TECHNICAL APPENDIX

No mangos in the tundra: spatial heterogeneity in agricultural productivity analysis

by

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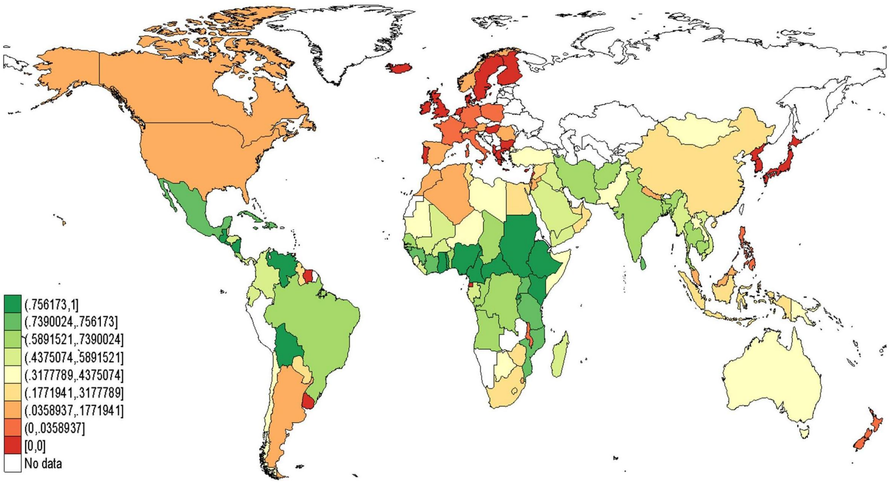
1 Climate Zones

Table 1: Climate Zones following Köppen-Geiger

A	Equatorial climates	Af	Equatorial rainforest, fully humid
		Am	Equatorial monsoon
		As	Equatorial savannah with dry summer
		Aw	Equatorial savannah with dry winter
B	Arid climates	Bs	Steppe climate
		Bw	Desert climate
C	Warm temperate climates	Cf	Warm temperate climate, fully humid
		Cs	Warm temperate climate with dry summer
		Cw	Warm temperate climate with dry winter
D	Snow climates	Df	Snow climate, fully humid
		Ds	Snow climate with dry summer
		Dw	Snow climate with dry winter
E	Polar climates	Ef	Frost climate
		Et	Tundra climate
H	Highland climate		above 2,500m elevation

Notes: This classification is taken from Kottek et al. (2006). The Highland category was added after the creation of the Köppen-Geiger classification, with an elevation cut-off of 2,500m suggested in a number of online databases. The Matthews (1983) data has a marginally different classification where As and Ds are not classified and the two polar climates are combined to a single H category — this results in 12 rather than 15 categories.

Figure 1: Agro-climatic 'distance' — the view from Kenya



Notes: The map provides an illustrative example of the 'agro-climatic distance' measure we discuss in Section III of the main text. We use the share of cultivated land within each of twelve climatic zones (h_{im}) from Matthews (1983), such that for each country i the values in the twelve zones sum up to unity ($\sum_m h_{im} = 1$). The Jaffe measure for 'agro-climatic distance' between countries i and j is then

$$\omega_{ij} = \frac{\sum_m h_{im} h_{jm}}{\left(\sum_m h_{im}^2\right)^{1/2} \left(\sum_m h_{jm}^2\right)^{1/2}}$$

In this example countries marked in green have a similar agro-climatic makeup to Kenya, the reference country, whereas countries in yellow and orange are quite different. Countries marked in red do not share any of Kenya's agro-climatic characteristics. (40% in zone Aw, 19% in zone BS, 17% in zone BW, 25% in zone H).

