorporating animal husbandry and multiple cropping. The hypothesis has, to my knowledge, not yet been formally tested in a neoclassical economic framework, e.g. by including population pressure as a dependent variable in a production function or similar analysis.

Hayami, Ruttan and Southwoth (1979) for example compare the evolution of rice yields in Japan and the Philippines. They plot the yields over time resulting in two parallel, upward sloping lines (fig.1). This graph implies that different countries go through the same evolution at different times, but offers no explanation as to why the yields increase or why they increase at the same rate in different countries. If the same yields are plotted against PPAL then the two lines merge (fig. 2), suggesting that this variant of Boserup's hypothesis could be an important explanatory variable in models of agricultural development.

FIG. 1: EVOLUTION OF RICE YIELD

In Japan and the Philippines

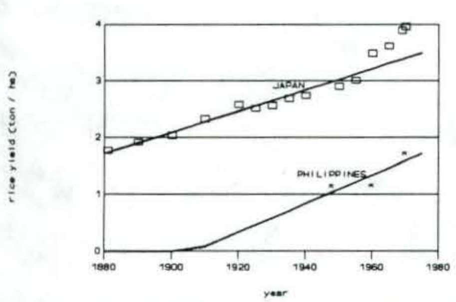
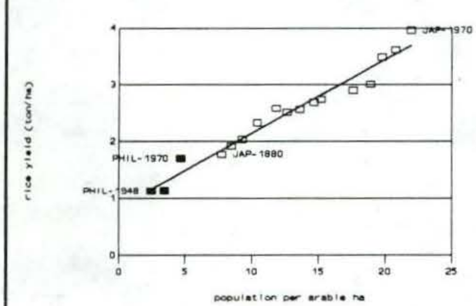


FIG. 2: RICE YIELD & POPULATION PRESSURE

In Japan and the Philippines



Hayami and Ruttan (1985) accept the Boserup hypothesis to help explain the transition from traditional to modern agriculture, but do not let population pressure play a role in later development. They work out the induced innovation hypothesis, which states that changing relative input/output prices induce innovation of technology towards a better use of the scarce factor.

Most authors on agricultural production use time as a variable to measure technological change, see e.g. Capalbo and Antle (1988) for an overview. They usually estimate a production function

$y = f(t,\mathbf{x})$ where $\mathbf{x}$ is a vector of inputs and t is time.

and the rate of technological change is then defined as $\frac{\partial \ln y}{\partial t}$. The basic assumption is that technical change does not requite new inputs and that the production function maintians the same basic form over time, also referred to as disembodied technological change (Chambers, 1988). A critique to this approach is that it does not offer any explanation of the technological change.

1.3. Overview of Data

Population is increasing in almost all countries, noteable exceptions are a few highly industrialized countries (World Bank 1990). At the same time arable land has increased only slightly in most countries, again with the exception of some higly industrialized countries were urbanization is appropriating some arable land (FAO 1980-1989). As a result PPAL increases monotonically over time, with very few exceptions (see Appendix I for more an overview).

1.4. Brief Outline

The purpose of this paper is to explore the possibilities of using PPAL as a parameter in explaining agricultural technological change. A theory will be developed and compared to other approaches in the literature. A production function will then be estimated and the effect of PPAL tested. It will be shown that PPAL has an important impact on the evolution of agricultural technology, and could be very useful in explaining differences between countries and changes over time.

2. Model

2.1. The PPAL hypothesis, formal statement

In an economy with a closed agricultural sector, inelastic demand for its output, growing population and gradual socio-economical change, the technological change in agriculture is driven by the population pressure, expressed as Population Per Arable Land (PPAL).

In the closed economy under consideration here, no trade of output or inputs is alowed. The closed economy requirement specifically excludes areas where large groups of farmers immigrated from areas with higher PPAL, as in the Americas and Australia. There is no reason to assume that immigrant farmers would abandon the technological level reached in their home country. It seems more logical that from the obtained level they would steer the technological evolution in a new direction, adopting to their new environment. Technological change can be seen as having a rachet effect: once obtained it is rarely lost. This does not mean that PPAL does not play a role here, but rather that its effect is structurally different and probably more complicated than in areas without such drastic immigration.

2.2. The Model

The hypothesis will be tested on a production function that allows for a shift of technology influenced by PPAL. To compare the influence of PPAL to that of time both factors have to be included. The general form of the model becomes:

$y = f(PPAL,t,\mathbf{x})$ where y = agricultural output,

t = time, $\mathbf{x}$ = inputs

Arguments can be made to use the lagged values of PPAL or changes in PPAL as explanatory variables. Changes in PALL can be captured by its logarithm. Moreover, they are gradual so lagged values do not add much information.

2.3. Development of the Model

PPAL was choosen to measure population pressure because of its convenience in calculation and the link it forms between alternative approaches. In this section I will show that PPAL is an empirical improvement over Boserup's population density parameter, that under certain assumptions PPAL can be seen as a first order approximation to the input-output price ratio of the induced innovation hypothesis, and that it offers an important extension to the neo-classical approach.

PPAL is not very different from the population pressure on total area as used by Boserup. In certain applications Boserup (1981) excluded desert and arctic areas from the analysis. Non-arable land might have an impact on technological change through hunting and grazing on communal lands, but a developing country's agriculture typically evolves from those activities to crop production, which makes PPAL a more suitable parameter for population pressure.

