Wages and endowments in a globalised world[*]

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First draft: October 2014

This draft: June 2015

Abstract

This paper explores empirically the relationship between relative wages and relative
endowments of skilled and unskilled workers in open economies across the world.
It is guided by a version of Heckscher-Ohlin (HO) theory that is linked to recent
analytical work on trade and is more general (so labelled GHO) than the standard
HOS model. The observed sensitivity of relative wages to variation in endowments in
open economies, across countries and over time, is hard to reconcile with HOS. By
contrast, this sensitivity is intrinsic to GHO in which, as shown by our results, the
wage-endowment elasticity depends on the height of barriers to trade and on the share
of wages in goods prices. In GHO, openness to trade reduces - rather than eliminates
- the sensitivity of factor prices to variation in endowments.

Keywords: Heckscher-Ohlin, trade and wages, trade liberalisation.
JEL codes: F11, F16.

I   Introduction

A valuable but largely unrecognised by-product of recent advances in the economic analysis of trade is a specification of Heckscher-Ohlin (HO) theory that is more general than the usual Heckscher-Ohlin-Samuelson (HOS) model, which it nests as a special case. This more general model, which we label GHO, was implicit in the writings of Ohlin and in some earlier applications of HO theory. In this paper, we use GHO to guide an empirical investigation of worldwide relationships between wages, endowments and trade openness.

The distinguishing characteristic of GHO, compared to HOS, is that from the perspective of an individual country, demand and supply in world markets are less than infinitely elastic. A longstanding explanation of inelasticity, due to Armington (1969) and embodied in many CGE and gravity models (Anderson, 1979), and in Krugman (1979), is qualitative differences among the varieties of goods made by different countries or firms. More recently, however, inelasticity has emerged as a feature of models with stochastic variations in efficiency among countries (Eaton and Kortum, 2002) and firms (Melitz, 2003). As shown by Arkolakis et al. (2012) and Costinot and Rodriguez-Clare (2014), these alternative sources of inelasticity are on certain assumptions interchangeable, and between them they provide the basis of the GHO model (which collapses to HOS if elasticities are assumed to be infinite).

This paper sets out a GHO model, drawn from Wood (2012), of the determination of factor prices and applies it to the data, focusing on the question of how factor prices relate to variation in endowments in economies that are open to trade. For lack of data on the prices of other immobile factors, we are limited (like many other studies) to the wages of skilled and unskilled workers, using panel data from the recently developed World Input-Output Database (WIOD), which covers 40 countries during 1995-2009. Our empirical application of the GHO model includes both reduced-form estimation and structural estimation.

Our results confirm much earlier evidence (e.g. Robbins, 1996; Katz and Murphy, 1992; Blum, 2010) of an inverse relationship between the relative wages and relative supplies of skilled and unskilled workers, which is not consistent with the canonical HOS model. Multiple cones of diversification could reconcile HOS with an inverse wage-endowment relationship across countries, and we find some - albeit weak - evidence for their existence. It is harder, however, to find a good HOS explanation for the inverse wage-endowment relationship within countries over time. By contrast, all this evidence of factor price sensitivity is consistent with the GHO model, in which relative wages are predicted to vary with relative skill supplies, even in economies open to trade, because of the inelasticities of demand and supply mentioned above.

The degree of sensitivity of relative wages to relative skill supplies depends in GHO on the size of what Arkolakis et al. (2012) call 'trade elasticities' - the responsiveness of imports in individual sectors to changes in their purchaser prices relative to those of home-produced goods. It also depends, as our empirical results confirm, on the degree of openness of the economy, as reflected in the ratio of trade to output, and on the extent of non-iceberg trade (and other) costs. If home suppliers have smaller shares of the home market, as a result of low trade barriers, the outcome is less affected by elasticities of substitution among goods (which are lower than among varieties of goods). In addition, thinner non-iceberg trade cost wedges increase the responsiveness of purchaser prices to wages, which allows factor-market clearing adjustments of output mix to be achieved with smaller changes in wages.

At a theoretical level, our paper extends the multi-factor multi-sector analysis of Costinot and Rodriguez-Clare (2014, p. 221-3) and related work of Burstein and Vogel (2011) by including non-proportional variable trade (and trade-related) costs. This extension is based on Wood (2012), which links back to Alchian and Allen (1964) and Hummels and Skiba (2004), and in the present paper also includes discussion of the effects of traded intermediates and internationally mobile capital (as in Wood, 1994).

Empirically, our paper is the first application of a GHO model to the determination of factor prices. It thus adds to Romalis (2004) and Chor (2010), who used related theoretical frameworks to analyse the effect of factor endowments on the composition of trade. Though relying on different reasons for trade inelasticity, their common contribution was to support the HO explanation of trade patterns while avoiding the indeterminacy or extreme specialisation of HOS models with more goods than factors.[1] In this paper, we focus on the factor price implications of one type of GHO model and test them empirically using global data on wages and labor supplies.

Our paper also adds to empirical studies of non-equalisation of factor prices associated with multiple cones of diversification (e.g. Davis and Weinstein, 2001; Schott, 2003; Debaere and Demiroglu, 2003; Xiang, 2007; Kiyota, 2011, 2012a). Most of these studies, however, have been limited to the quantity side (relating differences among economies in product mix or choice of technique to differences in their endowments), with only Kiyota also analysing factor price differences and then only within one country. Our paper is the first, we believe, to test for multiple cones on the factor-price side of the model and using cross-country wage data.

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[1] This escape is possible because in GHO differences in factor intensity among goods affect the composition of output not only through their role in clearing factor markets (as in HOS) but also by influencing the relative prices of goods which, with inelastic demand, influence their relative sales.

Most studies of factor price equalisation - always rejected by their results - have also been within single countries (Hanson and Slaughter, 2002; Tomiura, 2005; Bernard et al., 2008, 2013). Data on wages by occupation in many countries are used by Blum (2010) to reject the HOS factor price insensitivity theorem - the relative wages of skilled workers fall over time when relative skill supplies rise - and by Marshall (2012). We extend their work by explicitly considering the influence of trade barriers on the relationship between wages and endowments, and by using data for the economy as a whole, not just for manufacturing, and for wages by level of education (which is more readily comparable with endowments).

Our paper tangentially relates also to the big and controversial literature on the effects of trade on wages (e.g. Wood, 1994, 1997; Anderson, 2005; Goldberg and Pavcnik, 2007; Harrison et al., 2011; Leamer, 2012; Burstein and Vogel, 2012; Edwards and Lawrence, 2013). However, it focuses on the narrow issue of how openness affects the sensitivity of wages to endowments and does not seek to analyse other effects of trade on wages, nor other determinants of wages in open economies. The GHO model in Wood (2012) contains a fuller theoretical explanation of the effects of trade on wages, but we are constrained by the lack of detailed data on prices and trade barriers in WIOD.

The rest of the paper is organised as follows. Section II sets out relevant theory. Section III introduces the WIOD data, with some descriptive statistics. Section IV presents the results. Section V concludes.

II   Theoretical framework

For simplicity we work mainly with a 2 × 2 model of a single country, using the familiar 'hat' algebra of Jones (1965), extended to many goods, but with only informal discussion of more factors and without introducing other countries (either bilateral trade or global general equilibrium). Support for the more general relevance of our analysis is provided by the work synthesised by Costinot and Rodriguez-Clare (2014). The main purpose of this section is to set out the GHO model, but to clarify the properties of this model it is convenient to start by discussing a closed economy and the HOS model of an open economy.

Closed economy

Two factors, H (high-skilled workers) and L (low-skilled workers) produce two goods, B (biochemicals, which are H-intensive) and G (garments, which are L-intensive). Changes in the relative prices of the goods, p, which equal their factor costs, c, are related to changes

in factor prices, w, by the zero-profit condition

$$(1) \quad \widehat{p}_B - \widehat{p}_G = \widehat{c}_B - \widehat{c}_G = (\theta_{HB} - \theta_{HG})(\widehat{w}_H - \widehat{w}_L)$$

where θ_{ij} is the share of factor i in the producer price or production cost of good j. A rise in the relative wage of skilled workers causes a rise in the relative cost and price of the skill-intensive good. Factor-market clearing requires

$$(2) \quad \widehat{v}_H - \widehat{v}_L = -\sigma_{BG}(\widehat{w}_H - \widehat{w}_L) + (\lambda_{HB} - \lambda_{LB})(\widehat{q}_B - \widehat{q}_G)$$

where the endowment of a factor is denoted by v, the output of a good by q, λ_{ij} is the share of the endowment of factor i used by good j, and

$$(3) \quad \sigma_{BG} = \sum_{j=B,G} [\lambda_{Hj}(1 - \theta_{Hj}) + \lambda_{Lj}\theta_{Hj}]\,\sigma_j$$

combines the elasticities of substitution in production between H and L for the goods, σ_B and σ_G. A rise (say) in the relative endowment of H must be matched by a rise in the relative demand for H, which can be achieved by a fall in the relative price of H that induces a rise in the H-intensity of the techniques used in producing both goods (the first rhs term in (2)) and/or by a shift in the composition of output towards the H-intensive good B (the second term).[2]

The final element of the closed-economy model is a demand function that links the relative quantities of goods sold to their relative prices

$$(4) \quad \widehat{q}_B - \widehat{q}_G = -\gamma_{BG}(\widehat{p}_B - \widehat{p}_G)$$

where γ_{BG} is the elasticity of substitution in consumption between B and G. The effect of changes in endowments on factor prices in a closed economy can then be derived as

$$(5) \quad \widehat{w}_H - \widehat{w}_L = -\frac{1}{\sigma_{BG} + (\lambda_{HB} - \lambda_{LB})\,\gamma_{BG}\,(\theta_{HB} - \theta_{HG})}\,(\widehat{v}_H - \widehat{v}_L)$$

The first term in the denominator of the rhs ratio shows that endowments have more effect on factor prices if factors are less substitutable in production. The second term shows how changes in factor prices alter goods prices in ways that shift the composition of output in a

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[2]Changes in the mix within sectors of goods of differing factor intensity are observationally equivalent to changes in technique.

direction that helps to absorb changes in endowments. The second term is the product of three elasticities: of relative goods prices with respect to relative factor prices $(\theta_{HB} - \theta_{HG})$, of relative outputs with respect to relative goods prices (γ_{BG}), and of relative factor use with respect to relative outputs $(\lambda_{HB} - \lambda_{LB})$. The lower the elasticities of substitution in production and consumption, the more does a rise in the relative endowment of skilled workers in a closed economy depress their relative wage. The effect of varying the difference in factor intensity between the goods (as measured by $\theta_{HB} - \theta_{HG}$ and $\lambda_{HB} - \lambda_{LB}$) is less obvious because, as can be seen from (3), this alters the first as well as the second term in the denominator of (5), but if there is more substitutability in consumption than in production, a smaller difference in factor intensity has, as (5) suggests, an effect similar to that of lower substitution elasticities.[3]

Heckscher-Ohlin-Samuelson

The key assumption of the HOS model is that, in an open economy, goods prices are no longer influenced by domestic demand, as in equation (4), but instead are determined by world prices and trade costs, requiring that

$$(6) \quad \widehat{c}_B - \widehat{c}_G = \left(\widehat{p}_B^* + \widehat{T}_B\right) - \left(\widehat{p}_G^* + \widehat{T}_G\right)$$

where p_j^* is the world price of good j and $T_j = \frac{c_j}{p_j^*}$ is the trade cost ratio (greater than unity if j is an import substitute and less than unity if j is an export good). With the usual assumption of iceberg (or other ad valorem) trade costs, the elasticities of demand for traded goods are infinite, which makes the ratio on the rhs of equation (5) zero (as if γ_{BG} had become infinite). Within a cone of diversification - a range of relative endowments bounded by the relative factor intensities of the two goods - variation in endowments does not affect relative factor prices, which are determined by

$$(7) \quad \widehat{w}_H - \widehat{w}_L = \frac{\widehat{c}_B - \widehat{c}_G}{\theta_{HB} - \theta_{HG}} = \frac{\left(\widehat{p}_B^* + \widehat{T}_B\right) - \left(\widehat{p}_G^* + \widehat{T}_G\right)}{\theta_{HB} - \theta_{HG}}$$

with the effect of changes in relative goods prices on relative factor prices magnified because $(\theta_{HB} - \theta_{HG})$ is less than unity.

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[3]To support this conclusion, (3) can be simplified by assuming that $\sigma_B = \sigma_G = \sigma$ and substituted into (5) to yield: $\widehat{w}_H - \widehat{w}_L = -\frac{1}{\sigma + (\lambda_{HB} - \lambda_{LB})(\theta_{HB} - \theta_{HG})(\gamma_{BG} - \sigma)} (\widehat{v}_H - \widehat{v}_L)$, bearing in mind that with two goods the differences between the λ's and the θ's must be of the same sign and hence their product positive.

Equation (7) can illustrate the impact on factor prices of moving from autarky to trade, which involves both T_j's getting closer to unity. Consider for example a skill-abundant country, where in autarky $T_B < 1$ and $T_G > 1$ (the internal relative price of skill-intensive goods being low by comparison with the world): movements towards unity make $\widehat{T}_B > 0$ and $\widehat{T}_G < 0$, raising the relative wage of skilled workers. Similarly and more generally, across-the-board cuts in trade costs in an open economy raise the relative price of its abundant factor (given world prices, changes in which also alter factor prices).

