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Abstract

With a modified formalization of Heckscher–Ohlin theory as the basis of a novel econometric specification, this paper uses worldwide data over three decades to estimate how the effects of greater openness on industrialization vary among countries with differing endowments of land relative to labour. The results confirm the theoretical prediction that greater openness reduces manufactured output shares in land-abundant countries, while increasing them in land-scarce countries. The implications of these results for trade and development policy are debatable.

JEL codes: F11, F16, F63, O14
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1. Introduction

A long history of concern (since List, 1841) that greater openness to trade in poorer countries may hinder them from catching up with richer countries intersects with concern (e.g., Sachs & Warner, 1995a) that development may be slowed by natural resource abundance. Matsuyama (1992) shows theoretically how openness could reduce growth in resource-abundant countries by causing them to do less manufacturing. Casual observation also suggests that, during the boom in world trade after 1980, successful development was concentrated on export-oriented countries with few natural resources.

There has been much econometric work on each of these concerns separately (on openness and development surveyed by Winters, 2004 and Harrison & Rodriguez-Clare, 2010, on resources and development surveyed by Smith, 2015 and Venables, 2016), but little on their intersection. This paper's contribution is thus to estimate how the interaction between a country's openness and its resources affects the relative sizes of its manufacturing and primary sectors, using data for 1985, 2000, and 2014 that cover almost all of the world.

Sectoral size is measured by share in GDP, and openness by a synthetic index of the height of trade policy barriers. Total land area – though rarely used – provides an unbiased, exogenous, and statistically powerful measure of a country's natural resources, from which the land–labour ratio is derived by dividing by its adult population. The – apparently novel – specification of the regressions relates the manufactured–primary GDP ratio to the land–labour ratio, openness, and the interaction between them, using a range of methods of estimation.

The theoretically expected negative coefficient on the openness–land–labour ratio interaction is of similar size when estimated across countries and within countries. It is robust to alternative specifications and to the addition of controls, as well as being substantial. For a country of average size and average schooling with a high (top decile) land–labour ratio, manufacturing's share of the value of goods output (primary plus manufactured) would be 11 percentage points lower with a trade policy at the top decile rather than the bottom decile of openness, compared to 18 points higher for a country with a bottom decile land–labour ratio.

From a policy perspective, the implications of these results are debatable. Interaction between land abundance and openness does not appear to have amplified cross-country differences in levels of income. During 1985–2014, however, income growth was inversely related to land abundance, and more strongly so in countries that adopted more open policies. It would now be hard to offset the comparative disadvantage of land-abundant developing countries in manufacturing by sectoral protection, as earlier in some land-abundant developed countries. It also seems doubtful that land-abundant countries could pursue an alternative development path in services, which share with manufacturing much lower land intensity than primary production. Trade and development policies probably should differ between land-scarce and land-abundant countries, but mainly in their intra-sectoral and cross-sectoral specifics.

From an academic perspective, this paper contributes an extra dimension to the application of Heckscher–Ohlin (HO) theory. Many studies have sought to estimate the effects of variation in factor endowments on sectoral structure – usually the structure of trade (e.g., Leamer, 1984; Wood & Berge, 1997; Chor, 2010), but in a few cases, as in this paper, the structure of output (e.g., Harrigan, 1997; Schott, 2003; Wood, 2003; Blum, 2010). Those that have used appropriate specifications have confirmed that factor endowments strongly influence sectoral structure (as illustrated in the worldwide map in Figure A1 of the Appendix).

None of the output structure studies, though, has investigated how the effects of endowments vary with the height of barriers to trade. Their results refer implicitly to outcomes at the average degree of openness of the countries in their data. However, in this paper's modified HO model, which draws on that of Rotunno & Wood (2020), the elasticity of output structure with respect to endowments increases with a country's openness to trade.

The reason is that larger foreign-firm shares of home markets and larger home-firm shares of foreign markets cause demand for a country's outputs to depend more on the higher elasticities of substitution between home and foreign varieties and less on the lower substitution elasticities among goods. Derived demand for factors becomes more elastic, so relative factor prices respond less to variation in endowments. The share of an endowment change that is absorbed by intrasectoral factor-price-induced changes in technique is thus smaller, and the effect of the endowment change on relative sectoral outputs larger, than in a less open country.

This paper offers reduced-form estimates of the effect of openness on the relationship between output structure and factor endowments. Structural estimation of the causal links underlying this effect would require more information on land rents and land use than is available for the range of countries and years covered in this study. Indirect evidence of the links, however, can be derived from the results of Rotunno & Wood (2020), who estimate a similar model, with a different pair of factors, both in reduced form and structurally. They find that, with greater openness to trade, factor prices are less affected by variation in endowments.

As mentioned, the paper adds also to two other bodies of econometric work. First, it contributes to the trade and development literature by interacting an openness measure with endowments (not done in any of the 175 studies reviewed in Harrison & Rodriguez-Clare, 2010). Second, it contributes to the 'resource curse' literature (Smith, 2015) by interacting a broad measure of natural resource abundance with a measure of openness to trade, which can be seen as a generalization of studies of the 'Dutch disease' effects of high-value mineral exports.

In addition, this paper's results contribute to the literature on 'premature deindustrialization', which Rodrik (2016) argues to be a widespread feature of recent development. Haraguchi et al. (2017), by contrast, show that developing countries in aggregate have not deindustrialized. These two seemingly conflicting views are actually consistent, because during the globalization of 1985–2014 manufactured output shares fell in land-abundant developing countries, while rising in (a smaller number of larger) land-scarce developing countries.

Section 2 of the paper outlines the modified version of HO theory. Section 3 describes the data and the specification of the regressions. Section 4 presents the regression results and subjects them to robustness checks. Section 5 assesses their economic significance with counterfactual predictions. Section 6 concludes.

2. Theory: Heckscher and Ohlin reconsidered

Heckscher–Ohlin (HO) theory is of obvious relevance in analysing how the effects of trade on industrialization differ among countries of differing land abundance. Because manufacturing production requires less land relative to labour than primary production, the theory implies that greater openness in countries with above world average endowments of land relative to labour will (over the medium term, and with balanced trade) reduce manufactured output relative to primary sector output. To estimate this relationship, however, requires some modifications to the Heckscher–Ohlin–Samuelson (HOS) formalization of HO theory, which are outlined in this section, with supporting algebra in Smith & Wood (2023).

In the HOS model of a small trading country with two goods and two factors, the causes of variation in the structure of output can be summarized in the notation of Jones (1965) by

$$\hat{q}_M - \hat{q}_A = \frac{1}{(\lambda_{NM} - \lambda_{LM})}(\hat{v}_N - \hat{v}_L) + \sigma\left[\frac{1}{(\lambda_{NM} - \lambda_{LM})(\theta_{NM} - \theta_{NA})} - 1\right](\hat{p}_M - \hat{p}_A) \qquad (1)$$

where q_M and q_A are the outputs of manufactures and primary products, v_N and v_L are supplies of land and labour, and p_M and p_A are the prices of manufactures and primary products (world prices adjusted for trade costs), all expressed in small proportional changes ($\hat{x} = dx/x$). θ_{ij} is the share of factor i in the cost of good j, with the greater land intensity of primary production implying that ($\theta_{NM} - \theta_{NA}$) is negative, λ_{ij} is the share of the supply of factor i used by good j, again with ($\lambda_{NM} - \lambda_{LM}$) negative, and σ is the elasticity of substitution in production between land and labour, assumed for simplicity to be the same within both sectors.

The first right-hand-side (rhs) term specifies the elasticity of the manufactured–primary output ratio with respect to the land–labour ratio. Because manufacturing is less land-intensive than primary production, maintaining full employment of land and labour after a rise in the land–labour ratio requires a fall in the manufactured–primary output ratio. This fall in the output ratio is 'magnified' – i.e., proportionally greater than the change in the land–labour ratio – though less so, the larger is the difference in land intensity between the sectors.

The second rhs term, if world prices are fixed, determines the elasticity of the manufactured–primary output ratio with respect to the height of barriers to trade in manufactures relative to barriers to trade in primary products. For example, increasing tariffs on manufactured imports raises the relative output of manufactures by raising the relative price of manufactures, which raises the wage of labour relative to the rent of land. This change in relative factor prices induces firms to switch to techniques using less labour and more land, reducing the relative

supply of land and requiring a higher manufactured–primary output ratio to keep both factors fully employed.

Equation (1) neatly describes some causal relationships that are highly relevant to the present paper, but appears to provide no basis for the empirical analysis it proposes to undertake. The manufactured-output-reducing effect of greater land abundance in its first term is not increased by greater openness, and the effect on relative output of changes in relative trade barriers in its second term does not depend on the land–labour ratio. The equation thus looks inconsistent with the HO intuition – which will be seen to be empirically well-supported – that a country's manufactured–primary output ratio depends on the interaction between its land–labour ratio and its openness. To incorporate this interaction into the equation requires some rethinking of both its terms.

To generate an interaction in the second term, all that is needed is to recognize that variation in the relative height of barriers to trade in manufactures and primary products typically reflects variation both in countries' openness (defined as the average height of their barriers to trade across all goods) and in the levels of their land–labour ratios relative to the world average. In HO theory, greater openness tends to reduce the amounts that trade barriers add to the prices of imports of goods in which endowments create a comparative disadvantage (and/or to raise the prices received from exports of comparative-advantage goods). So, for example, increases in openness in land-abundant countries usually reduce tariffs mainly on manufactures, but in land-scarce countries mainly on primary products.[1] Extended in this way, the second term of (1) can be labelled the 'endowment-conditioned output-openness elasticity'.

The required modifications to the first term of equation (1) are more substantive. As written, it assumes that in countries that trade internationally – as all do, to some extent – goods prices and factor prices are fixed by world prices, including the costs created by trade barriers. More recent theory, however, recognizes that even for individual countries demand and supply in world markets are less than infinitely elastic. One widely accepted explanation of this inelasticity is qualitative differences – and thus imperfect substitutability – among varieties of the same good produced by different countries (Armington, 1969) or different firms (Krugman, 1979). Another widely accepted explanation is differences in efficiency and location among countries (Eaton & Kortum, 2002) and among firms (Melitz, 2003).

With finite demand elasticities, absorbing a change in the land–labour ratio by a change in the manufactured–primary output ratio requires relative goods prices to change in the opposite direction. In competitive markets, this change in relative goods prices also alters relative factor prices, making the factor whose relative supply has increased relatively cheaper and thus inducing changes in techniques in both sectors to use relatively more of it. This change in

[1] A rise in openness would thus usually make $\hat{p}_M - \hat{p}_A$ in equation (1) negative in a land-abundant country and positive in a land-scarce country. However, for lack of a good way of formalizing theoretically the endowment-conditioned relationship between changes in openness and in relative sectoral trade costs, section 4.2 of Smith & Wood (2023) analyses only the effect of changes in relative sectoral trade costs on output structure.

techniques absorbs part of the change in the land–labour ratio, which reduces the size of the change in the manufactured–primary output ratio that is needed to clear factor markets. The output– endowment elasticity is therefore smaller than in the first term of equation (1).

What creates an interaction in this term is that the effective size of the finite demand elasticities is likely to rise with a country's openness to trade (Rotunno & Wood, 2020). Where lower barriers to imports cause home firms to have smaller shares of the home market, the prices they charge for their varieties have a smaller effect on the average prices of all varieties of the goods concerned, so the relative sales of home varieties of different goods depend more on the higher elasticities of substitution in consumption between foreign and domestic varieties and less on the lower elasticities of substitution among goods. Moreover, lower barriers to exports increase the share of the output of home firms sold in foreign markets, of which they usually have small shares and where their sales depend mainly on the high elasticities of substitution between their varieties and those of their foreign competitors.

For these reasons, the more open a country is to trade – the lower its barriers to importing and exporting – the more do its endowments tend to affect its output structure. In autarky, where the relative prices of goods (and of factors) are governed by domestic supply and demand, only the low elasticity of substitution in consumption between manufactures and primary products would matter, minimizing the response of output structure to changes in the land–labour ratio. By contrast, in a country where trade barriers were so low that home firms had only tiny shares of the home market and sold only tiny shares of their output in the home market, only the high elasticities of substitution between foreign and domestic varieties would matter, maximizing the response of output structure to changes in the land–labour ratio. The modified first term of equation (1) can thus be labelled the 'openness-conditioned output-endowment elasticity'.

