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► **To cite this version:**

Lorenzo Rotunno, Adrian Wood. Wage Inequality and Skill Supplies in a Globalised World. 2016.  
halshs-01370816v1

**HAL Id: halshs-01370816**

**<https://shs.hal.science/halshs-01370816v1>**

Preprint submitted on 23 Sep 2016 (v1), last revised 10 Nov 2017 (v2)

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# Wage Inequality and Skill Supplies in a Globalised World

Lorenzo Rotunno  
Adrian Wood

# Wage inequality and skill supplies in a globalised world\*

Lorenzo Rotunno<sup>†</sup>

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This draft: September 2016

## Abstract

We investigate empirically how the relative wages of skilled and unskilled workers vary with their relative supplies in open economies. The investigation is based on a Heckscher-Ohlin model that is more general than the canonical version and related to recent advances in trade theory. Our results bridge the gap between trade economists and labour economists in views on the role of national labour markets in wage determination when countries trade. As labour economists believe, relative wages are sensitive to variation in skill supplies in open economies. As trade economists believe, however, this sensitivity decreases with openness to trade.

Keywords: Heckscher-Ohlin, trade and wages, wage inequality, labour markets.

JEL codes: F11, F16, J23, J31.

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\*We are grateful to seminar participants at Oxford, Sussex, Birmingham, Louvain-la-neuve, RCEA workshop, LETC Slovenia, EEA meetings, DEGIT Geneva, Bari, LSE, Melbourne, UNSW, CEPPII Paris, Adelaide, Marseille, Bank of Canada, St Andrews and WU Vienna, and to Marcelo Olarreaga, for very useful comments. Earlier versions of this paper were entitled ‘Wages and endowments in a globalised world’.

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# I Introduction

More than twenty years after it started ([Leamer, 1992](#); [Lawrence and Slaughter, 1993](#); [Wood, 1994](#); [Berman et al., 1998](#)), the debate among economists about the effects of trade on the relative wages of skilled and unskilled workers remains lively ([Haskel et al., 2012](#); [Burstein and Vogel, 2016](#); [Autor et al., 2016](#)).<sup>1</sup> Most of this literature has asked how relative wages are affected by reduction of trade barriers. In this paper, we take a different perspective and ask how the relative wages of skilled and unskilled workers in countries that are open to trade are affected by variation in their relative supplies.

Trade economists and labour economists tend to give different answers to this question. The simplest trade-economist answer (in a one-cone Heckscher-Ohlin (HO) model) is that national skill supplies (or in HO terms endowments) have no effect: wages are pinned down by world prices and trade costs. Labour economists, though, resist the idea that “your wages are set in Beijing” ([Freeman, 1995](#)), and expect the relative wages of skilled workers to vary inversely with relative skill supplies, as in a closed economy. Multi-cone HO models ([Markusen and Venables, 2007](#); [Leamer, 2012](#)) offer some common ground, by allowing countries in widely differing endowment ranges to have different wages because they produce different goods, but the predicted insensitivity of wages to variation in skill supplies within cones is still hard for labour economists to accept.<sup>2</sup>

We provide an answer to this question that could potentially satisfy both sorts of economists. Our empirical analysis shows that relative wages in open economies vary continuously with relative skill supplies, as labour economists believe, but the response of wages to variation in skill supplies is smaller in countries with lower barriers to trade and in very open economies comes close to the trade economist view that wages are unaffected by endowments. Our estimates are based on HO theory, but using a specification that we label GHO, since it is more general than the usual Heckscher-Ohlin-Samuelson (HOS) model.

A 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](#)), as well as 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

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<sup>1</sup>Recent surveys of the literature are [Anderson \(2005\)](#); [Goldberg and Pavcnik \(2007\)](#); [Harrison et al. \(2011\)](#).

<sup>2</sup>[Panagariya \(1999\)](#) criticises arguments based on multi-cone HO models that the demand for labour is more elastic in an open than in a closed economy, as well as similar arguments by [Rodrik \(1997\)](#).

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 one essential basis of any GHO model.

Imperfect substitutability of home and foreign varieties creates inelasticity of demand in labour markets and thus helps to explain why relative wages vary with skill supplies in open economies. Our model, however, includes two other sources of labour demand inelasticity (drawn from [Wood, 2012](#)). First, the goods price elasticities faced by firms depend also on the degree of openness of the economy: if home suppliers have larger shares of the home market, as a result of high trade barriers, their sales become more affected by elasticities of substitution among goods (which are lower than those among varieties of goods). Second, other costs that do not vary in proportion to labour costs (per-unit trade costs, for example) and thus require larger relative wage changes to achieve price-induced skill-supply-absorbing changes in the composition of output.

The relative elasticity of demand for skilled and unskilled workers in an open economy thus depends on three forces - substitutability between home and foreign varieties, the degree of openness of the economy, and the size of costs that do not vary in proportion to labour costs. This paper sets out a GHO model that includes all three forces, and uses the World Input-Output Database (WIOD) to estimate the response of relative wages to variation in skill supplies in 40 countries during 1995-2009.

Our reduced-form results confirm earlier evidence (e.g. [Katz and Murphy, 1992](#); [Robbins, 1996](#); [Blum, 2010](#)) of a continuous inverse relationship between the relative wages and relative supplies of skilled and unskilled workers. As predicted by our model, however, the inverse relationship is weaker where countries are more open to trade and where the ratio of wages to non-proportional trade and production costs is higher. For countries in the upper quartile of trade openness, the inverse relationship disappears.

These inferences from the reduced-form results are supported by structural estimation of the GHO relationship between the relative wages and relative supplies of skilled workers. Predicted changes in relative wages match the variation in the data, both across countries and within countries over time, and the fit of the predictions is improved by incorporating the two new forces in the model - trade openness and non-proportional cost wedges.

Comparison of the reduced-form and structural estimates of the model exposes a further interesting fact, which is that a large fraction of variation in skill supplies is absorbed into employment without variation in relative wages. About half of this non-wage absorption is due to the higher income elasticity of demand for more skill-intensive goods (as in [Caron](#)

et al., 2014), in conjunction with the effects of skill supply on income. A possible explanation for the rest (not explored in this paper) is skill-biased changes in production techniques that are induced directly by changes in the relative supply of skilled workers (Acemoglu, 2007).

At a theoretical level, our paper extends in a simplified way the multi-factor multi-sector analysis of Costinot and Rodriguez-Clare (2014, 221-3) by emphasising variation of goods price elasticities with the degree of openness and by including non-proportional variable cost wedges (linking back to Alchian and Allen, 1964 and Hummels and Skiba, 2004). Empirically, our paper is the first application of a GHO model to the determination of factor prices. It thus adds to the work of Romalis (2004) and Chor (2010) on the effect of factor endowments on the composition of trade. Both authors used HO models involving inelasticity and in both cases their results provided support for the HO explanation of trade patterns.

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; Kiyota, 2011, 2012). Most of these studies, however, are limited to the quantity side (differences in product mix or choice of technique), 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.

Most studies of factor price equalisation have also been within single countries (Hanson and Slaughter, 2002; Tomiura, 2005; Bernard et al., 2008, 2013). Their consistent rejection of equalisation accords with the emphasis on segmentation of labour markets in Autor et al. (2016)'s review of work on the impact on the US of trade with China.

Data on wages by occupation in manufacturing in many countries are used by Blum (2010) - and by Marshall (2012) - to show that the relative wages of skilled workers fall over time when relative skill supplies rise. We extend their work by explicitly considering the influence of openness to trade and by using data on wages by level of education, which can be compared with much work by labour economists (e.g., Goldin and Katz, 2008).

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

To explain our argument in a simple way, drawing on Wood (2012), we set out a two-factor two-good model of a single country in the small-proportional-changes ‘hat’ algebra of Jones (1965), extended for empirical analysis to many goods and countries. The destination of

this section is a 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 labour costs,  $c$ , are related to changes in relative wages,  $w$ , by

$$(1) \quad \widehat{p}_{B/G} = \widehat{c}_{B/G} = (\theta_{HB} - \theta_{HG}) \widehat{w}_{H/L}$$

where  $\theta_{ij}$  is the share of labour type  $i$  in the cost of good  $j$ ,  $\widehat{x} = dx/x$ , and  $\widehat{x}_{1/2} = \widehat{x}_1 - \widehat{x}_2$ . Since  $\theta_{HB} > \theta_{HG}$ , a rise in the relative wage of skilled workers causes a rise in the relative cost and price of the skill-intensive good. Labour-market clearing requires

$$(2) \quad \widehat{v}_{H/L} = -\sigma_{BG} \widehat{w}_{H/L} + (\lambda_{HB} - \lambda_{LB}) \widehat{q}_{B/G}$$

where the economy-wide supply of a labour type is denoted by  $v$ , the output of a good by  $q$ ,  $\lambda_{ij}$  is the share of the supply of labour type  $i$  used by good  $j$  (so  $\lambda_{HB} > \lambda_{LB}$ ), and

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

combines  $\sigma_B$  and  $\sigma_G$ , the elasticities of substitution between  $H$  and  $L$  in the production of the two goods. A rise (say) in the relative supply of skilled labour must be matched by a rise in the relative demand for skilled labour, which can be achieved by a fall in the relative skilled wage that induces a rise in the skill-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 skill-intensive good  $B$  (the second term).

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

$$(4) \quad \widehat{q}_{B/G} = -\gamma_{BG} \widehat{p}_{B/G}$$

where  $\gamma_{BG}$  is the elasticity of substitution in consumption between  $B$  and  $G$ . The effect of changes in the relative supplies of skilled and unskilled workers on relative wages in a closed

economy can then be derived as

$$(5) \quad \widehat{w}_{H/L} = -\frac{1}{\sigma_{BG} + (\lambda_{HB} - \lambda_{LB}) \gamma_{BG} (\theta_{HB} - \theta_{HG})} \widehat{v}_{H/L}$$

The first term in the denominator of the rhs ratio shows how changes in wages induce supply-absorbing substitution between skill categories within sectors. The second term shows how changes in wages alter goods prices in ways that shift the sectoral composition of output in a direction that helps to absorb changes in skill supplies. It is the product of three elasticities: of relative goods prices with respect to relative wages ( $\theta_{HB} - \theta_{HG}$ ), of relative outputs with respect to relative goods prices ( $\gamma_{BG}$ ), and of relative employment of skilled and unskilled workers with respect to relative outputs ( $\lambda_{HB} - \lambda_{LB}$ ).

The lower are the elasticities of substitution in production and consumption,  $\sigma_{BG}$  and  $\gamma_{BG}$ , the more does a rise in the relative supply of skilled workers in a closed economy depress their relative wage. The effect of varying the difference in skill 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 skill intensity has, as (5) suggests, an effect similar to that of lower substitution elasticities.<sup>3</sup>

### *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

$$(6) \quad \widehat{c}_{B/G} = \widehat{p}_{B/G}^* + \widehat{T}_{B/G}$$

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). For a country too small to influence world prices, and with the usual assumption of ad valorem trade costs (varying in strict proportion to production costs or world prices), the elasticities of demand for traded goods are infinite, which makes the ratio on the rhs of equation (5) zero (as if  $\gamma_{BG}$  had become infinite). So within a cone of diversification - a range of relative endowments

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



bounded by the relative skill intensities of the goods - variation in skill supplies does not affect relative wages, which are determined (from equation (1)) by

$$(7) \quad \hat{w}_{H/L} = \frac{\hat{c}_{B/G}}{\theta_{HB} - \theta_{HG}} = \frac{\hat{p}_{B/G}^* + \hat{T}_{B/G}}{\theta_{HB} - \theta_{HG}}$$

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

Equation (7) can illustrate the impact on wages 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  $\hat{T}_B > 0$  and  $\hat{T}_G < 0$  (and hence  $\hat{T}_{B/G} > 0$ ), raising the relative wage of skilled workers. Similarly and more generally, across-the-board cuts in trade costs in an open economy tend to 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 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 such countries, relative wages respond inversely to variation in skill supplies to a degree governed by the elasticity of substitution in production,  $\sigma$ , but are not affected by trade costs (though these reduce absolute wages by worsening the country's effective terms of trade: [Markusen and Venables, 2007](#)).