The Jones algebra is not suited to the analysis of multiple cones of diversification, which is most conveniently (and familiarly) presented in a Lerner diagram (e.g. Schott, 2003; Xiang, 2007). In a model with two goods, countries with extreme endowment ratios lie outside the single cone and specialise in producing only one of the goods. In each region of specialisation, factor prices respond inversely to variation in endowments to a degree governed by the elasticity of substitution in production, σ, but are not affected by trade costs, though higher trade costs reduce absolute levels of factor prices by worsening the country's effective terms of trade (Markusen and Venables, 2007).

With many goods arranged in order of their relative factor intensity (still with only two immobile factors), there can be multiple cones, the countries in each of which produce a few goods of adjoining factor intensity (in the simplest case, only two). Between the cones can be regions in which only one good is produced. All other goods are imported from countries in other cones, implying a lot of trade and intense specialisation in each cone (rather than, as the label misleadingly suggests, diversification). Within each cone, factor prices are unrelated to endowments, but they are affected by trade costs. Across cones, factor prices vary inversely with endowments.

Given equation (7), the range of influences on relative factor prices in the HOS model is strikingly limited. Within a cone, variations in the internal demand for factors - due for example to differences in the size of nontraded sectors - affect only the composition of output and trade. Differences in technology affect factor prices, but only in certain ways: relative factor prices are affected by sector-biased technical differences, but not by factor-biased differences (though factor earnings will vary with factor quality).

General Heckscher-Ohlin

In the GHO model of an open economy (and in the theoretical frameworks of Costinot and Rodriguez-Clare, 2014, p.222-3; and Burstein and Vogel, 2011), factor prices are determined by the balance of supply and demand in the country's factor markets, which is influenced

both by endowments (on the supply side) and by world prices and trade costs (on the demand side). The influence of endowments in described by a modification of equation (5), in which the elasticity of demand for goods, instead of being γ_{BG} (as in a closed economy) or infinite (as in HOS), becomes

$$(8) \quad \epsilon_{BG}\delta_{BG}$$

where ϵ_{BG}, the 'purchaser-price elasticity', measures the response of the relative sales and outputs of goods B and G to their relative purchaser prices, while δ_{BG}, the 'price-ratio elasticity', measures the response of the relative purchaser prices of goods B and G to their relative factor costs.

(a) Purchaser-price elasticity

The relative sales of goods B and G by home producers depend on their relative prices, unlike HOS, where there is no such relationship. This relationship exists because in each sector there is a finite 'trade elasticity' that links the share of imports in domestic expenditure to the relative prices of imported and home-produced varieties.[4] As in Arkolakis et al. (2012) and Costinot and Rodriguez-Clare (2014), we assume a CES utility function

$$(9) \quad C_j = \left[\left(C_j^H\right)^{\frac{\beta_j-1}{\beta_j}} + \left(C_j^M\right)^{\frac{\beta_j-1}{\beta_j}}\right]^{\frac{\beta_j-1}{\beta_j}}$$

where C_j^H and C_j^M are composites of home-produced and imported varieties in sector j, and β_j equals one plus the trade elasticity (since the latter refers to the value rather than the volume of sales). This elasticity may reflect adjustments at either the intensive margin (more or less consumption of qualitatively different varieties, as in Armington, 1969, and Krugman, 1979) or the extensive margin (purchases of identical varieties from different countries or firms, as in Eaton and Kortum, 2002, and, partly, in Melitz, 2003). It is convenient to assume that in each sector j the elasticities of substitution within the home-produced and imported composites are equal to β_j, though this is not always so (Costinot and Rodriguez-Clare, 2014, p. 244-6; Feenstra et al., 2014).

Relative expenditure on goods B and G from all sources depends on the relative prices

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[4]Strictly speaking, the trade elasticity refers to the ratio of imported to home-produced varieties rather than to the share of imports in expenditure, and is defined with respect to changes in trade costs rather than in prices more generally (Costinot and Rodriguez-Clare, 2014, p. 201).

of the B and G aggregates, in a way that is governed by a higher-level CES utility function

$$(10) \quad C = \left[\alpha C_B^{\frac{\gamma_{BG}-1}{\gamma_{BG}}} + (1-\alpha) \, C_G^{\frac{\gamma_{BG}-1}{\gamma_{BG}}} \right]^{\frac{\gamma_{BG}}{\gamma_{BG}-1}}$$

where α is a preference parameter and γ_{BG} as before is the elasticity of substitution between the goods, which is likely to be much lower than either β_B or β_G. The elasticity of the relative sales of domestic producers of B and G with respect to their relative purchaser prices is an average of γ_{BG} and the sectoral elasticities β_B and β_G. With (9) and (10) being CES, the average elasticity in any particular market can be written precisely, following Sato (1967), as a weighted harmonic mean, where the weights involve the shares of each of the goods in total expenditure and the shares of the country concerned in the sales of these goods in this market (Wood, 2012, section 2.1). For purposes of exposition, this average elasticity can temporarily be written more simply, and omitting the market superscript on all its terms, as a weighted arithmetic mean

$$(11) \quad \epsilon_{BG} = s_{BG} \gamma_{BG} + (1 - s_{BG}) \beta_{BG}$$

where s_{BG} is the country's average share of the sales of these goods in the market concerned and β_{BG} is an average of β_B and β_G. In the world market, s_{BG} is likely to be small, so ϵ_{BG} is close to β_{BG}. In the home market, however, domestic producers have a cost advantage, so that s_{BG} is likely to be big enough to make γ_{BG} matter, too. Home market shares vary among goods, depending on the country's comparative advantage, but for all goods depend also on the country's international trade costs and policies.

The effect of relative purchaser prices on a country's relative sectoral outputs depends on the average ϵ_{BG} across all its markets, at home and abroad, weighted by the shares of its total sales in each market. This average elasticity decreases with the height of a country's international trade costs - or equivalently increases with its openness to trade - for two reasons. Higher trade costs raise s_{BG} and thus lower ϵ_{BG} in its home market.[5] They also reduce the share of exports in its output and so the weight in the average ϵ_{BG} of the higher ϵ_{BG}'s in its foreign markets (where s_{BG}'s are small). A more precise definition of this average ϵ_{BG} will be introduced later.

(b) Price-ratio elasticity[6]

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[5] More precisely, s_{BG} depends on the average across the two sectors of the proportional cost disadvantage of foreign suppliers relative to home suppliers and on the average 'trade elasticity' $(\beta_j - 1)$.

[6] For a fuller exposition of the next two paragraphs, see sections 2.2 and 2.3 of Wood (2012).

The price-ratio elasticity $(\delta_{BG} = \frac{\widehat{p}_B - \widehat{p}_G}{\widehat{c}_B - \widehat{c}_G})$ is less than unity because the purchaser price of each good is the sum of its internationally immobile factor costs (IFC) and an other-cost wedge (OCW) that usually does not vary in proportion to IFCs and is often big. The OCW includes trade costs, purchases of traded intermediates and payments to mobile factors (not least, by assumption in this paper, capital). Denoting the OCW per unit of output of good j by t_j, the IFC of good j by c_j (as before), and defining $\tau_j \equiv \frac{t_j}{c_j}$, the price-ratio elasticity δ_{BG} is determined approximately by

$$(12) \quad \delta_{BG} = \frac{1 + \eta_{BG}\tau_{BG}}{1 + \tau_{BG}}$$

where τ_{BG} is the geometric mean of τ_B and τ_G, and η_{BG} is the elasticity of $\frac{t_B}{t_G}$ with respect to $\frac{c_B}{c_G}$.

To understand equation (12), consider the expression $\frac{1}{1+\tau_{BG}}$, which is what (12) would become if $\eta_{BG} = 0$ and is the average share of IFCs in the purchaser prices of b and g. The smaller this share, as a result of a larger τ_{BG}, the smaller the effect on relative purchaser prices of a proportional change in relative IFCs (just as, for example, with c_j half of p_j, a 10% rise in c_j, with no change in t_j, would raise p_j by only 5%). However, insofar as relative OCWs vary in proportion to relative IFCs, for example because some trade costs are ad-valorem, η_{BG} will be positive, tending to increase δ_{BG} (and if η_{BG} were unity, as if for example OCWs consisted only of ad-valorem trade costs, δ_{BG} would be unity, too).

(c) Relative wages

The influence of endowments on relative wages in GHO, holding world prices and trade costs constant, is thus described by the modified version of equation (5),

$$(13) \quad \widehat{w}_H - \widehat{w}_L = -\frac{1}{\sigma_{BG} + (\lambda_{HB} - \lambda_{LB})\,\epsilon_{BG}\delta_{BG}\,(\theta_{HB} - \theta_{HG})}\,(\widehat{v}_H - \widehat{v}_L)$$

which can conveniently be abbreviated as

$$(14) \quad \widehat{w}_H - \widehat{w}_L = -\phi_{HL}\,(\widehat{v}_H - \widehat{v}_L)$$

while the influence on relative wages of world prices and trade costs, holding endowments

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constant, is described by

$$(15) \quad \widehat{w}_H - \widehat{w}_L = \phi_{HL} \left(\lambda_{HB} - \lambda_{LB} \right) \left(1 - s_{BG} \right) \left(\beta_{BG} - \gamma_{BG} \right) \left[\left(\widehat{p}_B^* + \widehat{T}_B \right) - \left(\widehat{p}_G^* + \widehat{T}_G^* \right) \right]$$

in which the terms to the right of ϕ_{HL} show how changes in the prices of foreign goods alter the relative demand for skilled and unskilled workers.[7] Of particular interest are $(1 - s_{BG})$ and $(\beta_{BG} - \gamma_{BG})$, which describe the effect on the relative outputs of B and G, which $(\lambda_{HB} - \lambda_{LB})$ as usual translates into changes in relative factor demands.

The effect of world prices and trade costs increases with β_{BG}, the degree of substitutability between varieties (though not so fast as equation (15) may suggest, since a rise in β_{BG} also makes ϕ_{HL} smaller). If β_{BG} were infinite, equation (15) would reduce to the HOS equation (7), with extra magnification if δ_{BG} is less than unity (and endowments would have no influence on factor prices, since ϕ_{BG} in (14) would be zero). With finite $\beta_{BG}(> \gamma_{BG})$, the effect of foreign prices on factor prices is in the same direction as in HOS, but smaller.[8]

The effect of world prices and trade costs on relative outputs decreases with the market share of home producers. With a larger s_{BG}, rises (say) in the prices of foreign varieties of good B cause less of an increase in the relative sales of B by home producers because the scope for substitution towards domestic varieties is reduced by the initially smaller sales of foreign producers. And if s_{BG} is unity, as in a closed economy or with non-traded goods, the whole expression becomes zero: changes in the prices of foreign varieties have no effect.

Combining the effects of endowments and of foreign prices, relative factor prices in GHO are determined by an expression with two additive terms

$$(16)$$
$$\widehat{w}_H - \widehat{w}_L = -\phi_{HL} \left(\widehat{v}_H - \widehat{v}_L \right) + \phi_{HL} \left(\lambda_{HB} - \lambda_{LB} \right) \left(1 - s_{BG} \right) \left(\beta_{BG} - \gamma_{BG} \right) \left[\left(\widehat{p}_B^* + \widehat{T}_B \right) - \left(\widehat{p}_G^* + \widehat{T}_G^* \right) \right]$$

of which the closed-economy equation (5) and the HOS equation (7) are special cases, and to which in principle terms capturing the effects of changes in technology or domestic demand could be added. The focus of this paper is on the first of these two terms, as a result of the availability of data in WIOD on wages and endowments but not on world prices or (a full enough set of) trade costs. In other words, this paper does not offer a compete explanation

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[7] For a fuller exposition of this equation, see sections 3.4 and 5.3 of Wood (2012).

[8] If $\beta_{BG} = \gamma_{BG}$, including the Cobb-Douglas case of both parameters being unity (Abrego and Whalley, 2000), changes in foreign prices would not affect factor prices, and if $\beta_{BG} < \gamma_{BG}$ the direction of the effect would be reversed. β_{BG} and γ_{BG} act in opposite directions because (for example) a rise in the price of foreign varieties both raises the demand for domestic varieties and reduces demand for all varieties of the good in total.

of the determination of wages in open economies, but seeks more narrowly to explain the size and determinants of ϕ_{HL}, the responsiveness of wages to endowments.

In doing so, however, it will be essential to allow for other influences on wages. Changes in openness to trade or price-ratio elasticities, in particular, affect both the terms in equation (16), though in different ways. Greater openness, for example, tends to lower ϕ_{HL} by reducing s_{BG} and thus raising ϵ_{BG}, but it also tends to increase the impact of foreign prices by raising $(1 - s_{BG})$, and is likely to alter relative foreign prices through changes in T_B relative to T_G. A rise in the price-ratio elasticity would also lower ϕ_{HL}, but (with no other change in equation (16)) it would reduce the influence on wages of both endowments and foreign prices.

(d) Extensions and limitations

For the purposes of the ensuing empirical analysis, we extend the model to include n goods, indexed by j and with good 1 as the numeraire (but still with only two factors), so that (13) becomes

(17)
$$\widehat{w}_H - \widehat{w}_L = -\frac{1}{\sum_{i=1}^{n} \left[\lambda_{Hj} \left(1 - \theta_{Hj} \right) + \lambda_{Lj} \theta_{Hj} \right] \sigma_j + \sum_{j=2}^{n} \left(\lambda_{Hj} - \lambda_{Lj} \right) \epsilon_{j1} \delta_{j1} \left(\theta_{Hj} - \theta_{H1} \right)} \left(\widehat{v}_H - \widehat{v}_L \right)$$

Relative factor prices are affected by variation in endowments, even in open economies producing more than one good, because the ϵ_{j1}'s are finite. Changes in output mix require changes in relative goods prices (because demand is less than infinitely elastic), which in turn require changes in factor prices, whose size is amplified because the δ_{j1}'s are less than unity, muting the effect on relative purchaser prices of changes in relative IFCs. The inverse relationship between endowments and factor prices is continuous (rather than stepped as in multi-cone HOS), but tends to be less steep in a more open economy. As explained above, lower international trade costs increase the average ϵ_{j1}. Lower per-unit international trade costs also raise the δ_{j1}, increasing the average price-ratio elasticity.