Greater openness could affect the output-endowment elasticity in other ways, too, not all in the same direction. More use of imported intermediate inputs would cause changes in a country's relative factor costs to have less effect on the relative prices of its varieties of different goods, reducing the elasticity. Imported input use also widens the gap in local factor intensity between manufacturing and primary sectors, though with an ambiguous effect on the elasticity.[2] Greater openness might reduce the output-endowment elasticity, moreover, by raising the intra-sectoral elasticity of substitution between factors, which depends on induced changes in intra-sectoral product mix as well as in choice of techniques (Schott, 2003). The greater influence of higher elasticities of substitution among varieties, for example, might cause a higher land–labour ratio to raise the relative output of more land-intensive goods within both sectors, and so lessen the relative fall in aggregate manufactured output. On balance, however, greater openness seems likely in theory to increase the output-endowment elasticity.

[2] The wider gap, due to replacing locally supplied intermediate inputs by cheaper or better imported ones, tends to reduce the elasticity, because a given change in endowments can be absorbed by a smaller change in relative output, but also to increase it, because the change in relative goods prices caused by endowment-induced changes in output has less effect on relative factor prices, so less of an endowment change is absorbed intra-sectorally.

In summary, modification of the HOS equation (1) exposes two interactions between the effects of the land–labour ratio and of openness to trade on a country's relative output of manufactured and primary products. One is the openness-conditioned output-endowment elasticity, obtained by extending the first term of (1) to include imperfect substitutability between the varieties of goods made in different countries, which causes relative sectoral outputs to be more responsive to changes in relative endowments in countries that are more open. The other interaction is the endowment-conditioned output-openness elasticity, obtained by extending the second term of equation (1) to include changes in openness (defined as the average height of trade barriers), the direction of whose effect on relative barriers to trade in (and hence relative output of) manufactures and primary products usually depends on whether the land–labour ratio of the country concerned is above or below the world average land–labour ratio.

Estimation needs to allow for other theoretical influences on the manufactured–primary output ratio. Manufacturing and primary production differ not only in land-intensity but also in human capital intensity, so that the manufactured–primary output ratio will vary also with the education of a country's labour force. These two sectors may differ in non-human capital intensity, too, but with less effect on manufactured–primary output ratios because of the international mobility of financial capital. Non-HO theory suggests that, because of external economies of scale in manufacturing, the manufactured–primary output ratio will depend on country size, and also suggests that this output ratio may vary because of non-price influences on domestic demand and uneven access to production technologies.

3. Data and estimation

How the effect of land abundance on industrialisation is conditioned by openness to trade will be addressed empirically by reduced-form estimation of the modified HOS equation.

3.1 Data sources

The data are a panel for three widely separated years (1985, 2000, 2014) of countries with more than 1 million inhabitants in 1990, of which in 2014 there were about 150, containing 99% of the world's population. During the period, some countries divided, for example the USSR and Yugoslavia, so their data are combined – for example, adding up all the countries that emerged from the USSR. Of the resulting 130 'countries', data could be obtained for 125. More details of most of the data used are in the statistical appendix of Wood (2017).

The dependent variable – the manufactured-primary output ratio – is based on sectoral shares of GDP, mainly from the UN National Accounts Main Aggregates database.[3] Manufacturing thus includes processing of primary products as well as production of the goods more narrowly defined as manufactures in trade statistics, while primary production refers only to agriculture (including livestock, forestry, and fishing) and mining.

[3] Supplemented (with difficulty) for mining, which is not distinguished as a separate sector in the Main Aggregates database, using individual-country national accounts data from UN and national sources.

The output ratio combines the value-added content of many manufactured and primary goods, and is measured at current national prices.[4] Changes over time in the output ratio are therefore influenced partly for accounting reasons by changes in the world price of manufactures relative to primary products, which, compared to 1985, was higher in 2000 but lower in 2014, especially relative to fuels and minerals.[5] Variation in internal goods prices among individual countries also affects economic interpretation of the estimated effects of both openness and endowments on the output ratio (as discussed in section 5.2).

A notable feature of the output data, in relation to HO theory, is that complete specialisation of production in one of these broad sectors is not observed, even with extreme land-labour ratios – all countries report some output of both manufactures and primary products. The reasons are that each broad sector contains many goods (with varying land-labour intensities), trade costs (including internal trade and transport costs), and demand inelasticity. For example, it could be profitable for remote regions of a land-scarce country to produce perishable foodstuffs for local consumption. Complete specialisation might also be observed if the data were extended to include small countries (with 1990 populations below 1 million), many of which face serious problems related to sectoral structure, resources and trade (Winters & Martins 2004).

A country's land/labour endowment ratio is measured by its total land area divided by its adult (over-15) population, using data from World Development Indicators. Total land area, though rarely used, has the advantage of being a single measure of natural resources that is potentially relevant to all sorts of primary products (so not a 'specific factor') and is statistically powerful: the correlation across countries between the log of the manufactured-primary output ratio and the log of the ratio of total land area to adult population is -0.47 (Table A2).[6] It also avoids the endogeneity of narrower resource measures – for example, the area of arable land depends on incentives for cultivation, and the size of mineral reserves on capacity for prospecting.

Total land area is clearly not an ideal measure of natural resource availability, because it fails to allow for variation among countries in the characteristics or quality of their land. But it is an unbiased measure, because what each country has, per square kilometre of its surface area, in terms of soil fertility, water resources, minerals, and so on, can be seen as the outcome of a random draw. Earlier attempts to improve on the total land area measure were unsuccessful: data on specific natural resources were useful in explaining the composition of primary exports (for example, the division between agricultural and mineral products), but not in explaining the

[4] There are no PPP data for the sectoral output components of GDP, though estimates for the 42 countries of the Groningen 10-sector database in 2005 are reported in Timmer et al. (2014). The UN database provides constant-price sectoral output data, which would be inappropriate for 'levels' regressions but could have been used in the 'changes' regressions, though they are probably less accurate than the current-price data because of the conceptual difficulty of deflating value added and lack of suitable price indices for many of the countries involved.

[5] Export unit value indices (2005 = 1.00) derived from Table A1 of the WTO's *International Trade Statistics 2015* are in 1985, 2000 and 2014 for agricultural products 0.61, 0.78, and 1.52, for fuels and mining products 0.53, 0.56 and 1.80, and for manufactures (excluding most primary processing activities) 0.58, 0.84 and 1.18.

[6] The usefulness of this simple land-labour measure was first recognised by Keesing & Sherk (1971).

division of exports between manufactures and all primary products together (Wood & Berge 1997, Owens & Wood 1997, Wood & Mayer 1998).

It seems obvious that manufacturing is less natural-resource-intensive than primary production: for example, the Global Trade Analysis Project (GTAP) has estimates of land and resource cost shares only in its agricultural and mining sectors (Hertel et al. 2016). However, there is little direct information on sectoral land-use intensities at the country level.[7] Nor are there readily available data that would allow comparison across countries of rental rates per physical unit of natural resources.[8] Structural estimation of this paper's theoretical model, to complement its reduced-form estimates, would therefore be at best difficult.

The main measure of openness to trade is the 'de jure trade globalisation' index of Gygli et al. (2018), converted to a 0-1 scale, with higher values indicating greater openness.[9] This index is an average of the prevalence of non-tariff barriers (weight about 1/6), compliance costs of exporting and importing (weight about 1/6), income from taxes on international trade as a share of government revenue (weight about 1/3), and the unweighted mean tariff rate (weight about 1/3). It is by no means an ideal measure of the average height of trade policy barriers (Kee et al., 2009), but by comparison with most other composite indices (e.g., Sachs & Warner, 1995b; Wacziarg & Welch, 2008; Kee et al., 2009), it has exceptionally wide coverage of countries and years, albeit achieved partly by interpolation.[10]

This trade policy index is strongly correlated across countries with the quality of trade-related infrastructure and logistics, also influenced by policy.[11] Moreover, it is positively correlated ($R = 0.61$) across countries with their potential foreign market access, measured by the inverse of a GDP-weighted average of their distances from all other countries –which is consistent with evidence of a tendency for lower natural trade barriers to motivate lower policy barriers (Jiao & Wei 2020). It makes no allowance for internal trade costs, including those that are affected by policies. The estimated influence of differences in this index on other variables thus needs to be interpreted carefully from a policy perspective.

Because the trade barriers faced by a country depend on both its own policies and those of other countries, the regressions allow for variation among countries in the policies of their potential

[7] The detailed factor intensity estimates of Shirotori et al. (2010) are inferred from variation across countries in resources and export composition, not calculated from input or cost data. Very few of the applications or tests of HO theory that use independent information on factor intensity cover both natural resource inputs and all traded sectors – the most thorough being Bowen et al. (1987). The environmental accounts of the World Input-Output Database (WIOD) include detailed information, but only on sectoral energy use (and measured in kilojoules).

[8] Sources explored include: the Global Trade Analysis Project, GTAP (rent share of sectoral value added); the International Comparison Program, ICP (housing rents); World Development Indicators (resource rents).

[9] Six country gaps were filled with data for other countries judged to be similar, and the index was aggregated across 'combined' countries (data for Russia alone were used for the former USSR).

[10] Estefania-Flores et al. (2022) is a more recent composite index with exceptionally wide coverage, based on IMF data on exchange arrangements and restrictions.

[11] In 2014, the only one of the three years for which data are available (from World Development Indicators), the correlation across countries between the trade policy index and the quality of trade and transport infrastructure index is $R = 0.75$ (and for the overall logistics performance index 0.77).

trading partners. The trade policy variable for each country is calculated as its own index value multiplied by a weighted average of all other countries' index values, with the weight for each other country being its GDP divided by its distance from the country concerned.[12] The possible alternative of weighting by the amount of trade with each other country (as in Kee et al. 2009's MA-OTRI) would understate average partner policy barriers.

A second openness measure is the residual of the trade-GDP ratio from a regression across all countries of this ratio on two measures of country size – adult population and land area. This adjustment of the ratio lessens the influence on it of variation among countries in the scope for (external) economies of scale in manufacturing and in diversity of natural resources, both of which reduce the need for trade.[13] The trade-GDP data used in this regression are at current national prices and refer to the sum of exports and imports (of goods and services), with 'intra'-trade among 'combined' countries cut out.[14]

A third openness measure (related to section 4 of Smith & Wood 2023) is the weighted average share of foreign firms in all the markets in which a country's firms sell, reflecting the average height of the country's trade barriers. This share can be estimated as a transformation of the export-GDP ratio, x. The weights of home and foreign markets in home-firm sales are $(1 - x)$ and x, respectively. Assuming balanced trade, x is also the share of foreign firms in home consumption, while foreign firms can be assumed to have a near-unity share of foreign market sales, so the required weighted average is[15]

$$(1-x)\times x + x\times 1 = 2x - x^2 \qquad (2)$$

This measure is approximate because of the assumptions mentioned and because x is the ratio of gross exports to the value-added content of output. Calculated with the residual trade-GDP ratio as x, it will be used in the robustness checks as an alternative to the policy index measure of openness.

[12] Own and partner indices are combined into a single openness variable to simplify the econometric specification. The GDP/distance weighting causes the combined index to reflect variation in potential foreign market access as well as in potential partner policies. The logic of multiplication is that a country could then, as in reality, be closed to trade by prohibitive partner policies, even if its own policies were liberal, and could be fully open only if both its own and its partners' policies were liberal. Using a geometric mean instead scarcely alters the results.

[13] The land area adjustment is debatable, since it obscures the tendency for bigger countries to have higher internal trade costs (as well as more diverse natural resources), but its inclusion makes no material difference to the results (for example, the only notable differences using the AVCS method of estimation are a much smaller coefficient on the residual trade-GDP variable and a slightly smaller coefficient on its interaction with country size).

[14] Trade-GDP ratios are derived from the UN National Accounts Main Aggregates database, with Comtrade data used to eliminate intra-trade, and halved to yield more easily interpreted numbers. All variables in the regression were logged, but its residuals were then unlogged, with 0.331 added to all of them to avoid negative values. This residual measure differs slightly from that in Rotunno & Wood (2020), who regressed the trade-GDP ratio on total population alone and used the logged values of the residuals.

[15] This transformation of x has the same value as x if $x = 0$ or $x = 1$, but in between these values it rises initially faster than x and subsequently more slowly, as would the log of x.