With many goods arranged in order of their skill intensity, there can be multiple cones, the countries in each of which produce a few goods of adjoining skill intensity. 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 suggests, diversification). Within each cone, relative wages are unrelated to skill supplies, but are affected by trade costs. Across cones, relative wages vary inversely with skill supplies.

Given equation (7), the range of influences on relative wages in HOS is strikingly limited. Within a cone, variations in internal demand for factors - due for example to differences in tastes or income - affect only the composition of output and trade. Differences in technology affect wages, but only in certain ways: relative wages are affected by sector-biased technical differences, but not by factor-biased differences.

*General Heckscher-Ohlin*

In any GHO model of an open economy (as for example in [Costinot and Rodriguez-Clare, 2014](#), p.222-3), relative wages are determined by the balance of supply and demand for skilled and unskilled workers in the labour market, which is influenced both by skill supplies and by world prices and trade costs (on the demand side). In the particular GHO model of this paper, the influence of skill supplies is described by a modification of equation (5), in which the relative demand elasticity for goods, which is greater than the  $\gamma_{BG}$  of a closed economy but less than infinite (as in HOS), becomes the product of two terms,

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

that depend on how open the country concerned is to trade. The ‘purchaser-price elasticity’,  $\epsilon_{BG}$ , measures the response of the relative sales (and thus outputs) of goods  $B$  and  $G$  to their relative purchaser prices, while  $\delta_{BG}$ , the ‘price-ratio elasticity’, measures the response of the relative purchaser prices of goods  $B$  and  $G$  to their relative labour 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 for each good there is a finite ‘trade elasticity’ that links the share of imports in domestic expenditure to the relative prices of its imported and home-produced varieties.<sup>4</sup> As in [Arkolakis et al. \(2012\)](#) and [Costinot and Rodriguez-Clare \(2014\)](#), we assume within each sector a CES utility function

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

where  $C_j^H$  and  $C_j^M$  are composites of home-produced and imported varieties in sector  $j$ , and  $\beta_j$  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

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<sup>4</sup>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).

firms, as in [Eaton and Kortum, 2002](#), and, partly, in [Melitz, 2003](#)). It is convenient to assume that the elasticities of substitution within the home-produced and imported composites are equal in each sector  $j$  to the elasticity of substitution between them,  $\beta_j$ , though this is not always so ([Costinot and Rodriguez-Clare, 2014](#), p. 244-6; [Feenstra et al., 2014](#)).

The relative sales of the two goods depend on the relative prices of the  $B$  and  $G$  utility aggregates of home-produced and imported varieties, 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  $\alpha$  is a preference parameter and  $\gamma_{BG}$  as before is the elasticity of substitution between the goods, which is likely to be much lower than  $\beta_B$  or  $\beta_G$ , the elasticities of substitution among varieties. The elasticity of the relative sales of domestic producers of  $B$  and  $G$  with respect to their relative purchaser prices is thus an average of  $\gamma_{BG}$ ,  $\beta_B$  and  $\beta_G$ . With (9) and (10) being CES, this average elasticity in any particular market can be written precisely, following [Sato \(1967\)](#), as a weighted harmonic mean ([Wood, 2012](#), section 2.1). For purposes of exposition, this average 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  $\beta_{BG}$  is an average of  $\beta_B$  and  $\beta_G$ . In the world market,  $s_{BG}$  is likely to be small, so  $\epsilon_{BG}$  is close to  $\beta_{BG}$ . In the home market, however, domestic producers have a cost advantage, so that  $s_{BG}$  is likely to be big enough to make  $\gamma_{BG}$  matter, too. Home market shares vary among goods, depending on the country's comparative advantage, but for all goods they depend also on the country's international trade costs and policies.

The effect of relative purchaser prices on a country's relative outputs of  $B$  and  $G$  depends on the average  $\epsilon_{BG}$  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  $\epsilon_{BG}$  in its home market.<sup>5</sup> They also reduce the share of exports in its output and so the weight in the average  $\epsilon_{BG}$  of the

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<sup>5</sup>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' ( $\beta_j - 1$ ).

higher  $\epsilon_{BG}$ 's in its foreign markets (where  $s_{BG}$ 's are small).

(b) Price-ratio elasticity

The relative purchaser prices of goods vary by proportionally less than their relative unit immobile factor costs, which here are just their relative unit labour costs (ULC), because the purchaser price of each good also contains an other-cost wedge (OCW) that does not vary in proportion to labour costs and is often big. The OCW includes trade costs, purchases of traded intermediates and payments to mobile factors. Denoting the OCW per unit of output of good  $j$  by  $t_j$ , its ULC by  $c_j$  (as before), and defining  $\tau_j \equiv \frac{t_j}{c_j}$ , the price-ratio elasticity  $\delta_{BG} = \frac{\hat{p}_{B/G}}{\hat{c}_{B/G}}$  is usually less than unity and determined approximately by

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

where  $\tau_{BG}$  is the geometric mean of  $\tau_B$  and  $\tau_G$ , and  $\eta_{BG}$  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 OCWs were strictly independent of ULCs ( $\eta_{BG} = 0$ ) and is simply the average share of labour costs in the purchaser prices of  $B$  and  $G$ . The smaller this share, as a result of a larger  $\tau_{BG}$ , the smaller the effect on relative purchaser prices of a proportional change in relative ULCs (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 with relative ULCs, for example because some trade costs are ad-valorem,  $\eta_{BG}$  will be positive, tending to increase  $\delta_{BG}$  (and if  $\eta_{BG}$  were unity, as if for example OCWs consisted only of ad-valorem trade costs,  $\delta_{BG}$  would be unity, too).

(c) Relative wages

The impact of variation in skill supplies on relative wages, holding world prices and trade costs constant, can thus be described by a modified version of equation (5),

$$(13) \quad \hat{w}_{H/L} = -\frac{1}{\sigma_{BG} + (\lambda_{HB} - \lambda_{LB}) \epsilon_{BG} \delta_{BG} (\theta_{HB} - \theta_{HG})} \hat{v}_{H/L}$$

in which the size of the impact (the absolute value of the negative elasticity) is increased by higher barriers to trade (which pull down  $\epsilon_{BG}$ ), including higher per-unit barriers to

trade and per-unit production costs (both of which pull down  $\delta_{BG}$ ). Equation (13) is simply a downward-sloping relative demand curve for skilled and unskilled labour, whose slope is shallower in a more open economy. Abbreviating it for convenience as

$$(14) \quad \widehat{w}_{H/L} = -\phi_{HL}\widehat{v}_{H/L}$$

the influence on relative wages of world prices and trade costs, holding skill supplies constant, is in effect a vertical shift of this demand curve that can be described by a variant of the HOS wage determination equation (7)

$$(15) \quad \widehat{w}_{H/L} = \phi_{HL}(\lambda_{HB} - \lambda_{LB})(1 - s_{BG})(\beta_{BG} - \gamma_{BG})\left(\widehat{p}_{B/G}^* + \widehat{T}_{B/G}\right)$$

in which the terms to the right of  $\phi_{HL}$  show how changes in the local prices of foreign goods alter the relative demand for skilled and unskilled workers.<sup>6</sup> 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 labour demands.

The effect of world prices and trade costs on relative wages increases with  $\beta_{BG}$ , the degree of substitutability among varieties (though not so fast as equation (15) may suggest, since a rise in  $\beta_{BG}$  also makes  $\phi_{HL}$  smaller). If  $\beta_{BG}$  were infinite, equation (15) would reduce to the HOS equation (7), with extra magnification if  $\delta_{BG}$  is less than unity (and skill supplies would have no influence on wages, since  $\phi_{HL}$  would be zero). With finite  $\beta_{BG}(> \gamma_{BG})$ , the effect of foreign prices on wages is in the same direction as in HOS, but smaller.<sup>7</sup>

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 skill supplies and of foreign prices in equations (13), (14), (15),

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<sup>6</sup>For a fuller exposition of this equation, see sections 3.4 and 5.3 of Wood (2012).

<sup>7</sup>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 wages, and if  $\beta_{BG} < \gamma_{BG}$  the direction of the effect would be reversed.  $\beta_{BG}$  and  $\gamma_{BG}$  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.

relative wages in our GH0 model are determined by an expression with two additive terms

$$(16) \quad \widehat{w}_{H/L} = -\phi_{HL}\widehat{v}_{H/L} + \phi_{HL}(\lambda_{HB} - \lambda_{LB})(1 - s_{BG})(\beta_{BG} - \gamma_{BG})(\widehat{p}_{B/G}^* + \widehat{T}_{B/G})$$

of which the closed-economy equation (5) and the HOS equation (7) are special cases. The focus of this paper is on the first of these two terms, for lack of data in WIOD on world prices or (a full enough set of) trade costs. In other words, the empirical analysis in this paper does not provide a complete explanation of the determination of wages in open economies, but seeks more narrowly to explain the size and determinants of  $\phi_{HL}$ , the elasticity of relative wages with respect to skill supplies.

In doing so, however, it will be essential to recognise that changes in openness to trade or in price-ratio elasticities affect both terms in equation (16), though in different ways. Greater openness, for example, tends to lower  $\phi_{HL}$  by reducing  $s_{BG}$  and thus raising  $\epsilon_{BG}$ , 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  $T_G$ .

#### (d) Extensions and limitations

For the empirical analysis, we extend the model to include  $n$  final goods, indexed by  $j$  and with good 1 as the numeraire, so that the elasticity relationship (13) becomes

$$(17) \quad \widehat{w}_{H/L} = -\frac{1}{\sum_{j=1}^n [\lambda_{Hj}(1 - \theta_{Hj}) + \lambda_{Lj}\theta_{Hj}]\sigma_j + \sum_{j=2}^n (\lambda_{Hj} - \lambda_{Lj})\epsilon_{j1}\delta_{j1}(\theta_{Hj} - \theta_{H1})}\widehat{v}_{H/L}$$

Traded intermediate goods are part of the OCW. They are a component of costs that is common to all countries and does not vary with labour costs, thus tending to reduce price-ratio elasticities. However, trade in intermediates also affects the skill intensities of goods. More specifically, the splitting up of production processes associated with offshoring makes differences in skill intensity among goods larger than they would be if all the processes happened in a single country. So trade in intermediates also shows up in (17) as absolutely larger  $\lambda_{Hj} - \lambda_{Lj}$  and  $\theta_{Hj} - \theta_{H1}$ , offsetting the falls in  $\delta_{j1}$  caused by higher ratios of OCWs to ULCs.<sup>8</sup> The net effect of more trade in intermediates on the sensitivity of wages to variation in skill supplies could therefore be either positive or negative.

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<sup>8</sup>Assuming again that elasticities of substitution are greater in consumption than in production. With more than two countries, however, 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  $\delta_{j1}$ , for example if a relatively skill-abundant country sourced skill-intensive intermediates from an even more skill-abundant country.