In a closed agricultural economy, evolving gradually over time and without migration, the major input constraint is land. According to the induced innovation hypothesis the increased price of land w_r relative to the price of output p will induce innovation towards landsaving technology. This price ratio w_r/p is closely related to PPAL by the following theorem.

THEOREM: *In a closed economy with an agricultural production sector and consumers with a linear expenditure function PPAL is related to the ratio w_r/p by the formula*

$$\frac{w_r}{p} = PPAL \ \epsilon_r [\gamma + \frac{\delta}{p}(M - \Sigma_j p_j \gamma_j)]$$

where w_r = rent

p = price of food, p_j = price of other goods

ϵ_r = output elasticiy of land

m = income

γ = food requirement per person

γ_j = miminal needs of other goods j

δ = demand elasticity for food

PROOF: *see Appendix II*

In order to appreciate this theorem we have to specify ϵ_r. I will do this first with a second order approximation, then followed by a first order approximation.

COROLLARY 1: *In a second order approximation to the production function PPAL is related to w_r/p by*

$$PPAL = \frac{w_r}{p}[\alpha_r + \Sigma_j \alpha_{rj} \ln(x_j)][\gamma + \frac{\delta}{p}(m - \Sigma p_j \gamma_j)]$$

PROOF: In a second order approximation the production technology can be described by a translog production function

$$ln(y) = \alpha_0 + \Sigma_i \alpha_i ln(x_i) + 0.5\ \Sigma_i \Sigma_i \alpha_{ij} ln(x_i) ln(x_j)$$

where α_i, $\alpha_{i,j}$ are coefficients

The output elasticities are then given by:

$$\epsilon_i = \alpha_i + \Sigma_j \alpha_{ij} ln(x_j)$$

and the relationship becomes

$$PPAL = \frac{w_r}{p}[\alpha_r + \Sigma_j \alpha_{rj} \ln(x_j)][\gamma + \frac{\delta}{p}(m - \Sigma p_j \gamma_j)]$$

Q.E.D.

COROLLARY 2: *In a closed economy with inelastic demand for food, and with a first order approximation to the agricultural production function PPAL is directly related to w_r/p*

PROOF: In a first order approximation of the technology (Cobb-Douglas production function) the output elasticity ϵ_i is held constant. For an agricultural product with perfectly inelastic demand, $\delta=0$ and

$$w_r/p = PPAL \times Constant$$

or the input/output price ratio is directly related to PPAL

Q.E.D.

Note that in the above proof the functional form of the food demand is not relevant as long as demand is perfectly inelastic.

Following corollary 2 PPAL can be seen as a first order approximation to the input/output price ratio. The advantage of PPAL over price ratios is clear: figures are readily available, cross-sectional data as well as time series, and no adjustments have to be made for different currencies and inflation. Because PPAL can be easily calculated it allows the inclusion in the analysis of countries with little or no developed land market such as most of sub-saharan Africa.

Agriculture includes animal husbandry and forestry, but the products of these sectors do not typically exhibit the inelastic demand necessary for the above theory. Therefore only land in crop production is considered here in the variable T. To allow for extensive agricultural systems fallow has to be included, which makes cultivated land approximately equal to arable land.

The standard approach to measure technological change in the neo-classical production literature is to include a shift variable t for time in the production function $y = f(t,\mathbf{x})$. This time variable captures all unknown factors. Following the above PPAL-hypothesis different countries would be in different stages of PPAL at a given t. Therefore PPAL has to be introduced in the production function, while t can remain to capture the state of technology in the world. Thus the PPAL model is a production function with shift variables time and PPAL:

$$y = f(t, PPAL, \mathbf{x})$$

This approach can be regarded as a synthesis of the previous models: it allows for population pressure to influence technological change as in the Boserup model, it can be seen as a first order approximation to input-output price ratios as in the induced innovation model, and it allows for a change of technology over time as in the neoclassical model. Moreover, the PPAL model allows estimation of the meta-production function.

The meta-production function is described by Hayami and Ruttan (1985) as the envelope of short-term, constant-technology, neo-classical production functions. Their basic assumption is that this envelope approximates the innovation curve and therefore the long-run production function equal to all countries, which can thus be estimated directly on cross-country data. They acknowlegde that the meta-production function shifts over time, but assume that this shift is not important for empirical estimation. Moreover, they hypothesize "that technical advance in agriculture occurs primarily as a result of new economic opportunities created by developments in the nonagricultural sector" (Hayami and Ruttan 1985, p. 137).

The PPAL-hypothesis, in contrast, assumes that shifts in the meta-production function are important and come from within the agricultural sector, or rather the relationship between the output demand in the whole economy with respect to the input constraint in the agricultural sector, expressed in the variable Population Per Arable Land. Therefore the PPAL model can be estimated on pooled time series data of different countries, hereby assuming that these countries go through the same changes of technology according to population pressure per arable land.