Table 2: Sample of countries and number of observations

Country	Code	Obs	PWT-Q	FAO-Q	Country	Code	Obs	FAO-Q	FAO-Q
Afghanistan	AFG	40		5%	Cambodia	KHM	33	D	25%
Angola	AGO	40	D	45%	South Korea	KOR	42	B	95%
Albania	ALB	42	C	69%	Kuwait	KWT	24	C	43%
United Arab Emirates	ARE	31	D	23%	Lao PDR	LAO	38	D	52%
Argentina	ARG	42	B	50%	Lebanon	LBN	42	C	13%
Australia	AUS	42	A	100%	Liberia	LBR	30	D	
Austria	AUT	42	A	76%	Libya	LBY	42		15%
Burundi	BDI	37	C	28%	Sri Lankla	LKA	42	C	50%
Benin	BEN	42	C	13%	Lesotho	LSO	42	D	20%
Burkina Faso	BFA	42	C	17%	Morocco	MAR	42	C	56%
Bangladesh	BGD	42	C	5%	Madagascar	MDG	42	C	17%
Bulgaria	BGR	42	C	79%	Mexico	MEX	42	C	21%
Belgium-Luxembourg	BLX	39	A	85%	Mali	MLI	42	C	12%
Belize	BLZ	42	C	36%	Myanmar	MMR	42	D	88%
Bolivia	BOL	42	C	28%	Mongolia	MNG	34	D	80%
Brazil	BRA	42	C	12%	Mozambique	MOZ	42	D	20%
Botswana	BWA	42	C	33%	Mauritania	MRT	33	C	14%
Central African Republic	CAF	42	D	22%	Malawi	MWI	42	C	63%
Canada	CAN	42	A	62%	Malaysia	MYS	42	C	51%
Switzerland	CHE	42	A	17%	Niger	NER	34	D	63%
Chile	CHL	42	B	33%	Nigeria	NGA	42	C	5%
China	CHN	42	C	90%	Nicaragua	NIC	42	C	16%
Côte d'Ivoire	CIV	42	C	27%	Netherlands	NLD	42	A	29%
Cameroon	CMR	42	C	32%	Norway	NOR	42	A	71%
Congo, Republic	COG	41	C	93%	Nepal	NPL	42	C	23%
Colombia	COL	42	C	68%	New Zealand	NZL	42	B	62%
Costa Rica	CRI	42	C	31%	Oman	OMN	30	C	38%
Cuba	CUB	42	D	57%	Pakistan	PAK	42	C	43%
Cyprus	CYP	42	D	50%	Panama	PAN	42	C	13%
Germany	DEU	42	B	93%	Philippines	PHL	42	C	53%
Denmark	DNK	42	A	90%	Papua New Guinea	PNG	42	D	62%
Dominican Republic	DOM	42	C	5%	Poland	POL	42	B	100%
Algeria	DZA	42	D	48%	Korea, DPR	PRK	42		50%
Ecuador	ECU	42	C	33%	Portugal	PRT	42	B	33%
Egypt	EGY	42	C	45%	Paraguay	PRY	42	C	2%
Spain	ESP	42	B	100%	Qatar	QAT	27	C	45%
Ethiopia	ETH	42	C	25%	Romania	ROM	42	C	100%
Finland	FIN	30	A	62%	Rwanda	RWA	34	C	24%
France	FRA	42	A	79%	Saudi Arabia	SAU	42	D	21%
Gabon	GAB	31	C		Sudan	SDN	42	D	21%
United Kingdom	GBR	42	A	76%	Senegal	SEN	42	C	10%
Ghana	GHA	42	C	5%	Sierra Leone	SLE	42	C	35%
Guinea	GIN	41	C	10%	El Salvador	SLV	42	C	9%
Gambia	GMB	39	C	22%	Somalia	SOM	36	D	33%
Guinea-Bissau	GNB	26	D	14%	Suriname	SUR	42	D	14%
Equatorial Guinea	GNQ	19	D		Sweden	SWE	42	A	52%
Greece	GRC	42	B	100%	Swaziland	SWZ	42	C	74%
Guatemala	GTM	42	C	30%	Syria	SYR	42	C	100%
Guyana	GUY	42	D	6%	Chad	TCD	41	D	100%
Honduras	HND	42	C	25%	Togo	TGO	37	D	19%
Haiti	HTI	42	D	8%	Thailand	THA	42	C	45%
Hungary	HUN	42	C	79%	Trinidad & Tobago	TTO	42	C	0%
Indonesia	IDN	42	C	28%	Tunisia	TUN	42	C	33%
India	IND	42	C	83%	Turkey	TUR	42	C	100%
Ireland	IRL	42	A	50%	Tanzania	TZA	42	C	10%
Iran	IRN	42	C	33%	Uganda	UGA	39	D	59%
Iraq	IRQ	42	D	45%	Uruguay	URY	42	B	17%
Iceland	ISL	42	B	79%	United States	USA	42	A	40%
Israel	ISR	42	B	83%	Venezuela	VEN	42	C	71%
Italy	ITA	42	A	100%	Vietnam	VNM	42	C	65%
Jamaica	JAM	42	C	70%	Yemen, Republic	YEM	37	D	15%
Jordan	JOR	42	C	83%	South Africa	ZAF	42	C	60%
Japan	JPN	42	A	85%	Congo, DR	ZAR	41	D	18%
Kenya	KEN	42	C	60%	Zimbabwe	ZWE	42	C	32%

Notes: The full sample contains n=5,162 observations, sample period is from 1961 to 2002. PWT-Q reports a data quality rating for aggregate economy data from the Penn World Table project (Heston, Summers and Aten, 2009), where A denotes a high score and D a low score (http://pwt.econ.upenn.edu/Documentation/append61.pdf, Table A, we report column 11). FAO-Q reports the share of observations for the tractor variable which are not estimated but taken from official publications or international organisations (FAO codes: I, W, Q), which is reported for most FAO observations.

2 Time-series properties of the data

In this section we report results relating to the time-series properties of the data. Since the time dimension of the panel is sizeable (T ranges from 19 to 42, average $T = 40.3$), we first carry out Augmented Dickey-Fuller (Dickey and Fuller, 1979) and KPSS (Kwiatkowski, Phillips, Schmidt and Shin, 1992) tests for the variable series within each individual country.[a] We use this combination of tests since the ADF test has the null of nonstationary variable series, whereas the KPSS test has the null of stationary variable series. The **time-series unit root test** rejection frequencies for variables in *levels* and in *first differences* are shown in Table 3: we report the share of countries (in %) for which the null hypothesis (stationarity or nonstationarity as indicated) is rejected. The theoretical rejection frequencies at our sample size are 12.8% (H_0 : nonstationarity) and 87.2% (H_0 : stationarity) for the 10% significance level we adopted.

Table 3: Time-series unit root tests — rejection frequency

Test			output pw	labour	tractors pw	livestock pw	fertilizer pw	land pw
Testing for levels-stationarity								
ADF without trend	H_0: nonstationary	H_1: levels-stationary	9%	9%	48%	16%	41%	10%
KPSS without trend	H_0: levels-stationary	H_1: nonstationary	82%	91%	81%	85%	70%	82%
Testing for trend-stationarity								
ADF with trend	H_0: nonstationary	H_1: trend-stationary	16%	15%	24%	12%	21%	11%
KPSS with trend	H_0: trend-stationary	H_1: nonstationary	65%	71%	88%	65%	74%	66%
Testing for difference-stationarity								
ADF with drift	H_0: nonstationary	H_1: stationary	94%	16%	48%	88%	78%	67%
KPSS with drift	H_0: stationary	H_1: nonstationary	13%	38%	81%	81%	70%	82%

Notes: All variables are in logs. We report the share of countries (out of $N = 128$) for which the respective unit root test is rejected at the 10% level of significance. All unit root tests for variables in levels contain an intercept term in the estimating equation. ADF refers to the augmented Dickey-Fuller test, which has the null of nonstationarity. KPSS refers to the Kwiatkowski et al. (1992) unit root test, which has the null of (trend-)stationarity. Lag-augmentation or bandwidth selection in these tests to account for serial correlation in the variables is allowed to vary by country. For the ADF test we determined 'ideal' lag-augmentation using the Akaike Information Criterion (AIC). For the KPSS tests an automated bandwidth selection following Newey and West (1994) and discussed in Hobijn et al. (2004) is used. For KPSS we use the `kpss` command in `Stata` written by Kit Baum.

For the majority of countries the ADF tests for the variables in levels cannot reject nonstationarity, with the notable exceptions of tractors per worker and fertilizer per worker. Consistently with this finding the majority of country KPSS tests reject the null of level stationarity. The tests for trend stationarity reveal a similar pattern. The difference stationarity tests show considerable differences across variables: in the ADF tests the labour and tractors per worker variables reject the nonstationarity null in far less countries than we would expect (87.2%) and the KPSS tests reject stationarity in the vast majority of countries for the tractors, livestock, fertilizer and land (all in per worker terms) variables. Our analysis based on standard time-series (non)stationarity tests therefore has no clearcut message regarding variable properties. It needs to be emphasised that country-specific unit root tests suffer from low power, in particular in the case where the persistence in the variable is high — i.e. in the case when the test matters most (Harris, 1994).