In all the output ratio regressions, to allow for economies of scale in manufacturing, the adult population measure of country size is used as a control variable. It is a proxy for the size of a country's labour force, which limits the division of labour within its manufacturing sector.

All the output regressions also control for the skill level of a country's labour force, because of the usually greater skill intensity of manufacturing than of primary production. The proxy for labour force skill is average adult years of schooling, using data from Barro & Lee (2013) with gaps filled using UNESCO data on adult literacy.[16] Years of schooling is not an ideal measure of skill, since it fails to allow for differences among countries and over time both in how much is learned in school and in skills acquired outside school (Pritchett 2013). It is the best available measure for worldwide analysis over a long period, but must be interpreted cautiously.

3.*2 Specification and estimation*

The linkages between output structure, endowments of land and labour, and openness to trade in the modified version of HOS theory discussed in section 2 above and Smith & Wood (2023) are approximated by a regression of the form

$$\ln r_{M/A} = \zeta_0 + \zeta_1 \ln v_{N/L} + \zeta_2 o \times \ln v_{N/L} + \zeta_3 o + \mu \qquad (3)$$

in which $r_{M/A}$ is the ratio of manufactured to primary GDP (writing *r*, for revenue, rather than *q*, as in Smith & Wood, because the data are output values), $v_{N/L}$ is the ratio of total land area to adult population, and *o* (which is unlogged) is the trade policy index.[17] Its key feature is the interaction between the land-labour ratio and openness. The counterpart in this regression to the 'openness-conditioned output-endowment elasticity' in section 2 above and equation (55) of Smith & Wood is $\zeta_1 \ln v_{N/L} + \zeta_2 o \times \ln v_{N/L}$, while the terms $\zeta_3 o + \zeta_2 o \times \ln v_{N/L}$ correspond to the 'endowment-conditioned output-openness elasticity' explained in section 2.

Looked at differently, the coefficient ζ_1 is the elasticity of the output ratio with respect to the endowment ratio at a zero value of the trade policy index, while the sum of ζ_1 and ζ_2 is the size of the output-endowment elasticity if the policy index is unity. The average level of the trade policy index (combining own and partner index values) in individual countries during 1985-2014 varied from 0.12 to 0.77, with 1985-2014 changes in the index varying among countries from -0.18 to 0.45 (Table A1). Zero and unity levels of the policy index could thus be taken as being close to autarky and free trade, respectively.

[16] The greater schooling intensity of manufacturing is documented in the Socioeconomic Accounts of the World Input-Output Database, analysed in section A of the Statistical Appendix of Wood (2017).

[17] Not logging the openness variable is clearly consistent with equation (55) of Smith & Wood (2023), where the relationship between changes in the output ratio and in the endowment ratio is conditioned by the level of openness (reflected in the size of ε). Its consistency with the 'endowment-conditioned output-openness elasticity' is much less clear, partly because this elasticity is not fully formalised mathematically and partly because of the ambiguous effect on it of the initial level of openness discussed in section 4.2 of Smith & Wood.

The estimated version of (3) includes two other control variables, both also interacted with openness. A country's average years of schooling, denoted by *h* and interpreted as another factor endowment ratio (human capital/labour), is, like the land-labour ratio, interacted with the trade policy index.[18] Country size, denoted by *L* and included to capture economies of scale in manufacturing, is treated differently. Trade is crucial for small countries to be able to engage profitably in manufacturing (exporting a few manufactured outputs while importing many other manufactured final goods and inputs). A better measure of openness in this context, however, is the residual trade-GDP ratio, denoted by *O*, because it captures the scale of a country's trade, dependent both on trade barriers and on the size and proximity of trading partners.

The full specification of the basic regression is then

$$\ln r_{M/A} = \zeta_0 + \zeta_1 \ln v_{N/L} + \zeta_2 o \times \ln v_{N/L} + \zeta_3 \ln h + \zeta_4 o \times \ln h + \zeta_5 \ln L + \zeta_6 O \times \ln L + \zeta_7 o + \zeta_8 O + \mu \quad (4)$$

As with the land-labour ratio, the coefficients ζ_3 and $\zeta_3 + \zeta_4$ in the schooling terms show the effects of schooling on output at zero and unity values of the policy index. The coefficient ζ_5 shows the effect of variation in country size, independently of openness, which is expected to be positive, while ζ_6 on the size-openness interaction is expected to be negative, because more scope for trade reduces the manufacturing cost advantage of being a larger country.

Adding the control variables does not alter d*r*/d*v* – the effect on the output ratio of variation in endowment ratios at different values of the openness variable, but it importantly alters d*r*/d*o*. In particular, the effect on the output ratio of variation in openness for a country with any given land-labour ratio will depend also on its level of schooling and its size.

The validity of estimates obtained with equation (4) depends on its right-hand-side variables being exogenous. For land and adult population, exogeneity is a good assumption. A country's total land area is determined by its geography and history. Nor is there any reason to expect a direct causal effect of output structure on birth and death rates. Immigration in some countries and periods has been affected by sectoral labour shortages, but the sectors have varied – for example, manufacturing in Germany, agriculture in the US, mining in South Africa – making it unlikely that the manufactured-primary output ratio in itself was the driving force.

There is, however, a causal link between this output ratio and the schooling variable. Because manufacturing is more skill-intensive, a higher manufactured-primary output ratio raises the demand for skilled workers, strengthening the incentives of people to acquire schooling and of

[18] Extending the type of formal model in Smith & Wood (2023) to include more than two factors is discussed in Appendix D of Wood (2012), which proposes simplifying higher-dimensional HOS by assuming that different factor pairs act independently. Variation in the human capital-labour endowment ratio would thus influence sectoral structure by changing the relative cost of skill and labour, but would not modify the influence of the land-labour ratio. This simplification is consistent with the present empirical results: the addition of average years of schooling to the regression hardly changes the coefficients involving the land-labour ratio.

governments to provide it, as shown by Atkin (2016) and Blanchard & Olney (2017). The ζ_3 schooling and ζ_4 openness-schooling coefficients will thus be biased.

There are theoretical reasons, too, for supposing that output structure might affect the openness measures. The greater import intensity of manufacturing than of primary production could in principle cause a higher manufactured-primary output ratio to increase the trade/GDP measure of openness, and could also affect the trade policy index through political economy channels (e.g., Blanchard et al. 2021). But there is no evidence of strong effects of these sorts.

Simple tests for their existence are cross-country correlations between changes in the openness measures during 1985-2000 and 2000-14 and the manufactured-primary output ratio at the start of each period, and between changes in openness during 2000-14 and changes in the output ratio during 1985-2000. All but one of these correlations, both for the trade/GDP ratio and for the own-country trade policy index, are negligible (Rs between 0.03 and 0.14). The exception is an R of 0.44 between the 1985-2000 change in the policy index and the 1985 level of the output ratio. It partly reflects Uruguay-round liberalisation in OECD countries, omitting which lowers it to 0.38, but it is not driven by any other group of countries, nor reduced by controlling for resources and country size. There was simply a widespread tendency for greater reduction of trade policy barriers in countries that were initially more industrialised.

A plausible explanation of this correlation is advocacy by the World Bank and other agencies of 'export-oriented industrialisation' as a better development strategy than 'import-substituting industrialisation', motivated by the success of Korea, Taiwan and other East Asian 'miracles' (World Bank 1993). This advocacy, and these country examples, were particularly influential in countries that already had large manufacturing sectors, many of which also had high policy barriers to manufactured imports. Its effects on their trade policies can reasonably be regarded as an exogenous shock.

Even if a country's trade policies – its chosen degree of openness – are exogenous with respect to its output ratio, they may be influenced by its factor endowments, in a HO framework most plausibly through political action by potential gainers and losers from trade. For example, if in democracies workers had greater influence than land-owners, they might be able to raise the wage-rent ratio by lobbying for more openness in land-scarce countries and less openness in land-abundant ones – as is consistent with the weak inverse cross-country correlation between the policy index and the land-labour ratio (R = -0.24: Table A2). This sort of endogeneity does not bias estimates of the effect of variation in the policy index and in endowments on the output ratio, though it would make them less precise if it resulted in a high degree of collinearity. What it would affect is the actual global pattern of output ratios, with – to continue the example – the variation of output ratios across countries with their land-labour ratios being smaller than would be observed if workers had no political influence on trade policies.

A country's manufactured-primary output ratio could be affected by many things beyond the scope of the theory in Smith & Wood (2023) and the variables in equation (4). Some can be added to the regression, but omission of the others could bias the estimated coefficients on the

included variables. Reducing this problem by including country fixed effects, moreover, is made less straightforward by two features of this paper's data. An obvious impediment is the constancy of country land areas over time. Adult populations rose everywhere, so land/labour ratios fell, but there was little variation over time in relative land-labour ratios, either, with a correlation (R) across countries of 0.98 between 1985 and 2014 values.

In addition, the changes in schooling over time are misleading. There was strong convergence during 1985-2014 between less-educated countries and more-educated countries.[19] However, the big rises in enrolment in less-educated countries were often accompanied by big falls in the average quality of schooling (Pritchett 2013), with little or no convergence in learning.

Because the available data on changes in land-labour ratios and schooling are therefore liable to yield misleading results, the analysis that follows will make extensive use also of two non-standard methods of estimation. One is average cross-section (AVCS), using the 1985-2014 mean values of variables, which avoids these changes altogether (and reduces the effect on the output ratio of fluctuations over time in relative world prices in a more satisfactory way than including year dummies in a pooled OLS regression).[20]

The other method (labelled LVCH) also uses average 1985-2014 levels of the land-labour ratio, schooling, and country size, but its dependent variable is the 1985-2014 change in the output ratio, and its openness measures are the 1985-2014 changes in the policy index and the residual trade-GDP ratio.[21] Its interaction coefficients show how the effects of increases or decreases in openness on the manufactured-primary output ratio varied across countries with the levels of their land-labour ratios, schooling and size.

4. Regression results

This section first presents the results of applying different methods of estimation to a common set of variables. It then checks their robustness to changes in variables and country coverage.

4.1 Alternative methods of estimation

Table 1 shows the results of estimating equation (4) by four different methods: pooled OLS with year fixed effects for 1985 and 2000 (POLS), average cross-section (AVCS), fixed effects for both years and countries (FE), and the levels-changes (LVCH) approach described above. Summary statistics and a correlation matrix are in Tables A1 and A2.

[19] As evidenced by a correlation (R) of -0.80 between 1985-2014 changes and 1985 levels of logged average years of schooling, and a fall in the cross-country coefficient of variation from 0.44 to 0.25. The ranking of countries hardly altered, with a correlation across countries of R = 0.95 between 1985 and 2014 schooling levels.

[20] Averaging is better because it accommodates fluctuations in the relative prices of the different primary products in which different countries specialise because of the nature of their land. Year dummies in POLS control only for changes in the price of manufactures relative to the average price of all primary products.

[21] The 1985-2014 fall in the relative world price of manufactures is absorbed in the constant term. Using 1985-2014 average (rather than 1985) levels in the LVCH specification makes little difference to the results but avoids them being contaminated by the misleading 1985-2014 changes in the land-labour ratio and schooling.