2.4. Working Hypothesis

The hypotheses to be tested are

1) $\frac{\partial lny(t,PPAL,x)}{\partial lnPPAL} > 0$ or PPAL has a positive effect on production with other inputs kept constant, implying a technological change

2) $\frac{\partial lny(t,PPAL,x)}{\partial t} = 0$ or if population pressure has been taken into account time has no more effect on agricultural technology. Rejecting this hypothesis, however, does not imply rejecting

the PPAL hypothesis.

2.5. Functional Form

Two specifications will be used:

- the Cobb-Douglas production function, linear in the logarithms and a general first order approximation of any production function (Chambers 1988)
- the translog production function, quadratic in the logarithms and a general second order approximation.

The model will be estimated on pooled cross-country and time series data, hereby taking maximum advantage of the availability of PPAL. Since the error terms of an Ordinary Least Squares estimation of a specific country for different times are unlikely to be independent, a pooled time series approach will be used. The assumptions, to be tested first, are:

- a first order auto-correlation of the error term within countries, between consecutive years
- heteroskedasticity between countries

The model will then be estimated by Feasible Generalized Least Squares.

3. Data

The inputs to be included in the model are chosen those published by the Food and Agriculture Organization, FAO (1980-1989): fertilizers (total in metric ton, $N+P^2O5+K$), agricultural labor, arable land (land in temporary crop production, temporary meadow or fallow, in 1000 ha) and tractors (all types combined).

The FAO does not publish an aggregate variable for agricultural output, apart from indices per country. Therefore Added Value in Agriculture (AVA), published by the World Bank (1990), was chosen as output variable. For the present analysis AVA is converted to constant 1980 dollars using

World Bank indices.

PPAL is expressed as total population per hectare of arable land. Population data are published by the World Bank (1989). To allow for an evolution over time the data for 1978 to 1988 were included. An overview of the data for 1978 and 1988 is shown in Appendix I.

As explained above the Americas and Australia would not fall under the PPAL-hypothesis. Even though the major immigrations took place before the time period under study these regions combine a low PPAL with a high level of technology. Therefore only countries in Europe, Asia and Africa were included in the data set. Complete data were available for about 90 countries. Countries are separated into six regions according to the FAO: North-Africa, Sub-Saharan Africa, Middle-East, Far-East, Western Europe and Eastern-Europe.

4. Analysis

4.1. Cobb-Douglas Production Function

4.1.1. The model

Since the data are pooled time series, adjustments have to be made for auto-correlation among countries and heteroskedasticity between countries. The basic assumption is that all countries face the same production function, except for the intercept which is allowed to shift by region to account for climatological differecnces. All variables are linear in the logarithms except for the variable time which is strictly linear. The error term is assumed to follow a first order auto-regressive process. The variance of the adjusted error term is assumed to be constant within, but varying between countries.

The formal model is as follows (after Kmenta, 1971):

$$ln(y_{it}) = \Sigma_j \delta_j d_j + \alpha_t t + \alpha_p ln(PPAL_{it}) + \Sigma_k \alpha_k ln(x_{kit}) + \epsilon_{it} \qquad (1)$$

$$\epsilon_{it} = \rho\, \epsilon_{i,t-1} + u_{it} \qquad \text{(auto-correlation)}$$

$$u_{it} \sim N(0,\sigma^2_i) \qquad \text{(heteroskedasticity)}$$

$$E(u_{i,t-1}\epsilon_{jt}) = 0 \qquad \forall \quad i,j,t$$

$$\epsilon_{i0} \sim N(0, \frac{\sigma^2_i}{1-\rho^2})$$

where: y_{it} = agricultural output in country i at time t

x_{kit} = agricultural input k in country i at time t

and: $t= 1 \ldots 11$ where 1=1978, 11=1988

i= 90 countries from Europe, Asia and Africa

$k= 1, 2, 3, 4$: fertilizer, labor, land, tractors

d_j= regional dummy variables, j = 1 (N.Africa), 2 (Sub-Saharan Africa, 3 (Middle-East), 4 (Far-East), 5 (E.Europe) and 6 (W.Europe)

4.1.2. Estimation

The parameters are estimated by Feasible Generalized Least Squares, in three steps:

1) OLS estimation of (1), which allows to estimate from the error terms

$$\hat{\rho} = \frac{\Sigma_i \Sigma_t e_{it} e_{i,t-1}}{\Sigma_i \Sigma_t e^2_{i,t-1}} \quad (i=1,2,\ldots N;\ t=2,3,\ldots T) = 0.90$$

2) OLS estimation of (1) on the variables adjusted for auto- correlation:

$$Z^*_{it} = Z_{it} - \rho\, Z_{i,t-1} \qquad \text{where } Z = \text{all var. } Y, X, PPAL, d$$

which allows to estimate for each country i the variance of the error term

$$s^2_{ui} = \frac{1}{T-K-1} \sum_{t=2}^{T} \hat{u}^{*2}_{it}$$

3) Weighted Least Squares estimation of (1) on the adjusted variables, with weight= s_{ui}

The error terms were tested for auto-correlation after the first step, with an ajusted Durbin-Watson test, calculated as:

$$d' = \frac{\Sigma_i \Sigma_t (e_{it} - e_{i,t-1})^2}{\Sigma_i \Sigma_t e^2_{i,t-1}} \quad (i=1,2,\ldots N;\ t=2,3,\ldots T)$$

The calculated value is d'= 0.0564, for Nx(T-1)=642.