Next we apply **'first generation' panel unit root tests** to the data. These were developed due to the desirable property of increased power from pooling the results from many low-powered country unit root tests. It is important to stress that rejection of the unit root null hypothesis does

[a]Whereas the `Stata` command for ADF allows us to run country regressions with gaps in the data, this is not possible for the KPSS tests. We interpolate data in order to run the KPSS for a balanced panel.

not imply that the panel is stationary, but rather that the variable series does not follow a unit root process *in all countries*. Table 4 presents the results for the Maddala and Wu (1999) (MW) panel unit root test and a panel version of the Phillips and Perron (1988) (PP) test, for which serial correlation is accounted for using nonparametric methods rather than lagged differences. Following Fisher's suggestion the MW statistic is constructed as $P = -2\sum_i log(p_i)$, where p_i is the p-value for the individual country ADF statistics. The PP test is constructed in analogy. For both tests the theoretical distribution of the statistic is $\chi^2(2N)$, s.t. critical values are 97.35 for 5% and 92.16 for 10%.

Table 4: First generation panel unit root tests: Fisher test

Maddala & Wu (1999) unit root test

Variables in levels: ADF equation contains intercept												
variable †	**ly**		**lL**		**ltr**		**llive**		**lf**		**ln**	
lags	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
0	264.33	.35	836.91	.00	2776.92	.00	318.88	.00	713.80	.00	202.25	.99
1	248.31	.62	212.39	.98	897.70	.00	269.52	.27	672.69	.00	174.36	1.00
2	216.15	.97	161.97	1.00	716.62	.00	298.71	.03	593.96	.00	185.48	1.00
3	205.40	.99	137.31	1.00	707.83	.00	274.18	.21	561.27	.00	172.74	1.00
4	198.13	1.00	139.56	1.00	614.63	.00	236.64	.80	586.15	.00	252.63	.55
5	217.60	.96	138.40	1.00	663.07	.00	236.17	.81	551.27	.00	189.16	1.00
6	180.78	1.00	140.82	1.00	532.05	.00	219.06	.95	399.06	.00	159.21	1.00
Variables in levels: ADF equation contains intercept & trend												
variable †	**ly**		**lL**		**ltr**		**llive**		**lf**		**ln**	
lags	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
0	473.86	.00	205.02	.99	916.00	.00	272.79	.22	411.14	.00	160.72	1.00
1	322.37	.00	676.49	.00	499.77	.00	326.65	.00	319.24	.00	340.40	.00
2	241.67	.73	293.71	.05	423.53	.00	318.07	.00	256.12	.49	255.62	.50
3	230.43	.87	266.99	.31	335.91	.00	319.78	.00	235.53	.82	269.17	.27
4	224.20	.92	249.02	.61	449.23	.00	286.63	.09	256.61	.48	305.17	.02
5	205.05	.99	254.56	.51	479.71	.00	286.74	.09	313.58	.01	290.07	.07
6	184.29	1.00	230.35	.87	436.98	.00	248.59	.62	190.53	1.00	275.99	.19
Variables in first differences: ADF equation contains drift												
variable ‡	**Δly**		**ΔlL**		**Δltr**		**Δllive**		**Δlf**		**Δln**	
lags	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
0	5893.19	.00	513.12	.00	2092.88	.00	2780.22	.00	5138.24	.00	2408.11	.00
1	2875.38	.00	538.34	.00	1206.83	.00	1561.93	.00	2475.73	.00	1153.82	.00
2	1571.83	.00	414.45	.00	773.43	.00	1052.88	.00	1437.93	.00	806.68	.00
3	1048.43	.00	338.69	.00	603.03	.00	867.15	.00	956.45	.00	616.82	.00
4	779.00	.00	289.06	.08	534.76	.00	669.12	.00	662.53	.00	473.58	.00
5	564.99	.00	312.39	.01	627.47	.00	601.37	.00	517.31	.00	441.97	.00
6	425.31	.00	341.73	.00	534.53	.00	504.60	.00	420.91	.00	426.10	.00

Notes: †Output per worker (lo), labour (lL), tractors per worker (ltr), livestock per worker (llive), fertilizer per worker (lf) and land per worker (ln) — all in logs. ‡The Δ symbolise the growth rates for the above variables (first differences of the variables in logs). The null is nonstationarity in all countries' variable series, the alternative stationarity in *all* countries' variable series.

For both tests tractors per worker and fertilizer per worker in levels reject nonstationarity in both the standard ADF equation and the ADF equation with a trend. All other variables in levels seemingly cannot reject the null of nonstationarity once augmented with sufficient lags or once a trend is added to the ADF equation. For the variables in first differences the tests unanimously reject nonstationarity.

Similarly to the above analysis we cannot definitely reject nonstationarity in all variables. However, as Baltagi, Bresson and Pirotte (2007) point out the first generation panel unit root tests which do not account for cross-section dependence can be subject to considerable size distortions, such that the test tends to overreject. This issue led to the development of **'second**

Table 5: Second generation panel unit root tests

Pesaran (2007) unit root test (CIPS)