Payments to mobile factors are another part of OCWs that does not vary with labour costs, reducing price-ratio elasticities. An important assumption of our empirical analysis is that capital is a mobile factor (for reasons explained in [Wood, 1994](#), section 2.2 and supported by the evidence in [Caselli and Feyrer, 2007](#)). However, changes in the world price of capital could affect relative wages, either by altering the relative costs (and thus prices and sales) of goods that differed in both capital intensity and skill intensity, or by inducing changes in the capital intensity of production processes that also altered their skill intensity. Relative wages could be affected, too, by the supply of other immobile factors such as land, depending on their substitutability with skilled and unskilled workers.<sup>9</sup>

The usefulness of our GHO model is in explaining not only why wages vary with skill supplies in open economies, without the awkwardness of HOS cones, but also why the sensitivity of wages to skill supplies 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, which omits important determinants both of trade (notably, economies of scale) and of relative wages (notably, labour market institutions), as well as other dimensions of wage inequality and other channels through which globalisation affects inequality ([Wood, 2002](#); [Harrison et al., 2011](#); [Burstein and Vogel, 2016](#)).

Another limitation concerns the periods over which HO theory is relevant ([Leamer, 2012](#); [Blum, 2010](#), pp. 7-8, 108-13). Its mechanisms require factors to move within countries, which labour does only gradually, so that the immediate impact of trade shocks on wages is largely specific to sectors and localities ([Autor et al., 2016](#)). Over long periods and across countries, moreover, other forces are at work. Skill supply responses to changes in relative wages damp the impact of trade barrier changes on wages and make it less appropriate to treat skill supplies as ‘endowments’ ([Atkin, 2016](#); [Blanchard and Olney, 2016](#)). Exogenous variation in skill supplies may also affect incomes, institutions and technologies in ways that alter the relative demand for skilled labour. HO influences thus seem likely to be clearest and of most practical relevance within countries over periods of intermediate length.

### III Data and descriptive statistics

The data used in this paper are from the World Input-Output Database (WIOD), described by its creators in [Timmer \(2012\)](#). The core of WIOD is annual international input-output tables for 1995-2009 and 35 industries that connect 40 countries in total accounting for 85%

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<sup>9</sup>For a fuller discussion of GHO models with more than two factors, see [Wood \(2012, Appendix D\)](#).

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. Price 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 each country, industry and year. Skill is measured by schooling, following the International Standard Classification of Education (ISCED). 'Low skilled' workers are ISCED categories 0, 1 and 2 (everything below completed upper secondary). 'Medium skilled' are ISCED categories 3 and 4 (complete upper secondary and some tertiary, but below a college degree), and '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, not previously collated in this form. We use these data to derive wage rates per hour - the form in which wages were typically reported in the sources. 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.

An important maintained assumption of our analysis is that WIOD data on economy-wide employment by skill category are a good proxy for skill supplies (or endowments). Because of differences in participation rates, unemployment rates and working hours (the unit of employment in WIOD), there are differences across countries and over time in the relationship between total employment at specified levels of education and the numbers of adults with those levels of education (which is probably the best measure of endowments). This raises identification issues, since observed variation in relative employment of skilled and unskilled workers arises not only from supply shocks but also from demand shocks and institutional influences on relative wages. However, the strong correlation with variation in the corresponding population ratios in [Barro and Lee \(2013\)](#) implies that the variation in skilled employment ratios in WIOD is mainly due to variation in skill supplies.<sup>10</sup>

Another reservation about using WIOD to analyse relationships between trade and wages

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<sup>10</sup>The correlation between the Barro-Lee measure of relative skill supply (based on the level of education attained) and the WIOD relative skill employment measure is around 0.75. In the reduced-form estimates in section IV A, replacing the employment variable with the Barro-Lee measure yields similar results in cross-section, but less robust results in the panel specification, probably because the employment data are annual while the Barro-Lee data are available only at 5-year intervals.



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 typical country. With more and smaller countries, our results might have been different.

Figure 1 plots the relative wage of skilled workers against their relative employment across countries 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 all those with less than a college degree - the relative wage can thus be seen as the “college premium”.

[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 supplies: India, Brazil and Indonesia have the highest skilled wage premia, but China one of the lowest, especially in the early years. Moreover, the negative relationship with wages is not consistent at intermediate levels of skill supply.

Other variables are used in the empirical analysis to control for the level of economic development, additional factors of production, and labour market institutions. GDP per capita (in 2005 constant US\$) and population are sourced from World Development Indicators, while data on human capital are from the [Barro and Lee \(2013\)](#) database. To control for the role 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 A.1 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 our 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 supplies, 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 supplies match the changes observed in the data. Part D compares the reduced-form and structural estimates of the model.

## A Reduced-form relationships

### *Cross-country evidence*

All WIOD countries in all years were open in the sense relevant to the HOS model, which is compatible with high trade barriers and nontraded sectors, but but Figure 1 shows that the one-cone HOS prediction of insensitivity of relative wages does not hold across countries.<sup>11</sup> Averaging over time for each country and with both variables in logs, the regression results in column (1) of Table 2 suggest that a country with a 10% higher relative supply of skilled workers has a 2.7% lower skilled wage premium, with a similar elasticity for each year in the sample (Figure A.1 in the [Online Appendix](#)).<sup>12</sup>

Our GHO model allows for sensitivity and, as explained in section II, makes two testable predictions about variation among countries and over time in the elasticity of relative wages with respect to relative skill supplies:

1. This elasticity is reduced (brought 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 skill intensity among goods.
2. This elasticity is reduced also by a higher price-ratio elasticity - the responsiveness of relative purchaser prices of goods to relative labour costs - which permits skill supply-absorbing changes in output mix with smaller changes in relative wages.

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.<sup>13</sup> However, this ratio tends to be substantially lower in large countries than in small countries, not mainly

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<sup>11</sup>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.

<sup>12</sup>Standard errors in all cross-country regressions are heteroskedasticity-robust and estimated with the HC3 method to account for small sample bias.

<sup>13</sup>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. Achieving this match, instead, by using the value added of trade in the numerator, did not significantly alter our results, and nor did the use of trade/GDP data from World Development Indicators rather than WIOD.

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.<sup>14</sup> 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).<sup>15</sup>

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

We measure the size of  $\tau$  for the economy as a whole and, for lack of enough information to estimate  $\eta$ 's, use as a regressor  $\tilde{\delta}$ , whose coefficient should pick up (among other things) the average  $\eta$  across the units of observation in the regression. Given this average  $\eta$ , in units with a higher  $\tilde{\delta}$  the skill supply-absorbing response of the output mix tends to be larger and hence the depressing effect on the relative skilled wage smaller.

A key issue is how to measure  $\tau$  at the country level. We confidently put internal trade costs and taxes into the OCWs, since they drive a wedge between ULCs and purchaser prices, whatever the location of the purchaser. More specifically, for each country and year we sum across sectors internal transport margins and net product taxes in WIOD's national Supply-and-Use tables. Given the assumption in this paper that capital is internationally mobile, we also assign WIOD's "capital compensation" to OCWs, since it too creates a wedge between ULCs and purchaser prices regardless of where products are sold.

To calculate  $\tau$  for each country and year, we then divide the sum of these OCW elements by the total national wage bill. In principle, OCWs should also include foreign trade costs and purchases of traded intermediate goods, but this proved infeasible. The only information in WIOD on foreign trade costs is the international transport margin, and with the data available there was no practical way to measure the extent of traded intermediates (which include not only imports, but also domestically supplied inputs that are import-competing or exportable, whose wage costs should be omitted from the denominator of  $\tau$ ). However, the influence of the omitted per-unit foreign trade costs and traded intermediates on the wage-skill supply elasticity should be at least partly picked up by our measure of openness.

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

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<sup>14</sup>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 as measured by GDP.

<sup>15</sup>Logging the trade/output ratio yields an approximation to the height of trade barriers if price elasticities of choices between domestic and foreign suppliers/markets are similar across countries and over time. We get similar results if instead we include (as additional variables in the regressions) country size and its interaction with skill supplies. Results are available upon request.

equation:

$$(18) \quad \ln(w_c) = \alpha + \beta_1 \ln(v_c) + \beta_2 \ln(o_c) + \beta_3 (\ln(v_c) \times \ln(o_c)) + \beta_4 \tilde{\delta}_c + \beta_5 (\ln(v_c) \times \tilde{\delta}_c) + \varepsilon_c$$

where  $w_c$  is the relative wage of skilled workers,  $v_c$  is their relative supply, and  $o_c$  is openness. We expect the coefficients ( $\beta_3$  and  $\beta_5$ ) on both interaction terms to be positive, since higher levels of both  $o_c$  and  $\tilde{\delta}_c$  offset the negative  $w$ - $v$  elasticity.

A limitation of this specification is that a positive openness interaction could be picking up more than the effect of greater openness on the wage-skill supply 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 skill supplies. 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 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-skill supply elasticity.<sup>16</sup>

Columns (2) and (3) of Table 2 presents the results. Column (2) includes the openness interaction only. As predicted, 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 predictions, the  $\tilde{\delta}$  interaction is positive and significant at the 10% level, and the openness interaction is also positive and similar to that 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 ULCs) soften the otherwise inverse relationship between relative wages and relative skill supplies.

Columns (4) to (6) report the results 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).<sup>17</sup> The interaction terms remain positive, but the

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<sup>16</sup>In other words, the openness interaction necessarily captures the influence of variation in skill supplies on the relationship between openness and wages as well as the influence of variation in openness on the relationship between skill supplies and wages.

<sup>17</sup>We take the ratio (in logs) of people with no education to people with "attained" (not completed)

$\tilde{\delta}$  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 with no education is the main driver of this composition effect.<sup>18</sup>

In column (5) we allow for other factors of production, which, as explained in section II, can affect the wage-skill supply relationship. An immobile other factor is land, which is likely to be complementary to labour with little or no education, and whose influence we proxy by the ratio of a country’s area to its unskilled labour supply. A mobile other factor is capital, whose influence we proxy by the ratio in each country of the capital rental rate to the average wage.<sup>19</sup> 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 interaction coefficient larger and more significant than in column (3), but has the opposite effect on the  $\tilde{\delta}$  interaction (probably because of the strong inverse accounting relationship created by the inclusion of capital compensation in our measures of both  $\tilde{\delta}$  and the rental-wage ratio). The coefficient on the land abundance variable is not significant, while the positive and significant coefficient on the capital variable suggests that countries where capital is relatively more costly also have 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 effects could be driven by other country-level influences. Given the limited sample size, we focus in column (6) on level of 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<sup>20</sup>), the mitigating influence of openness on the wage-skill

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secondary education at most - i.e. the most comparable category to the ‘unskilled’ definition from WIOD data. While WIOD data on employment by skill category are in hours worked, the Barro and Lee data refer to the number of people regardless of their employment status.

<sup>18</sup>Assigning medium-skill labour to the skilled category does not change our findings (estimates not reported). The wage-skill supply 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).

<sup>19</sup>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.

<sup>20</sup>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.

supply elasticity is twice as large and more significant than in column (3), while the influence of  $\tilde{\delta}$  is halved, mainly because our measure of  $\tilde{\delta}$  is negatively correlated with GDP per capita (countries with higher OCW/ULC tend to be less developed).<sup>21</sup>

As an extension of these robustness tests, in columns (2) to (4) of Table A.2 in the [Online Appendix](#), we report estimates of the GHO interaction terms controlling for the interactions of the skill supply variable with the other variables used in Table 2 (which considers only the direct relationship between these variables and wages - not reported in Table A2). The openness and  $\tilde{\delta}$  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-skill supply elasticity. We now turn to the panel regressions, where we exploit variation within countries over time.

We first estimate the wage-skill supply 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 skill supplies, although the coefficient 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 our GHO model would suggest.