For k=11, T=200 the critical values are d_L^*=1.665, d_U^*=1.874

Since d'< d_L^* the hypothesis that the error terms are positively correlated can not be rejected.

The estimated parameters and standard errors are given in table 1. A full model was estimated with results shown in column (1), as well as three shorter models to follow the effect of different specifications: without time (2), without PPAL (3) and without both time and PPAL (4).

4.1.3. Interpretation

The estimated coefficient for *lnPPAL* is 0.61 and significantly larger then zero at the 5% significance level (*t*-value=14.776)[2] . Thus the hypothesis $\frac{\partial \ln y}{\partial \ln PPAL} > 0$ cannot be rejected. If Population Per Arable Land increases by 1%, the production increases by 0.61%, keeping all inputs constant. This means that PPAL influences positively the productivity of the inputs, implying that a shift in technology takes place with increasing population pressure. This provides strong evidence that PPAL is an important factor in agricultural development.

The parameter for time is significantly larger then 0 at the 5% level so the hypothesis $\partial \ln y / \partial t = 0$ has to be rejected (*t*-value=2.97). The coefficient for time is 0.01, meaning that every year the productivity increases by 1% if all other factors stay constant.

It is clear that PPAL can not fully replace time as a shift variable for technology. There seem to be factors that improve technology over time across countries, regardless of the population density. Since the relationship between PPAL and input/output ratios is only constant if the ouput elasticity for land and the demand elasticity for food is constant, it could be that the increase of PPAL over time does not quite reflect the changing price ratios.

A more appealing explanation, however, is that some technological improvements are easily disseminated across borders and adopted, independent of PPAL. Say for example that one country

[2] In this paper a significance level of 5% will be used, unless otherwise specified

develops a technological improvement in inputs, such that its marginal productivity increases more than its marginal cost. An example would be the development of a new insecticide. If there are no additional costs or externalities involved, other countries would replace their old input with this new one. Chemical technology is easily disseminated.

The influence of the parameters time and PPAL can be examined by estimating shorter models without the respective variables. The F-tests for the short models reflect a significant difference, thus the short models are misspecifications (the calculated F-values are respectively 8.8, 218.3 and 126.9).

The effect of dropping time is minimal, as can be seen by comparing columns (1) and (2) in table 1. Although statistically a misspecification, dropping time does not change the estimated coefficients in a meaningful way. Dropping PPAL on the other hand causes major changes as can be seen by comparing column (1) and column (3). Thus estimation of a neoclassical model $y(t,\mathbf{x})$ on cross-country data is a misspecification that results in major errors in coefficient estimates.

Western Europe is the dummy variable dropped in the estimation, so the intercept can be seen as the intercept for Western Europe. The coefficients of the other regions are deviations from this intercept.

Note that the coefficients on the inputs are all between zero and one, the standard errors are relatively small and that the size elasticity is 0.93, with a standard error of 0.022. Thus the estimated parameters are of dimensions acceptable for a Cobb-Douglas production function, according to production theory.

TABLE 1

Estimated Parameters for the Cobb-Douglas Production Function, Corrected for auto-correlation (ρ=0.90) and Heteroskedasticity, Dependent Variable is ln(Added Value in Agriculture), Standard Errors in Parentheses.

	full model	shorter models		
	(1)	(2)	(3)	(4)
Intercept	0.98	0.95	1.71	1.71
	(0.05)	(0.05)	(0.02)	(0.05)
Sub-Saharan Africa	-1.22	-1.12	-1.74	-1.57
	(0.12)	(0.12)	(0.14)	(0.14)
East-Europe	-0.67	-0.46	-1.35	-0.99
	(0.25)	(0.25)	(0.29)	(0.28)
Far-East	-0.57	-0.53	-0.39	-0.30
	(0.11)	(0.11)	(0.13)	(0.13)
Mid-East	-0.66	-0.59	-0.71	-0.57
	(0.14)	(0.14)	(0.16)	(0.16)
North-Africa	-0.82	-0.73	-1.09	-0.94
	(0.12)	(0.12)	(0.13)	(0.13)
time (1978=1)	0.01		0.02	
	(0.00)		(0.00)	
ln(PPAL)	0.61	0.64		
	(0.04)	(0.04)		
ln(fertilizer)	0.03	0.04	0.06	0.06
	(0.01)	(0.01)	(0.01)	(0.01)
ln(land)	0.68	0.70	0.11	0.11
	(0.04)	(0.04)	(0.02)	(0.02)
ln(labor)	0.16	0.15	0.43	0.44
	(0.03)	(0.03)	(0.02)	(0.02)
ln(tractors)	0.06	0.06	0.10	0.11
	(0.01)	(0.01)	(0.02)	(0.02)
R^2	0.87	0.87	0.83	0.82
N	681	681	671	681
Root MSE	0.21	0.21	0.24	0.24

4.2. Translog Production Function

4.2.1. The model

The basic assumptions are maintained. Output is transformed into its logarithm, as are inputs and PPAL. Time and the regional dummy variables are not transformed. The resulting variables are then combined in a quadratic model.