Table 1. Manufactured-primary output ratio regressed on endowments and openness

	POLS	AVCS	FE	LVCH
Core variables				
Log of square kilometres of land per adult	0.03	0.04		-0.13
	(0.07)	(0.12)		(0.06)**
(Log land per adult) x (Openness policy index)	-0.64	-0.68	-0.65	-0.59
	(0.17)***	(0.31)**	(0.18)***	(0.31)*
Sum of land and land-openness coefficients	-0.61	-0.63		-0.72
	(0.11)***	(0.20)***		(0.26)***
Openness policy index	1.51	1.68	0.20	0.27
	(0.40)***	(0.67)**	(0.52)	(0.45)
Control variables				
Log of average adult years of schooling	0.49	0.49	-0.26	-0.01
	(0.16)***	(0.33)	(0.33)	(0.17)
(Log yrs of school) x (Openness policy index)	1.60	1.63	0.53	0.45
	(0.55)***	(1.04)	(0.55)	(1.08)
Log of country size (adult population)	0.21	0.25	-0.24	-0.10
	(0.08)**	(0.15)*	(0.25)	(0.05)*
(Log country size) x (residual trade/GDP)	-0.23	-0.35	-0.06	0.43
	(0.22)	(0.40)	(0.30)	(0.35)
Residual trade (exports + imports) / GDP	0.07	0.10	0.27	-0.43
	(0.57)	(1.03)	(0.91)	(0.81)
R-squared	0.61	0.67	0.93	0.27
Number of observations	369	123	369	123

Notes Dependent variable is log of ratio of manufactured to primary GDP (ISIC definition of manufacturing, 'primary' = agriculture + mining). Openness policy index is product of own index value and weighted (by distance and GDP) average of other countries' index values. Interactions of policy index with land and schooling estimated with all-country means subtracted from land and schooling variables. Residual trade/GDP from regression on adult population and land area. POLS = pooled OLS (includes year fixed effects for 1985 and 2000). FE = fixed effects for years and countries, with land-labour ratio omitted because of perfect collinearity in changes between it and the country size variable. AVCS = average cross-section in levels (means of 1985, 2000 and 2014 values). LVCH = 1985-2014 changes in output ratio, policy index, and residual trade/GDP, with average levels of land-labour ratio, schooling and country size. All regressions omit land-labour-ratio outliers Hong Kong and Singapore. Standard error of sum of coefficients from a separate regression. OLS regressions, with robust (HC1) standard errors in parentheses: statistical significance * (10%), ** (5%), *** (1%).
Sources. GDP and trade (goods plus services) data mainly from UN National Accounts Main Aggregates database. Total land area and adult (over 15 years) population from World Development Indicators. Schooling from Barro & Lee (2013), with gaps for nine countries filled using UNESCO data on adult literacy. Openness policy index from Gygli et al. (2018). Distances between countries from CEPII database.

The core results are in the upper panel, with the most important for this paper being the row of coefficients on the interaction between the openness policy index and the land-labour ratio. As expected from the HO model in section 2 and Smith & Wood (2023), all these coefficients are negative: greater openness to trade tends to increase the adverse effect of a higher land-labour ratio on the manufactured-primary output ratio.

Across all methods of estimation, moreover, these coefficients are of about the same size: -0.6. The conditioning influence of greater openness on the effect of variation in land abundance on the output ratio thus appears similar, whether it is estimated in levels (AVCS), in changes (FE), or in a mixture of levels and changes (POLS and LVCH). All four coefficients, moreover, are statistically significant, though none is precisely estimated.[22] The economic significance of the common coefficient size will be assessed in section 5 below.

The coefficients on the land-labour ratio in the first row refer, because of the interaction term, to the effect on the manufactured-primary output ratio of variation in land abundance at a zero value of the openness policy variable. The levels (AVCS) estimate of this coefficient therefore refers to hypothetical countries that are almost closed to trade, and its near-zero value implies that differences in their land-labour ratios would have little effect on their output ratios.

This result may seem inconsistent with theory: even in a closed economy, a higher land-labour ratio should reduce the manufactured-primary output ratio (Smith & Wood 2023, eq. (26)). But output is measured here in terms of value, so a reduction in the output quantity ratio tends to be offset by a rise in the price ratio. Indeed, a zero coefficient is what theory would predict in a closed economy if the elasticity of substitution in consumption between manufactures and primary products were unity (as often assumed with the sort of two-tier utility function used in analysing the effects of openness on output elasticities in Smith & Wood).

The land-labour cell in the FE column is blank. Constant land areas cause perfect correlation between changes in the land-labour ratio and in country size (measured by adult population), so one of them must be omitted from the FE regression. Neither of them has much effect on the results, as evidenced by the similarity between the AVCS and POLS land-labour and size coefficients. Nor does either of them on its own have an economically sensible FE coefficient, because of a misleading negative correlation between changes in population and in the output ratio.[23] So, because omitting the size variable would have yielded a nonsense land-labour ratio FE coefficient of 0.24 (equal to the size coefficient in the FE column of Table 1, but with its sign reversed), it seemed better to omit the land-labour ratio.

[22] The FE and POLS estimates, which involve 1985-2000 and 2000-2014 changes, would also appear less precise if their standard errors were clustered across years. The LVCH estimate involves only 1985-2014 changes.
[23] This correlation (R = -0.20, Table A2, between changes in adult population and in the manufactured-primary output ratio) is misleading because it probably arises from omitted variables, particularly institutional or political influences on development, which through various channels affect both birth rates and the costs of establishing and operating manufacturing firms.

In the LVCH specification, the coefficient on the land-labour ratio is negative. Its sign (unlike that of an FE estimate) is not saying anything about the effect of changes over time in the land-labour ratio, whose level is held constant. What it says is that in hypothetical countries whose openness policy indices did not change during 1985-2014, manufactured-primary output ratios fell in land-abundant countries relative to land-scarce countries. A plausible explanation is the big transfer of labour-intensive manufacturing technology through outsourcing by developed-country firms to land-scarce low-wage developing countries whose policies were already open enough (or who improved their infrastructure enough) to make this transfer profitable.

The sum of the interaction and the land-labour coefficients, in the third row of the table, shows how variation in the land-labour ratio would affect the output ratio in a country whose openness policy index value was unity. In the POLS and AVCS columns, where this sum is almost equal to the interaction coefficient, it implies that in a country with close to free-trade policies a 10% difference in the land-labour ratio would cause a 6% opposite difference in the output ratio.

This effect of variation of endowments is well above the 2% that the POLS/AVCS coefficients would predict at the average actual openness index value of 0.38 during 1985-2014, but well below the magnification that would be predicted by the HOS model of an open economy. The modifications of HOS theory in section 2 and Smith & Wood (2023) reduce the likelihood of magnification, though it would be likeliest in a very open economy.[24] Two other things help to explain the absence of magnification: understatement by output value ratios of endowment-induced HOS variation in quantity ratios (section 5.2); and greater use of traded intermediates and mobile capital in a more open economy offsetting the tendency for its higher elasticity of demand to make relative output more responsive to endowments.[25]

The coefficient sum in the LVCH column shows how the 1985-2014 change in the output ratio in a hypothetical country that moved from autarky to free trade policies would have varied with the level of its land-labour ratio. Being 10% more land-abundant would have lowered such a country's output ratio by about 7%.

The coefficients on the policy index in the fourth row of Table 1 suggest that more openness might benefit manufacturing even in land-abundant countries (of given size and schooling). For instance, because the demand for manufactures is income-elastic, a rise in income from primary exports could increase the relative demand for domestically-produced manufactures, or manufacturing might benefit more than primary production from better access to world-class intermediate inputs. The way the interaction term is estimated, with means subtracted from the land-labour ratio and schooling variables, causes the policy index coefficient to measure the

[24] Where there would be a high value of ε in equation (55) of Smith & Wood (2023).

[25] In the modified HOS model in Smith & Wood (2023), a higher effective demand elasticity, ε, means that to achieve any given change in relative outputs requires less change in relative goods prices and thus in relative factor prices, so less of a relative endowment change is absorbed within sectors and more by a change in relative sectoral outputs. However, greater costs other than those of immobile factors, especially (in open countries) imported intermediate inputs and payments to mobile factors, mean that any given relative goods price change requires a larger relative factor price change, and hence more of a relative endowment change being absorbed within sectors. This point is articulated formally in Rotunno & Wood (2020, sections 2.2-2.4).

effect on the output ratio of a unit increase in the index – roughly from autarky to free trade – in a country of world-average land abundance and schooling. In a pure HO model, this effect should be zero, but all the coefficients are positive.

The POLS and AVCS coefficients are implausibly large, implying a five-fold rise in the output ratio, almost certainly because they are picking up the effects of omitted variables. Countries with more open policies may also have other policies or institutions that raise their per capita incomes or help the supply of manufactures more than of primary products, such as better legal, regulatory or internal transport systems. The coefficients in the FE and LVCH columns are of a more believable size. They imply that moving from autarky to free trade would increase the manufactured-primary output ratio of a country with average factor endowments by about one-quarter – though in reality this would require not only changes in trade policies but also much investment in trade-related infrastructure.

The lower panel of Table 1 shows the coefficients on the control variables (omitting which would not greatly alter the openness-land interaction coefficients, making the POLS and AVCS ones somewhat smaller and the FE and LVCH ones somewhat larger).[26] Across countries (the POLS and AVCS columns), more schooling is associated with a higher manufactured-primary output ratio and its effect is amplified by more open trade policies, as expected, though these estimates are biased by the endogeneity of schooling.[27] Also as expected from theory, larger countries produce more manufactures but the advantage of greater country size decreases with greater openness (as measured by the residual trade-GDP ratio).

As regards changes within countries over time, the coefficient on schooling in the FE column is nonsensically negative, because of the misleading rise in years of schooling in less educated countries mentioned earlier. In the LVCH column, the schooling coefficient is near zero, and in both FE and LVCH columns the openness-schooling interaction coefficient is positive but much smaller than across countries. The near-zero value of the LVCH schooling coefficient (which refers to the level of schooling, not to its change) is consistent with outsourcing, which in the highly-educated developed countries had little effect on total manufactured output but changed the composition of manufacturing away from labour-intensive activities. This change

[26] Without control variables, the openness-land interaction coefficients are in POLS -0.48, in FE -0.71, in AVCS -0.43 and in LVCH -0.74. There are offsetting changes in the land-labour coefficients in POLS (to -0.13) and AVCS (to -0.14). The positive coefficients on the policy index all become larger, particularly in POLS and AVCS (due to the strong cross-country correlation between the index and schooling discussed in the next note).

[27] Interpreting them is complicated also by the supply-side effect of schooling identified in Porzio et al. (2022), which in these regressions is observationally equivalent to differences in the skill intensity of manufacturing and primary production. The strong correlation across countries between schooling and the policy index ($R = 0.65$: Table A2) increases the standard errors of the schooling and openness-schooling interaction coefficients. This correlation is probably due largely to omitted variables, though it could also reflect political economy pressures – highly educated workers successfully demanding more open policies in countries where they are more abundant relative to less educated workers. As a result of its size (combined with the -0.24 correlation between the policy index and the land-labour ratio), omitting all the openness-related variables from the AVCS regression in Table 1 lowers its R^2 only from 0.67 to 0.57. This restricted specification, with just the land-labour ratio, schooling, and country size, was used in a succession of papers from Wood & Mayer (1998) to Wood (2017) and originally, without country size, in Wood & Berge (1997), in most cases to explain the composition of exports.

in composition increased total manufactured output in land-scarce developing countries with good basic schooling, but much less so in those with the lowest levels of schooling.

The coefficients on country size in the FE and LVCH columns are both negative – the opposite of their expected (and POLS and AVCS) signs – but for different reasons. The negative FE sign reflects the inverse and probably spurious correlation already mentioned between changes in the manufactured-primary output ratio and population growth. The negative LVCH sign indicates that the manufactured-primary output ratio rose more in smaller countries, which during this period of globalisation probably benefited from reductions in barriers to trade in manufactures that are not fully captured by changes in their openness policy indices or residual trade-GDP ratios. The unexpectedly positive LVCH size-openness interaction coefficient may reflect concentration of outsourcing on relatively populous Asian countries.

4.2 Robustness checks

Table 2 shows four alternative specifications of the AVCS and the LVCH regressions (which between them capture the essence of all four specifications in Table 1). The first alternative replaces the combined own-and-partner openness policy index with the value of the own index alone. Surprisingly, since restrictive partner policies could in principle obstruct trade as much as restrictive own policies, this change has little effect. It reduces the openness-land interaction and policy index coefficients, but mainly just because of a change in scale: own policy index values vary more widely among countries than combined index values (Table A1).

The small effect of omitting partner policies reflects the fact that the world market is dominated by developed countries. Their high GDPs give them a lot of weight in every country's partner-average index value, which thus varies little among countries (Table A1). Developed countries are also unusually open, so the partner index value is generally much higher than the own index value. In cross-section, moreover, own and partner indices are positively correlated ($R = 0.52$, Table A2): countries' trade policies tend to align with those of their neighbours, partly because of formal regional trade agreements.[28]

[28] Neighbours also tend to be similar in land-labour ratios and schooling, as noted by Macleod (2013) and evident in Figure A1, so there is more scope for endowment-variation-based trade with countries further away. Macleod estimates regressions similar to those in the present paper whose independent variables include size-and-distance-adjusted partner endowments as well as own-endowments, but this extension adds little to the explanatory power of his regressions. Moreover, the coefficients on his partner-endowment variables have the same signs as on own-endowments, not the opposite signs expected from comparative advantage, which Macleod suggests may reflect (a) the effect of partner endowments on demand for exports and (b) the gains in manufacturing efficiency from agglomeration of countries with endowment-based comparative advantage in manufacturing.