In GHO, traded intermediates are part of the OCW, since they are a component of costs that is common to all countries and does not vary with factor endowments, so they tend to reduce price-ratio elasticities. However, trade in intermediates also affects the immobile factor intensities of goods, and more specifically tends to make differences in factor intensity among goods larger than they would be if all inputs had to be produced domestically. Trade in intermediates thus shows up in (17) as absolutely larger $\lambda_{Hj} - \lambda_{Lj}$ and $\theta_{Hj} - \theta_{H1}$, pulling

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in the opposite direction to the fall in δ_{j1} caused by the higher ratio of OCWs to IFCs.[9] The net effect of more trade in intermediates on the sensitivity of relative factor prices to variation in relative endowments in GHO could thus be either positive or negative.

In GHO, payments to mobile factors are also part of OCWs, reducing price-ratio elasticities. Changes in the world prices of mobile factors can alter the prices of immobile factors through sector-biased channels and factor-biased channels, the latter depending on substitutability and complementarity between the factors. With more than two immobile factors, substitutability and complementarity also influence the effects of variation in immobile factor endowments on factor prices, since the effect of a change in the supply of one factor on the relative prices of other factors depends in GHO on how it affects the relative demand for them.

The usefulness of GHO is in explaining not only why factor prices vary with endowments in open economies, without the awkwardness of HOS cones, but also why the sensitivity of factor prices to endowments varies among countries and time periods, being greater where barriers to trade are higher and other-cost-component wedges are larger. It is important, though, to recognise the limitations of all HO theory, particularly with regard to the time periods over which it is relevant (Blum, 2010; Leamer, 2012, pp. 7-8, 108-13). Its mechanisms require factors to move across sectors, which some natural resources cannot do. At best, factor mobility is gradual, so the immediate impact of shocks on factor prices will be largely sector-specific, with HO effects taking several years to work themselves out and thus in principle being most clearly observable across countries and over long periods.

For skilled and unskilled labour, however, the picture is complicated by long-term non-HO causal relationships, in both directions, between supply and demand, due, e.g., to shifts in the education supply curve and induced skill-using technical progress (Wood, 1998). These forces can act also across countries. Over time, their existence makes it likely that HO influences on wages will be most clearly discerned in periods of intermediate length.

III   Data and descriptive statistics

The data used in this paper are drawn from the World Input-Output Database (WIOD), a recent resource described by its creators in Timmer (2012). It offers a single and consistent source of global data on output, trade, factor use and factor prices, putting its users at an

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[9]With more than two countries, however, it is possible that trade in intermediates could reduce rather than increase $\theta_{Hj} - \theta_{H1}$ and $\lambda_{Hj} - \lambda_{Lj}$ and thus act in the same direction as the lower δ_{j1} (assuming, as discussed in footnote 3, that elasticities of substitution are greater in consumption than in production. Details available on request.

advantage over the authors of earlier studies reviewed in section I, who have had to put together their data from several different sources.

The core of WIOD is annual international input-output tables for 1995-2009 and 35 industries that connect 40 countries - 27 members of the European Union and 13 other major economies, in total accounting for 85% of world GDP, plus a composite rest of the world. Trade flows are computed from these tables. Values are at basic prices, but information is also available on trade and transport margins for internal and international transactions. Prices deflators can be computed from the same tables valued at previous year's prices.

WIOD's auxiliary tables include socio-economic accounts providing (among other things) information on the levels of employment and wage bills of three skill categories of worker in every country, industry and year. Skill is measured by length of schooling, following the International Standard Classification of Education (ISCED). 'Low skilled' workers are ISCED categories 0, 1 and 2 (everything below completed upper secondary). The 'medium skilled' are ISCED categories 3 and 4 (complete upper secondary and some tertiary, but below a college degree), and the 'high skilled' are categories 5 and 6 (a 2-4 year college degree or its vocational equivalent and above). The data do not distinguish between males and females.

WIOD wage and employment data were assembled from national labour force surveys and censuses, which have not previously been collated in this form. We use these data to derive wage rates per hour worked - the form in which wages were typically reported in the sources. Labour endowments are proxied by the total number of hours worked by skill category. Though these data are by far the best available, their accuracy is open to doubt, especially in poorer countries with large numbers of self-employed workers, for whom wages comparable to those of employees had to be imputed. In some countries, gaps had to be filled by using data from other similar countries. In addition, of course, the quality of schooling varies widely.

In applying HO to WIOD, it needs to be borne in mind that employment does not correspond exactly with endowments. Because of differences in participation rates, unemployment rates and hours of work (the employment unit in WIOD), the relationship between the numbers of adults with specified levels of education and employment at those levels of education varies across countries and over time. In short periods, for example, the college-educated population hardly changes, but the college/non-college employment ratio fluctuates significantly because there is less output volatility in college-intensive sectors and greater reluctance to fire and rehire more skilled workers. Across countries and over longer periods, however, variation in skilled/unskilled employment ratios in WIOD and variation in

the corresponding population ratios in Barro and Lee (2013) are strongly correlated (results available on request).

Another reservation about using WIOD to analyse relationships between trade and factor prices is that the countries in the dataset are atypically large and therefore trade atypically little. Though these countries account for 85% of world GDP, they are only about one-fifth of all the countries in the world and thus on average about four times as big as a world average country. With smaller countries, our results might have been different.

A first glance at the data is in Figure 1, which plots the relative wage of skilled workers across countries against relative endowments of skilled labour in four years spanning the full period. As in Timmer et al. (2014), we aggregate the three WIOD skill categories into two by combining 'low-skilled' and 'medium-skilled' into 'unskilled', who are thus all those with less than a college degree.

[Insert Figure 1 here]

Though purely descriptive, the plots show a negative linear relationship: in countries with relatively more skilled workers, the relative wage of skilled workers tends to be lower. This relationship is however far from perfect, with wide dispersion among countries with low skill abundance: India, Brazil and Indonesia have the highest skill premia, but China one of the lowest, especially in the early years. Moreover, the negative relationship with wages is not consistent at intermediate endowment levels.

Other variables are used in the empirical analysis to control for the level of economic development, additional factors of production and their composition, and labour market institutions. GDP per capita (in 2005 constant US$) and population are sourced from the World Development Indicators, while data on human capital are from the Barro and Lee (2013) database. To control for the stringency of labour market institutions, we use data on unionization and collective bargaining from the ICTWSS database (Visser, 2013).

Table 1 reports summary statistics for the (unlogged) variables used in the regressions. Table A1 in the Online Appendix is a correlation matrix for the main variables.

[Insert Table 1 here]

IV   Empirical analysis and results

The confrontation of theory with data in this section proceeds as follows. In Part A, we apply the GHO model in reduced form, examining whether variation in openness and in price-ratio elasticities helps to explain variation in the strength of the inverse relationship

between relative wages and relative skill endowments, both across countries (cross-section) and within countries over time (panel). In Part B we control for variation in worker quality and test for the existence of multiple cones of diversification. In Part C, we estimate a structural version of the GHO model and assess how accurately its predictions of changes in relative wages as a result of changes in skill endowments match the changes observed in the data.

A   Wage-endowment relationship and GHO in reduced form

Cross-country evidence

All WIOD countries in all years engaged substantially in trade and thus were open in the sense relevant to the HOS model, which is compatible with high trade barriers and nontraded sectors.[10] So the HOS prediction of insensitivity of factor prices to variation in endowments within cones should apply to them. Our first simple test of this prediction is to regress the relative wage of skilled workers on relative endowments of skilled labour across countries, averaging over time for each country and with both variables in logs.[11] As expected from Figure 1, the results in column (1) of Table 2 strongly reject insensitivity: a country with a 10% higher relative supply of skilled workers is estimated to have a 2.7% lower skilled wage premium, and we obtain a similar elasticity for each year in the sample, as shown in Figure A1 in the Online Appendix.[12]

The GHO model by contrast allows naturally for sensitivity, and thus provides a useful framework in which to apply HO theory to factor prices, much as essentially similar models proved useful in applying HO theory to the composition of trade in Romalis (2004) and Chor (2010). As explained in section II, the GHO model also makes two testable predictions about variation among countries and over time in the elasticity of relative wages with respect to relative endowments:

1. This elasticity is made smaller (closer to zero) by more openness to trade, because firms have smaller shares of their home market and export more of their output, per-unit trade costs are lower, and more trade in intermediates amplifies differences in factor intensity among goods.

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[10]In 2000 five of them - China, Estonia, India, Malta and Russia - were still classified as "closed" on Sachs-Warner criteria (Wacziarg and Welch, 2008), but even they were not autarkic.

[11]Standard errors in all cross-country regressions are heteroskedasticity-robust and estimated with the HC3 method to account for small sample bias.

[12]Unlogged regressions in Figure A2 in the Online Appendix generate a similar pattern of significantly negative coefficients, but fit less well.

2. This elasticity is also made smaller by a higher price-ratio elasticity - the responsiveness of relative purchaser prices of goods to relative factor costs - which permits endowment-absorbing changes in output mix to be achieved with smaller changes in factor prices.

To test the first prediction, we follow many other scholars and measure openness to trade by the ratio of a country's total trade (exports plus imports) to its total output.[13] However, this ratio tends to be substantially lower in large countries than in small countries, not mainly because of higher trade barriers (though longer internal distances do add to trade costs), but because of more potential for realising economies of scale internally and greater diversity of natural resources.[14] To alleviate this size bias, we measure openness by the residuals of a cross-section regression of the trade/output ratio on population (both in logs).[15]

To test the second prediction, we exploit equation (12), in which the price-ratio elasticity depends on (a) the ratio, τ, of the other-cost wedge (OCW) to immobile factor production costs (IFCs) and (b) the degree, η, to which the relative OCWs of goods vary with their relative IFCs. If η were zero, the price-ratio elasticity would be approximately $1/(1+\tau)$, or for short $\widetilde{\tau}$.

In the absence of more detailed information on OCWs, we measure the size of τ for the economy as a whole and use as a regressor $\widetilde{\tau}$, whose coefficient should pick up (among other things) the average η across the units of observation in the regression. Given this average η, in units with a higher $\widetilde{\tau}$, the endowment-absorbing response of the output mix to changes in endowments should be larger and hence the depressing effect on the relative skilled wage smaller.

A key issue is evidently how to measure τ at the country level: accounting and the WIOD data tell us what makes up the purchaser price, but judgement is required in assigning these elements between OCWs and IFCs. We confidently put internal trade costs and taxes into OCWs, since they drive a wedge between IFCs and purchaser prices, whatever the location of the purchaser. WIOD provides such data in its national Supply-and-Use tables, from which we can extract the sum of the internal transport margin and net product taxes across sectors in each country and year. If capital is internationally mobile, as assumed in this

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[13]An advantage of WIOD is that the denominator can be gross output, matching the gross measure of trade in the numerator, rather than, as in most earlier studies, GDP.

[14]Gravity-based measures of trade barriers (e.g. the Constructed Home Bias by Anderson and Yotov, 2010), while properly controlling for internal distance, are also strongly (and inversely) correlated with country size.

[15]We get similar results if instead we include (as additional variables in the regressions) country size and its interaction with endowments. Results are available upon request.

paper, WIOD's "capital compensation" also belongs in OCWs, since it too creates a wedge between IFCs and purchaser prices regardless of where products are sold.

The resulting measure of τ includes OCWs that are mainly 'domestic' ($\tau \equiv \frac{dom.margin+tax+cap.bill}{totalwagebill}$) but are relevant to both internal and international transactions. In principle, OCWs should also include foreign trade costs and purchases of traded intermediate goods. However, we have only limited information on foreign trade costs (the international transport margin in WIOD) and we cannot measure the amplification of differences in immobile factor intensities as a result of trade in intermediates. Moreover, the effects of foreign trade costs and traded intermediates on the wage-endowment elasticity should be picked up by our openness measure. So we limit τ to its domestic elements, recognising that it is only part of the true price-ratio elasticity.

Across countries, allowing for both GHO predictions, we specify the following regression equation:

$$(18) \quad \ln(w_c) = \alpha + \beta_1 \ln(v_c) + \beta_2 \ln(o_c) + \beta_3 \left(\ln(v_c) \times \ln(o_c) \right) + \beta_4 \widetilde{\tau}_c + \beta_5 \left(\ln(v_c) \times \widetilde{\tau}_c \right) + \varepsilon_c$$

We expect the coefficients (β_3 and β_5) on both interaction terms to be positive, since higher levels of both o_c and $\widetilde{\tau}_c$ offset the negative w-v elasticity.