When we add the GHO interaction terms, the results become strongly consistent with the theoretical predictions. In column (2), the openness interaction term is positive and of similar magnitude to that in the cross-country specification. Our baseline specification in column (3) shows the effect of interacting skill supplies and the price-ratio elasticity to be strongly positive, as is that of interacting skill supplies and openness, both supporting the GHO prediction that higher price-ratio elasticities and greater openness diminish the inverse relationship between relative wages and skill supplies. The panel estimates are more precise than the cross-country ones, though the  $\tilde{\delta}$  interaction coefficient is smaller - because OCW/ULC ratios vary more across countries than within them.

These more precise estimates can be used to show graphically how the wage-skill supply elasticity varies with the two mediating variables: openness and price-ratio elasticity. Since

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<sup>21</sup>If we omit GDP per capita from the relevant regressions, the coefficient on the  $\tilde{\delta}$  interaction is 1.2-1.4 and hence similar in magnitude to the baseline estimate in column (3).

there are two interaction terms, the elasticity depends jointly on  $o$  and  $\tilde{\delta}$ . Figure 2 shows how the wage-skill supply elasticity is affected by trade openness, holding the level of  $\tilde{\delta}$  at its median value. In a relatively closed economy (such as Brazil: average  $\ln(o) = -0.52$ ), a 10% increase in relative skill supply is associated with a 3% drop in the skill premium. At the minimum level of openness in the sample, the drop would be 3.5%, and in a hypothetical closed economy (with near-zero trade), it would be a strikingly large (but very inaccurately estimated) 16%. By contrast, countries in the upper quartile of openness (such as Germany: average  $\ln(o) = 0.31$ ) are in a region of relative wage insensitivity, where there is no significant variation in the skill premium with skill supplies.

In Figure 3 we use the same approach to trace out how the wage-skill supply elasticity varies with our measure of the price-ratio elasticity,  $\tilde{\delta}$ , holding log openness at its median value. The wage-skill supply elasticity rises slower with the price-ratio elasticity than with trade openness. The estimates imply that if, say, Turkey had median openness and increased its price-ratio elasticity from a low value of 0.3 to 0.55 (about three standard deviations in the sample), the relative wages of its skilled workers would no longer be sensitive to changes in skill supplies.

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  $\tilde{\delta}$  interaction, 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  $\tilde{\delta}$  interaction coefficient compared to the column (3) baseline (as it did also in the cross-country estimates). The wage-skill supply 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 A.2 in the [Online Appendix](#).

In summary, our reduced-form evidence is broadly consistent with the predictions of our GHO model concerning the wage-skill supply relationship. Both greater trade openness and higher price-ratio elasticities attenuate the negative elasticity of the skill premium in wages with respect to skill supplies - and high openness and high price-ratio elasticities can cause wages to vary only slightly or even not at all with variation in skill supplies. 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  $\tau$  omits foreign trade costs and traded intermediates, whose influence is 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 influence 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 explanations of inelasticity

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

### *Cross-country differences in labour 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 workers might thus vary much less across countries with skill supplies 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 wage rates), in which, assuming cost minimisation, unobserved factor qualities cancel out. Our application of this method is relegated to section A.III of the [Online Appendix](#), mainly because our results, like those of [Bernard et al. \(2013\)](#) for the US, strongly reject the hypothesis of relative wage equalisation.

Adjusting for differences in quality in this way, moreover, the inverse relationship between relative wages and relative skill supplies 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, we treat these results just 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 skill supplies 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 wages do not respond to variation in skill supplies.

Kiyota (2011, 2012) 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 relative wages to skill supplies is downward-sloping, in between the relative wage ‘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:

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

where  $\bar{v}_d$  is the threshold value of  $\ln(v_c)$  that identifies the  $d$ th 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  $\ln(v_c)$  from its minimum to its maximum and using a grid interval of 0.2.<sup>22</sup> 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 supplies of skilled labour

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<sup>22</sup>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.

(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 23%. China is alone in the lowest cone, and without it relative wages decline across cones as predicted with relative skill supplies.<sup>23</sup>

[Insert Figure 4 here]

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 cross-country regression of log relative wages on log relative skill supplies. However, the fact that the statistical fit improves progressively with the number of cones suggests that the linear specification may better approximate the true relationship, though we do not have enough countries to test this hypothesis by further increasing the number of cones.

## C Structural relationships

The reduced-form estimates in part A support our GHO model by showing that the inverse association between the relative wages of skilled workers and skill supplies is weaker in countries and periods with greater openness to trade and higher price-ratio elasticities. They do not, however, establish that this weakening is due to the GHO mechanisms described by equation (17), particularly because the crucial interaction coefficients may be biased. We therefore now estimate directly the relationship in (17), in order to assess whether the variation in relative wages with respect to skill supplies 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 skill supplies 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 labour for another within each sector  $j$ , as mandated by the technology parameter  $\sigma_j$ . 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 caused by structural shifts *between* sectors.

Our 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

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<sup>23</sup>Movement of countries among cones over time is explored in section A.IV of the [Online Appendix](#).

respect to relative prices is finite (rather than infinite, as in HOS). The technique channel is the same in GH0 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 skill supplies 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 labour use and cost shares (the  $\lambda$  and  $\theta$  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.

To measure the price-ratio elasticity  $\delta_{j1}$ , 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 ULC'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 ULC's and OCW's, respectively; and  $\tau = \sqrt{\tau_j \tau_1}$ , where  $\tau_j = \frac{t_j}{c_j}$ . If relative ULC's equal relative OCW's ( $t = c$ ), this expression conveniently reduces to  $\tilde{\tau} = \frac{1}{1+\tau}$ , 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:  $\sigma$ 's and  $\epsilon$ 's. The elasticity of substitution in production,  $\sigma$ , measures the extent to which changes in relative wages alter the relative use of skilled and unskilled workers in each sector ([Jones, 1965](#)):

$$(21) \quad \sigma_j = \frac{\widehat{a}_{jL} - \widehat{a}_{jH}}{\widehat{w}_H - \widehat{w}_L}$$

We thus estimate  $\sigma$  for each sector as the coefficient in a panel regression of relative skill 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, 2007](#)).<sup>24</sup> The estimated sector-specific  $\sigma$ 's are reported in column (1) of Table A.3 in the [Online Appendix](#). When significantly different from zero, the point estimates of  $\sigma$ '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  $\sigma$ 's across all service sectors.<sup>25</sup>

To measure  $\epsilon$ , we first estimate the two demand parameters  $\gamma$  and  $\beta$ . To this end, we apply the approach pioneered by [Feenstra \(1994\)](#) to estimate  $\beta$ '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.<sup>26</sup> 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  $\beta$ 's across countries for each sector are reported in columns (2) and (3) of Table A2. The overall median value is 2.57 (and mean 5.87), which is in line with the estimated elasticities available in the literature.<sup>27</sup> The  $\gamma$  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  $\gamma$ 's range between 1.21 and 5.87 (for Slovakia, the next highest  $\gamma$  being 2.21) and, consistently with theoretical expectations, are generally lower than the  $\beta$ 's.<sup>28</sup>

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<sup>24</sup>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  $\sigma$ 's.

<sup>25</sup>Notice that this exercise is fundamentally different from estimating the responsiveness of relative wages to changes in skill supplies at the country-level. The underlying and widely accepted assumption in HO trade models (e.g. [Leamer and Levinsohn, 1995](#); and [Slaughter, 1997](#)) is that at the national level wages endogenously respond to exogenous changes in skill supplies, while at the industry level relative labour demand responds to changes in relative wages which are exogenous to that industry.

<sup>26</sup>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. We use the within-sector median  $\beta$ 's for the missing observations. As in [Patel et al. \(2014\)](#), the estimated  $\beta$  for each country-sector equals the median estimate across 100 bootstrap replications. In estimating  $\gamma$ '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 median  $\gamma$  (itself equal to the median across 100 bootstrap estimates of  $\gamma$  for each country) for these countries.

<sup>27</sup>[Broda and Weinstein \(2006\)](#), for instance, obtain a median estimated  $\beta$  (their  $\sigma$ ) of 3.39 using a similar methodology with more detailed trade data (excluding home sales) for 73 countries.

<sup>28</sup>On average, 7% of sectors have estimated  $\beta$ 's below  $\gamma$  for each country (18 countries out of 40 have all

The estimated  $\beta$ 's and  $\gamma$ 's are then combined into the purchaser-price elasticity  $\epsilon$ , 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  $\gamma$  and  $\beta$  (Sato, 1967)

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

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  $s_j^z$  is the share of good  $j$  in country  $z$ 's total consumption. As intuitively conveyed by the simplified arithmetic average in equation (11)<sup>29</sup>, 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  $\beta$  relative to the across-good elasticity  $\gamma$ .

The elasticity for country  $z$  producers across all markets is a weighted harmonic average:  $\epsilon_{j1}^z = \left( \sum_{\check{z}} \frac{x_{1j}^{z\check{z}}}{\epsilon_{j1}^{z\check{z}}} \right)^{-1}$ , where the weights ( $x$ 's) are the shares of their sales in each market. The purchaser-price elasticity increases with greater openness to trade: easier access to varieties from abroad reduces home market shares ( $s_j^{z\check{z}}$ ), giving more weight to the generally higher  $\beta$ 's; and also increases export shares (higher  $x$ 's in foreign markets), giving more weight to the  $\epsilon$ '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.<sup>30</sup>

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-skill supply elasticity, and hence the comparisons with actual outcomes. The estimates reported use as the reference sector 'Other non-metallic minerals', which had the fewest missing estimated elasticities.<sup>31</sup> We show the sensitivity of our results to the choice of other sectors in the [Online Appendix](#).

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$\beta$ 's above  $\gamma$ ), with only Slovakia where more than 80% of the sectoral  $\beta$ 's are lower than the country's  $\gamma$ .

<sup>29</sup>The expression in equation (11) follows from assuming two-level symmetrical CES utility (where the upper-level shares  $s^z$  do not vary across goods) and two markets - a domestic and a foreign one.

<sup>30</sup>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).

<sup>31</sup>We avoided choosing service sectors because more of their estimated elasticities seemed problematic and because trade data on services are less accurate.

## *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), given the actual changes in relative skill supplies are regressed on actual changes in relative wages. In the cross-country analysis, ‘changes’ in relative wages and skill supplies refer to deviations from the relevant means across countries in each year, then averaged across years for 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 the model gives a remarkably accurate explanation of the way in which variation in skill supplies 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 as well as variation across countries in the determinants of actual relative wages other than skill supplies - 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). With ‘Trade Protection’ (TP), we retain the same specification of  $\epsilon$ , 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  $\beta$  (averaged across 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 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 skill abundance 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 ( $\tilde{w}$ ) 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 skill supplies is almost three times greater than the actual variance of relative wages (though only half as large as the variance of skill supplies, since the aggregate elasticity of wages with respect to skill supplies 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 skill abundance, 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’ ( $\tilde{w}$  on  $w$ ) and ‘reverse’ ( $w$  on  $\tilde{w}$ ) 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 0.53 and 1.12, with a much better fit ( $R^2=0.59$ ). 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 our GHO model is a useful and empirically relevant tool to understand how variation among open economies in relative wages relates to variation in skill supplies 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 might be partly due to non-skill supply determinants of wages that narrow differences in skill premia across countries - most obviously, labour market and social security institutions.