Variables in levels: CADF equation contains intercept												
variable †	**ly**		**lL**		**ltr**		**llive**		**lf**		**ln**	
lags	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*
0	-7.19	.00	14.77	1.00	-0.38	.35	2.56	.99	-9.53	.00	12.13	1.00
1	-2.55	.01	11.70	1.00	-3.17	.00	-1.37	.08	-5.23	.00	7.95	1.00
2	-0.78	.22	13.78	1.00	-2.16	.02	-0.96	.17	-2.51	.01	7.94	1.00
3	-0.34	.37	16.22	1.00	-3.37	.00	0.14	.55	0.54	.71	6.33	1.00
4	0.29	.61	17.63	1.00	0.08	.53	3.06	1.00	1.54	.94	7.89	1.00
Variables in levels: CADF equation contains intercept & trend												
variable †	**ly**		**lL**		**ltr**		**llive**		**lf**		**ln**	
lags	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*
0	-2.31	.01	7.90	1.00	3.26	1.00	6.68	1.00	-9.31	.00	9.69	1.00
1	2.94	1.00	-0.82	.20	-1.09	.14	1.80	.96	-5.61	.00	1.70	.96
2	5.85	1.00	5.24	1.00	-0.59	.28	2.74	1.00	-2.33	.01	0.71	.76
3	7.15	1.00	8.98	1.00	-0.17	.43	4.51	1.00	0.63	.74	-0.07	.47
4	7.38	1.00	10.17	1.00	0.42	.66	6.97	1.00	1.90	.97	0.59	.72
Variables in first differences: CADF equation contains drift												
variable ‡	**Δly**		**ΔlL**		**Δltr**		**Δllive**		**Δlf**		**Δln**	
lags	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*	Ztbar	*p*
0	-48.44	.00	-1.37	.09	-32.95	.00	-33.72	.00	-48.55	.00	-28.58	.00
1	-33.63	.00	-0.84	.20	-20.81	.00	-21.62	.00	-35.92	.00	-15.30	.00
2	-20.34	.00	-0.52	.30	-14.15	.00	-13.72	.00	-25.44	.00	-7.51	.00
3	-14.30	.00	1.84	.97	-8.11	.00	-8.41	.00	-16.36	.00	-4.64	.00
4	-7.54	.00	3.41	1.00	-4.26	.00	-4.01	.00	-10.44	.00	-0.92	.18

Notes: †Output per worker (ly), labour (lL), tractors per worker (ltr), livestock per worker (llive), fertilizer per worker (lf) and land per worker (ln) — all in logs. ‡Δ symbolises the growth rates for the above variables (first differences of the variables in logs). The null is nonstationarity in all countries' variable series, the alternative stationarity in *some* countries' variable series.

generation' panel unit root tests, namely the Pesaran (2007) and Pesaran, Smith and Yamagata (2009) tests, results for which are presented in Tables 5 and 6. These tests explicitly allow for cross-sectional dependence in the data and therefore have better performance than the 'classic' panel unit root tests that assume cross-sectional independence. The former can only account for a single unobserved common factor as the cause for cross-sectional dependence in the data. The more recent extension of this test (CIPSM) can accommodate **multiple unobserved common factor**s, which is achieved by further augmenting the Dickey-Fuller equation with the lagged cross-section average and (in the ADF case) additional lagged growth term(s) of an additional regressor x.[b] The intuition is that there exists a number of macro variables which are simultaneously affected by the set of unobserved common factors.

Our CIPS results provide a more consistent theme across the different variables and specifications: following augmentation with lags or a linear trend term the levels variables cannot reject the null of nonstationarity. For the variables in first differences all variables reject nonstationarity with the exception of labour.

We conduct the CIPSM test for up to 4 lags, using one or two X variables. As the unbalanced nature of our panel is primarily driven by the availability of fertilizer data, we exclude this variable from the analysis. For the remaining variables we have $N = 126$ for labour, output per worker, livestock per worker and tractors per worker and $N = 125$ for land per worker. The results are generally in line with our previous findings of nonstationary input and output series.

[b]These tests were carried out in `Gauss` using code provided by Takashi Yamagata — see Hashem Pesaran's personal website at Cambridge.

Table 6: Panel unit root tests for multifactor errors

Pesaran, Smith & Yamagata (2009) Panel Unit Root Test (CIPSM*)

Variable	**output pw**	**labour**	**tractors pw**	**livestock pw**	**land pw**	**Crit. values**	
X	labour	output pw	output pw	output pw	output pw	5%	1%
No lags	-2.785**	-1.010	-2.081	-1.733	-1.368	-2.31	-2.44
1 lag	-2.351*	-2.192	-2.330*	-2.116	-1.922	-2.30	-2.43
2 lags	-2.015	-1.666	-2.226*	-1.969	-1.875	-2.22	-2.35
3 lags	-1.778	-1.549	-2.035	-1.850	-1.903	-2.19	-2.33
4 lags	-1.548	-1.494	-1.958	-1.715	-1.886	-2.11	-2.23

Variable	**output pw**	**labour**	**tractors pw**	**livestock pw**	**land pw**	**Crit. values**	
X_1	labour	output pw	output pw	output pw	output pw	5%	1%
X_2	livestock pw	livestock pw	labour	tractors pw	livestock pw		
No lags	-3.014**	-1.275	-2.056	-1.736	-1.389	-2.53	-2.66
1 lag	-2.538*	-2.307	-2.307	-2.107	-1.783	-2.47	-2.61
2 lags	-2.181	-1.646	-2.182	-1.952	-1.661	-2.37	-2.50
3 lags	-1.964	-1.345	-1.986	-1.850	-1.686	-2.29	-2.44
4 lags	-1.558	-1.453	-1.914	-1.726	-1.649	-2.16	-2.31

Variable	**Δoutput pw**	**Δlabour**	**Δtractors pw**	**Δlivest pw**	**Δland pw**	**Crit. values**	
X	Δlabour	Δoutput pw	Δoutput pw	Δoutput pw	Δoutput pw	5%	1%
No lags	-5.900**	-1.992	-4.141**	-4.264**	-3.789**	-2.32	-2.44
1 lag	-4.456**	-2.056	-3.205**	-3.297**	-2.810**	-2.30	-2.43
2 lags	-3.319**	-1.698	-2.717**	-2.737**	-2.223*	-2.22	-2.35
3 lags	-2.736**	-1.423	-2.361**	-2.377**	-1.959	-2.19	-2.33
4 lags	-2.088	-1.274	-1.936	-1.892	-1.594	-2.11	-2.23

Variable	**Δoutput pw**	**Δlabour**	**Δtractors pw**	**Δlivest pw**	**Δland pw**	**Crit. values**	
X_1	Δlabour	Δoutput pw	Δoutput pw	Δoutput pw	Δoutput pw	5%	1%
X_2	Δlive pw	Δlive pw	Δlabour	Δtractors pw	Δlive pw		
No lags	-5.818**	-2.300	-4.114**	-4.265**	-3.675**	-2.53	-2.66
1 lag	-4.271**	-2.165	-3.141**	-3.289**	-2.726**	-2.47	-2.61
2 lags	-3.081**	-1.850	-2.656**	-2.734**	-1.941	-2.37	-2.50
3 lags	-2.556**	-1.480	-2.297*	-2.342*	-1.630	-2.29	-2.44
4 lags	-1.927	-1.390	-1.840	-1.807	-1.317	-2.16	-2.31
Countries (N)	125	125	125	125	125		