A limitation of this specification is that a positive openness-endowment interaction could be picking up more than the effect of greater openness on the wage-endowment elasticity (as in the first rhs term of the GHO equation (16) in section II). It could also be picking up the effect of greater openness on the local prices of foreign goods via the T's in the second rhs term of that equation, since, as explained in connection with equation (7), the direction of the changes in the T's is likely to vary with endowments. Greater openness tends to increase the relative wage of skilled workers in a high-v country, but to decrease it in a low-v country, in both cases favouring the country's abundant factor - a basic principle of HO theory. This mechanism would generate a positive coefficient on the openness-endowment interaction, but without information on T's for specific goods we cannot disentangle its effect from the also positive effect of greater openness on the wage-endowment elasticity.[16]

Columns (2) and (3) of Table 2 presents the results. Column (2) includes the endowment-openness interaction only. As GHO predicts, the interaction term has a positive coefficient, though it is imprecisely estimated, perhaps because of the small sample. Column (3) includes all the variables of (18). Consistently with the theoretical

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[16]In other words, the openness-endowment interaction necessarily captures the influence of variation in endowments on the relationship between openness and wages as well as the influence of variation in openness on the relationship between endowments and wages.

predictions, the $\widetilde{\tau}$-endowment interaction is positive and significant at the 10% level, and the openness-endowment interaction is also positive and similar to the estimate in column (2). These positive interaction terms imply that both higher trade openness and a higher price-ratio elasticity (reflecting a lower value of our measure of the ratio of OCWs to IFCs) soften the otherwise inverse relationship between relative wages and relative endowments.

Columns (4) to (6) report the result of robustness checks. In column (4), we recognise that our 'unskilled' category includes a wide range of schooling - from none to some tertiary education. We control for the share of 'low' in the unskilled (low + medium) aggregate, and within the 'low' category for the share of workers without any education (computed from the Barro and Lee, 2013 database[17]). The interaction terms remain positive, but the $\widetilde{\tau}$-endowment interaction is smaller and not significant. The positive and significant coefficient on the share of workers with no education and the insignificant coefficient on the share of low-skilled workers suggest that the skilled wage premium is higher in countries where unskilled workers have less education and that the proportion of people without any education is the main driver of this composition effect.[18]

In column (5) we allow for other factors of production, which, if they are substitutes or complements for skill or labour, can affect the wage-endowment relationship. One such factor is land, which is likely to be complementary to unskilled labour, and whose influence we proxy by the ratio of a country's area to its unskilled labour supply. Another one is capital, which we treat as mobile - following Wood (1994) and the corroborating evidence from Caselli and Feyrer (2007) - and whose influence we proxy by the ratio in each country of the rental rate of capital to the average wage.[19] The usual assumption of capital-skill complementarity predicts a negative coefficient (with more expensive capital reducing the demand for skill). Adding both these variables in column (5) makes the openness-endowment interaction effect larger and more significant than in column (3), but has the opposite effect on the $\widetilde{\tau}$-endowment interaction. The coefficient on land abundance variable is not significant, while the positive and significant coefficient on the capital variable suggests that countries

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[17]We take the ratio (in logs) of people with no education to people with "attained" (not completed) secondary education at most - i.e. the most comparable category to the 'unskilled' definition from WIOD data. While WIOD data on labor endowments are in hours worked, the Barro and Lee data are in number of people regardless of their employment status.

[18]Assigning medium-skill labor to the skilled category does not change our findings (estimates not reported). The wage-endowment elasticity remains negative and significant, but smaller than in our baseline specification, supporting our assumption that medium-skilled workers (those with complete upper secondary education, who on average in WIOD countries are about half of labour supply) are more substitutable for low-skilled workers than for high-skilled ones (with a college degree or more).

[19]The rental rate of capital is derived imperfectly from WIOD as the ratio of capital compensation (non-wage value added) to the value of the fixed capital stock.

where capital is relatively more costly have also higher skill premia. The rental-wage ratio is however strongly and negatively correlated with GDP per capita (correlation coefficient of 0.95), which makes it difficult to interpret the positive association with the skill premium.

The inverse relationship between skilled wages and skill abundance and the interaction effect could be driven by other country-level influences. Given the limited sample size, we focus in column (6) on economic development and labour market institutions as two plausible candidates. When we control for GDP per capita and the share of unionised workers (as a proxy for labour market rigidity[20]), the mitigating influence of openness on the inverse wage-endowment relationship is twice as large and more significant than in column (3), while the influence of $\widetilde{\tau}$ is halved, mainly because our measure of τ is negatively correlated with GDP per capita (countries with higher OCW/IFC tend to be less developed).[21]

As an extension of these robustness tests, in columns (2) to (4) of Table A2 in the Online Appendix, we report estimates of the GHO interaction terms controlling for the interactions of the endowment variable with the other variables used in Table 2 (which considers only the direct effect of these variables on wages - not reported in Table A2). The endowment-openness and endowment-$\widetilde{\tau}$ interaction coefficients stay positive, though the influence of price-ratio elasticities is less robust.

[Insert Table 2 here]

Time-series evidence

The cross-section estimates are thus consistent with GHO predictions, at least regarding the directions of heterogeneity among countries in the wage-endowment elasticity. We now turn to the panel regressions, where we exploit variation within countries over time.

We first estimate the wage-endowment elasticity in our panel annual data (with country fixed effects and year dummies) without controlling for any other influences. The results in column (1) of Table 3 show that relative wages move inversely with relative endowments, although the effect is imprecisely estimated and smaller than across countries (column (1) of Table 2). This average elasticity might however be distorted downwards by variation in openness and price-ratio elasticities over time, as the GHO model would suggest.

When we add the GHO interaction terms, the results become strongly consistent with the theoretical predictions. In column (2), the endowment-openness interaction term is positive

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[20]Alternative measures such as the Employment Protection Legislation index from the OECD (2013) and the "Labour Freedom" index from the Heritage Foundation give qualitatively similar findings.

[21]If we omit GDP per capita from the relevant regressions, the coefficient on the $\widetilde{\tau}$-endowment interaction is indeed 1.2-1.4 and hence similar in magnitude to the baseline estimate in column (3).

and of similar magnitude to that in the cross-country specification. Our baseline specification in column (3) shows the effect of interacting endowments and the price-ratio elasticity to be strongly positive, as is that of interacting endowments and openness, both supporting the GHO prediction that higher price-ratio elasticities and greater openness diminish the inverse relationship between relative wages and endowments. The panel estimates are more precise than the cross-country ones, though the $\widetilde{\tau}$ interaction coefficient is smaller - because OCW/IFC ratios vary more across countries than within them.

These more precise estimates can be used to show graphically how the wage-endowment elasticity varies with the two mediating variables: openness and price-ratio elasticity. Since there are two interaction terms, the effect of endowments on wages depends jointly on o and $\widetilde{\tau}$. Figure 2 shows how the wage-endowment elasticity is affected by trade openness, holding the level of $\widetilde{\tau}$ at its median value. As countries reach the average (adjusted) trade/output ratio (around 1), they move into a region of factor price insensitivity, where the skill premium does not vary with skill abundance. In countries that become relatively open to trade in our sample such as China (average $\ln(o) = 0.22$), the wage-endowment relationship is nil, while in more closed economies such as Brazil (average $\ln(o) = -0.52)$), a 10% increase in relative skill endowment is associated with a 3% drop in the skill premium. We can also assess factor price sensitivity in an 'almost closed' economy. Keeping the price-ratio elasticity at its median value, at the minimum level of openness in the sample (unlogged adjusted trade/output = 0.44) the estimated wage-endowment elasticity is -0.35. In a totally closed economy (e.g. an unlogged trade/output ratio of 0.01), the estimates imply that a 10% increase in relative skill abundance would depress the skilled wage premium by as much as 16%.

In Figure 3 we use the same approach to trace out how the wage-endowment elasticity varies with the price-ratio elasticity, $\widetilde{\tau}$, holding log openness at its median value. The wage-endowment elasticity rises slower with the price-ratio elasticity than with trade openness. The estimates imply that if, say, Turkey had median level openness and increased its price-ratio elasticity from a low value of 0.3 to 0.5 (i.e. by about two standard deviations in the sample), the relative wages of skilled workers would no longer be sensitive to changes in skill abundance.

The remaining columns of Table 3 report the results of robustness tests. Controlling for the composition of unskilled labour in column (4) halves the coefficient of the $\widetilde{\tau}$-openness interaction, a result that is due to the very restricted sample (with the Barro-Lee data at five-year intervals). Controlling for other factors in column (5) makes little difference, but controlling for GDP per capita and union membership in column (6) again almost halves the

$\widetilde{\tau}$-endowment interaction coefficient compared to the column (3) baseline (as it did also in the cross-country estimates). The wage-endowment relationship thus seems to be attenuated more consistently by greater openness than by a higher price-ratio elasticity. These results are confirmed when we control for additional interaction terms, as shown in columns (6) to (8) of Table A2 in the Online Appendix.

In summary, our reduced-form evidence is broadly consistent with the predictions of the GHO model concerning the wage-endowment relationship. Both greater trade openness and higher price-ratio elasticities attenuate the negative elasticity of relative wages of skilled workers with respect to skill endowments - and high openness and high price-ratio elasticities can cause wages to vary only slightly or even not at all with variation in endowments. In both the cross-country and the panel estimates, the attenuating influence of greater openness appears more robust than that of higher price-ratio elasticities. This could be because our measure of τ is restricted to its domestic elements, with its omitted foreign elements being picked up by the openness variable. The role of greater openness might also be overstated in our estimates because the positive coefficient on the o-v interaction is increased by the impact of greater openness on the relative trade costs of more and less skill-intensive goods.

[Insert Table 3 here]

[Insert Figure 2 here]

[Insert Figure 3 here]

B Alternative HOS mechanisms

The inverse relationship between skill premia and skill endowments that emerges from both the cross-country and the panel reduced-form estimates is inconsistent with the textbook one-cone HOS model. However, two extensions of the HOS framework could reconcile it with this empirical regularity and thus demand consideration as an alternative to the GHO model: variation in worker quality and multiple cones of diversification.

Cross-country differences in factor quality or productivity

One possible reconciliation, in light of evidence that the effectiveness of schooling varies enormously, is that the observed cross-country differences in the relative wages of workers with different amounts of schooling are an illusion arising from differences in the quality or productivity of skilled or unskilled workers. For example, the quality of basic education may

vary more than that of higher education because expansion of higher education provides a larger supply of qualified teachers at lower levels. Adjusted for quality, the relative wages of skilled and unskilled workers might thus vary much less across countries than the unadjusted wage data suggest. To test this hypothesis, we apply to our cross-country data the ingenious method that Bernard et al. (2013) developed to test for factor price equalisation across US states. They allow for locality- and sector-specific differences in factor quality by using data on relative wage bills (rather than relative wage rates), in which, assuming cost minimisation, unobserved factor qualities cancel out. Our application of this method is relegated to section AIII of the Online Appendix, mainly because our results, like those of Bernard et al. (2013) for the US, strongly reject the hypothesis of relative factor price equalisation.

Adjusting for differences in quality in this way, the inverse relationship between relative wages and relative endowments becomes even stronger, both across countries and (especially) over time. This implies that the quality of more educated workers relative to the quality of less educated workers rises (rather than, as hypothesised, falls) as the proportion of more educated workers in the labour force increases. However, because the size of the quality adjustment depends on assumptions about the size of elasticities of substitution across factors, we take these results as robustness checks and revert to using unadjusted wages in the rest of the analysis.

Multiple cones of diversification

The negative elasticity of relative wages with respect to relative endowments across countries reported above could exist in a HOS model with multiple cones of diversification. In such a model, countries in different endowment ranges specialise in subsets of sectors of different skill intensity, and have different relative wages, though within each cone relative factor prices do not respond to variation in endowments.

Kiyota (2011, 2012a) finds evidence of multiple cones of diversification in Japan, looking at both output mix and factor prices. We focus on factor prices, leaving for the future a check for matching patterns of output specialisation. Further, we follow Schott (2003) in assuming that there are no regions of complete specialisation, where the response of factor prices to endowments is downward-sloping, in between the factor price 'plateaux' of the cones. We adopt this simplifying assumption mainly because of the fewness of our countries (only 40), which makes it statistically difficult to identify many different cones and regions.

Given these assumptions, we take the multiple-cone HOS prediction at face value and

estimate in the within-country averaged data:

$$(19) \quad \ln\left(w_c\right) = \sum_{d=1}^{D} \beta_d I_d\{\ln\left(v_c\right) > \overline{v}_d\} + \varepsilon_c$$

where $\overline{v}_d$ is the threshold value of $\ln\left(v_c\right)$ that identifies the dth interior knot. The term $I\{\cdot\}$ denotes an indicator function equal to one if the expression in brackets is satisfied and to zero otherwise. In a model with N cones of diversification, $N-1$ interior knots are estimated. We search for interior knots by gridding over values of $\ln\left(v_c\right)$ from its minimum to its maximum and using a grid interval of 0.2.[22] We test for a maximum of four cones (with three interior knots) and choose the set with the lowest Akaike Information Criterion (AIC).

The results are consistent with the existence of multiple cones of diversification in the sense that specifications with more cones fit the data better - the best fit is for four cones. Figure 4 plots a scatter of relative skilled wages against relative endowments of skilled labour (averaged over time and in logs), with a horizontal line showing the predicted wages from the four-cone model and vertical lines showing the knots, which correspond to college-educated labour force shares of 6%, 12% and 20%. China is alone in the lowest cone, excluding which relative wages decline across cones with relative endowments, as predicted by theory.