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 A.2](#) 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 A.3](#) 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 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 especially  $R^2$  in manufacturing hint that forces outside GHO are more important in explaining the supply and demand for skills in services.<sup>32</sup>

[Insert Figure 6 here]

### *Time-series evidence*

To define changes in relative wages and skill supplies within countries over time (the  $\hat{\phantom{x}}$  terms in equation (17)), we follow Blum (2010) and take annualised differences (in logs) over windows of 5, 10 and 14 years, over which the coefficient in equation (17) is averaged. Predicted wage changes are then regressed on actual changes and, for 5- and 10-year regressions, also 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 skill supplies, particularly in the 10-year window, when the variance ratio is close to unity, too, suggesting that the skill supply 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 skill supply changes - and uncorrelated also with actual skill supply changes. As can be seen in Figure A.4 in the [Online Appendix](#), over the full period 1995-2009 there is not a clear inverse relationship across countries between

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<sup>32</sup>Similar patterns are observed in the TP and AC specifications - results available upon request.



changes in relative wages and changes in skill abundance. In this respect, our results differ from those of [Blum \(2010\)](#), who finds a consistently stronger inverse relationship over longer periods.<sup>33</sup> For three-quarters of the countries in our sample, too, the 14-year relationship is strongly inverse, but for the other quarter, the pattern is highly diverse, probably as a result of forces outside the GHO framework.

The TP and AC specifications in the last 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 A.5-A.7](#) 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 trade barriers having fallen relatively faster in services than in manufacturing during the period under study, which is a relevant possibility at least for our 27 EU countries.

[Insert [Table 6](#) here]

Overall, the results of the structural tests are consistent with the conclusions of the reduced-form analysis. The explanatory power of the model seems to derive more from variation in openness to trade (through its influence on purchaser-price 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 skill supplies is by no means the only cause of variation in relative wages, and suggest that the GHO model does not capture some of the longer-term effects of skill-supplies on wages through both supply-side and demand-side channels.

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<sup>33</sup>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](#).

## D Comparing reduced-form and structural elasticities

Both the reduced-form and the structural estimates suggest that our GHO model contributes substantially to explaining how in open economies the relative wages of skilled workers vary with skill supplies, across countries and over time. We now directly compare the structurally estimated wage-skill supply elasticities (the ratio on the right-hand side of equation (17)) with the reduced-form elasticities (using the panel estimates in column (3) of Table 3).<sup>34</sup>

[Insert Figure 7 here]

The correlation coefficient between the two sets of elasticities across all 600 country-year observations equals 0.39 and is significantly different from zero (standard error=0.036). Figure 7 confirms graphically this strong positive association, but also shows that the reduced-form elasticities are consistently higher than the structural ones.

[Insert Figure 8 here]

Figure 8 (a) explores further by plotting the kernel densities of the two elasticity estimates.<sup>35</sup> The structural estimates are both much lower and less dispersed than the reduced-form ones, with the median value of the reduced-form estimates being -0.17 and that of the structural estimates being -0.72.<sup>36</sup>

The greater dispersion of the reduced-form density is probably due to overestimation of the openness interaction. Equation (17) implies that this coefficient should capture how greater openness reduces the weights of  $\beta$ 's relative to  $\gamma$ 's in the determination of  $\epsilon$ 's (equation (22)), weakening the inverse relationship between wages and skill supplies. The reduced-form estimate of this coefficient, however, is likely to be biased upward by other influences.

One such influence is the Stolper-Samuelson mechanism in the second term of equation (16): in HO theory, the effect of changes in openness on relative wages varies with a country's skill supplies. Non-HO mechanisms may have a similar effect: for example, [Burstein and Vogel \(2016, figure 3\)](#) show how a rise in the skill premium in wages as a result of lower trade costs can be systematically larger in countries with relatively more skilled workers. In addition, the openness coefficient picks up the influence of international trade costs and traded intermediates omitted from our measure of the price-ratio elasticity.

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<sup>34</sup>As per our model with two interaction terms (see equation (18) for the cross-country specification), the estimated wage-skill supply elasticity for each country  $i$  and year  $t$  is:  $\widehat{\beta}_{w-v} = \widehat{\beta}_1 + \widehat{\beta}_3 \times \ln(o) + \widehat{\beta}_5 \times \widetilde{\delta}$ .

<sup>35</sup>The structural elasticity for each country and year equals the median of elasticities across all possible of reference sectors.

<sup>36</sup>We do not isolate at this stage elasticities that are not statistically different from zero. In the reduced-form estimates, around 35% of the sample has insignificant elasticities at the 10% level. If we restrict our sample only to significant elasticities, the median reduced-form elasticity is -0.21.

For all these reasons, the wage-skill supply elasticity varies more with openness than in equation (17). Omitting the openness interaction from the calculations (Figure 8 (b)) makes the dispersion of the reduced-form density similar to that of the structural density, but has little effect on its median and hence on the horizontal gap between the distributions.<sup>37</sup>

To explain this gap, we must thus also consider the possibility that our GHO model (and thus our structural estimates) omit, while the reduced-form estimates capture, one or more mechanisms by which changes in the relative supply of skilled and unskilled labour can be to some extent absorbed by changes in the structure of employment without changes in relative wages. To clarify this point, we can rewrite the wage-skill supply relationship (see equations (14) and (17)) schematically as:

$$(23) \quad \widehat{w}_{H/L} = -(1 - \Psi)\phi_{HL}\widehat{v}_{H/L}$$

The GHO elasticity  $\phi_{HL}$  refers to the absorption of an increase in  $v$  by mechanisms that require falls in  $w$ : adoption of more skill-intensive processes (or product mix) within sectors and goods-price-induced shifts in the sectoral composition of output. The  $(1 - \Psi)$  term, replacing 1 in the numerator of equation (17), is the fraction of the increase in  $v$  whose absorption requires relative wage changes.

Our reduced-form elasticity estimates are of  $-(1 - \Psi)\phi_{HL}$ , while our structural elasticity estimates are of  $-\phi_{HL}$ . If both sets of estimates were accurate, they would imply that, at their median values, about four-fifths of any change in the relative supply of skilled labour is absorbed into employment without a change in relative wages.

This apparently high proportion is of course lower than in the standard HOS model of an open economy, in which changes in the relative supply of skilled labour would be fully absorbed by shifts in sectoral output mix at constant wages. But even our reduced-form estimates of the wage-skill supply elasticity are significantly below the predicted HOS value of zero, and our estimated goods-price  $\beta$  elasticities in the structural calculation (like other Armington-type estimates) are far below the implied HOS value of infinity.

A plausible ‘non-wage’ mechanism is skill supply-induced changes in the composition of domestic demand. Caron et al. (2014) hypothesise and confirm empirically that the income elasticities of goods rise with their skill intensity, and explore the implications of this fact

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<sup>37</sup>Another possible explanation for this gap is our benchmark assumption in the structural calculations that  $\eta_{j1} = 0$ , which is likely to underestimate all the  $\delta_{j1}$  and thus overestimate the wage-skill supply elasticity. However, we made the same assumption in the reduced-form estimation, the results of our structural tests were not greatly altered by setting  $\delta_{j1} = 1$  (in the TP experiments), and the effects on the median of including or excluding the price-ratio elasticity term are much the same for the reduced-form and the structural distributions (results available upon request).

for HO predictions. It is also widely believed that increases in the average skill level of the workforce tend to cause income growth. So in our framework, a higher relative skill supply, by raising per capita income, could be absorbed at least in part by a rise in the relative demand for more skill-intensive goods.

As a first check on this mechanism, we estimate the reduced-form elasticity at the country level of the skill intensity of demand with respect to skill supply. The skilled/unskilled labour content of final demand (for both domestically supplied and imported goods) is calculated at the sector level by combining yearly input-output tables and factor use tables from WIOD (following [Timmer et al., 2013](#)), aggregated to the country level and regressed on aggregate skilled/unskilled employment. The estimated elasticity is consistently around 0.8, in both panel and cross-section specifications (see Table A.4 in the [Online Appendix](#)).

Remarkably, if this estimated elasticity were treated as the value of  $\Psi$  in equation (23), it would cause the average difference between the structural and the reduced-form wage-skill supply elasticity to disappear. This result, however, needs to be treated with caution. The skill intensity of demand is measured ex-post (conditional on the technology matrix and on trade flows), rather than ex-ante. Its variation, furthermore, reflects not only the goods composition of final demand but also the skill mix of inputs used to produce particular goods, both of which might be influenced by skill supplies.

As a more direct test of the final-demand mechanism, we revise our structural estimates by including a term similar to the Constant Relative Income Elasticity (CRIE) of [Caron et al. \(2014\)](#) in a modification of the numerator, formerly just unity, of equation (17), whose denominator is unaltered.

$$(24) \quad \widehat{w}_{H/L} = - \frac{1 - \left( \sum_{j=1}^n [\lambda_{Hj}(1 - \theta_{Hj}) + \lambda_{Lj}\theta_{Hj}] \omega_j + \sum_{j=2}^n (\lambda_{Hj} - \lambda_{Lj}) \frac{\mu_j}{\mu_1} \right) \pi_v}{\sum_{j=1}^n [\lambda_{Hj}(1 - \theta_{Hj}) + \lambda_{Lj}\theta_{Hj}] \sigma_j + \sum_{j=2}^n (\lambda_{Hj} - \lambda_{Lj}) \epsilon_{j1} \delta_{j1} (\theta_{Hj} - \theta_{H1})} \widehat{v}_{H/L}$$

The three new terms in the numerator, explained more fully in the [Online Appendix](#) (section A.V), are:  $\pi_v$ , the elasticity of per-capita income with respect to skill supplies;  $\mu_j$ , the income elasticity of demand for good  $j$ ; and  $\omega_j$ , which captures the effect of income on the skill intensity of the composition of demand for varieties of each good (if the data on goods were so detailed as to include every variety, there would be no need for this term).

Measuring the effect of skill supply on national income has long been seen as difficult, and there is not even a consensus range of values of  $\pi_v$  in the literature ([Pritchett, 2001](#); [Hanushek and Woessmann, 2015](#)). For simplicity, we assume  $\pi_v = 1$ , in line with the emphasis of new growth theory on the externalities associated with human capital.

To estimate  $\mu_j$ , we follow the two-step procedure of [Caron et al. \(2014\)](#), which corrects for differences in prices among countries caused by trade costs. Despite using different data, we obtain similar results, described in the [Online Appendix](#) (section A.VI), including the strong correlation with skill intensity.

The  $\omega_j$  term is the income elasticity of the skill intensity of final expenditure on good  $j$  (skilled/unskilled labour content). It is estimated by a reduced-form method similar to that used for  $\sigma_j$ . We regress skill intensity at sector level on GDP per capita, controlling for the relative skilled wage and including country and time fixed effects. The estimated  $\omega_j$ 's average about 0.22, and vary mildly among sectors (with one third of the parameters being imprecisely estimated - see the last column of Table A.3 in the [Online Appendix](#)).<sup>38</sup>

Figure 9 shows the distribution of the modified structural elasticity, derived by plugging these estimates of the elasticity parameters into equation (24), alongside the distributions of the benchmark structural and reduced-form elasticities. The addition of the demand-side mechanism does shift the distribution to the right, and it now overlaps with the reduced-form distribution. Yet, the median of the modified structural elasticity, at -0.51, is still well below the reduced-form median of -0.17. The only way to close this gap that would not be strongly inconsistent with the data used to estimate its parameters would be to assume, implausibly, a much higher value of  $\pi_v$ .

Thus an income-related final-demand mechanism similar to that of [Caron et al. \(2014\)](#), and also to [Leonardi \(2015\)](#), does indeed help to explain how changes in skill supplies can be absorbed without changes in relative wages. However, about half the non-wage-related absorption remains unexplained.

Possible explanations for the rest include wage inflexibilities that create persistent excess demand for skilled workers and (over longer periods) skill-biased changes in production techniques that are induced directly by increased relative supplies of skilled workers ([Acemoglu, 2007](#)) or are not captured by conventional ways of estimating elasticities of substitution in production. The race between education and technology ([Goldin and Katz, 2008](#)) has usually been a close-run contest, and is one about which there is probably still more to learn.