Notes: * and ** indicate statistical significance at the 5% and 1% level respectively. In all cases we present the 'trucated' version of the test statistic. Truncation is done for $CADFM_i$ in such a way that when $CADF_i < k1$, $CADF_i = k_1$ and when $CADF_i > k_2$, $CADF_i = k_2$,where $k_1 = -6.65$ and $k_2 = 2.57$. The null hypothesis is nonstationarity in all country series, the alternative stationarity in at least one country series. Critical values are nonstandard and taken from the respective tables in Pesaran et al. (2009). Tests were conducted using the `Gauss` code written by Takeshi Yamagata — see Hashem Pesaran's website for details.

3 Cross-section dependence in the data

In this section we investigate the potential for cross-section dependence in the data. We initially focus on the full sample 'global' data ($N = 128$, average $T = 40.3$ for the variables in levels). Table 7 details the share of the variance accounted for by the first two principal components (PCs) to indicate the factor structure of the data, as suggested by Coakley, Fuertes and Smith (2006). In principal component analysis (PCA) the eigenvalues (ordered by magnitude) over the cumulated eigenvalues give an indication of the variance in the standardized data explained by the different 'principal components'. The latter are linear combinations of the $N(N-1)$ data time-series to account for the maximum variation in the overall dataset. In Panel [a] we apply this method to the variables in levels (log) and find that the first two principal components account for 76-93% of the variance. We also investigate whether the residuals from pooled OLS ($\hat{e}^{POLS^*}$) and 2-way Fixed Effects ($\hat{e}^{2FE^*}$) regressions[c] show signs of factor structures. Again the

[c]These are production function regressions as outlined in the main section of the paper.

share of the first two PCs is very high, around 65% in both cases. In Panel [b] we carry out the same analysis for the variables in first differences (for the residuals the production function OLS and 2FE regressions are run with variables in first differences); the explained variance is now considerably lower, although labour force growth (dlL) and growth in tractors per worker (dltr) still exhibit strong underlying factor structures.

Table 7: Cross-section Dependence (i)

Principal Component Analysis
Share of variance (in %) accounted for by the first two Principal Components

Panel [a]	**Variables in levels**†						**Residuals**‡	
	ly	lL	ltr	llive	lf*	ln	$\hat{e}^{POLS^*}$	$\hat{e}^{2FE^*}$
%V Comp1	66.8	83.2	75.0	59.4	62.8	67.5	48.3	44.5
%V Comp2	11.5	9.5	15.0	17.0	13.8	16.0	16.8	20.3
sum	78.4	92.7	90.0	76.3	76.7	83.5	65.1	64.8
Panel [b]	**Variables in first differences**†						**Residuals**‡	
	Δly*	ΔlL*	Δltr*	Δllive*	Δlf*	Δln*	$\hat{e}^{FD-OLS^*}$	$\hat{e}^{FD2FE^*}$
%V Comp1	12.03	28.6	29.7	10.7	15.4	13.8	12.5	12.3
%V Comp2	5.97	22.3	11.9	7.4	8.9	10.5	6.1	7.6
sum	18.0	50.9	41.6	18.0	24.3	24.2	18.6	19.9
N	127	127	127	126	128	126	128	128
excluded	FIN	FIN	FIN	BLX,FIN	-	BLX,FIN	-	-

Notes: †Output per worker (ly), labour (lL), tractors per worker (ltr), livestock per worker (llive), fertilizer per worker (lf) and land per worker (ln) — all in logs. Δ identifies data in first differences. ‡These are the residuals from a pooled OLS regression with $T-1$ year dummies (POLS), the 2-way Fixed Effects regression (2FE), the pooled OLS regression with variables (and year dummies) in first differences (FD-OLS) and the 2-way Fixed Effects regression with variables in first differences (FD2FE). *This indicates that the variable had to be interpolated since there were not enough common years of data across all countries to carry out PCA. Otherwise we excluded some countries from the analysis as indicated.

In Table 8 we report the means for the $N(N-1)$ correlation coefficients for variable series or regression residuals, as well as the Pesaran (2004) Cross-Section Dependence (CD) test statistics. The former represents the simple average of the pairwise correlation coefficients between all country series ($\hat{\rho}_{ij}$) or the average of their absolute values ($|\hat{\rho}_{ij}|$). The CD test statistic is also based on the mean pairwise correlation coefficients. In the unbalanced panel case it is defined as

$$CD = \sqrt{\left(\frac{2}{N(N-1)}\right)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\sqrt{T_{ij}}\hat{\rho}_{ij}\right)$$

were T_{ij} is the number of observations used to estimate the correlation coefficient between the series in country i and j and $CD \sim N(0,1)$ for $T_{ij} > 3$ and sufficiently large N under the null of cross-section independence. This test is robust to the presence of nonstationary processes, parameter heterogeneity or structural breaks, and was shown to perform well even in small samples (Moscone and Tosetti, 2009). For the analysis of regression residuals in the main section of the paper we also compute two alternative CD-tests, defined as

$$CD_{LM} = \sqrt{\left(\frac{1}{N(N-1)}\right)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}T_{ij}\hat{\rho}_{ij}^2 - 1\right)$$

$$CD_Z = \sqrt{\left(\frac{2(T-3)}{N(N-1)}\right)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}Z_{ij}\right) \qquad Z_{ij} = 0.5\,ln\left(\frac{1+\hat{\rho}_{ij}}{1-\hat{\rho}_{ij}}\right)$$

which were suggested by Frees (1995) and Moscone and Tosetti (2009) respectively. Under the null of cross-section independence these test statistics also converge to a standard normal distribution as in the Pesaran (2004) CD case.[d]

Table 8: Cross-section Dependence (ii)