[Insert Figure 4 here]

The multi-cone HOS model allows us to analyse the "paths" of development that countries may follow while moving across cones of diversification (Leamer, 1987). While a fuller treatment is beyond the scope of this paper and left for future work (see Deardorff, 2001; Kiyota, 2012b for theoretical studies), here we empirically explore the evolution of skill abundance within countries holding the values of the cones boundaries (the knots) fixed at those estimated in Figure 4. As shown in Figure A3 in the Online Appendix, skill abundance rises between 1995 and 2009 in all countries except Mexico, where it stays constant. Half of the countries move to a more skill-abundant cone during the sample period, with most of the action occurring in the later years. This type of analysis however does not allow the boundaries of the cones to vary over time. We thus also estimates equation (19) year by year. Figure A4 in the Online Appendix shows the results in a way similar to Figure 4, but highlighting countries that moved up or down the spectrum of skill-abundance cones relative to the previous period. The four-cone specification is the preferred one in all years

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[22]We experimented with even smaller intervals of 0.1 and 0.05. The optimal number of cones stays the same, although countries' location across cones varies slightly. Reducing the interval can only support the finding of additional cones.

and the position of the knots does not vary much over time. Most of the movements of countries to more skill-abundant cones occur between 2005 and 2009, though this partly reflects downward shifts of the upper two knots, which end up in roughly their 1995 positions.

These results give support to the multi-cone version of HOS not only because the fit with four cones is much better than with one cone (where log relative wages are regressed on a constant term) but also because the four-cone specification fits better than the linear model above which regressed log relative wages on log relative endowments. However, the fact that the statistical fit improves progressively with the number of cones suggests that the linear specification may approximate the true relationship between relative wages and endowments - in other words, that the true relationship is continuously declining rather than stepped. We could not test this hypothesis by increasing the possible number of cones since, as is already evident with four cones, the role of single-country observations would become even greater.

C   Structural estimation of the GHO model

The reduced-form estimates in part A support the GHO model by showing that the inverse association between the relative wages of skilled workers and skill endowments is weaker in countries and periods with greater openness to trade and higher shares of wages in purchaser prices (our proxy for price-ratio elasticities). These estimates do not, however, establish that this weakening is due (let alone due entirely) to the GHO mechanisms described by equation (17), particularly because the coefficients on the crucial interaction variables may be biased by other mechanisms for which we could not control. We therefore now estimate directly the relationship in (17), in order to assess whether the variation in relative wages with respect to relative endowments predicted by the model (the right-hand side of equation (17)) matches the observed variation in the data.

As explained in section II, relative wages absorb changes in relative endowments through two main channels. One, given algebraically by the first term in the denominator of equation (17), is the 'technique' channel through which firms adjust by substituting one type of labor for another within each sector j, as mandated by the technology parameter σ_j. This channel includes other *within*-sector adjustments, such as intra-sectoral product mix changes, which have been shown to play a quantitatively important role (Schott, 2003). The second term in the denominator describes the 'output-mix' adjustment channel, which captures changes in relative labour demand induced by structural shifts *between* sectors.

The GHO model is distinctive in its treatment of the output-mix channel since it

specifies that in an open economy the elasticity of relative sales of different sectors with respect to relative prices is finite (rather than infinite, as in HOS). The technique channel is the same in GHO as in HOS (although it plays no role in a one-cone HOS model because the output-mix channel absorbs all of any changes in endowments with no change in relative prices or wages). In the structural tests, we thus focus on how alternative specifications of the relative output elasticity fare in matching predicted with actual changes in relative wages.

Estimation of parameters

To operationalise our exercise, we need to measure the parameters on the right-hand side of equation (17). The factor use and cost shares (the λ's and θ's parameters) can be computed directly from the WIOD Socio-Economic accounts for each sector, country and year in the sample. For each observation, we calculate direct use and compensation for skilled and unskilled labour as shares of total labour use and compensation (the two types of labour being assumed to be the only immobile factors).

To measure the price-ratio elasticity δ_{j1}, we assume for simplicity that all OCW's are per-unit and hence set $\eta_{j1} = 0$. On this assumption, the price-ratio elasticity - of relative purchaser prices with respect to relative IFC's - is (as on p.10 of Wood, 2012, but omitting the sector-pair subscripts for clarity)

$$(20) \quad \delta = \frac{1 + \frac{\tau}{2}\left(\sqrt{\frac{c}{t}} + \sqrt{\frac{t}{c}}\right)}{1 + \tau\left(\sqrt{\frac{c}{t}} + \sqrt{\frac{t}{c}}\right) + \tau^2}$$

where $c = \frac{c_j}{c_1}$ and $t = \frac{t_j}{t_1}$ are relative IFC's and OCW's, respectively; and $\tau = \sqrt{\tau_j \tau_1}$, where $\tau_j = \frac{t_j}{c_j}$. If relative IFC's equal relative OCW's ($t = c$), this expression conveniently reduces to $\widetilde{\tau} = \frac{1}{1+\tau}$, which was the basis on which we approximated the price-ratio elasticity at the country level in the reduced-form analysis. Here we follow the analytical expression in (20), working at the sector level, but still including only internal trade costs, (net) taxes and capital compensation in the OCW's (t).

It remains to estimate the substitution elasticity parameters: σ's and ϵ's. The elasticity of substitution in production, σ, measures the extent to which changes in relative factor prices alter relative factor use in each sector (Jones, 1965):

$$(21) \quad \sigma_j = \frac{\widehat{a_{jL}} - \widehat{a_{jH}}}{\widehat{w_H} - \widehat{w_L}}$$

We hence estimate σ for each sector as the coefficient in a panel regression of relative factor use on relative wages. By doing so, we exploit variation within each country-sector over time in an attempt to (partly) control for technical change (see Acemoglu, 2002) [23]. The estimated sector-specific σ's are reported in column (1) of Table A3 in the Online Appendix. When significantly different from zero, the point estimates of σ's are always larger than 1, with an average across sectors of 1.34, which is close to the 1.41 found by Katz and Murphy (1992) for the U.S. and within the range of 1 to 3 that Katz and Autor (1999) consider plausible. The estimates are low and imprecise in a few service sectors, for which we use the average of the significant σ's across all service sectors.[24]

To measure ϵ, we first estimate the two demand parameters γ and β. To this end, we apply the estimation approach pioneered by Feenstra (1994) and estimate β's varying across sectors and purchasing country. A variety is thus defined as good j (i.e. a WIOD sector) sold by country z to country $\check{z}$, where $z=\check{z}$ for a domestic variety. The value of shipments for final demand at the sector level is taken from the WIOD international input-output table. We follow Patel et al. (2014) and proxy prices with the sectoral price deflators from WIOD.[25] The CES demand system is estimated with the LIML estimator and constrained search algorithm introduced by Soderbery (2015) to ensure that $\beta > 1$. The median (and mean) of the estimated β's across countries for each sector are reported in columns (2) and (3) of Table A2. The overall median value is 2.69 (and mean 20.5), which is in line with the estimated elasticities available in the literature.[26] The γ elasticities are estimated with the same methodology exploiting variation across sectors in final consumption purchases and prices at the country level (see also Patel et al., 2014). Estimated γ's range between 1.15

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[23]The Arellano-Bond system GMM estimator is applied to correct for the attenuation bias from measurement error in relative wages at the country-level. Panel estimates of the regressions in first-differences with country fixed effects deliver low σ's.

[24]Notice that this exercise, while somewhat similar to, is fundamentally different from what we are ultimately after, namely the responsiveness of relative wages to changes in labour endowments at the country-level. The underlying and widely accepted assumption in HO-type trade models (see e.g. Leamer and Levinsohn, 1995; and Slaughter, 1997) is that at the national level wages endogenously respond to exogenous changes in factor endowments, while at the industry level relative labour demand responds to changes in relative wages which are regarded as exogenous to that industry.

[25]To alleviate the inherently large measurement error especially on the price side, we drop the top and bottom 1% of the sample in each product. To make sure we have a minimum level of identifying variation, we also keep purchasing-country-product combinations only if we observe at least ten seller countries throughout the sample period. Finally, we drop estimated β's with implausibly large values (i.e. above 400) - 2% of the sample. We use the within-sector average β's for the missing observations. In estimating γ's, we keep countries for which we have data (after dropping outliers) for at least ten sectors throughout the period. This leaves out Bulgaria, Estonia, Indonesia, Ireland and Russia. We use the average γ for these countries.

[26]Broda and Weinstein (2006), for instance, obtain a median estimated β's (what they refer to as σ's) of 3.39 using a similar methodology on more detailed trade data (excluding hence domestic shipments) for 73 countries.

and 2.57 and, consistently with theoretical expectations, are generally lower than the β's.[27]

The estimated β's and γ's are then combined into the purchaser-price elasticity ϵ, which can vary across country-pairs in our multi-country setting. Denoting with superscript z the origin country and $\check{z}$ the destination one, the elasticity of country z's relative sales of goods j and 1 in market $\check{z}$ with respect to its relative prices in that market is, in a two-level CES demand system, a weighted harmonic mean of γ and β (Sato, 1967)

$$
(22)\quad \epsilon_{j1}^{z\check{z}} = \frac{\frac{1}{s_j^{z\check{z}} s_j^{\check{z}}} + \frac{1}{s_1^{z\check{z}} s_1^{\check{z}}}}{\frac{1}{\beta_j^{\check{z}}}\left(\frac{1}{s_j^{z\check{z}} s_j^{\check{z}}} - \frac{1}{s_j^{\check{z}}}\right) + \frac{1}{\beta_1^{\check{z}}}\left(\frac{1}{s_1^{z\check{z}} s_1^{\check{z}}} - \frac{1}{s_1^{\check{z}}}\right) + \frac{1}{\gamma^{\check{z}}}\left(\frac{1}{s_j^{\check{z}}} + \frac{1}{s_1^{\check{z}}}\right)}
$$

where the weights depend on market shares. Specifically, $s_j^{z\check{z}}$ is the share of z's varieties in country $\check{z}$'s consumption of good j, while $s_j^{\check{z}}$ is the share of good j in country $\check{z}$'s total consumption. As intuitively conveyed by the simplified arithmetic average in equation (11)[28], the smaller are the shares $s_j^{z\check{z}}$, the lower is the influence of country z's varieties on the overall prices of goods in country $\check{z}$ and hence the higher is the weight on the within-good elasticity β relative to the across-good elasticity γ.

The elasticity for country z producers across all markets is a weighted harmonic average: $\epsilon_{j1}^z = \sum_{\check{z}} \frac{x_{1j}^{z\check{z}}}{\epsilon_{j1}^{z\check{z}}}$, where the weights x's are the shares of their sales in each market. The purchaser-price elasticity increases with greater openness to trade. In export markets, $s_j^{z\check{z}}$ is lower than at home because of tougher competition from foreign suppliers, while in the home market this share is lower since consumers have easier access to varieties from abroad, in both cases giving more weight to the generally higher β's. Moreover, higher export shares (higher x's in foreign markets) give more weight to the ϵ's in foreign markets, which are usually higher than in the home market. Crucially, the hypothesis that the purchaser-price elasticity increases with trade openness is strongly confirmed in our data, both across countries and sectors and over time, which supports our interpretation of the reduced-form estimates.[29]

Finally, estimation of equation (17) requires us to choose a reference sector. Since the underlying parameters vary among sectors, this choice affects the predicted economy-wide wage-endowment elasticity, and hence the comparisons with actual outcomes. The estimates reported use as the reference sector 'Other non-metallic minerals', which had the fewest

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[27]On average,14% of sectors have estimated β's below γ for each country, with only two countries (Slovakia and Bulgaria) where more than half of the sectoral β's are higher than the country's γ.

[28]The expression in equation (11) follows from assuming a two-level symmetrical CES utility (where the upper-level shares $s^{\check{z}}$ do not vary across goods) and two markets - a domestic and a foreign one.

[29]Regressions of our estimated purchaser-price elasticities on sector-level trade openness deliver positive and significant coefficients both across and within country-sectors (results available upon request).

missing estimated elasticities.[30] We show the sensitivity of our results to the choice of other sectors in the Online Appendix.

Cross-country evidence

As in the reduced-form analysis, we apply the structural tests to both cross-country and panel data. The first step with both sorts of data is a slope test: the changes in relative wages predicted by our estimate of equation (17) in conjunction with the actual changes in relative endowments are regressed on actual changes in relative wages. In the cross-country analysis, 'changes' in relative wages and endowments refer to deviations from the means of relative wages and endowments across countries in each year, then averaged over time within each country.

Figure 5 portrays the results of the cross-country slope tests. The left-hand panel refers to the GHO model in section II, but with the less-than-unity price-ratio elasticity calculated as in equation (20) and the finite purchaser-price elasticity calculated as in equation (22) - we refer to this baseline scenario as the P-RE case. The point estimate of the slope is almost equal to one and precisely estimated, suggesting that GHO gives a remarkably accurate explanation of the way in which variation in skill endowments across countries affects the relative wages of skilled workers. The fit is far from perfect (R^2=0.36), which could reflect errors in the relative wage predictions but must also reflect variation across countries in the determinants of actual relative wages other than endowments - the sectoral structure of trade barriers (as in equation (16)), consumer preferences, technology and labour market institutions. Of particular interest are the ten countries in the north-east quadrant, including China, which have below-average skilled wage premia despite also having below-average skill abundance.

The other two panels of Figure 5 try simpler specifications of the output-mix elasticity - the second term in the denominator of (17). In the 'Trade Protection' (TP) scenario, we retain the P-RE specification of ϵ, but assume all trade costs and other OCWs to be ad-valorem ($\delta = 1$), which lowers the predicted wage changes. The slope becomes slightly shallower and the fit hardly changes. A more drastic experiment in the right-hand panel is the 'Armington Case' (AC), in which the purchaser-price elasticity in each market is simply β (averaged across the two sectors), continuing to assume as in TP that $\delta = 1$. This case is equivalent to a one-level CES specification where the demand elasticities are

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[30]We avoided choosing service sectors because more of their estimated elasticities seemed problematic and because trade data on services are less accurate.

equal ($\gamma = \beta$) and is the standard setting in recent quantitative trade models (Costinot and Rodriguez-Clare, 2014), related gravity applications (Anderson, 2011) and empirical tests of HO theory on the output side (Trefler, 1995). The estimated slope is almost halved from the baseline P-RE scenario, suggesting that the two-level CES specification and, to a lesser extent, per-unit trade costs are key to explaining how skill premia vary with endowments across countries.