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<sup>38</sup>Our estimates use GMM, without which the  $\omega_j$ 's are lower and even less precise. Replacing the insignificant estimates with the median across the significant ones does not alter the main findings.

## V Concluding remarks

We have analysed how the wages of skilled and unskilled workers are determined in open economies. Our empirical analysis has shown that, as labour economists believe, wages vary systematically with skill supplies across countries and over time, but also that, as trade economists believe, wages are less - sometimes much less - sensitive to skill supplies where barriers to trade are lower.

Bringing trade and labour economists together could contribute to more constructive dialogue between economists and policy makers. For example, in our general HO model a trade-induced widening of the wage gap between skilled and unskilled workers could be narrowed by educating unskilled workers (which it could not in one-cone HOS). But because the wage effects of educational expansion are reduced by trade-related shifts in the sectoral structure of output, other measures may also be needed to achieve any desired reduction of wage inequality at minimum cost.

As ever, there is much scope for further work. Data constraints caused our empirical work to focus on the wage effects of supply shocks rather than of the trade barrier and world price shocks studied in most earlier work in this field. Our measures of trade barriers and of per-unit trade and production costs could be improved, including a fuller investigation of the effects of trade in intermediate inputs and of payments to capital. The price and output sides of HO forces could be analysed jointly, in conjunction with the influence of non-HO forces.

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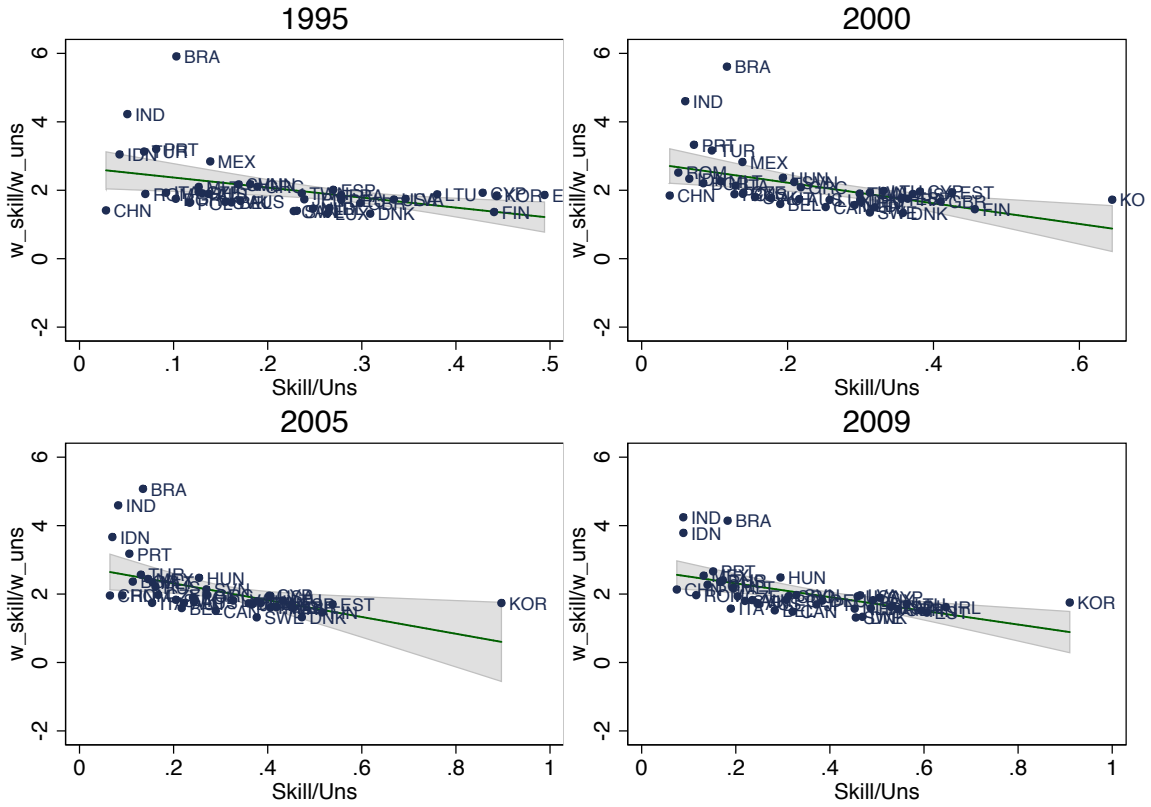
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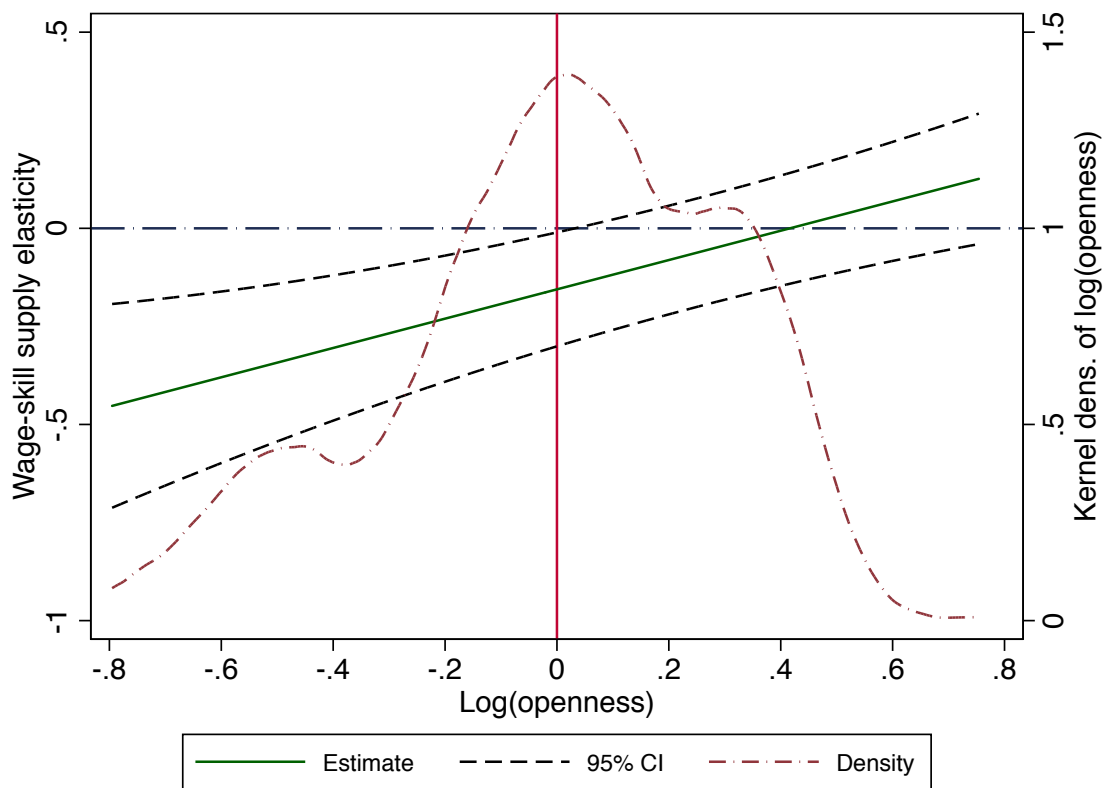
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Figure 1: Relative wages and employment



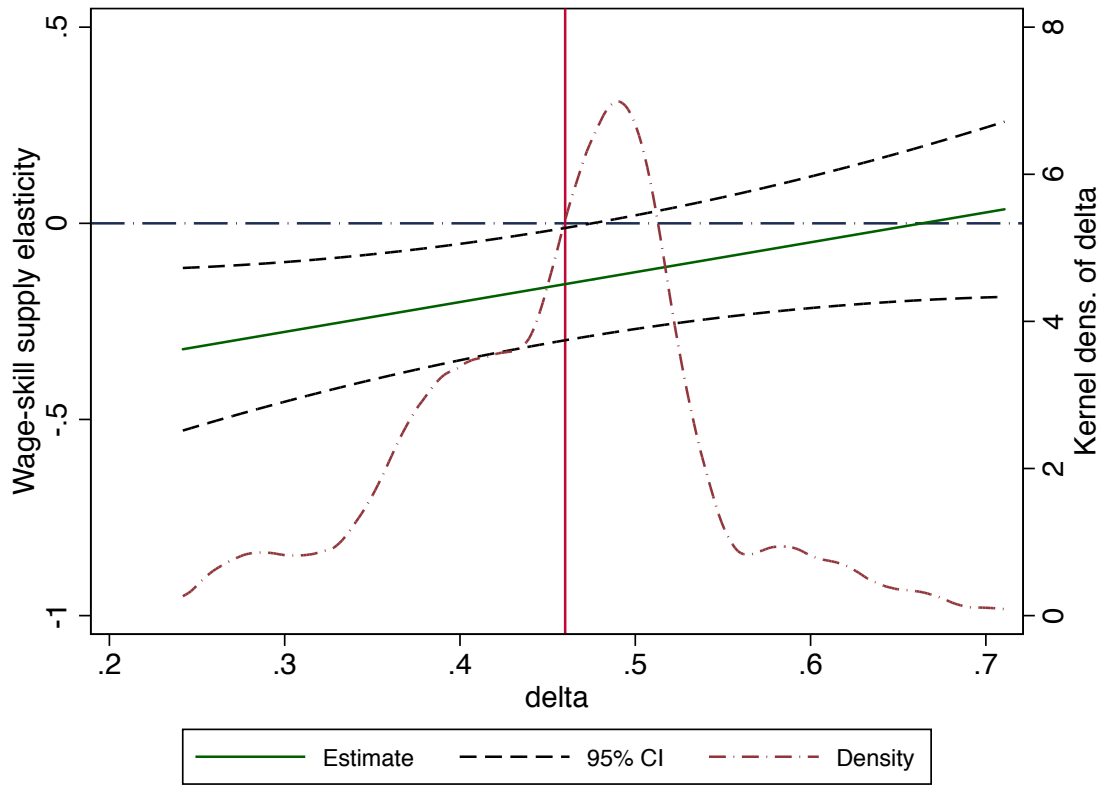
Linear prediction line with 90% confidence bands (based on HC3-robust standard errors) are shown.