Mean Correlation Coefficients and Pesaran (2004) CD test♯

Panel [a]			**Variables in levels†**				**Residuals‡**	
	ly	lL	ltr	llive	lf	ln	$\hat{e}^{POLS}$	$\hat{e}^{2FE}$
$(N(N-1))^{-1}\sum_i \sum_j \hat{\rho}_{ij}$	0.372	0.100	0.532	0.125	0.458	-0.007	-0.005	0.015
$(N(N-1))^{-1}\sum_i \sum_j \hat{\rho}_{ij}$	0.611	0.799	0.699	0.561	0.544	0.645	0.424	0.408
Pesaran CD Statistic							-2.49	9.64
Panel [b]			**Variables in first differences†**				**Residuals‡**	
	dly	dlL	dltr	dllive	dlf	dln	$\hat{e}^{FD-OLS}$	$\hat{e}^{FD2FE}$
$(N(N-1))^{-1}\sum_i \sum_j \hat{\rho}_{ij}$	0.021	0.053	0.210	0.020	0.051	0.008	0.000	0.023
$(N(N-1))^{-1}\sum_i \sum_j \hat{\rho}_{ij}$	0.141	0.351	0.276	0.144	0.147	0.172	0.145	0.149
Pesaran CD Statistic							0.04	12.84
Panel [c]			**AR regression residuals♮**				**Residuals‡**	
	$\hat{e}^{ly}$	$\hat{e}^{lL}$	$\hat{e}^{ltr}$	$\hat{e}^{llive}$	$\hat{e}^{lf}$	$\hat{e}^{ln}$	$\hat{e}^{MG}$	$\hat{e}^{CCEMG}$
$(N(N-1))^{-1}\sum_i \sum_j \hat{\rho}_{ij}$	0.020	0.075	0.012	0.013	0.025	0.008	0.017	0.001
$(N(N-1))^{-1}\sum_i \sum_j \hat{\rho}_{ij}$	0.137	0.301	0.143	0.134	0.143	0.141	0.147	0.150
Pesaran CD Statistic	11.52	42.23	7.02	7.47	14.63	4.36	9.16	0.06

Notes: †Variables as defined in Table 8. ‡These are the residuals from a pooled OLS regression with $T-1$ year dummies (POLS), the 2-way Fixed Effects regression (2FE), individual country regressions with intercept and linear trend (MG) and from the Pesaran (2006) Common Correlated Effects MG estimator (CCEMG) — unrestricted models. ♮ Each of the variables in levels is entered into a regression $z_{it} = \pi_{1,i}z_{i,t-1} + \pi_{2,i}z_{i,t-2} + \pi_{t,i}t + \pi_{0,i}$, conducted separately for each country i. The correlations and cross-section dependence statistic are then based on the residuals from these AR regressions. ♯ $\hat{\rho}_{ij}$ where $i \neq j$ refers to the correlation coefficient for the variable/residuals in question between countries i and j. $|\hat{\rho}_{ij}|$ is the absolute value of the same statistic. The construction of the CD test statistic (for unbalanced panels) is described in the main text. Note that we adjusted the residual series for each i by subtracting their mean for the period T_{ij} since they may not sum to zero otherwise (Pesaran, 2004, p.17). For $N \to \infty$ the CD statistic is distributed standard normal under the null of cross-section independence.

Panel [a] of Table 8 again investigates the variable series in levels and residuals from the pooled OLS and 2FE regressions. Average correlation varies considerably across the variables, from .53 in the case of tractors per worker (ltr) to virtually no correlation in land per worker (ln). Average correlation is low for the regression residuals, however the CD statistic rejects the null of cross-section independence at $p < .01$ in both cases. This result emphasises the importance of parameter heterogeneity (in the presence of nonstationarity): if production function parameters and the influence of the unobserved common factor(s) were *identical* across countries the $2FE$ transformation should be able to eliminate all the cross-section dependence in the data (Coakley et al., 2006). This is seemingly not the case here.

Panel [b] shows the average correlations for the data in first differences and the CD statistic for residuals from OLS and 2FE regressions with the data in first differences. A similar pattern to the PCA results emerges, in that the average correlations are considerably lower than in the levels case in panel [a]. The CD test cannot reject cross-section independence for the FD-OLS residuals (CD=0.04) — recall that this regression includes $T-1$ year dummies which seem to capture the average impact of the unobserved common factor(s) across countries. In contrast the residuals from the 2FE regression with data in first differences (*after* the 2FE transformation) display cross-section dependence.

Finally, we follow Pesaran (2004) and run autoregressions for each variable in each country. Panel [c] reports CD statistics and the mean correlations across countries for the residuals ($\hat{e}_{it}$) from an AR(2) regression defined $z_{it} = \pi_{1,i}z_{i,t-1} + \pi_{2,i}z_{i,t-2} + \pi_{t,i}t + \pi_{0,i} + e_{it}$. We also report these statistics for the residuals from individual country regressions ($\hat{e}^{MG}$) and the Pesaran (2006)

[d] Note that we do not report these results as they match those from the CD tests quite closely.

Common Correlated Effects country regressions ($\hat{e}^{CCEMG}$) — again, these are the production functions discussed in the main section. The AR regression and country regression residual series fail the test for cross-section independence since these regressions do not account for the impact of unobserved common factors. In contrast we cannot reject cross-section independence for the CCEMG residuals (CD=0.06).

In summary, the investigation of the full sample offers strong evidence of cross-section dependence in the variable series studied. The basic assumption of the standard panel estimators that data is cross-sectionally independent is therefore violated. We can see this in our analysis of the regression residuals from the pooled OLS and 2-way Fixed Effects estimators, as well as the individual country regressions (MG).