[Insert Figure 5 here]

Another test is the variance ratio (see Trefler, 1995; Blum, 2010), calculated by dividing the variance of predicted changes in relative wages ($\widetilde{w}$) by the variance of actual changes (w). The upper panel of Table 4 shows that the variance of relative wages across countries predicted by our baseline P-RE specification as a result of variance in endowments is 2.7 times greater than the actual variance of relative wages (though only half as large as the variance of endowments, since the aggregate elasticity of wages with respect to endowments is well below unity). Using the TP and AC specifications, which further reduce this elasticity by increasing the responsiveness of output structure to changes in endowments, the predicted wage dispersion decreases, bringing the variance ratio closer to unity.

Both predicted and actual changes in wages are arguably measured with error. In such a situation, Klepper and Leamer (1984) show that bounds of the true slope coefficient are given by the estimated slopes of the 'direct' ($\widetilde{w}$ on w) and 'reverse' (w on $\widetilde{w}$) regressions. The lower panel of Table 4 shows these bounds. In the P-RE case, the reverse regression yields a far smaller (0.37), though still positive and significant, slope than the direct regression. This difference is amplified by the ten countries where the skill premium is unusually low. If we drop them, the estimated slope is between 0.55 and 1.09, with a much better fit (R^2=0.6). The bounds of the slope parameter in the TP and AC specifications are narrower, with the 'indirect' slope being close to the one estimated in the P-RE case.

[Insert Table 4 here]

In sum, these tests suggest that the GHO model is a useful and empirically relevant tool to understand how variation among open economies in endowments relates to variation in relative wages as a result of finite elasticities of demand for goods and factors. However, the variance ratio and reverse regression tests also suggest that the baseline (P-RE) GHO model over-predicts the variation of relative wages across countries. The smaller variation of actual than of predicted wages must be partly due to non-endowment determinants of wages that narrow differences in skill premia across countries - most obviously, labour market and

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social security institutions. But it could also reflect the omission from the GHO model of skill supply responses to relative wages over long periods, as revealed by observations across countries.

Our findings survive a number of robustness checks. To see whether they are driven by specific time periods, we conduct the slope test for each year in the sample between 1995 and 2009. As shown in Figure A5 in the Online Appendix, the slope increases slightly over time in all three specifications, although not significantly. As a further robustness check, we replicate the slope test with different choices of the reference sector. Figure A6 in the Online Appendix reports the estimated slopes for the three model specifications. The point estimates do not vary markedly across reference sectors and they preserve the ordering across specifications, with the P-RE scenario generating a higher 'direct' slope than the two alternative ones.

We also compare manufacturing and services, which may differ in the extent to which labour is reallocated within and between sectors. We apply the slope test to manufacturing and services separately, treating their labour forces as endowments specific to (and immobile between) them. Figure 6 shows the results using the P-RE specification. The greater variation of predicted relative wages across countries in manufacturing than in services reflects greater variation in the average skill-intensity of manufacturing than of services - as expected from the greater tradability of (and hence scope for specialization in) manufacturing. The higher slope and R^2 in manufacturing hint that forces outside GHO are more important in explaining the supply and demand for skills in services.[31]

[Insert Figure 6 here]

Time-series evidence

To define changes in relative wages and endowments within countries over time (the^ terms in equation (17)), we follow Blum (2010) and take annualised differences (in logs) over windows of 5, 10 and 14 years. Longer windows might provide greater statistical power in identifying our coefficient of interest, since national endowments change only slowly. HO theory, however, suggests the opposite pattern (Leamer and Levinsohn, 1995), with the initial impact on factor prices of a change in endowments fading as the output mix adjusts, which would predict a stronger relationship in shorter windows and in HOS a zero coefficient in a long enough window.

The structural coefficients in equation (17) are averaged over these windows. Predicted wage changes are then regressed on actual changes and, for 5- and 10-year regressions, also

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[31]Similar patterns are observed in the TP and AC specifications - results available upon request.

on country and time dummies, controlling respectively for country-specific and global trends. Table 5 reports the results of the (direct and reverse) slope and variance-ratio tests.

Starting with the baseline P-RE column, the estimated slope is positive and significant in both the 5- and 10-year windows, and is greater in the longer window, though still well below unity. The same is true of the reverse regressions, whose slopes are shallower, as (though less drastically than) in the cross-country test. Relative wages are thus moving in the directions predicted by changes in endowments, particularly in the 10-year window, when the variance ratio is close to unity, too, suggesting that the endowment changes are largely being absorbed through the technique and output-mix channels of the GHO model.

By contrast, in the longest possible window of 14 years, although the variance ratio is again close to unity, the slopes are near zero, implying that actual relative wages are moving in ways uncorrelated with GHO predictions from endowment changes - and uncorrelated also with actual endowment changes. As can be seen in Figure 7, over the full period 1995-2009 there is not a clear and consistent inverse relationship across countries between changes in relative wages and changes in endowments. In all countries but one, the relative supply of skilled workers increased, but in about half of the countries the skill premium also increased. This pattern could reflect liberalization of labour markets that let unskilled wages fall, or technical change that raised the demand for skilled workers, but in any event it exposes the influence of forces outside the GHO framework.

The TP and AC specifications in the first two columns of Table 5 confirm these results. In the 5- and 10-year windows, the directly estimated slopes are slightly lower than with P-RE, and the reverse-regression slopes are slightly higher, though in all cases higher in the longer than the shorter window. Over the 10-year window, moreover, the variance ratio with P-RE is closer to unity than with either TP or (particularly) AC. Over the 14-year window, the slopes are insignificantly different from zero for all three specifications.

[Insert Table 5 here]

These findings are again robust to the choice of the reference sectors as shown in Figures A7-A9 in the Online Appendix. When we split the data between manufacturing and service sectors, with results shown in Table 6, the ('direct') slopes are higher with P-RE than with TP or AC, and in the 10-year than the 5-year windows. Interestingly, the GHO model seems to explain changes over time better in services than in manufacturing, as shown by the higher estimated slopes in the S than in the M columns of Table 6. Given the importance of trade openness in determining the output-mix adjustment, this pattern is consistent with a scenario where trade barriers have fallen relatively faster in services than in manufacturing

during the period under study, which is a relevant possibility at least for EU countries.

[Insert Table 6 here]

Our results for the 14-year changes differ from those of Blum (2010), who finds that relative wages respond more negatively to (unadjusted) relative employment changes over a decade than over shorter periods. He attributes this pattern to induced scarce-factor-biased technical progress. This difference is not due to his data covering only manufacturing: our results differ from his in the same way for manufacturing alone, as shown in Table 6. A likely explanation is differences in time period and in measure of skill (Blum's is occupational - operatives and non-operatives - while ours is educational). During his 1971-90 period in the manufacturing sectors of richer countries there were big cuts in the numbers of less-skilled workers within the operative category, reducing the operative to non-operative employment ratio but raising the corresponding wage ratio. The inverse association between the changes in these two ratios was particularly strong over the full period, as this structural change, which was driven by reduction of barriers to North-South trade, not by changes in endowments, spread to more industries and more countries.[32]

Overall, the structural tests confirm the conclusions of the reduced-form analysis. The GHO model contributes substantially to explaining how in open economies the relative wages of skilled workers vary with relative skill endowments, both across countries and over time. The explanatory power of the model seems to derive more from variation in openness to trade (through its influence on finite demand elasticities) than in price-ratio elasticities, but this asymmetry may reflect our stark assumptions of zero-or-all per-unit OCWs: allowing $\eta \in (0,1)$ might bring the model even closer to reality. The structural tests also confirm that variation in endowments is by no means the only cause of variation in relative wages, and that the GHO model does not capture some of the longer-term effects of endowments on wages through both supply-side and demand-side channels.

V   Concluding remarks

This paper has applied a more general HO (GHO) model to an empirical investigation of how and why the relative wages of skilled and unskilled workers vary with skill endowments in

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[32]Our suggested interpretation of Blum's results is based on Wood (1994). It could be tested using national-level data for individual countries that divide operatives by level of skill. Supporting evidence for our interpretation is that Blum (2010) finds the negative association to be stronger in OECD countries than in all his countries (see his Table 8). Moreover, the 11 non-OECD countries in his set of 27 countries include only one major developing-country exporter of manufactures (Korea) and five upper-middle-income Latin American countries whose experience was similar to that of OECD countries.

open economies, using WIOD's global panel dataset. Wages are found to vary systematically with endowments both across countries and over time, a pattern which cannot be reconciled with the HOS model, but is what the GHO model predicts. The results of both reduced-form and structural estimation are also consistent with the GHO predictions that the sensitivity of factor prices to endowments increases with the height of barriers to trade and decreases with the share of wages in purchaser prices.

The relative accuracy of the HOS and GHO models as explanations of reality is of more than academic significance. If the effects on wages and other factor prices of more or less openness to trade are just one element of a broader demand and supply system, as in the GHO model, rather than operating through a rigid link with world prices and trade barriers, as in HOS, the implications and options for policy are different. For example, in GHO a trade-induced widening of the wage gap between skilled and unskilled workers could be reversed by educating and training unskilled workers, which it could not in one-cone HOS. The GHO model could thus enable more constructive dialogue among trade economists, labour economists and policy makers.

As ever, there is much scope for further work. The analysis could be extended by a fuller investigation of the effects of trade in intermediate inputs, and by testing other likely influences on factor prices in GHO, including the sectoral structure of trade barriers, the composition of domestic demand and variations in technology. It could also be complemented by more empirical analysis of relationships between the composition of endowments, output and trade, including further comparisons of the performance of the HOS and GHO models. Another important step would be to use the WIOD data to test systematically the present paper's assumption that capital is an internationally mobile factor, which is at variance with the assumption of most HO empirical studies. More challenging in terms of the availability of data, especially on factor prices, would be to introduce land as another immobile factor.

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Figure 1: Relative wages and endowments
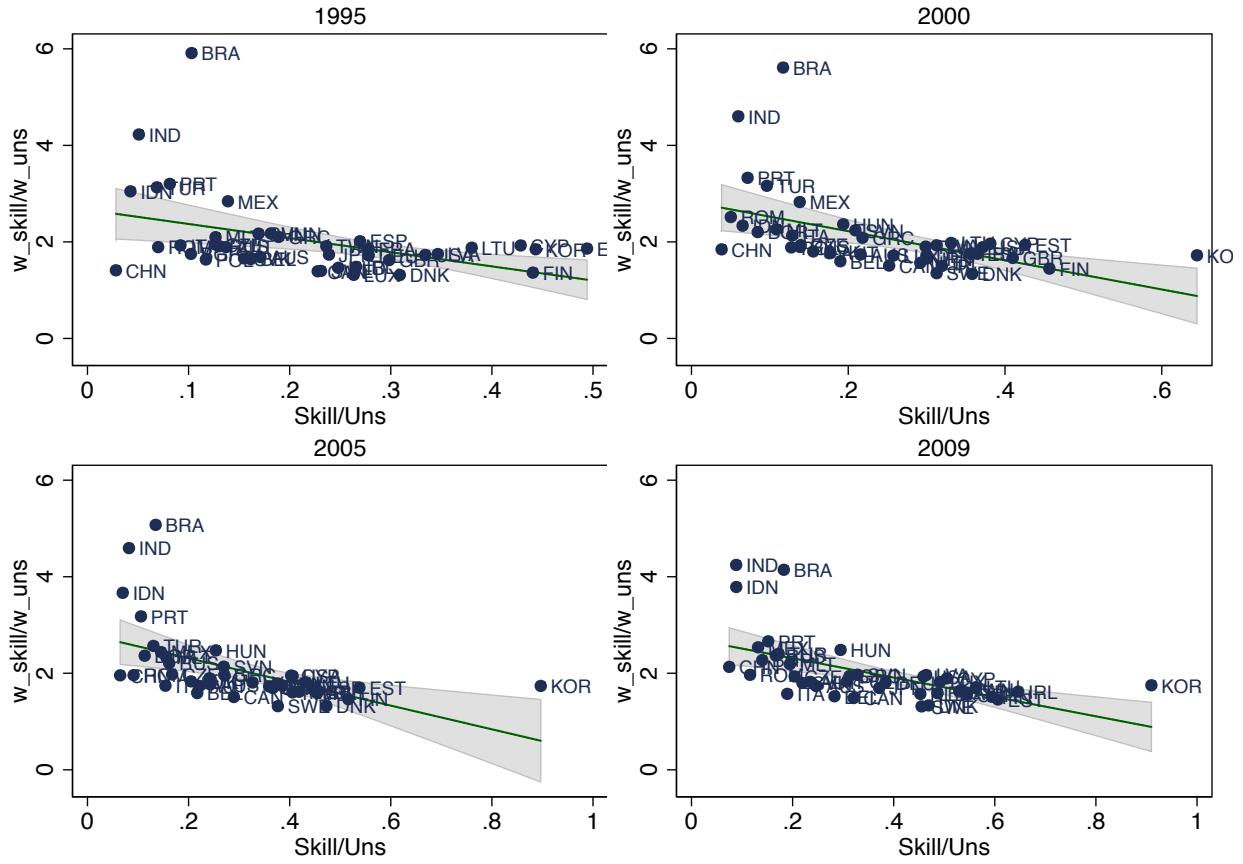
Linear prediction line with 90% confidence bands (based on HC3-robust standard errors) are shown.