Formally:

$z_{it}' = (e^t, PPAL, x_{1it}, x_{2it}, x_{3it}, x_{4it})$

$ln(y_{it}) = \Sigma_j \delta_j d_j + \alpha_1 ln(z_{it}) + 0.5\ ln(z_{it})' A2 ln(z_{it}) + \epsilon_{it}$ (2)

$\epsilon_{it} = \rho\ \epsilon_{i,t-1} + u_{it}$ (auto-correlation)

u_{it} distributed $N(0, \sigma^2_i)$ (heteroskedastic)

$E(u_{i,t-1}\epsilon_{jt}) = 0$ for all i, j, t

$\epsilon_{i0} \sim N(0, \sigma^2_i/(1-\rho^2))$

where: y_{it} = agricultural output in country i at time t

x_{kit} = agricultural input k in country i at time t

$t = 1 \ldots 11$ where 1=1978, 11=1988

i= 90 countries from Europe, Asia and Africa

$k = 1, 2, 3, 4$: fertilizer, labor, land, tractors

d_j= regional dummy variables, j = 1 (N.Africa), 2 (Sub-Saharan Africa, 3 (Middle-East), 4 (Far-East), 5 (E.Europe) and 6 (W.Europe)

α_1=6x1 vector of the direct effects

$A2$=6x6 matrix of the quadratic (diagonal) and cross effects

4.2.2. Estimation

The parameters were estimated with Feasible Generalized Least Squares, in the 3 steps as described above. The estimates are presented in table 2. Again the error terms in step 1 were tested for auto-correlation, the calculated test statistic was

d'= 0.220

Since d'< d_L^* the hypothesis that the error terms are positively correlated can not be rejected.

4.2.3. Interpretation

The coefficient of $ln(PPAL)$ is positive, and the coefficient on $ln(PPAL)^2$ is negative, both at the 5% significance level. The elasticity ϵ_{PPAL} is a scalar linear function of the parameters:

$$\epsilon_{PPAL} = a_{PPAL} + A_{PPAL,t}t + A_{PPAL,PPAL}ln(PPAL) + A_{PPAL,x1}ln(x_1)$$
$$+ A_{PPAL,x2}ln(x_2) + A_{PPAL,x3}ln(x_3) + A_{PPAL,x4}ln(x_4)$$

$$\epsilon_{PPAL} = \underset{(0.934)}{4.015^*} + \underset{(0.008)}{0.013t} - \underset{(0.039)}{0.139 ln(PPAL)} - \underset{(0.029)}{0.052 ln(fertilizer)}$$
$$+ \underset{(0.042)}{0.194^* ln(labor)} - \underset{(0.075)}{0.135 ln(land)} - \underset{(0.023)}{0.082^* ln(tractors)}$$

The variance of the scalar linear function of the form α'**h**,

$\alpha = (a_{PPAL}\ A_{PPAL,t}\ A_{PPAL,PPAL}\ A_{PPAL,x1}\ A_{PPAL,x2}\ A_{PPAL,x3}\ A_{PPAL,x4})$

$\mathbf{h} = (t\ lnPPAL\ lnx_1\ lnx_2\ lnx_3\ lnx_4)$

can be calculated by $\mathbf{h}'\Sigma\mathbf{h}$, where Σ is the variance-covariance matrix of α (Goldberger, 1991).

The elasticity ϵ_{PPAL} calculated at the data means is 0.83 with a standard error of 0.92. This means that ϵ_{PPAL} is not significantly different from zero and the first hypothesis has to be rejected with this specification of the model. The size of the standard error is partly explained by three non-significant parameters in A_{22} in the formula.

The change of output with respect to time is also not significantly different from zero. A joint hypothesis test that $\alpha_t=A_{tt}=0$ can not be rejected at the 5% level (F-value=1.085 for 2 degrees of freedom). The only coefficients concerning time that are significantly different from zero are $A_{t,x2}$ and $A_{t,PPAL}$.

TABLE 2

Estimated Parameters for a Translog Production Function, Corrected for Auto-correlation (ρ=.90) and Heteroskedasticity, Dependent Variable is ln(Added Value in Agriculture), Standard Errors in Parentheses.

Direct effects:

Dependent variables	parameter	dependent variable	parameter
Intercept	-1.140 *	time	-0.128
	(0.560)		(0.091)
Eastern Europe	-0.611 *	ln(PPAL)	4.015 *
	(0.281)		(0.934)
Middle East	-0.695 *	ln(fertilizer)	0.749 *
	(0.151)		(0.303)
North Africa	-0.700	ln(land)	-1.859 *
	(0.139)		(0.461)
Subsah. Africa	-0.946 *	ln(labor)	2.444 *
	(0.139)		(0.889)
Far East	-0.993 *	ln(land)	0.871 *
	(0.138)		(0.233)

Cross effects: parameters A2

	time	ln(PPAL)	ln(fert.)	ln(land)	ln(labor)	ln(tractors)
time	0.001	0.013	-0.005	-0.018 *	0.016	0.005
	(0.002)	(0.008)	(0.004)	(0.006)	(0.009)	(0.003)
ln(PPAL)		-0.139 *	-0.052	0.194 *	-0.135	-0.082
		(0.039)	(0.029)	(0.042)	(0.075)	(0.023)
ln(fertilizer)			-0.011 *	0.011	-0.082 *	0.047 *
			(0.005)	(0.022)	(0.028)	(0.011)
ln(land)				0.172	0.175 *	0.014
				(0.043)	(0.050)	(0.018)
ln(labor)					-0.100	-0.058 *
					(0.079)	(0.022)
ln(tractors)						-0.010
						(0.009)

R^2=0.916   N=681   MSE=0.022

* different from 0 at the 5% significance level

The coefficients of the dummy variables of North-Africa and the Middle-East are not significantly different from each other at the 5% significance level, and neither are the coefficients for Sub-Saharan Africa and the Far-East (F-value for the joint hypothesis test= 0.88 for 3 degrees of freedom).