Table 2. Alternative regression specifications

	Average levels cross-section (AVCS)					Changes in output and in openness (LVCH)				
Core variables	Base case	Without partners policies	Foreign share of markets	Adding per capita GDP	Adding services output	Base case	Without partners policies	Foreign share of markets	Adding per capita GDP	Adding services output
Log of square kilometres of land per adult	0.04	0.09	0.21	0.03	0.05	-0.13	-0.16	-0.19	-0.12	-0.11
	(0.12)	(0.12)	(0.22)	(0.13)	(0.11)	(0.06)**	(0.05)***	(0.06)***	(0.06)**	(0.06)*
(Log land per adult) x (Openness policy index)	-0.68	-0.61	-0.87	-0.68	-0.53	-0.59	-0.38	-0.26	-0.53	-0.63
	(0.31)**	(0.22)***	(0.37)**	(0.32)**	(0.29)*	(0.31)*	(0.22)*	(0.37)	(0.31)*	(0.31)**
Sum of land and land-openness coefficients	-0.63	-0.52	-0.66	-0.65	-0.48	-0.72	-0.54	-0.45	-0.65	-0.74
Openness policy index	1.68	1.30	7.38	0.98	0.58	0.27	0.18	-1.79	0.13	0.16
	(0.67)**	(0.52)**	(3.42)**	(0.85)	(0.45)	(0.45)	(0.31)	(0.99)*	(0.46)	(0.47)
Control variables										
Log of average adult years of schooling	0.49	0.33	0.47	0.36	0.23	-0.01	0.03	-0.06	-0.01	-0.09
	(0.33)	(0.34)	(0.64)	(0.32)	(0.28)	(0.17)	(0.14)	(0.13)	(0.18)	(0.20)
(Log yrs of school) x (Openness policy index)	1.63	1.61	1.64	1.51	0.33	0.45	0.19	0.29	0.30	0.45
	(1.04)	(0.77)**	(1.19)	(1.13)	(0.81)	(1.08)	(0.79)	(0.67)	(1.12)	(1.10)
Log of country size (adult population)	0.25	0.25	0.22	0.23	-0.08	-0.10	-0.10	-0.09	-0.10	-0.09
	(0.15)*	(0.15)*	(0.18)	(0.15)	(0.12)	(0.05)*	(0.05)*	(0.06)*	(0.05)*	(0.05)*
(Log country size) x (residual trade/GDP)	-0.35	-0.35	-0.43	-0.29	0.64	0.43	0.42	0.29	0.21	0.39
	(0.40)	(0.40)	(0.48)	(0.41)	(0.30)**	(0.35)	(0.36)	(0.38)	(0.35)	(0.33)
Residual trade (exports + imports) / GDP	0.10	0.14	-7.56	0.05	-0.66	-0.43	-0.39	1.72	-0.09	-0.30
	(1.03)	(1.04)	(4.20)	(1.07)	(0.71)	(0.81)	(0.83)	(1.20)	(0.78)	(0.80)
Log of per capita GDP (in 2005 US$)				0.13					0.28	
				(0.14)					(0.11)**	
Log of services/goods GDP					1.41					0.14
					(0.17)***					(0.15)
R-squared	0.67	0.67	0.62	0.67	0.80	0.27	0.27	0.28	0.31	0.28

Notes. All regressions include all 123 countries. In the 'without partners policies' regressions, the policy index is simply that of the country concerned. In the 'foreign share of markets' regressions, the openness policy index is replaced by the estimated average share of foreign firms in all markets in which home country firms sell (whose calculation is explained in section 3.1). In the LVCH regressions, 'per capita GDP' is the 1985-2014 change, and 'services output' is the average 1985-2014 level. Standard errors of the sum of land and land-openness coefficients are not reported. Otherwise as in notes to Table 1.

Sources. As in Table 1: per capita GDP and services GDP from UN National Accounts Main Aggregates database.

The second alternative specification replaces the trade policy index with the weighted average share of foreign firms in all the markets in which a country's firms sell, which decreases with the average height of a country's trade barriers, and is calculated as explained in section 3.1. This replacement has little effect on the core results.[29] The AVCS openness-land interaction coefficient is larger, but mainly because of the narrower range of variation of the foreign firm share than of the policy index, and it is offset by a larger land-labour coefficient (of opposite sign). The reduced LVCH interaction coefficient similarly reflects mainly the wider range of changes in the foreign-firm share than in the policy index.

The third alternative specification in Table 2 adds per capita GDP (at constant prices) to the independent variables, regarding it as a general measure of development correlated with many possible omitted influences on the manufactured-primary output ratio. Increasing income is also a way in which more openness might raise the output ratio (as implied by the positive trade policy coefficient), because of the higher income elasticity of demand for manufactures.

In neither the AVCS regression nor the LVCH regression does adding per capita GDP change the estimated effects of land abundance on the output ratio, as reflected in the land-labour and openness-land coefficients. In AVCS, the level of per capita GDP, whose coefficient is positive but small, also hardly alters the schooling and country size coefficients, and adds nothing to the fit. In LVCH, the change in per capita GDP has a larger positive coefficient and improves the fit, but again has little effect on the schooling and country size coefficients.

The strongest effect of adding per capita GDP, both in AVCS and in LVCH, is to halve the coefficient on the trade policy index, consistently with the hypothesis that greater openness, by raising income, increases domestic demand for manufactures. Offsettingly, however, greater openness should also reduce the influence of domestic demand structure on output structure. Interacting per capita GDP with the policy index yields AVCS results that are consistent with this prediction: at a policy index value of zero, the effect of income on output structure is four times greater than in Table 2, and the effect falls as the policy index value increases.[30]

Because per capita GDP levels are strongly correlated with perpetual-inventory measures of aggregate capital/labour ratios, the relevant AVCS column of Table 2 could be interpreted as checking the base-case regression for bias due to omitting national endowments of capital. The results suggest no such bias. The small per capita GDP coefficient and its decline with greater openness are also inconsistent with the hypothesis that greater national endowments of capital increase the relative output of (more capital-intensive) manufacturing.

[29] The dramatic changes in the coefficients on the (replaced) openness policy index and residual trade-GDP ratio are caused by these two variables being highly correlated ($R > 0.9$), both in levels and in changes.
[30] The coefficient on per capita GDP is 0.54 (s.e. 0.22) and on the openness-GDP coefficient -1.04 (s.e. 0.46).

In many countries, the service sectors employ more of the labour force than manufacturing and primary production combined, as well as substantial amounts of land.[31] Most services are also non-tradable, so variation in domestic demand for services, including as a result of changes in the prices of traded goods, could cause variation in the relative availability of land and labour to the goods sectors to differ from variation in the land-labour endowment ratio, distorting the regression results.[32]

Services-oriented alternative specifications, however, suggest little distortion. Table 2 shows the one that most alters the results, namely adding the services-goods output (GDP share) ratio to the regression.[33] In LVCH, this leaves the results largely unchanged. In AVCS, it somewhat reduces the openness-land interaction coefficient, and greatly reduces the openness coefficient. The improved fit of this augmented AVCS regression and a positive correlation between the services-goods output ratio and manufactured-primary output ratio suggest complementarity between manufacturing and services in production and/or consumption.

The base-case estimated effects of openness on the relationship between land abundance and output structure survived various other robustness tests. Hong Kong and Singapore, outliers in terms of land-labour ratios, and very open, are already omitted. Dropping outliers in terms of large size (China, India, USSR) or low schooling does not alter the land-related coefficients. The cross-section openness-land interaction coefficient varies across years because of changes in relative world prices, especially for oil, but omitting oil-dependent countries has little effect on the AVCS and LVCH interaction coefficients.[34] Nor does replacing adult population with land area as the measure of country size. The AVCS results are not sensitive, either, to the method of averaging across years (averages of logged variables, rather than logs of averaged variables or averaging the coefficients of individual-year cross-section regressions).

[31] Rotunno & Wood (2020, section 5) extend the type of two-factor model in Smith & Wood (2023) to include many goods (some of which could be services and/or nontradable). The openness-moderated relationship in eq. (54) of Smith & Wood applies to any pair of goods in a many-good HOS model with product differentiation, as does the logic of (55). A change in output mix caused by a change in factor supplies will be absorbed with smaller changes in domestic goods prices, so supply elasticities will be larger in a more open economy.

[32] This distortion would be smaller if, as seems likely, the average land-labour ratio of services lies between the land-labour ratios of manufacturing and primary production, rather than close to (or beyond) one of them.

[33] Adding the services-goods employment (instead of the output) ratio to the regression affects the AVCS results only by reducing the openness-schooling coefficient, and hardly alters the LVCH results. Replacing population as the country size measure with the sum of manufacturing and primary employment has little effect on the land-related coefficients in either AVCS or LVCH, though it alters the AVCS country size coefficients.

[34] Individual-year cross-section openness-land interaction coefficients are -0.83 in 1985, -0.32 in 2000, and -0.78 in 2014. 'Oil-dependent' countries are those where the average share of oil rents in GDP in these years was 10% or more, using data from World Development Indicators.

Table 3. Effects on regression results of omitting old OECD countries

	POLS	AVCS	FE	LVCH
Core variables				
Log of square kilometres of land per adult	0.19	0.28		-0.11
	(0.08)**	(0.13)**		(0.07)*
(Log land per adult) x (Openness policy index)	-1.25	-1.53	-0.80	-0.57
	(0.20)***	(0.39)***	(0.25)***	(0.34)*
Sum of land and land-openness coefficients	-1.06	-1.25		-0.68
	(0.14)***	(0.28)***		(0.30)**
Openness policy index	1.23	1.41	0.20	0.35
	(0.46)***	(0.80)*	(0.61)	(0.47)
Control variables				
Log of average adult years of schooling	0.72	0.83	-0.31	-0.04
	(0.17)***	(0.37)**	(0.35)	(0.19)
(Log yrs of school) x (Openness policy index)	0.65	0.33	0.36	0.36
	(0.64)	(1.26)	(0.65)	(1.16)
Log of country size (adult population)	0.20	0.27	-0.27	-0.11
	(0.09)**	(0.18)	(0.30)	(0.06)*
(Log country size) x (residual trade/GDP)	-0.21	-0.39	-0.03	0.61
	(0.24)	(0.47)	(0.31)	(0.36)*
Residual trade (exports + imports) / GDP	0.02	0.18	0.00	-0.99
	(0.63)	(1.24)	(0.98)	(0.83)
R-squared	0.50	0.57	0.90	0.24
Number of observations	306	102	306	102

Notes and sources. 'Old OECD' refers to 1985 and omits Turkey. Otherwise as in Table 1.

A further robustness test is to drop from the data 21 countries that were members of the OECD in 1985. These 'already developed' countries are similar in the average level and dispersion of their land-labour ratios and size to the other 102 countries (in 1985 almost all 'developing'),[35] but their manufactured-primary output ratios, openness policy indices, and schooling are on average much higher and less dispersed. Table 3 reports the results of re-running, with this reduced dataset, the four regressions with different methods of estimation in Table 1.

Dropping the old OECD countries hardly alters the LVCH results. The only notable difference in the FE results is an increase of about 25% in the openness-land interaction coefficient. The reason it increases, while the LVCH interaction coefficient does not, is that the FE interaction reflects changes over time in both the policy index and the land-labour ratio, whereas the LVCH estimate of the interaction depends on changes only in the policy index, holding each country's land-labour ratio constant (at its 1985-2014 average value).

[35] Apart from the USSR, Yugoslavia, Czechoslovakia (all statistically reunified), and five other East European countries, which were then categorised by the World Bank as 'East European nonmarket economies'.

Since land area is fixed, as mentioned earlier, changes in the land-labour ratio are determined only by changes in adult population, which on average grew less in the old OECD than in the non-OECD countries. Dropping the old OECD countries from the data thus reduces variation of changes over time in the land-labour ratio and also in the openness-land interaction, tending to raise the interaction coefficient. The 25% difference between the FE interaction coefficients, moreover, is close to the proportional difference between the two datasets in the range between the first and ninth deciles of 1985-2014 changes in the logged land-labour ratio.

The biggest effects of dropping the old OECD countries are in the POLS and AVCS columns of Table 3. Most notably, the openness-land interaction coefficients are twice as large as for all countries. These differences, however, mainly reflect differences in the influence of omitted variables, as can be inferred from the sizes of the (non-reported) individual-country fixed-effect coefficients in the all-countries FE regression in Table 1.