Figure 2: Wage-endowment elasticity and openness at median $\widetilde{\tau}$
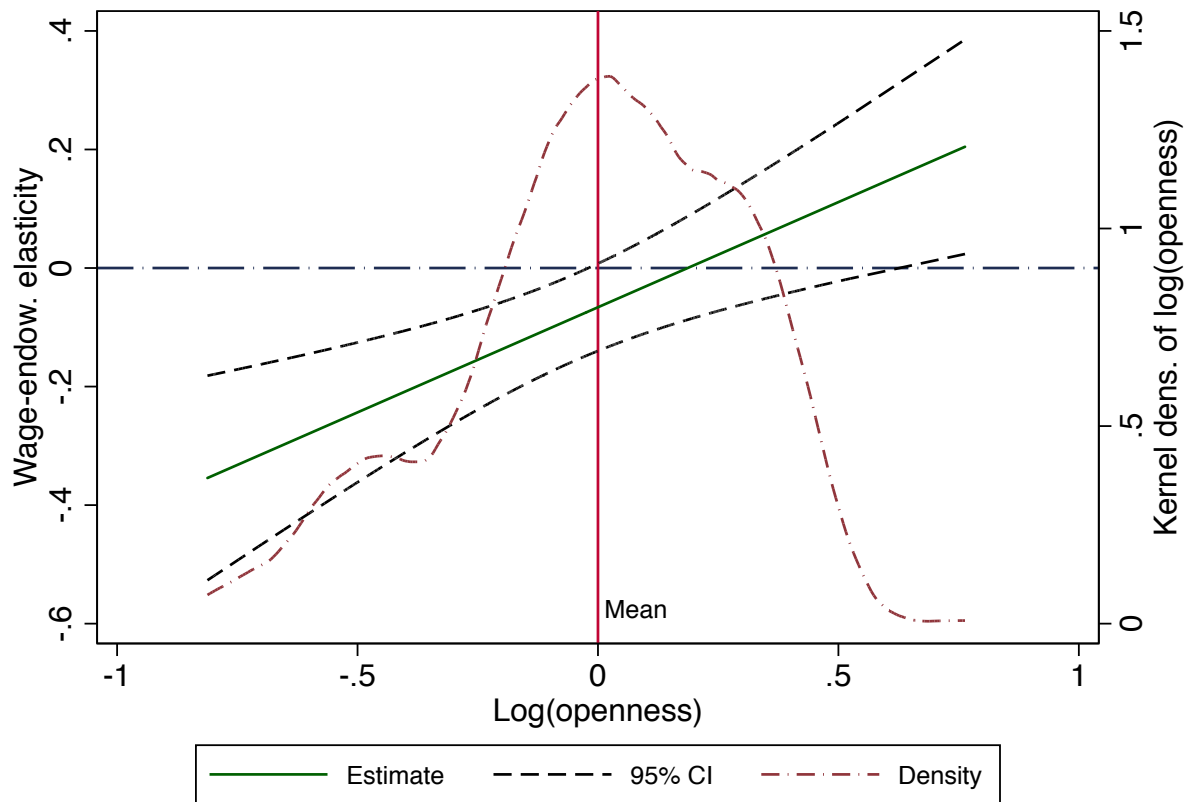
Vertical line is at the sample mean of $\ln(o)$.

Figure 3: Wage-endowment elasticity and $\widetilde{\tau}$ at median openness
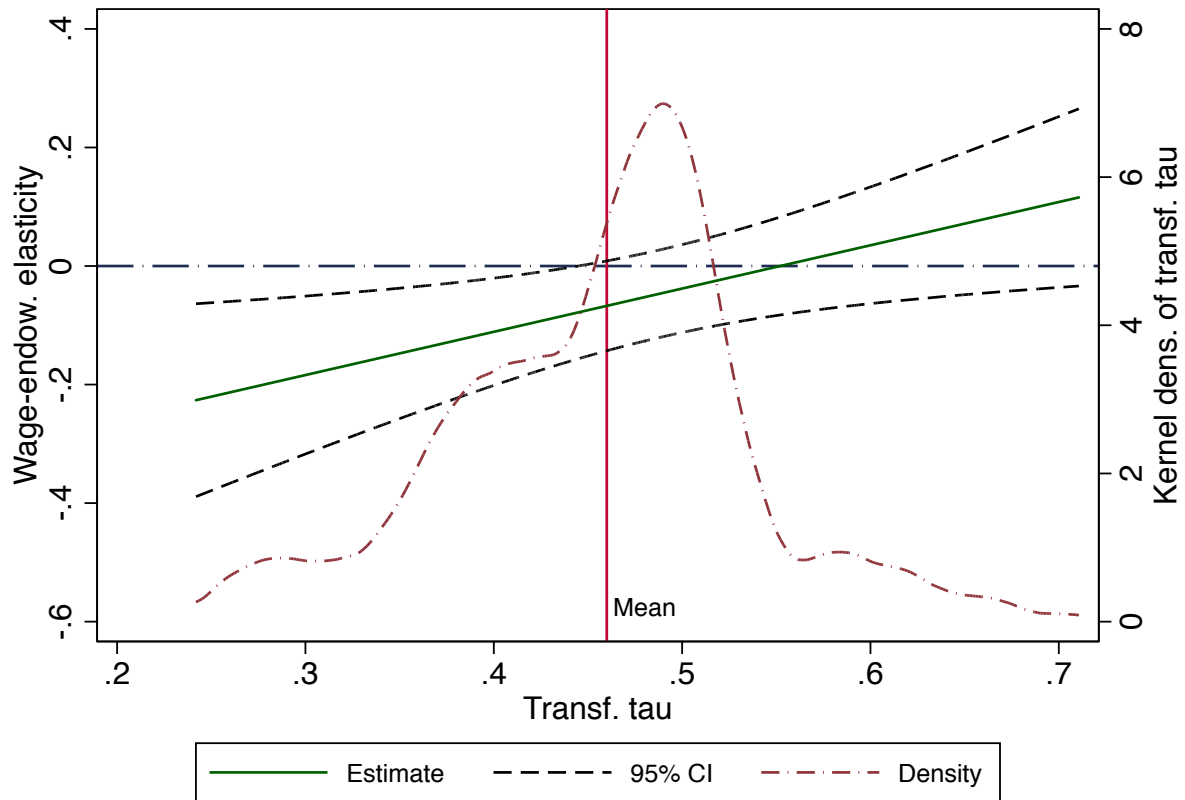
Vertical line is at the sample mean of $\widetilde{\tau}$.

Figure 4: Estimated cones of diversification
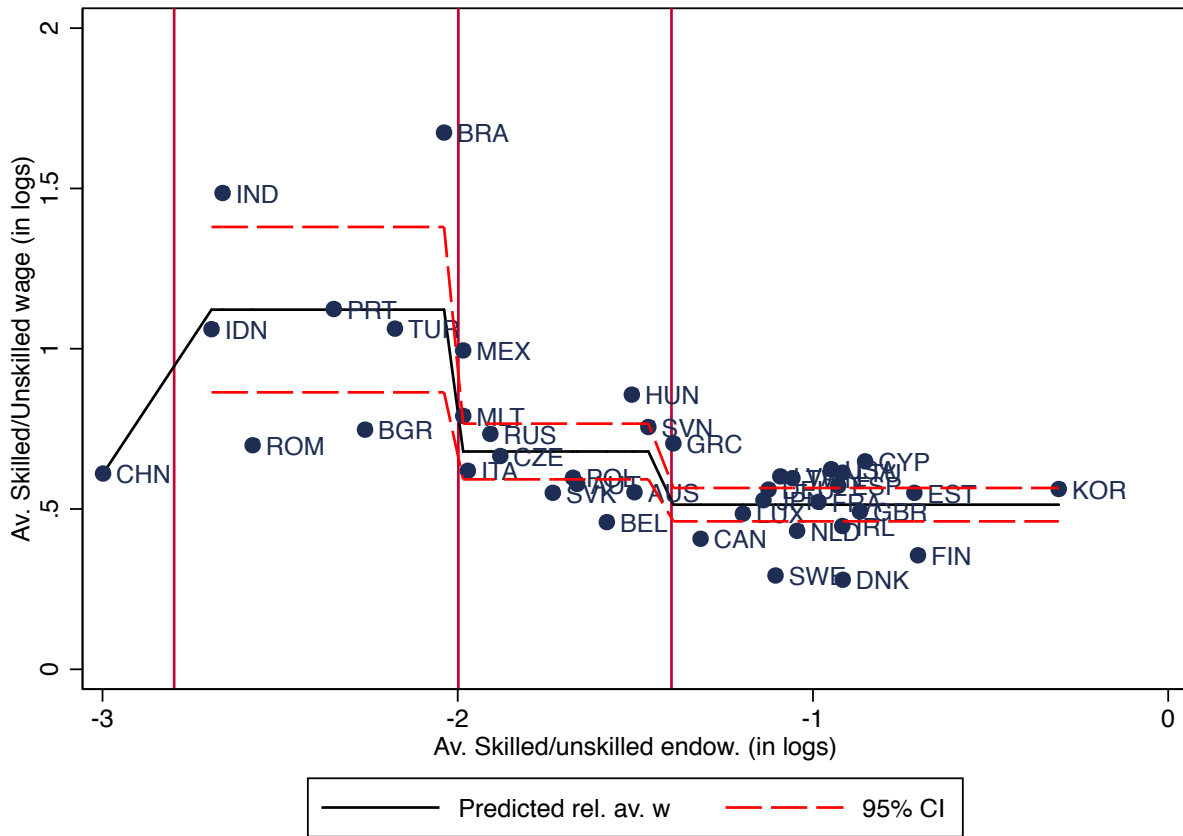
Vertical lines indicate the location of interior knots.

Figure 5: Slope tests - Cross-country estimates
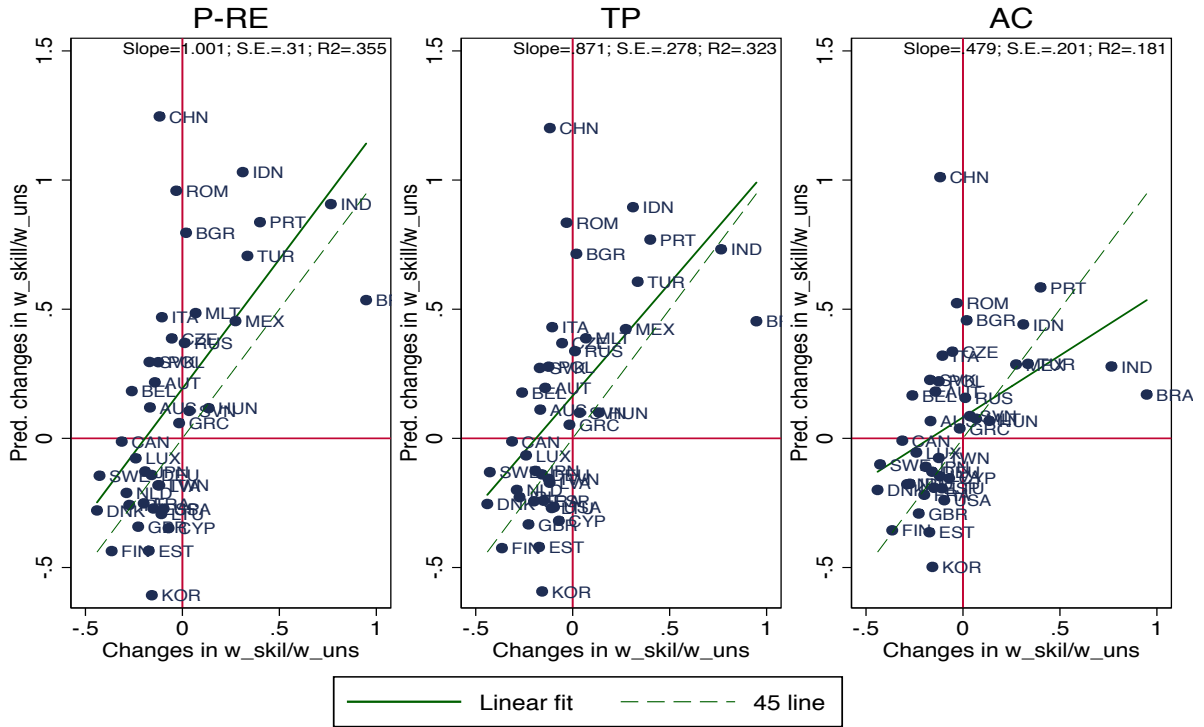
Standard errors are adjusted with the HC3 method.