4.3. Cobb-Douglas Production Function with Total Grains

A weak point in the above formulation is the correlation between PPAL, the shift variable, and Arable Land, the input in the production function. Thus including PPAL has a substantial influence on the coefficient of Arable Land.

To explore another formulation, Total Grains was used as a dependent variable, and Land Harvested in Grains was used as the land input. Unfortunately the other inputs fertilizer and tractors can not be split up between grains and other crops so they are here assumed to be proportionally divided in all countries. The result of the regression, again after correction for auto-correlation and heteroskedasticity, is given in table 3.

Indeed the inclusion of PPAL does not influence the other parameters as much, and the results support the PPAL-hypothesis. But the coefficients on the inputs labor and tractors are not significantly different from zero, indicating that those aggregate input data are not relevant for a Total Grains production function.

TABLE 3

Estimated Parameters for the Cobb-Douglas Production Function, Corrected for auto-correlation (ρ=0.7) and Heteroskedasticity, Dependent Variable is ln(Total Grains Produced), Standard Errors in Parentheses.

	full model	shorter models		
	(1)	(2)	(3)	(4)
Intercept	-0.65	0.08	-0.59	0.21
	(0.23)	(0.14)	(0.23)	(0.13)
Sub-Saharan Africa	-0.56	-0.62	-0.54	-0.60
	(0.20)	(0.20)	(0.20)	(0.20)
East-Europe	-0.59	0.50	0.60	0.52
	(0.49)	(0.50)	(0.50)	(0.51)
Far-East	-0.22	0.13	-0.21	0.17
	(0.26)	(0.25)	(0.26)	(0.25)
Mid-East	-0.46	-0.39	-0.44	-0.37
	(0.19)	(0.20)	(0.20)	(0.20)
North-Africa	-0.43	-0.35	-0.43	-0.35
	(0.19)	(0.19)	(0.19)	(0.20)
time (1978=1)	0.04	0.05		
	(0.02)	(0.02)		
ln(PPAL)	0.27		0.28	
	(0.07)		(0.07)	
ln(fertilizer)	0.07	0.07	0.07	0.08
	(0.02)	(0.02)	(0.02)	(0.02)
ln(land)	1.07	0.96	1.10	0.99
	(0.07)	(0.06)	(0.07)	(0.06)
ln(labor)	-0.12	-0.09	-0.14	-0.12
	(0.06)	(0.06)	(0.06)	(0.06)
ln(tractors)	0.03	0.05	0.03	0.05
	(0.03)	(0.03)	(0.03)	(0.03)
R^2	0.700	0.686	0.696	0.680
N	373	373	373	373
Root MSE	0.06	0.06	0.06	0.06

5. Summary and Implications

5.1. Findings

The PPAL model $y=f(t, PPAL, \boldsymbol{x})$ is a convenient way to study the effect of population pressure on technological change in agriculture across countries. The coefficients of the Cobb-Douglas production function are all different from zero at the 1% significance level, while the translog specification has many non-significant parameters and larger standard errors for the test statistics of the hypotheses. Therefore the Cobb-Douglas production function is preferred.

It can be concluded that in Europe, Asia and Africa output changes substiantially with increasing population pressure, keeping all inputs constant. It follows that farmers change their technology according to Population per Arable Land, in order to adjust their production to a growing population, facing a limited amount of arable land to take into production.

PPAL, however, cannot fully replace time as a shift variable in the production function. Time has a positive effect on technology apart from increasing population pressure. Hence some factors in technology are transferable independent from PPAL.

5.2. Policy Implications

In general, countries keep up with increased population pressure by increased food production. Facing a limited area of arable land, this is achieved by increasing inputs and improving agricultural technology. A growing population is not a burden on agricultural development but an incentive. This does not mean that occasionally population growth can not outpace the farmers' ability to adjust.

Good development policy, be it from governments or development agencies, should take into account this natural adjustment and create the conditions to facilitate it. Given the effect of PPAL on technological change, estimations of population growth can be used to predict the speed of technological change, and therefore the demand of farmers for new technology or inputs.

Policy implications are especially important for agricultural research stations, infrastructure and education. More precisely, agricultural research stations can be organized to be slightly ahead of the expected demand for technology from farmers and therefore fast to respond. Demand for infrastructure (roads, bridges, markets, etc.) can equally be foreseen and planned for. Similarly agricultural education and extension should follow the predictable demand.

Problems arise when policies do not run parallel to the PPAL-induced technological change. Imports of advanced technology far ahead of the demand are not uncommon. On the other hand, farmers often face problems in accessing the technology they demand, as with government monopolies or import restrictions on inputs.