4 Additional tables and figures

Table 9: Dynamic specification — Pooled regressions (CRS imposed)

	[1]	[2]	[3]	[4]	[5]	[6]
	POLS$^{\diamondsuit}$	**2FE**$^{\natural}$	**CCEP**	**CCEP**	**CCEP**	**CCEP**
weight matrix‡			none	neighbour	distance	agro-climate
long-run coefficients$^{\flat}$						
tractors pw	0.118	0.076	0.112	0.110	0.074	0.090
	[2.09]*	[5.58]**	[7.21]**	[7.77]**	[5.60]**	[6.17]**
livestock pw	0.224	0.402	0.337	0.283	0.313	0.403
	[2.77]**	[11.30]**	[10.51]**	[6.51]**	[9.58]**	[10.82]**
fertilizer pw	0.322	0.083	0.042	0.086	0.049	0.041
	[5.07]**	[8.09]**	[5.85]**	[8.31]**	[7.39]**	[5.64]**
land pw	0.238	0.314	0.323	0.241	0.342	0.357
	[2.56]*	[7.95]**	[5.34]**	[3.98]**	[5.95]**	[5.35]**
Implied β_L	0.098	0.125	0.186	0.280	0.222	0.109
Observations	5,013	5,013	5,013	5,013	5,013	5,013
order of integration †	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
Mean $\lvert\rho_{ij}\rvert$	0.14	0.15	0.17	0.16	0.17	0.17
CD statistic (p)‡	-0.16 (.86)	5.32 (.00)	-0.94 (.35)	6.57 (.00)	0.59 (.56)	-1.31 (.19)

Notes: Dependent variable: [1] & [3]-[6] growth rate of output per worker, [2] dto. in 2FE transformation. See Table 1 in the main section for details on the diagnostic tests. $\diamondsuit$ We include $T-1$ year dummies in [1].

Table 10: Dynamic Specification — MG-type estimators (unrestricted RS)

	[1]	[2]	[3]	[4]	[5]
	MG	**CCEMG**	**CCEMG**	**CCEMG**	**CCEMG**
weight matrix$^{\sharp}$		none	neighbour	distance	agro-climate
long-run coefficients					
labour	-0.578	-0.082	-0.221	-0.280	-0.161
	[2.87]**	[0.48]	[1.33]	[1.60]	[0.91]
tractors pw	0.035	0.086	0.056	0.051	0.064
	[1.22]	[2.64]**	[1.72]	[1.68]	[1.58]
livestock pw	0.250	0.250	0.309	0.316	0.284
	[6.36]**	[6.05]**	[6.26]**	[5.89]**	[5.26]**
fertilizer pw	0.056	0.057	0.043	0.058	0.072
	[5.39]**	[5.56]**	[3.87]**	[5.15]**	[6.42]**
land pw	0.208	0.197	0.146	-0.009	0.211
	[1.98]*	[1.97]	[1.43]	[0.08]	[2.16]*
implied β_L	-0.126	0.329	0.225	0.304	0.210
order of integration †	I(0)	I(0)	I(0)	I(0)	I(0)
Mean ρ_{ij}, $\lvert\rho_{ij}\rvert$ ‡	0.00, 0.14	0.00, 0.17	0.00, 0.15	0.00, 0.15	0.00, 0.15
CD statistic (p)	8.44 (.00)	-2.02 (.04)	0.75 (.46)	-0.54 (.59)	-1.10 (.27)

Notes: The values in square brackets are absolute t-statistics of the estimates, based on standard errors computed from the lagged levels estimates using the Delta method (Pesaran and Smith, 1995). * and ** indicate statistical significance at the 5% and 1% level respectively. $\diamond$ In the interest of space we omitted the MG estimates for the intercept. Residuals tested are those from the ECM regressions for each country. For the diagnostic tests refer to Table 2 in the main section for more details.

Table 11: Dynamic Specification — MG-type estimators (CRS imposed)

	[1]	[2]	[3]	[4]	[5]
	MG$^{\diamond}$	**CCEMG**	**CCEMG**	**CCEMG**	**CCEMG**
weight matrix$^{\sharp}$		none	neighbour	distance	agro-climate
long-run coefficients					
tractors pw	0.043	0.088	0.067	0.092	0.085
	[1.50]	[3.18]**	[2.11]*	[3.21]**	[2.85]**
livestock pw	0.288	0.307	0.297	0.331	0.327
	[6.97]**	[6.82]**	[6.24]**	[6.34]**	[6.67]**
fertilizer pw	0.046	0.054	0.064	0.069	0.077
	[4.50]**	[4.84]**	[5.59]**	[6.37]**	[6.42]**
land pw	0.188	0.215	0.189	0.124	0.191
	[2.50]*	[2.73]**	[2.62]**	[1.78]	[2.33]*
implied β_L	0.436	0.335	0.383	0.384	0.321
RMSE	0.055	0.044	0.041	0.029	0.039
order of integration †	I(0)	I(0)	I(0)	I(0)	I(0)
Mean ρ_{ij}, $\lvert\rho_{ij}\rvert$ ‡	0.02, 0.14	0.00, 0.16	0.00, 0.15	0.00, 0.15	0.00, 0.15
CD statistic (p)	8.57 (.00)	-1.68 (.09)	1.43 (.15)	-0.80 (.43)	-1.56 (.12)