Figure 6: Slope tests P-RE - Cross-country; Manuf. vs. Services
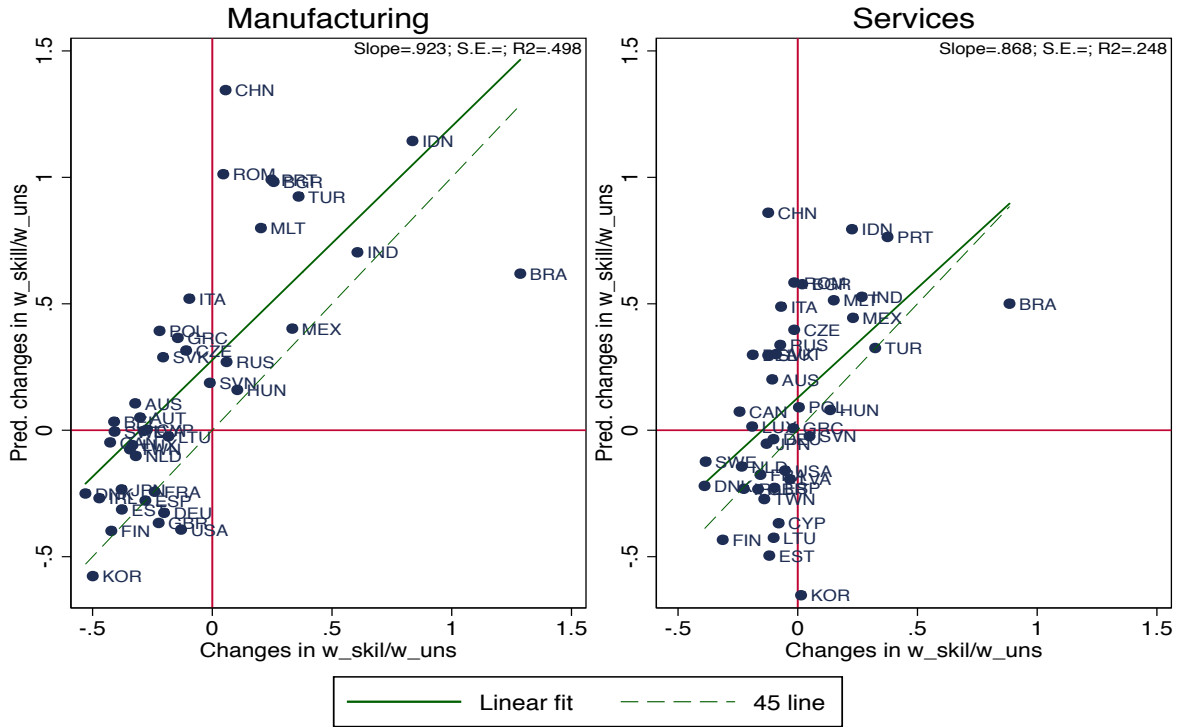
Standard errors are adjusted with the HC3 method.

Figure 7: 14-year changes in relative wages and endowments
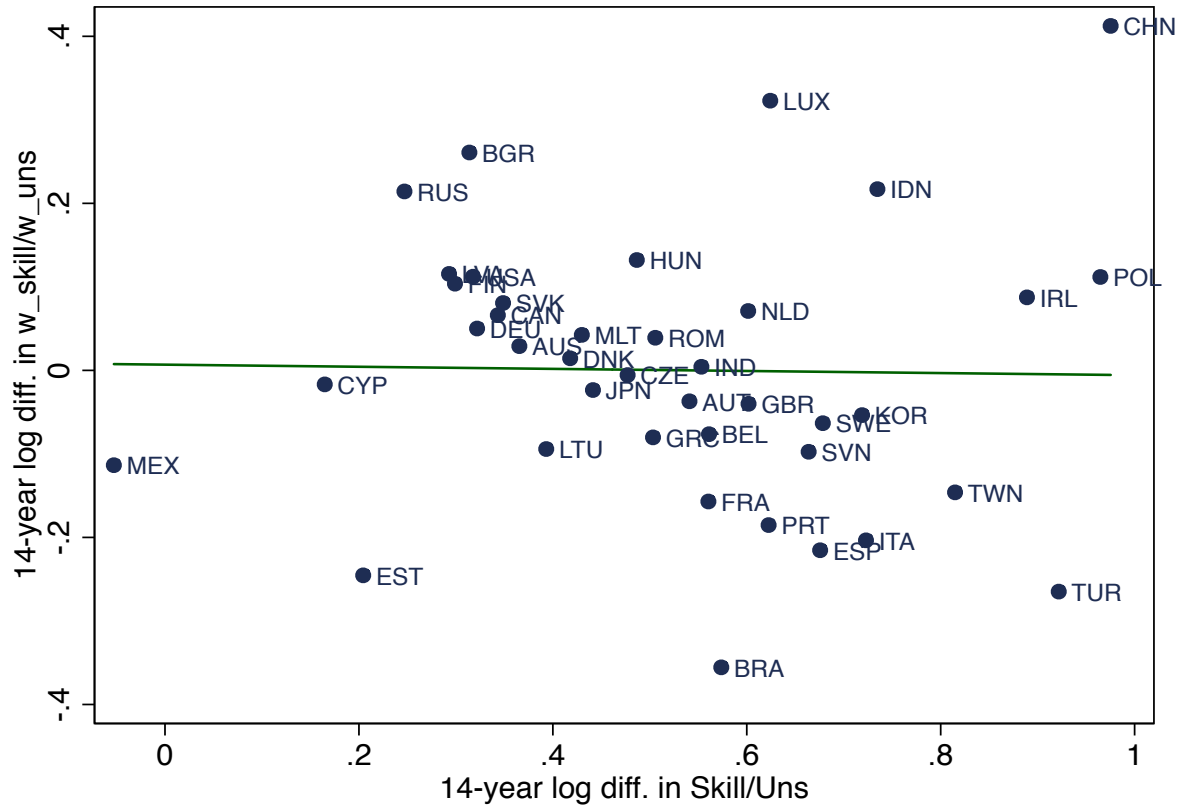
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Table 1: Summary statistics

	Obs	Mean	Std. dev.	Min	Max
w	600	2.053	0.793	1.277	6.059
v	600	0.265	0.157	0.028	0.910
o	600	1.040	0.281	0.444	2.145
$\widetilde{\tau}$	600	0.457	0.079	0.242	0.711
w_m	600	1.724	0.583	0.931	4.521
v_m	600	4.669	5.743	0.166	40.511
v_{ls}	600	0.408	0.251	0.032	0.900
v_{ns}	160	0.058	0.086	0.000	0.516
v_{land}	600	2.680	5.537	0.035	36.580
r/w_{tot}	600	0.057	0.130	0.002	0.930
$GDPpc$	600	21218	16288	469	87717
$union$	434	0.338	0.209	0.050	0.919

w_m and v_m are relative wages and endowments (respectively), calculated defining 'skilled' labor as the sum of high- and medium-skilled labor.

Table 2: Wage-endowment elasticity and GHO in reduced form - Cross-country

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(v)$	-0.269***	-0.308***	-1.008**	-0.690	-0.574	-0.451
	(0.0832)	(0.0732)	(0.420)	(0.427)	(0.404)	(0.437)
$\ln(o)$		0.499	0.401	0.309	0.659	0.890
		(0.426)	(0.393)	(0.397)	(0.444)	(0.552)
$\ln(v) \times \ln(o)$		0.543	0.476	0.425	0.680*	0.847**
		(0.349)	(0.327)	(0.326)	(0.348)	(0.422)
$\widetilde{\tau}$			1.590	0.721	1.291	1.082
			(1.140)	(1.197)	(1.295)	(1.478)
$\ln(v) \times \widetilde{\tau}$			1.607*	1.032	0.912	0.691
			(0.886)	(0.902)	(0.897)	(0.956)
$\ln(v_{ls})$				-0.0313		
				(0.0543)		
$\ln(v_{ns})$				0.0613*		
				(0.0358)		
$\ln(v_{land})$					-0.0206	
					(0.0204)	
$\ln\left(r/w_{tot}\right)$					0.100**	
					(0.0395)	
$\ln(GDPpc)$						-0.182**
						(0.0846)
$\ln(union)$						-0.0149
						(0.0624)
Obs	40	40	40	40	40	36
R^2	0.355	0.474	0.561	0.580	0.637	0.683

All variables are within-country averages. Column (6) includes a dummy for $EU15$ membership. All regressions include a constant term. Heteroskedasticity-robust HC3 standard errors are reported in parenthesis in column (1), standard errors bootstrapped with 500 replications are in parenthesis in other columns. Significant at: *10%, **5%, ***1% level.

Table 3: Wage-endowment elasticity and GHO in reduced form - Panel

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(v)$	-0.0781	-0.0309	-0.411***	-0.292*	-0.473***	-0.314**
	(0.0976)	(0.0448)	(0.151)	(0.152)	(0.146)	(0.156)
$\ln(o)$		0.574***	0.490***	0.442**	0.540***	0.724***
		(0.193)	(0.178)	(0.178)	(0.182)	(0.175)
$\ln(v) \times \ln(o)$		0.400***	0.355***	0.351***	0.365***	0.452***
		(0.109)	(0.104)	(0.105)	(0.104)	(0.0968)
$\widetilde{\tau}$			0.461	-0.0180	0.276	-0.00267
			(0.535)	(0.552)	(0.522)	(0.540)
$\ln(v) \times \widetilde{\tau}$			0.730**	0.370	0.760***	0.399
			(0.299)	(0.303)	(0.273)	(0.284)
$\ln(v_{ls})$				-0.115		
				(0.0749)		
$\ln(v_{ns})$				0.00392		
				(0.00752)		
$\ln(v_{land})$					-0.0816	
					(0.0750)	
$\ln\left(r/w_{tot}\right)$					-0.0331	
					(0.0331)	
$\ln(GDPpc)$						0.0877
						(0.0642)
$\ln(union)$						0.0479
						(0.0398)
Obs	600	600	600	160	600	434
R^2	0.069	0.158	0.246	0.328	0.260	0.330

All regressions include year dummies. Column (6) include a dummy for *EU* membership. Standard errors bootstrapped with 500 replications and country-level clustering are in parenthesis. Significant at: *10%, **5%, ***1% level.

Table 4: Variance-ratio test and bounds - Cross-country

	AC		TP		P-RE	
Variance ratio:	$\frac{Var(\tilde{w})}{Var(w)}$		$\frac{Var(\tilde{w})}{Var(w)}$		$\frac{Var(\tilde{w})}{Var(w)}$	
	1.133		2.232		2.700	
Bounds:	w on $\tilde{w}$	$\tilde{w}$ on w	w on $\tilde{w}$	$\tilde{w}$ on w	w on $\tilde{w}$	$\tilde{w}$ on w
	0.423**	0.479**	0.390***	0.871***	0.371***	1.001***
	(0.198)	(0.201)	(0.128)	(0.278)	(0.112)	(0.310)
Obs	40	40	40	40	40	40
R^2	0.181	0.181	0.323	0.323	0.355	0.355

All regressions include a constant term. HC3-adjusted standard errors are in parenthesis. Significant at: *10%, **5%, ***1% level.

Table 5: Slope and variance-ratio tests - Panel estimates

	AC		TP		P-RE	
	w on $\tilde{w}$	$\tilde{w}$ on w	w on $\tilde{w}$	$\tilde{w}$ on w	w on $\tilde{w}$	$\tilde{w}$ on w
5-year changes						
	0.329**	0.261***	0.246**	0.364***	0.222**	0.407***
	(0.130)	(0.0572)	(0.0939)	(0.0881)	(0.0840)	(0.0995)
Obs	400	400	400	400	400	400
Within R^2	0.217	0.192	0.220	0.218	0.220	0.221
Variance ratio: $\frac{Var(\tilde{w})}{Var(w)}$						
	0.685		1.181		1.455	
10-year changes						
	0.525***	0.378***	0.430***	0.565***	0.401***	0.628***
	(0.181)	(0.0942)	(0.129)	(0.129)	(0.115)	(0.144)
Obs	200	200	200	200	200	200
Within R^2	0.265	0.265	0.306	0.332	0.314	0.346
Variance ratio: $\frac{Var(\tilde{w})}{Var(w)}$						
	0.525		0.791		0.959	
14-year changes						
	-0.107	-0.0674	0.0182	0.0162	0.0370	0.0402
	(0.285)	(0.183)	(0.254)	(0.228)	(0.222)	(0.246)
Obs.	40	40	40	40	40	40
R^2	0.007	0.007	0.000	0.000	0.001	0.001
Variance ratio: $\frac{Var(\tilde{w})}{Var(w)}$						
	0.632		0.889		1.087	

All 5- and 10-year regressions include country and year dummies. Standard errors clustered at the country-level (for 5- and 10-year regressions) and HC3-adjusted (for 14-year regressions) are in parenthesis. Significant at: *10%, **5%, ***1% level.

Table 6: Slope tests - Panel estimates; Manuf. vs. Services

	AC		TP		P-RE	
	M	S	M	S	M	S
5-year changes						
$\widehat{w}$	0.238***	0.259***	0.265***	0.290**	0.271***	0.315**
	(0.0469)	(0.0902)	(0.0502)	(0.118)	(0.0511)	(0.131)
Obs	400	400	400	400	400	400
Within R^2	0.208	0.173	0.220	0.188	0.221	0.189
10-year changes						
$\widehat{w}$	0.338***	0.485***	0.366***	0.634***	0.372***	0.686***
	(0.119)	(0.110)	(0.128)	(0.136)	(0.130)	(0.147)
Obs	200	200	200	200	200	200
Within R^2	0.243	0.268	0.255	0.299	0.256	0.308
14-year changes						
$\widehat{w}$	0.0499	0.0139	0.155	0.0474	0.178	0.0584
	(0.111)	(0.192)	(0.123)	(0.220)	(0.133)	(0.228)
Obs	40	40	40	40	40	40
R^2	0.005	0.000	0.035	0.003	0.041	0.004

All 5- and 10-year regressions include country and year dummies. Standard errors clustered at the country-level (for 5- and 10-year regressions) and HC3-adjusted (for 14-year regressions) are in parenthesis. Significant at: *10%, **5%, ***1% level.