Finally a policy of importing cheap or subsidized food will decrease the effect of PPAL by artificially reducing the demand for local food products. It decreases the incentive for technological change and will impede agricultural development in the long term.

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APPENDIX I OVERVIEW OF THE DATA

Country_name	Regio	PPAL (pop./ha ar.land)		Added Value Agric ($/ha)		AVA/worker ($/worker		workers/ha	
		1978	1988	1978	1988	1978	1988	1978	1988
SUBSAH. AFRICA									
Benin	1	2.43	3.16	342	471	639	501	0.53	0.94
Botswana	1	0.62	0.84	82	51	372	269	0.22	0.19
Burkina_Faso	1	2.48	2.41	193	233	178	213	1.08	1.09
Burundi	1	3.62	4.60	473	631	298	286	1.59	2.20
Cameroon	1	1.45	1.89	298	447	543	1007	0.55	0.44
Cape_Verde	1	7.53	9.27		850		539	1.47	1.58
Central_African_Rep	1	1.18	1.46	167	185	304	409	0.55	0.45
Chad	1	1.36	1.69	132	143	293	316	0.45	0.45
Comoros	1			0			585		
Congo	1	11.25	14.58	1299	1650	962	528	1.35	3.13
Cote_d'Ivoire	1	4.01	4.79	1307		820		1.59	1.05
Ethiopia	1	2.74	3.50	133	140	168	128	0.79	1.10
Gabon	1	2.54	3.71					0.70	1.17
Gambia	1	3.84	4.70	421	636	292	364	1.44	1.75
Ghana	1	9.65	12.21	7956	7949	3998	3410	1.99	2.33
Guinea_Bissau	1	2.91	3.13	470	406	837	344	0.56	1.18
Kenya	1	8.60	11.93	1087	1379	426	369	2.55	3.74
Lesotho	1	4.45	5.23	403	311	201	156	2.00	1.99
Liberia	1	13.83	18.76	2733		745		3.67	4.98
Madagascar	1	3.37	4.40	439	523	310	351	1.42	1.49
Malawi	1	2.50	3.46	179	196	185	176	0.97	1.11
Mali	1	3.08	3.82	414	471	283	428	1.46	1.10
Mauritania	1	7.67	9.73	928	1223	447	595	2.07	2.06
Mauritius	1	9.33	10.48	1737	1687	1773	1687	0.98	1.00
Mozambique	1	4.03	5.21		395		175	0.89	2.25
Niger	1	1.67	1.94	351		785		0.45	0.84
Nigeria	1	2.90	3.82	928	889	1691	987	0.55	0.90
Rwanda	1	6.60	8.02	611	628	208	172	2.94	3.66
Senegal	1	1.05	1.37	107	145	322	313	0.33	0.46
Seychelles	1	61.60	67.70	8669			0		
Sierra_Leone	1	1.98	2.38	200		380		0.53	0.53
Somalia	1	4.56	5.76	1860	2460	1665	1228	1.12	2.00
South_Africa	1	2.16	2.75	422	463	1794	3204	0.24	0.14
Sudan	1	1.42	1.91	219	202	639	520	0.34	0.39
Swaziland	1	2.78	4.61	588	1002	620	794	0.95	1.26
Tanzania	1	4.27	5.95	472	653	339	275	1.39	2.38
Togo	1	1.81	2.45	208	295	387	430	0.54	0.69
Uganda	1	2.94	3.24	371	269	359	214	1.03	1.26
Zaire	1	3.53	4.64	399	524	324	447	1.23	1.17
Zambia	1	1.05	1.43	118	153	450	451	0.26	0.34
Zimbabwe	1	2.67	3.40	280	326	502	355	0.56	0.92
EASTERN EUROPE									
Hungary	2	2.12	2.10	735	944	4050	7204	0.18	0.13
Poland	2	2.38	2.62					0.42	0.30
Yugoslavia	2	3.05	3.35	1069	1269	1913	3549	0.56	0.36