Figure 2: Wage-skill supply elasticity and openness at median  $\tilde{\delta}$



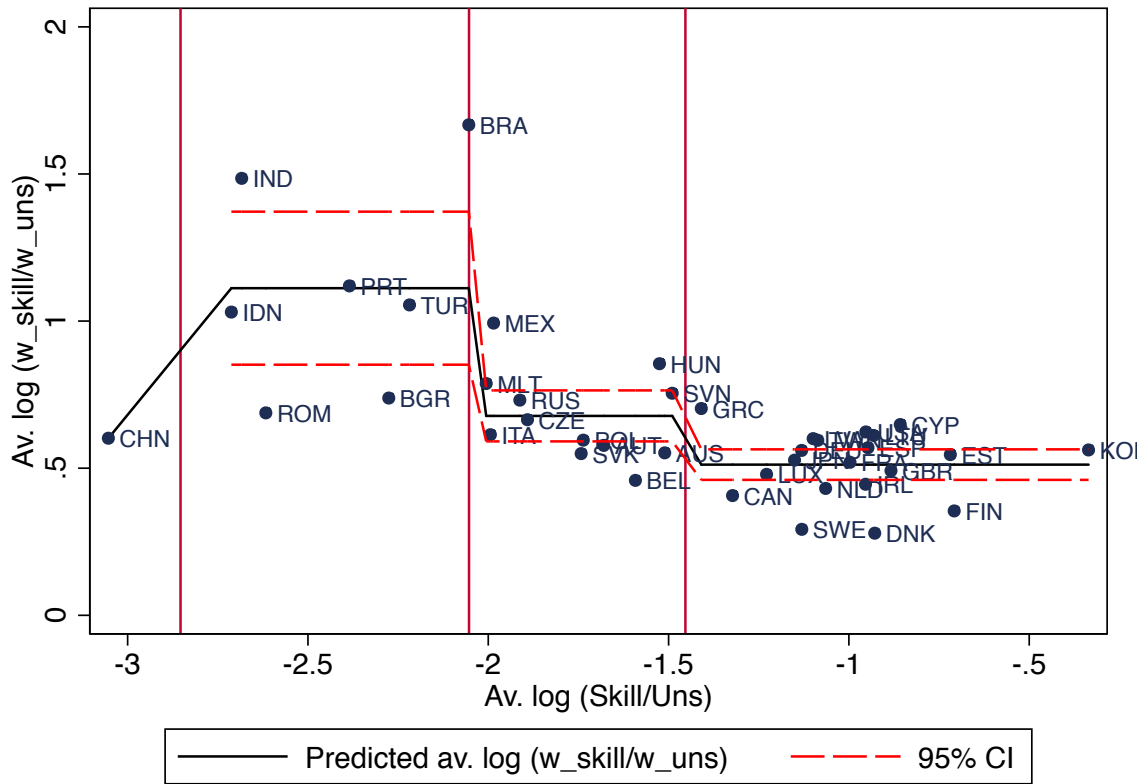
Vertical line is at the sample mean of  $\ln(o)$ .

Figure 3: Wage-skill supply elasticity and  $\tilde{\delta}$  at median openness



Vertical line is at the sample mean of  $\tilde{\delta}$ .

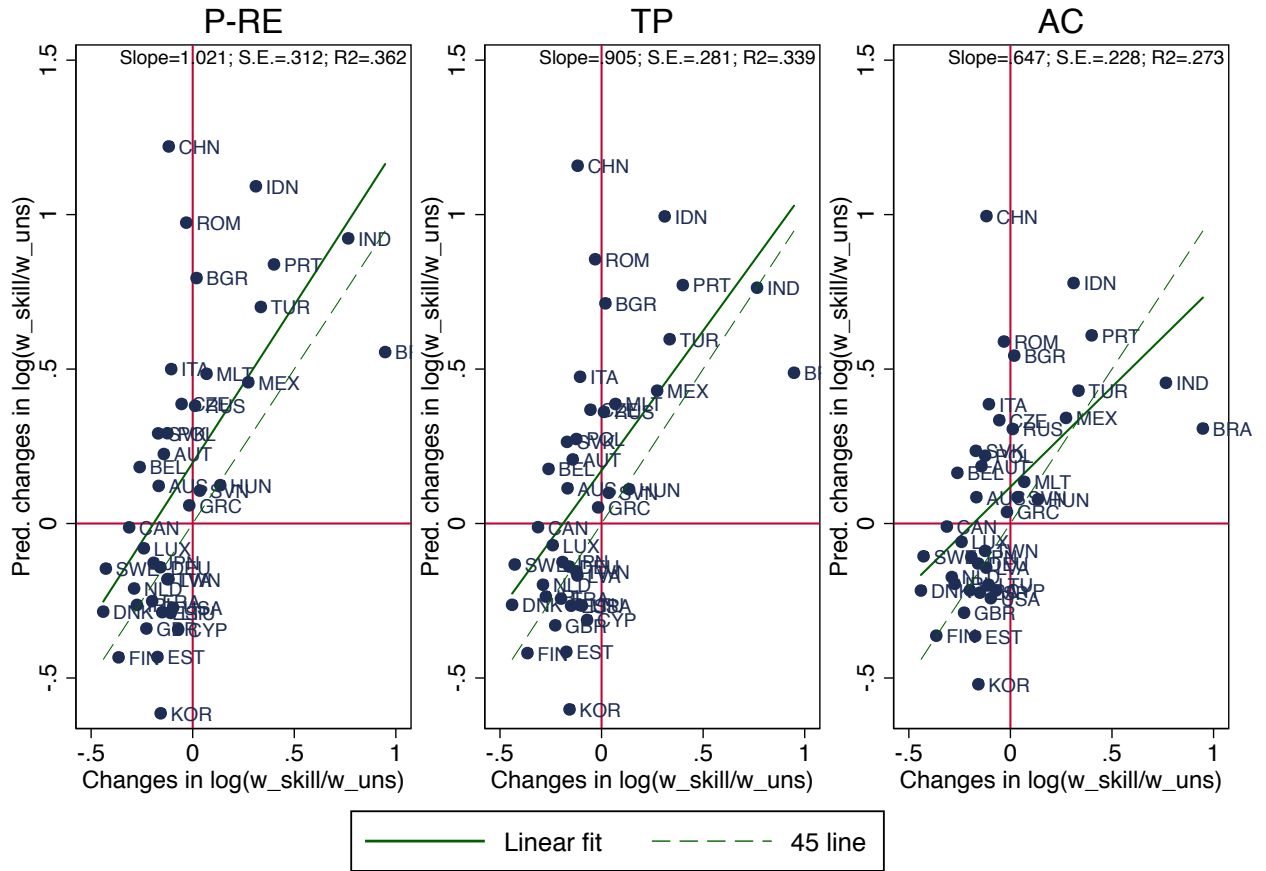
Figure 4: Estimated cones of diversification



Vertical lines indicate the location of interior knots.

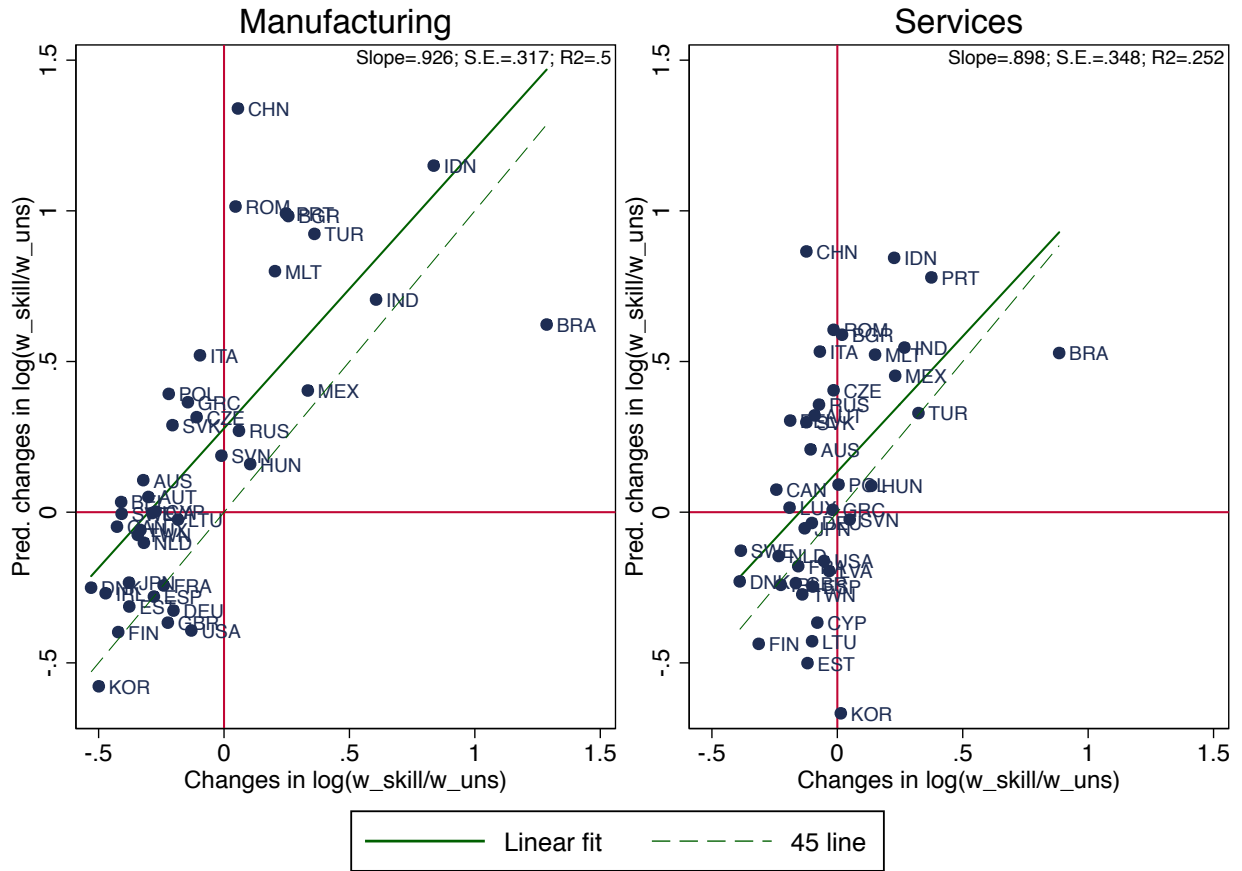


Figure 5: Slope tests - Cross-country estimates



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: Correlation between structural and reduced-form elasticities

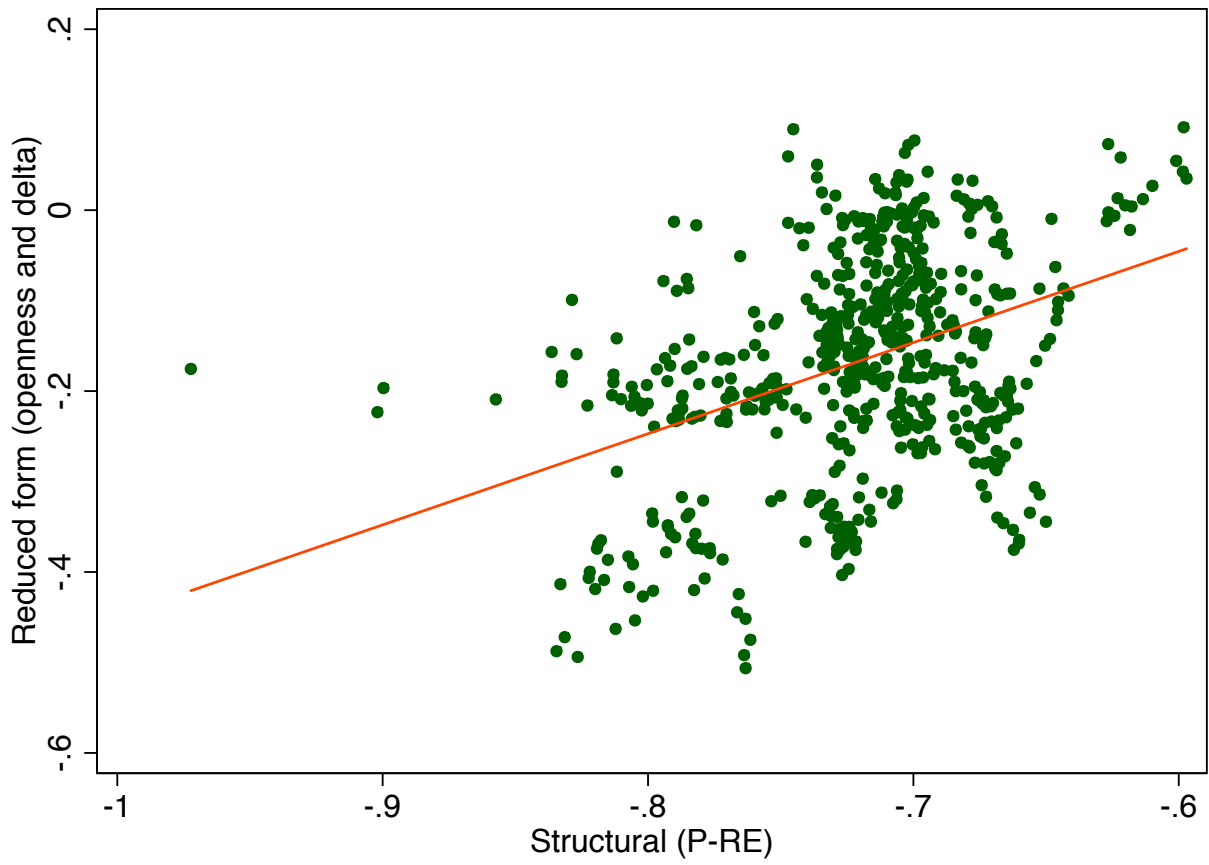
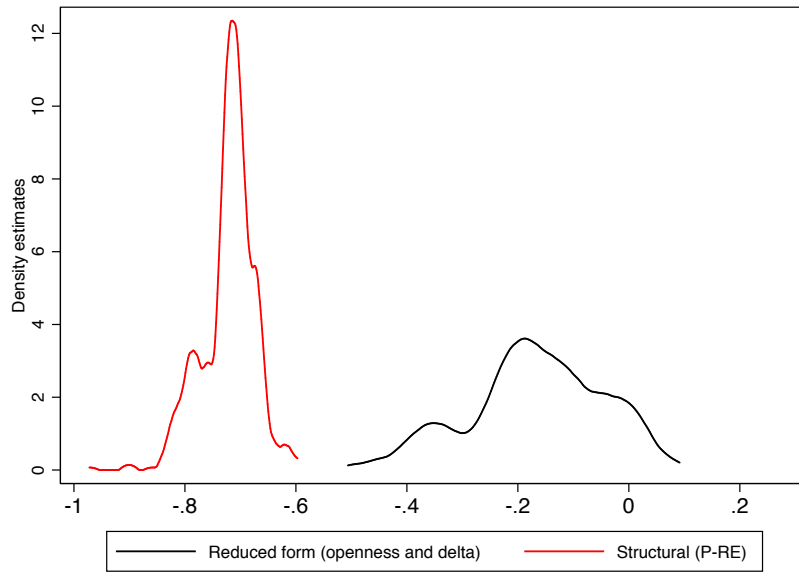