With Uruguay as the base country, the average fixed effect for land-scarce old OECD countries (Western Europe and Japan) is 0.23. For the land-abundant old OECD countries (US, Canada, Australia, New Zealand and Scandinavia except Denmark), it is 0.70. All old OECD countries have a higher ratio of manufactured to primary production than would be predicted from their factor endowments, size and openness, but in the land-abundant ones much more so. Dropping the old OECD countries from the data thus reduces the average manufactured-primary output ratio by more for land-abundant than for land-scarce countries, which, combined with the high openness of all old OECD countries, makes the POLS and AVCS interaction (and land-labour) coefficients larger than for all countries combined.

5. Economic significance

This section evaluates the sizes of the effects of changes in endowments and openness to trade predicted by the estimated regression coefficients. It then considers how the results might be altered by using data on output quantities rather than output values.

5.1 Counterfactual magnitudes

Table 4 uses the regression results in Table 1 to predict the relative sizes of manufactured and primary output for hypothetical countries with differing land-labour ratios and openness to trade. The predictions use coefficients mainly from the AVCS regression, in which the crucial openness-land interaction coefficient is close to that in all the other methods of estimation, and whose near-zero land-labour coefficient, almost identical to its POLS counterpart, was argued earlier to be explicable theoretically by the use of output value rather that output quantity data.[36] The openness index coefficient that is used in the predictions, however, is derived from the FE

[36] In the absence of a FE land-labour coefficient, for reasons explained earlier, the alternative would have been the -0.13 LVCH land-labour coefficient, which seemed less appropriate because it is estimated from a combination of variation in land-labour ratio levels with variation in output and openness changes.

and LVCH regressions and is far lower than the AVCS coefficient.[37] The AVCS regression also has sensible signs on its schooling and size related coefficients, though these are of minor importance because all countries are assumed to be of median schooling and size.

Predicted output ratios are converted in Table 4 into more easily understood predicted shares of manufacturing in goods (manufactured plus primary) output. These shares are reported for countries at the highest and lowest deciles and the upper and lower quartiles of both land-labour ratios and openness.[38] Down each column, which refers to a particular degree of openness, the manufacturing share falls as the land-labour ratio increases in successive rows, and by more in more open countries.[39] Across the rows, as openness increases, the manufacturing share rises for land-scarce countries, but falls for land-abundant countries. In the median land-labour ratio row, the output ratio rises slightly because of the positive policy index coefficient, which also lessens the fall of the share with greater openness in land-abundant countries.[40]

Table 4. Predicted sectoral structure at different land abundance and openness quantiles

Manufacturing's share of manufactured plus primary output (%)

	Openness to trade					
	D1 (least)	Q1	Median	Q3	D9 (most)	D9 – D1
Land/labour ratio						
D1 (lowest)	43	45	48	55	61	18
Q1	42	43	45	50	54	12
Median	40	40	41	42	43	3
Q3	38	38	37	36	34	-4
D9 (highest)	36	35	32	29	25	-11
D9 minus D1	-7	-11	-16	-27	-36	-30

Notes. D refers to deciles, Q to quartiles. Predictions using coefficients from regressions in Table 1, as explained in text. Evaluated at median levels of country size and years of schooling.

Among the least open countries, the share of manufacturing at the most land-scarce decile is 7 percentage points higher than at the most land-abundant decile, whereas among the most open countries the manufacturing share difference between the most land-scarce and land-abundant

[37] The constant term is offsettingly increased to keep the predicted median output share at its actual level. The predictions in Table 4 are based not on the openness coefficients for a country with world average endowments shown in Table 1, but on those for a country with zero (logged) values of the endowments: 1 square km of land per worker, and 1 year of schooling per worker. A hypothetical such country would have a strong comparative disadvantage in manufacturing, so that increased openness would greatly reduce its manufactured-primary output ratio (the estimated coefficient being -3.5).

[38] Allowing for variation in both the openness policy index and the residual trade-GDP ratio. Although countries are all of median schooling and size, the effects on the output ratio of both size and schooling vary with openness as described by the regression coefficients.

[39] The amount of variation in the output share with the land-labour ratio in the median openness column is roughly what would be observed on average across countries without controlling for variation in their openness.

[40] Across the median land-labour ratio row, the rise in the manufactured output share is only half of what would be implied by the FE and LVCH policy index coefficients in Table 1, because the highest-to-lowest decile range of the policy index is only about half the unit range of variation to which the coefficients refer.

ones widens to 36 points. Viewed differently, and of more relevance to policy choices, at the most land-scarce decile the share of manufacturing would be 18 points higher in a very open country than in a very closed one, while at the most land-abundant decile the manufacturing share would be 11 points lower in a very open country than in a very closed one.

5.2 Output values and output quantities

As mentioned earlier, the output data refer to the relative values of manufactured and primary output, which depend both on relative quantities and on relative prices. Variation in a country's land-labour ratio is a supply shock that drives relative quantities and relative prices in opposite directions, to a degree dependent on the elasticity of demand, causing changes in relative values of output to understate changes in relative quantities. The understatement is smaller, however, in more open countries, because greater openness makes demand more elastic.

Variation in openness to trade is a demand shock, which drives relative quantities and relative prices in the same direction. The direction depends in HO theory on whether a country's land-labour ratio is above or below the world average but, either way, the estimated effect of greater openness on relative output values overstates the effect on relative quantities, to a degree which depends on the elasticity of relative supply. Whether the estimated coefficient on the openness-land interaction understates or overstates the effect on relative quantities is ambiguous, since the misstatements by its two ingredients are in opposite directions.

Variation in openness can affect a country's output ratio also in non-HO ways, as suggested by the positive coefficients in Table 1 on the openness measure for a country with world average endowments (where in HO theory more openness should not alter relative quantities or prices). Whether these coefficients, estimated with value data, overstate or understate relative quantity changes depends on what the non-HO mechanisms are. For example, if manufacturing gained from the effect of higher income on relative domestic demand, the effect on relative quantities would be overstated, while if the gain were from better access to intermediate inputs – a supply-side mechanism – the effect on relative output quantities would be understated.

The numbers in Table 4, predicting the effects of variations in land-labour ratios and openness on manufactured output shares, would change if they could be calculated with output quantity data. The directions of the changes are clear. Down each column, with openness constant and the land-labour ratio rising, the falls in the manufactured output quantity share would be larger. Across the rows, with openness increasing, the output quantity share would rise by less in land-scarce countries, and fall by less in land-abundant countries, with the direction of change at the median land-labour ratio, due to non-HO influences, being uncertain.

The rest of this section assesses the likely size of the effects on the output shares in Table 4 of estimating them with quantity rather than value data, using the accounting identity that links changes in relative output values to changes in relative quantities and relative prices (where the 'hats' denote small proportional changes):

$$\hat{r}_M - \hat{r}_A = (\hat{q}_M - \hat{q}_A) + (\hat{p}_M - \hat{p}_A) \quad (5)$$

Its conclusion will be that the understatement of the effects of endowment changes is large, but the overstatement of the effects of openness changes is small.

(a) Understatement of endowment-induced relative output changes

In the analysis in section 4 of Smith & Wood (2023) of the effect of changes in endowments on sectoral structure, the relationship between changes in relative quantities and changes in relative goods prices is equation (54), reproduced here as

$$\hat{q}_M - \hat{q}_A = -\varepsilon(\hat{p}_M - \hat{p}_A) \quad (6)$$

Combining equations (5) and (6), the proportional mis-description of endowment-induced relative quantity changes by relative value changes is therefore

$$\frac{\hat{q}_M - \hat{q}_A}{\hat{r}_M - \hat{r}_A} = \frac{\varepsilon}{\varepsilon - 1} \quad (7)$$

so that if $1 < \varepsilon < \infty$ the change in relative output value understates the change in relative output quantity. The understatement declines with the size of ε, which increases with the openness of the country concerned.

The effect of this understatement on Table 4 can be quantified by assuming that the near-zero AVCS land-labour coefficient reflects an ε in a near-closed country of 1.1, slightly larger than unity (a value of unity would destroy equation (7)), implying that a quantity ratio change would be eleven times larger than a value ratio change. Assume also that the true AVCS land-labour coefficient is slightly (half a standard error) lower than estimated, at -0.02, and would therefore have been -0.22 with output quantity data. The predictions in Table 4 can then be recalculated using this value for the land-labour coefficient.

The resulting changes are large. In the least-open-decile column, the manufacturing shares at the least-land-abundant and most-land-abundant deciles become 55% and 26% respectively, a difference of 28 percentage points, compared to 7 points in Table 4. In the most-open-decile column, the manufacturing shares at the least-land-abundant and most-land-abundant deciles become 72% and 17% respectively, a gap of 54 points, compared to 36 points in Table 4. In proportional terms, the widening of this gap is as expected smaller in the most open countries, where demand elasticities are higher, than in the least open countries.

(b) Overstatement of openness-induced relative output changes

Changes in openness, in conjunction with the level of a country's land-labour ratio compared to the world average, change the relative height of barriers to trade in manufactures and primary products, with effects on relative quantities of output described for example by equation (64) of Smith & Wood (2023). These changes in relative quantities are linked to changes in relative goods prices by the final term of the HOS equation (number (23) in Smith & Wood 2023 and number (1) in section 2 above), which with endowments held constant is

$$\hat{q}_M - \hat{q}_A = \sigma\left[\frac{1}{(\lambda_{NM} - \lambda_{LM})(\theta_{NM} - \theta_{NA})} - 1\right](\hat{p}_M - \hat{p}_A) \qquad (8)$$

For given values of the parameters in (8), this relationship between changes in relative goods prices and in relative quantities is the same, no matter how relative goods prices are determined or changed.[41] Combining equations (5) and (8), the proportional misdescription of relative-trade-barrier-induced relative quantity changes by relative output value changes is thus

$$\frac{\hat{r}_M - \hat{r}_A}{\hat{q}_M - \hat{q}_A} = 1 + \frac{1}{\sigma\left[\frac{1}{(\lambda_{NM} - \lambda_{LM})(\theta_{NM} - \theta_{NA})} - 1\right]} \qquad (9)$$

Since the rhs ratio term in (9) is positive, changes in relative output values overstate changes in relative output quantities, to a degree that can be assessed by inserting numerical values into the equation.

Evidence on the intra-sectoral elasticity of substitution between land and labour, σ, is scarce, but casual observation of wide variation in agricultural land-labour intensities among countries with varying land-labour endowment ratios is consistent with the use in estimates of worldwide agricultural productivity of Cobb-Douglas production functions (e.g., Hayami & Ruttan 1970, Fuglie 2010).[42] Their elasticity of unity is assumed to apply also to the observed widely varying land-labour intensities in mining and manufacturing.

Manufacturing's share of overall land use, λ_{NM}, is assumed to be near zero, abstracting from its possible use of locally produced primary inputs, while its share of overall labour use in goods production, λ_{LM} (omitting the service sectors), can be calculated from this paper's data to be on average one-quarter across all countries and years. The share of rent in manufacturing costs,

[41] Changes in relative factor prices are tied to changes in relative goods prices by ($\theta_{NM} - \theta_{NA}$), changes in relative factor use in each sector are tied to changes in relative factor prices by σ, and changes in relative output quantities are tied to changes in relative factor availability by ($\lambda_{NM} - \lambda_{LM}$).

[42] Boppart et al. (2023) conclude that elasticities of substitution among agricultural inputs are higher than in Cobb-Douglas. Their estimated pairwise substitution elasticity between land and labour is below unity (Figure 11), but they use a measure of labour that includes human capital.

θ_{NM}, is again assumed to be near zero, while the average share of rent in primary sector costs in GTAP data is about 40%.[43]

On this basis, overstatement of proportional differences in relative output quantities by relative output values appears small: about one-tenth. For instance, the rise across the most-land-scarce row of Table 4 would be 16.5 percentage points for the quantity share, rather than 18 points for the value share, while the fall across the most land-abundant row would be 10 percentage points for the quantity share, rather than 11 points for the value share.[44]

6. Conclusions

The motivation of this paper was concern that greater openness to trade may slow development in land-abundant countries. The concern has two causal links: first, that greater openness may cause such countries to specialize in primary production, pulling labour, skill, and capital away from manufacturing; and second, that manufacturing may have more potential for growth than primary production.