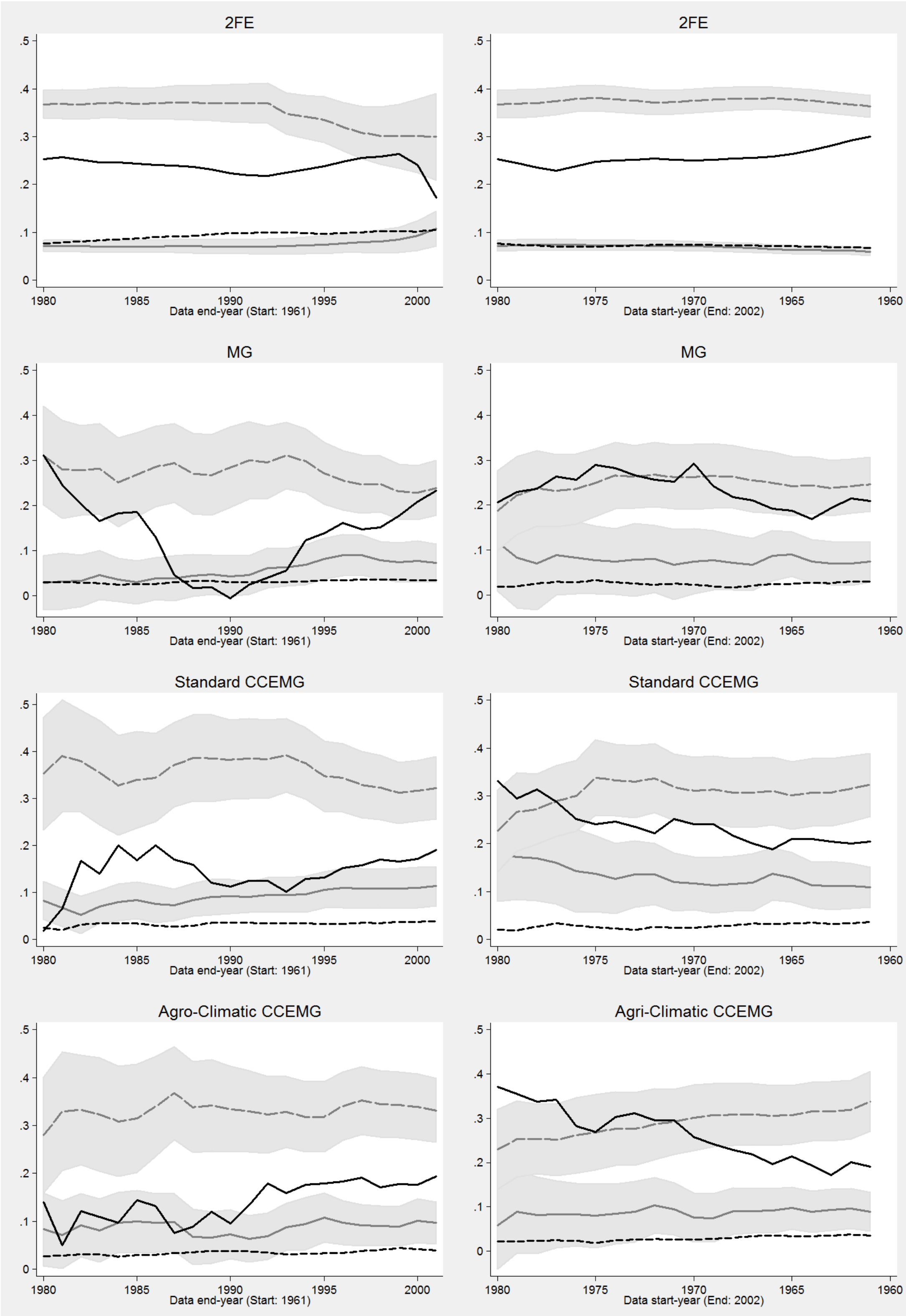
Notes: The values in square brackets are absolute t-statistics of the estimates, based on standard errors computed from the lagged levels estimates using the Delta method (Pesaran and Smith, 1995). * and ** indicate statistical significance at the 5% and 1% level respectively. See Table 10 above for more details.

Table 12: Correlation matrix

Variable averages	$\overline{ly}_i$	$\overline{ltr}_i$	$\overline{llive}_i$	$\overline{lf}_i$	$\overline{ln}_i$	$\hat{\beta}_i^{\text{Tr}}$	$\hat{\beta}_i^{\text{Live}}$	$\hat{\beta}_i^{\text{F}}$	$\hat{\beta}_i^{\text{N}}$
Output pw ($\overline{ly}_i$)	1								
Tractors pw ($\overline{ltr}_i$)	**0.911**	1							
Livestock pw ($\overline{llive}_i$)	**0.816**	**0.738**	1						
Fertilizer pw ($\overline{lf}_i$)	**0.902**	**0.917**	**0.695**	1					
Land pw ($\overline{ln}_i$)	**0.780**	**0.718**	**0.677**	**0.673**	1				
Standard CMG	$\overline{ly}_i$	$\overline{ltr}_i$	$\overline{llive}_i$	$\overline{lf}_i$	$\overline{ln}_i$	$\hat{\beta}_i^{\text{Tr}}$	$\hat{\beta}_i^{\text{Live}}$	$\hat{\beta}_i^{\text{F}}$	$\hat{\beta}_i^{\text{N}}$
$\hat{\beta}_i^{\text{Tr}}$	0.089	0.124	0.052	0.072	0.051	1			
$\hat{\beta}_i^{\text{Live}}$	0.003	-0.015	0.153	-0.051	-0.119	**-0.330**	1		
$\hat{\beta}_i^{\text{F}}$	0.115	0.123	0.075	**0.223**	0.116	-0.067	-0.119	1	
$\hat{\beta}_i^{\text{N}}$	0.105	0.139	0.076	**0.203**	0.108	**-0.203**	0.007	0.124	1
Agri-climatic CMG	$\overline{ly}_i$	$\overline{ltr}_i$	$\overline{llive}_i$	$\overline{lf}_i$	$\overline{ln}_i$	$\hat{\beta}_i^{\text{Tr}}$	$\hat{\beta}_i^{\text{Live}}$	$\hat{\beta}_i^{\text{F}}$	$\hat{\beta}_i^{\text{N}}$
$\hat{\beta}_i^{\text{Tr}}$	0.128	0.138	0.106	0.150	0.008	1			
$\hat{\beta}_i^{\text{Live}}$	0.040	0.024	0.126	-0.047	-0.007	**-0.238**	1		
$\hat{\beta}_i^{\text{F}}$	0.148	0.168	0.100	**0.282**	0.138	-0.002	**-0.218**	1	
$\hat{\beta}_i^{\text{N}}$	0.098	0.125	0.037	0.128	0.145	-0.062	-0.053	0.094	1

Notes: We correlate the country-specific variable series (means) with the standard and agri-climatic CMG technology estimates. Significant coefficients (5% level) are in bold (except for the diagonal). We employ the CRS-based estimates for the standard and agri-climate CCEMG respectively (Table 2, columns [3b] and [5b] in the main text). Coefficient estimates are for 'Tr' tractors, 'Live' livestock, 'F' fertilizer and 'N' land.

Figure 2: Investigating parameter constancy — recursive estimates



Notes: These graphs address the issue of slope parameter constancy over time by estimating each model with an increasing number of observations and plotting the resulting estimates. We plot the robust estimates for the 2FE, MG, standard and agro-climatic CCEMG (preferred specifications wrt returns to scale for each estimator). In the left panel all regressions include data from 1961-1980, the respective graphs then show the parameter estimates where we add one year of data at a time until we reach 2002. In the right panel all regressions include data from 1980-2002, the respective graphs then show the parameter estimates when we add one year at a time at the beginning of the data period, until we reach 1961. Thus in both columns the number of observations increases as we move to the right. In each plot: grey solid line — tractor elasticity, grey dashed line — livestock elasticity; black solid line — land elasticity, black dashed line — fertilizer elasticity. The shaded areas represent the 95% confidence interval for the tractor and livestock estimates respectively.

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