Figure 8: Reduced-form and structural wage-skill supply elasticities

(a) Structural vs. reduced-form



(b) With variants of reduced-form

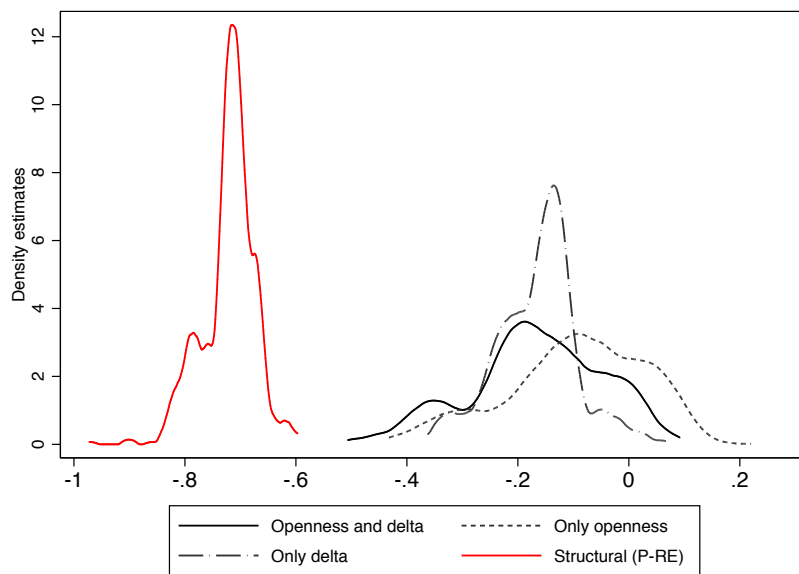
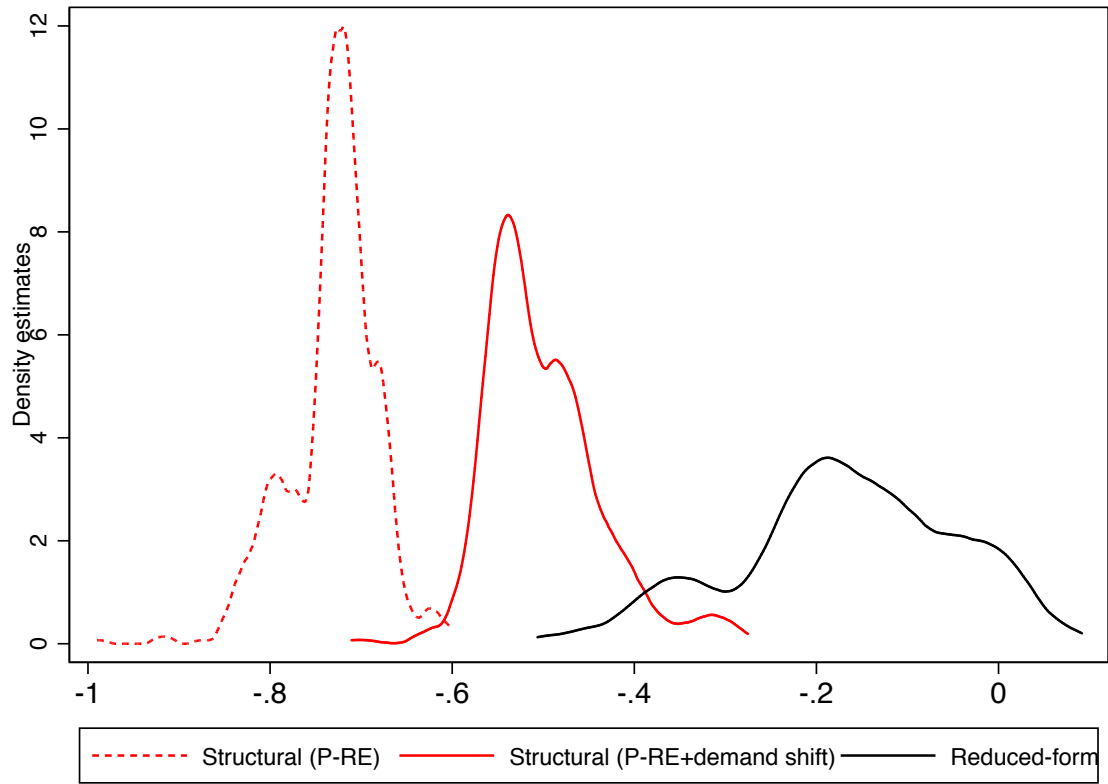


Figure 9: Structural wage-skill supply elasticities with income-related demand shift



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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
$\tilde{\delta}$	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
$GDP_{pc}$	600	21218	16288	469	87717
$union$	434	0.338	0.209	0.050	0.919

$w_m$  and  $v_m$  are calculated with medium-skilled labour in the “skilled” rather than the “unskilled” category.

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

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(v)$	-0.269*** (0.0832)	-0.308*** (0.0732)	-1.008** (0.420)	-0.690 (0.427)	-0.574 (0.404)	-0.451 (0.437)
$\ln(o)$		0.499 (0.426)	0.401 (0.393)	0.309 (0.397)	0.659 (0.444)	0.890 (0.552)
$\ln(v) \times \ln(o)$		0.543 (0.349)	0.476 (0.327)	0.425 (0.326)	0.680* (0.348)	0.847** (0.422)
$\tilde{\delta}$			1.590 (1.140)	0.721 (1.197)	1.291 (1.295)	1.082 (1.478)
$\ln(v) \times \tilde{\delta}$			1.607* (0.886)	1.032 (0.902)	0.912 (0.897)	0.691 (0.956)
$\ln(v_{ls})$				-0.0313 (0.0543)		
$\ln(v_{ns})$				0.0613* (0.0358)		
$\ln(v_{land})$					-0.0206 (0.0204)	
$\ln(r/w_{tot})$					0.100** (0.0395)	
$\ln(GDPpc)$						-0.182** (0.0846)
$\ln(union)$						-0.0149 (0.0624)
Obs	40	40	40	40	40	36
R <sup>2</sup>	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-skill supply elasticity and GHO in reduced form - Panel

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

	P-RE		TP		AC	
Bounds:	$w$ on $\tilde{w}$	$\tilde{w}$ on $w$	$w$ on $\tilde{w}$	$\tilde{w}$ on $w$	$w$ on $\tilde{w}$	$\tilde{w}$ on $w$
	0.371*** (0.108)	1.021*** (0.312)	0.393*** (0.120)	0.905*** (0.281)	0.451*** (0.155)	0.647*** (0.228)
Obs	40	40	40	40	40	40
R <sup>2</sup>	0.362	0.362	0.339	0.339	0.273	0.273
Variance ratio: $\frac{Var(\tilde{w})}{Var(w)}$						
	2.751		2.300		1.436	



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

	P-RE		TP		AC	
	$w$ on $\tilde{w}$	$\tilde{w}$ on $w$	$w$ on $\tilde{w}$	$\tilde{w}$ on $w$	$w$ on $\tilde{w}$	$\tilde{w}$ on $w$
<b>5-year changes</b>						
	0.220**	0.413***	0.244**	0.374***	0.316**	0.294***
	(0.0833)	(0.101)	(0.0931)	(0.0902)	(0.126)	(0.0681)
Obs	400	400	400	400	400	400
Within R <sup>2</sup>	0.221	0.220	0.221	0.216	0.223	0.201
Variance ratio: $\frac{Var(\tilde{w})}{Var(w)}$						
	1.473		1.199		0.742	
<b>10-year changes</b>						
	0.402***	0.636***	0.435***	0.579***	0.540***	0.446***
	(0.115)	(0.145)	(0.128)	(0.129)	(0.176)	(0.0924)
Obs	200	200	200	200	200	200
Within R <sup>2</sup>	0.318	0.349	0.314	0.338	0.304	0.311
Variance ratio: $\frac{Var(\tilde{w})}{Var(w)}$						
	0.959		0.785		0.515	
<b>14-year changes</b>						
	0.0434	0.0479	0.0320	0.0290	-0.0473	-0.0299
	(0.214)	(0.243)	(0.238)	(0.222)	(0.278)	(0.181)
Obs.	40	40	40	40	40	40
R <sup>2</sup>	0.002	0.002	0.001	0.001	0.001	0.001
Variance ratio: $\frac{Var(\tilde{w})}{Var(w)}$						
	1.105		0.907		0.632	

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

	P-RE		TP		AC	
	M	S	M	S	M	S
<b>5-year changes</b>						
$\hat{w}$	0.272*** (0.0512)	0.327** (0.135)	0.267*** (0.0504)	0.306** (0.123)	0.252*** (0.0481)	0.270** (0.101)
Obs	400	400	400	400	400	400
Within R <sup>2</sup>	0.221	0.187	0.220	0.185	0.214	0.175
<b>10-year changes</b>						
$\hat{w}$	0.372*** (0.130)	0.705*** (0.150)	0.367*** (0.129)	0.659*** (0.138)	0.347*** (0.124)	0.548*** (0.108)
Obs	200	200	200	200	200	200
Within R <sup>2</sup> 0.256	0.309	0.255	0.304	0.248	0.297	
<b>14-year changes</b>						
$\hat{w}$	0.132 (0.109)	0.0749 (0.269)	0.132 (0.106)	0.0597 (0.257)	0.114 (0.105)	0.00161 (0.223)
Obs	40	40	40	40	40	40
R <sup>2</sup>	0.034	0.005	0.035	0.003	0.028	0.000

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.