Country_name	Regio	PPAL (pop./ha ar.land) 1978	PPAL 1988	Added Value Agric ($/ha) 1978	Added Value Agric ($/ha) 1988	AVA/worker ($/worker 1978	AVA/worker 1988	workers/ha 1978	workers/ha 1988
FAR EAST									
Bangladesh	3	9.29	12.09	731	840	270	341	2.70	2.46
China	3	9.81	11.61	1054	1923	384	398	2.74	4.83
India	3	3.99	4.91	365	460	362	365	1.01	1.26
Indonesia	3	10.02	11.07	1158	1510	546	694	2.12	2.17
Japan	3	26.45	29.36	9501		5598		1.70	1.06
Korea_Rep	3	17.78	21.33	5230	6725	1920	2764	2.72	2.43
Malaysia	3	13.27	16.27	5060	7090	2311	3271	2.19	2.17
Nepal	3	6.05	7.75	400	569	152	190	2.64	2.99
Pakistan	3	3.95	5.16	290	439	495	531	0.58	0.83
Philippines	3	10.33	13.12	1657	2121	946	944	1.75	2.25
Singapore	3	1176.50	1319.50	72832	47807	6333	6830	11.50	7.00
Sri_Lanka	3	16.53	17.95	1150	1383	372	395	3.09	3.50
Thailand	3	2.77	3.04	464	565	482	543	0.96	1.04
NORTH AFRICA									
Algeria	4	2.55	3.42	395	581	1354	2938	0.29	0.20
Egypt	4	16.41	21.35	1547	2034	646	851	2.39	2.39
Libya	4	1.59	2.36	262		3588		0.07	0.09
Morocco	4	2.49	2.90	417	612	11858	1814	0.04	0.34
Tunisia	4	1.77	2.36	346	381	1929	1894	0.18	0.20
Cyprus	5	6.00	6.60	1832	2436	1926	3672	0.95	0.66
Israel	5	11.35	12.96					0.30	0.22
Jordan	5	9.40	12.78	638	1090	969	7297	0.66	0.15
Kuwait	5	1223.00	479.75	50213		8369	0	6.00	
Oman	5	68.08	87.63	7339		696		10.54	10.31
Saudi_Arabia	5	8.19	12.63	1207	3613	997	2579	1.21	1.40
Syria	5	1.60	2.36	429	632	2197	4281	0.20	0.15
Turkey	5	1.71	2.17	463	651	1121	1375	0.41	0.47
United_Arab_Emirate	5						20867	1.00	
Yemen_Arab_Republic	5	5.27	6.91	495	783	522	854	0.95	0.92
Yemen_Democratic	5	17.02	21.07	610		227		2.68	1.85
WESTERN EUROPE									
Austria	6	4.88	5.28	2086	2498*	9603	15262*	0.22	0.16
Belgium_&_Luxembour	6	11.39	12.27	3072	4033*	19635	36758*	0.16	0.10
Denmark	6	1.93	2.00	1143	1506*	15985	25898*	0.07	0.06
Finland	6	1.96	2.03	1513	1576*	10940	16598*	0.14	0.09
France	6	3.07	3.06	1528	1823*	12211	21761*	0.13	0.08
Germany_Federal_Rep	6	8.39	8.41	2359	2528*	13156	15075*	0.18	0.16
Greece	6	3.23	3.48	2050	2107*	3917	6042*	0.52	0.34
Iceland	6	28.00	31.13	46360		30906		1.50	1.25
Ireland	6	2.86	3.72					0.23	0.20
Italy	6	5.94	6.31	2506	3093*	8942	14770*	0.28	0.20
Malta	6	27.15	28.75					0.46	0.42
Netherlands	6	16.94	16.36	6671	8705*	17709	31289*	0.38	0.27
Norway	6	5.04	4.88	2624	3073*	16266	21041*	0.16	0.14
Portugal	6	4.64	4.98	986		2004		0.49	0.40
Spain	6	2.35	2.50		1016*		9028*	0.16	0.11
Sweden	6	2.76	2.85	1290	1500*	18975	23947*	0.07	0.06
Switzerland	6	16.85	16.74					0.47	0.38
United_Kingdom	6	8.09	8.23	1312		16313		0.08	0.09

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*Data from 1987

APPENDIX II PROOF OF THE THEOREM

THEOREM: *In a closed economy with an agricultural production sector and consumers with a linear expenditure function PPAL is related to the ratio w_r/p by the formula*

$$\frac{w_r}{p} = PPAL\ \epsilon_r[\gamma + \frac{\delta}{p}(M - \Sigma_j p_j \gamma_j)]$$

PROOF:

Assume all farms face the same production function:

$y = f(\mathbf{x})$ where y = agricultural output,

$\mathbf{x}$ = input bundle

Assume farmer are profit maximizers, then

$p\frac{\partial y}{\partial \mathbf{x}} = \mathbf{w}$ where p = output price

$\mathbf{w}$ = input prices

and $p\frac{y}{\mathbf{x}}\boldsymbol{\epsilon} = \mathbf{w}$ where ϵ = elasticities

Transformation of this first order condition for land gives the farm's supply

$y = w_r x_r \,/\, p\,\epsilon_r$ where r stands for land

If there are N_f identical farms then the aggregate agricultural supply is given by:

$$Q_s = \frac{N_f x_r w_r}{\epsilon_r p}$$

If the utility function is a linear expenditure function the demand for the agricultural good z is

$z^D = \gamma + \delta(m - \Sigma_j p_j)/p$ where p_j = price of other goods j

m = income per person

γ = food requirement per person

δ = demand elasticity for food

If all consumers are identical the aggregate demand becomes

$Q^D = N[\gamma + \delta(m - \Sigma_j p_j \gamma_j)/p]$ where N = population

In equilibrium supply equals demand or $Q^s = Q^D$

$$\frac{N_f x_r w_r}{p\epsilon_r} = N[\gamma + \frac{\delta}{p}(m - \Sigma p_j \gamma_j)]$$

$$\frac{w_r}{p} = \frac{N[\gamma + \frac{\delta}{p}(m - \Sigma_j p_j \gamma_j)]\epsilon_r}{N_f x_r} = \frac{N}{T}\epsilon_r[\gamma + \frac{\delta}{p}(m - \Sigma_j p_j \gamma_j)]$$

where T = cultivated land

Therefore, when there is no idle land, T = arable land and

$$\frac{w_r}{p} = PPAL\ \epsilon_r[\gamma + \frac{\delta}{p}(m - \Sigma_j p_j \gamma_j)]$$

Q.E.D.