The paper has focused on the first causal link and in particular on trying to establish empirically both its existence and its size. This required some modifications to the standard HO model, in which the usual concept of openness is not an explicit variable and in which the effect of factor endowments on output structure does not vary in a systematic way with a country's degree of openness. It also required a new econometric specification, which was applied to data covering most of the world's countries during 1985–2014 (and could potentially be used with other data and for other research purposes).

The results confirm that greater openness, across and within countries, strengthens the tendency for a higher land–labour ratio to reduce the manufactured–primary output ratio, and also show that this effect is substantial. In a very land-abundant country, the share of manufacturing in the value of goods output would be 11 percentage points lower with a trade policy at the top decile of openness than at the bottom decile of openness.

A proper analysis of the second causal link – that a larger primary output share tends to slow or prevent development – is beyond the scope of this paper. However, the data and regression specification used in this paper permit a simple test of both causal links combined by changing the dependent variable from the manufactured–primary output ratio to per capita GDP (in 2005 US dollars). The results are in Table A3 of the Appendix.

The average cross-section results must be interpreted with caution because of endogeneity and omitted variables. The variation in per capita GDP levels is not at PPP, and the only significant coefficients are on schooling and trade policy. But there is no evidence of openness worsening

[43] The data, from GTAP 8 and referring to 2007, were kindly provided by Tom Hertel.
[44] The predicted differences in logged output ratios across rows are scaled down by one-tenth, which has almost the same proportional effect on the differences across rows in output shares.

a malign cross-country relationship between land abundance and per capita income. This result conforms with casual observation of high land–labour ratios and high exposure to trade both in some of the world's poorest countries (in Africa) and in some of its richest countries (in North America, Oceania, and Scandinavia).

A less encouraging conclusion for land-abundant developing countries emerges from the level-change (LVCH) regressions. Although the estimates are imprecise, per capita GDP growth during 1985–2014 was inversely related to land abundance – as in the 'resource curse' literature – and more so in countries that adopted more open policies. All countries tended to gain from greater openness, but these gains were larger in land-scarce countries.

The practical implications of this LVCH result should not be overstated: the coefficients imply that the net effect of greater openness on growth was negative only in the most land-abundant quarter of developing countries. Moreover, the pattern of greater openness contributing more to growth in land-scarce developing countries might not persist: it could reflect just a one-off transfer of manufacturing technology from developed countries during 1985–2014.

Even if greater openness continues to slow the growth of land-abundant developing countries by reducing their manufactured output shares, the implications for trade policy are debatable. Today's international fragmentation of manufacturing would preclude replication of the earlier sectoral protection that arguably helped some now-open land-abundant developed countries to acquire manufacturing capabilities, though 'soft' and sub-sectoral industrial policies might still achieve similar results (e.g., Harrison & Rodriguez-Clare, 2010; Mayer, 2021).

The ever-increasing tradability of services has made them a potential alternative or complement to manufacturing in the process of development (e.g., Baldwin & Forslid, 2023). However, it is unlikely that exporting services could offset the comparative disadvantage in manufacturing of land-abundant countries, because the service sector shares with manufacturing much lower land intensity than primary production. The key distinction is therefore between the primary sectors and the combination of manufacturing and modern services.

Regardless of whether and how trade policies should differ between land-abundant and land-scarce developing countries, some other sorts of policies should differ (Wood, 2003). In land-abundant countries, more supply-side effort on schooling is needed because specialization in primary production reduces the demand for education (Blanchard & Olney, 2017). Their lower population density also requires more infrastructure per head. More abundant natural resources could finance this additional spending, but whether that happens depends on political choices (e.g., Cabrales & Hauk, 2011; Dercon, 2022).

Appendix: Additional figure and tables

Figure A1, with thanks to Jamie Macleod, who used the present paper's data to generate maps similar to that in Macleod (2013), illustrates visually the strong influence of factor endowments on sectoral structure.

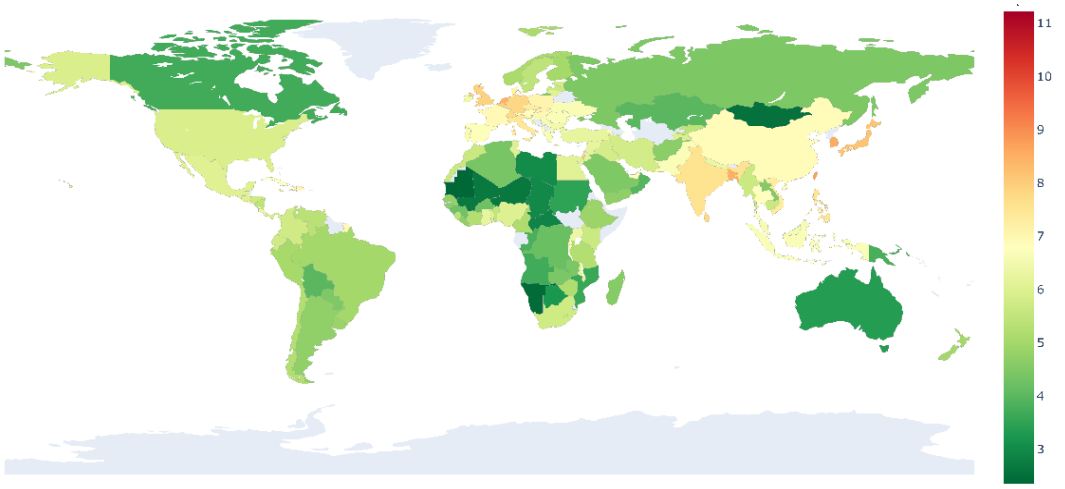
Its top panel shows the pattern of variation among almost all the world's countries in 2014 in the skill-to-land endowment ratio (average years of schooling multiplied by adult population and divided by land area). This single ratio, first used in Wood & Berge (1997), summarises most of the variation in the two endowment ratios used in this paper's regressions – the land-labour ratio and average years of schooling.

Its middle panel shows the corresponding pattern of variation in the ratio of manufactured to primary GDP. The many similarities to the map above reflect the positive correlation between this output ratio and the skill-land ratio, though with interesting deviations, some of which, as this paper's regressions show, are due to variation among countries in openness to trade.

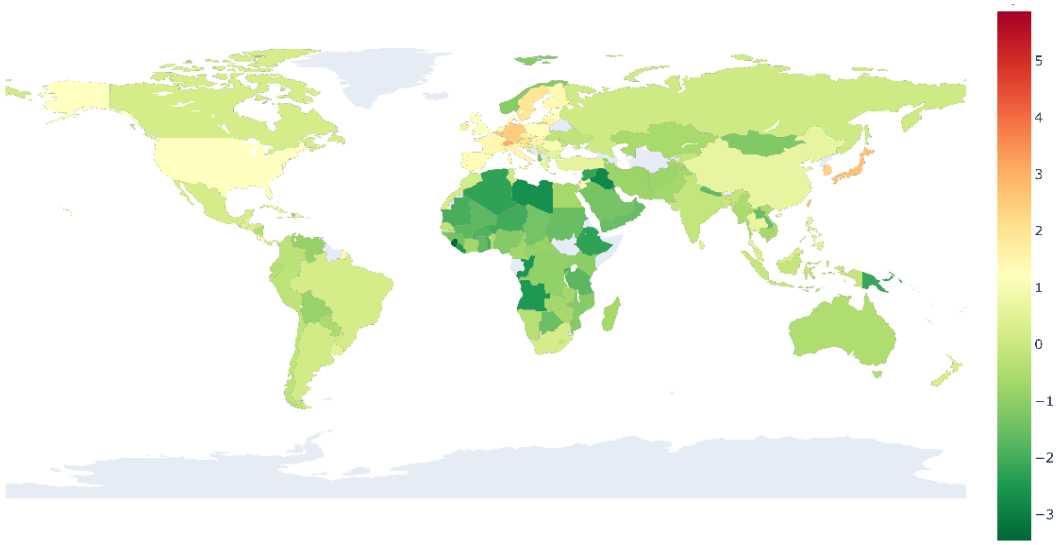
There is an even clearer similarity between the endowment map and the manufactured-primary export ratio map in the bottom panel. Degree of openness to trade matters less for the effect of a country's endowments on its export structure than on its output structure, as was recognised in Balassa's (1965) interpretation of export structure as 'revealed comparative advantage'.

Figure A1. Worldwide variation in endowments and sectoral structure 2014

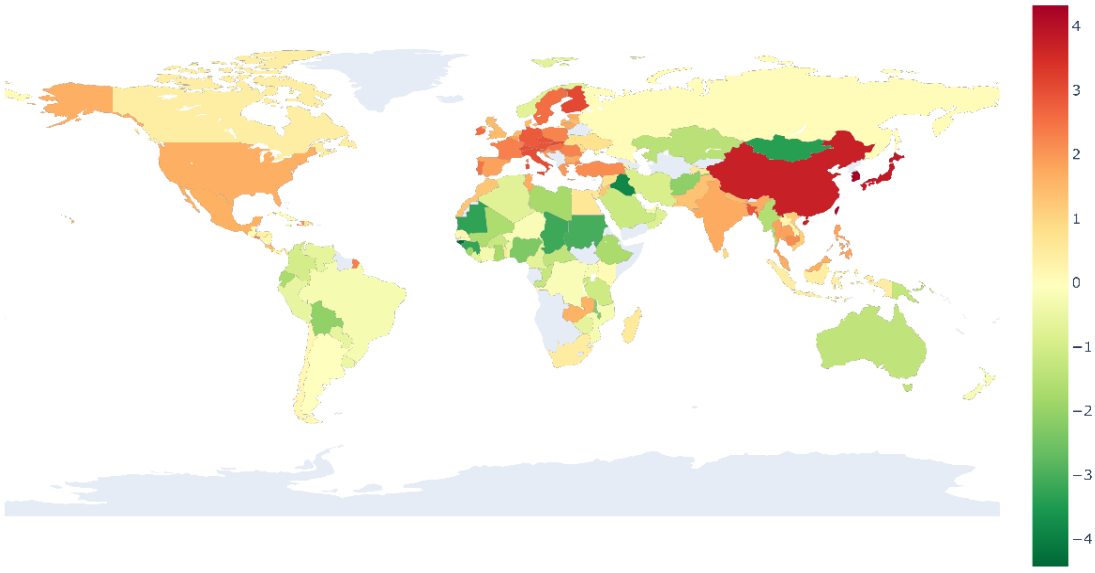
(a) Skill/land ratio (logged ratio of person-years of schooling to land area)



(b) Ratio of manufactured to primary output (GDP, logged)



(c) Ratio of manufactured to primary exports (logged)



Source. Jamie Macleod, using present paper's data as in Macleod (2013). Person-years of schooling is average adult years of schooling multiplied by adult population.

Table A1. Summary statistics of data used in regressions

Average levels during 1985-2014	Mean	Median	Std.dev	Min.	Max.
Log manufactured-primary GDP	-0.32	-0.42	1.30	-3.31	2.44
Log of square km of land per adult	-3.51	-3.53	1.38	-6.40	0.02
Log of average adult years of schooling	1.73	1.82	0.55	0.21	2.54
Log of country size (adult population)	2.28	2.14	1.38	-0.29	6.82
Own openness policy index	0.50	0.44	0.23	0.16	0.93
Other countries average policy index	0.74	0.73	0.04	0.66	0.85
Openness policy index (own x others)	0.38	0.33	0.19	0.12	0.77
Residual trade/GDP ratio	0.36	0.34	0.14	0.05	0.81
Changes from 1985 to 2014					
Log manufactured-primary GDP	0.14	0.15	0.65	-1.52	1.80
Log of square km of land per adult	-0.62	-0.69	0.33	-2.14	0.12
Log of average adult years of schooling	0.44	0.43	0.25	-0.06	1.80
Log of country size (adult population)	0.62	0.69	0.33	-0.12	2.14
Own openness policy index	0.13	0.11	0.17	-0.34	0.59
Other countries average policy index	0.09	0.09	0.02	0.05	0.14
Openness policy index (own x others)	0.13	0.12	0.13	-0.18	0.45
Residual trade/GDP ratio	0.13	0.11	0.16	-0.39	0.59

Notes and Sources. See Table 1.

Table A2. Correlation matrices of data used in regressions

Average levels during 1985-2014	Log mfd-prim GDP	Log land per adult	Log yrs school	Log ctry size	Own policy	Others policy	Policy index	Trade/ GDP
Log manufactured-primary GDP	1.00	-0.47	0.68	0.29	0.64	0.48	0.66	0.14
Log of square km of land per adult	-0.47	1.00	-0.25	-0.30	-0.22	-0.17	-0.24	0.14
Log of average adult years of schooling	0.68	-0.25	1.00	0.14	0.65	0.42	0.65	0.29
Log of country size (adult population)	0.29	-0.30	0.14	1.00	0.08	0.04	0.08	-0.07
Own openness policy index	0.64	-0.22	0.65	0.08	1.00	0.52	0.99	0.27
Other countries average policy index	0.48	-0.17	0.42	0.04	0.52	1.00	0.63	0.17
Openness policy index (own x others)	0.66	-0.24	0.65	0.08	0.99	0.63	1.00	0.28
Residual trade/GDP ratio	0.14	0.14	0.29	-0.07	0.27	0.17	0.28	1.00

Changes from 1985 to 2014	Log mfd-prim GDP	Log land per adult	Log yrs school	Log ctry size	Own policy	Others policy	Policy index	Trade/ GDP
Log manufactured-primary GDP	1.00	0.20	-0.12	-0.20	0.19	0.07	0.22	0.16
Log of square km of land per adult	0.20	1.00	-0.48	-1.00	0.25	0.23	0.36	-0.01
Log of average adult years of schooling	-0.12	-0.48	1.00	0.48	-0.24	-0.04	-0.31	0.05
Log of country size (adult population)	-0.20	-1.00	0.48	1.00	-0.25	-0.23	-0.36	0.01
Own openness policy index	0.19	0.25	-0.24	-0.25	1.00	0.12	0.98	0.09
Other countries average policy index	0.07	0.23	-0.04	-0.23	0.12	1.00	0.20	0.18
Openness policy index (own x others)	0.22	0.36	-0.31	-0.36	0.98	0.20	1.00	0.13
Residual trade/GDP ratio	0.16	-0.01	0.05	0.01	0.09	0.18	0.13	1.00

Notes and Sources. See Table 1.

Table A3. Regressions of per capita GDP (2005 US$, logged) on endowments and openness

	All countries		Non-old-OECD countries	
	AVCS	LVCH	AVCS	LVCH
Core variables				
Log of square kilometres of land per adult	0.10	-0.02	0.06	-0.04
	(0.09)	(0.05)	(0.13)	(0.06)
(Log land per adult) x (Openness policy index)	0.01	-0.22	0.11	-0.25
	(0.17)	(0.23)	(0.43)	(0.26)
Sum of land and land-openness coefficients	0.11	-0.24	0.17	-0.29
	(0.11)	(0.20)	(0.33)	(0.23)
Openness policy index	5.24	0.50	4.92	0.43
	(0.61)***	(0.29)*	(0.79)***	(0.33)
Control variables				
Log of average adult years of schooling	0.96	-0.01	1.11	0.01
	(0.27)***	(0.10)	(0.39)***	(0.12)
(Log yrs of school) x (Openness policy index)	0.96	0.52	0.34	0.67
	(0.98)	(0.57)	(1.44)	(0.66)
Log of country size (adult population)	0.13	0.00	0.05	0.02
	(0.13)	(0.05)	(0.16)	(0.05)
(Log country size) x (residual trade/GDP)	-0.44	0.77	-0.24	0.76
	(0.34)	(0.24)***	(0.41)	(0.26)***
Residual trade (exports + imports) / GDP	0.37	-1.21	0.23	-1.32
	(0.79)	(0.64)*	(0.94)	(0.70)*
R-squared	0.86	0.26	0.74	0.31
Number of countries	123	123	102	102

Notes and sources. As in Tables 1 and 3, except for change of dependent variable from log manufactured-primary GDP ratio to log per capita GDP in US dollars at 2005 prices and exchange rates (from UN National Accounts Main Aggregates database).

References

Armington, P. (1969). 'A Theory of Demand for Products Distinguished by Place of Production', *IMF Staff Papers* 16/11: 159-78.

Atkin, D. (2016). 'Endogenous Skill Acquisition and Export Manufacturing in Mexico', *American Economic Review* 106/8: 2046–85.

Balassa, B. (1965), 'Trade liberalization and "revealed" comparative advantage', *The Manchester School of Economic and Social Studies* 33: 92–123.

Baldwin, R., & R. Forslid (2023). 'Globotics and Development: When Manufacturing Is Jobless and Services Are Tradable', *World Trade Review* 22/3-4: 302-311.

Barro, R., & J. Lee (2013). A new data set of educational attainment in the world, 1950-2010. *Journal of Development Economics* 104: 184-198.

Blanchard, E, C. Bown & R. Johnson (2021). 'Global Value Chains and Trade Policy', forthcoming.

Blanchard, E., & W. Olney (2017). 'Globalization and human capital investment', *Journal of International Economics* 106: 165-83.

Blum, B. (2010). 'Endowments, Output, and the Bias of Directed Innovation', *Review of Economic Studies* 77/2: 534–559.

Boppart, T., P. Kiernan, P. Krusell & H. Malmberg (2023). 'The Macroeconomics of Intensive Agriculture', STEG Working Paper 063. London: Centre for Economic Policy Research.

Bowen, H., E. Leamer & L. Sveikauskas (1987). 'Multicountry, multifactor tests of the factor abundance theory', *American Economic Review,* 77/5: 791-809.

Cabrales, A., & E. Hauk (2011). 'The Quality of Political Institutions and the Curse of Natural Resources', *Economic Journal* 121 (March): 58-88.

Chor, D. (2010). 'Unpacking Sources of Comparative Advantage: A Quantitative Approach', *Journal of International Economics* 82/2: 152–67.

Dercon, S. (2022). *Gambling on Development*. London: Hurst.

Eaton, J., & S. Kortum (2002). 'Technology, Geography, and Trade', *Econometrica* 70/5: 1741-79.

Estefania-Flores, J., D. Furceri, S. Hannan, J. Ostry & A. Rose (2022). 'A measurement of aggregate trade restrictions and their economic effects'. IMF Working Paper WP/22/1. Washington DC: International Monetary Fund.

Fuglie, K. (2010). 'Total factor productivity in the global agricultural economy: evidence from FAO data', in J. Alston, B. Babcock & P. Pardey, *The Shifting Patterns of Agricultural Production and Productivity Worldwide,* Iowa State: CARD books.

Gygli, S., F. Haelg, & J-E. Sturm (2018). 'The KOF Globalisation Index – Revisited', Working Paper 439. Zurich: KOF Swiss Economic Institute.

Haraguchi, N., C. Cheng, & E. Smeets (2017). 'The Importance of Manufacturing in Economic Development: Has this Changed?', *World Development* 93 (May): 293-315.

Harrigan, J. (1997). 'Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model', *American Economic Review,* 87/4: 475- 494

Harrison, A., & A. Rodriguez-Clare (2010). 'Trade, foreign investment and industrial policy for developing countries', in D. Rodrik and M. Rosenzweig (eds), *Handbook of Development Economics*, vol 5, North-Holland.

Hayami, Y., & V. Ruttan (1970). 'Agricultural productivity differences among countries'. *American Economic Review* 60/5: 895-911.

Hertel, T., M. Tsigas, B. Narayanan & R. McDougall (2016), 'Primary factor shares', Purdue: GTAP 9 Data Base documentation, chapter 12A.

Jiao, Y., & S. Wei (2020). 'Natural barriers and policy barriers', NBER Working Paper 28171. Cambridge MA: National Bureau of Economic Research.

Jones, R. (1965). 'The Structure of Simple General Equilibrium Models', *Journal of Political Economy* 73/6: 557-572.

Kee, H., A. Nicita, & M. Olarreaga (2009), 'Estimating trade restrictiveness indices', *Economic Journal*, 119 (January): 172-99.

Keesing, D., & D. Sherk (1971). 'Population Density in Patterns of Trade and Development', *American Economic Review*, 61/5: 956-61.

Krugman, P. (1979). 'Increasing returns, monopolistic competition, and international trade', *Journal of International Economics*, 9/4: 469–479.

Leamer, E. (1984). *Sources of International Comparative Advantage.* Cambridge: MIT Press.

List, F. (1841). *The National System of Political Economy*, translated by S. Lloyd, Longmans, London, 1885.

Macleod, J. (2013), 'Endowments, trade, and development: how much does country location matter?', unpublished MSc thesis, Oxford University.

Matsuyama, K. (1992). 'Agricultural productivity, comparative advantage, and economic growth', *Journal of Economic Theory*, 58: 317-34.

Mayer, J. (2021). 'Development strategies for middle-income countries in a digital world', *The World Economy* 44/9: 2515-2546.

Melitz, M. (2003). 'The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity', *Econometrica* 71/6: 1695-1725.

Owens, T., & A. Wood (1997). 'Export-oriented industrialization through primary processing?', *World Development*, 25/9: 1453-70.

Porzio, T., F. Rossi & G. Santangelo (2022). 'The human side of structural transformation', *American Economic Review* 112/8: 2774-2814.

Pritchett, L. (2013). *The Rebirth of Education: Schooling Ain't Learning*. Washington, DC: Centre for Global Development.

Rodrik, D. (2016). 'Premature Deindustrialization.' *Journal of Economic Growth* 21/1: 1–33.

Rotunno, L., & A. Wood (2020). 'Wage inequality and skill supplies in a globalised world', *Journal of Comparative Economics*, 48/3: 529-47. doi:10.1016/j.jce.2019.12.006

Sachs, J., & A. Warner (1995a). 'Natural resource abundance and economic growth.' NBER Working Paper 5398. Cambridge MA: National Bureau of Economic Research.

Sachs, J., & A. Warner (1995b). 'Economic reform and the process of global integration', *Brookings Papers on Economic Activity* 1: 1-118.

Schott, P. (2003). 'One Size Fits All? Heckscher-Ohlin Specialization in Global Production', *American Economic Review* 93/3: 686-708.

Shirotori, M., B. Tumurchudur & O. Cadot (2010). 'Revealed factor intensity indices at the product level', Policy Issues in International Trade and Commodities Study Series No. 44, Geneva: UNCTAD.

Smith, A., & A. Wood (2023). 'Theoretical Underpinnings of "Land Abundance, Openness, and Industrialization"', *World Trade Review* 22/3-4: 323-333 (open access) doi:10.1017/S1474745623000149

Smith, B. (2015). 'The Resource Curse Exorcised: Evidence from a Panel of Countries', *Journal of Development Economics* 116: 57–73.

Timmer, M., G. de Vries & K. de Vries (2014). 'Patterns of structural change in developing countries', University of Groningen: GGDC Research Memorandum 149.

Venables, A. (2016). 'Using Natural Resources for Development: Why Has It Proven So Difficult?' *Journal of Economic Perspectives* 30/1: 161-84.

Wacziarg, R., & K. Welch 2008 'Trade liberalization and growth: new evidence', *World Bank Economic Review*, 22/2: 187-231.

Winters, L. A. (2004). 'Trade liberalisation and economic performance: an overview', *Economic Journal*, 114 (February): F4-F21.

Winters, L. A., & P. Martins (2004). 'When comparative advantage is not enough: business costs in small remote economies', *World Trade Review*, 3/3: 347-383.

Wood, A. (2003). 'Could Africa be like America?', in B. Pleskovic & N. Stern (eds), *Annual Bank Conference on Development Economics 2003* (World Bank and Oxford University Press, 2003).

Wood, A. (2012). 'Better-behaved Heckscher-Ohlin models through more consistent treatment of trade costs', Oxford University: QEH Working Paper 185. URL: http://workingpapers.qeh.ox.ac.uk/RePEc/qeh/qehwps/qehwps185.pdf

Wood, A. (2017). 'Variation in Structural Change Around the World, 1985-2015: Patterns, Causes, and Implications.' WIDER Working Paper 2017/34. Helsinki: World Institute for Development Economics Research. doi:10.35188/UNU-WIDER/2017/258-8

Wood, A., & J. Mayer (1998). 'Africa's export structure in a comparative perspective', Study No. 4: *African Development in a Comparative Perspective*. UNCTAD, Geneva.

Wood, A., & K. Berge (1997). 'Exporting Manufactures: Human Resources, Natural Resources, and Trade Policy', *Journal of Development Studies*, 34: 35-59.

World Bank (1993). *The East Asian Miracle*, New York: Oxford University Press.