Comparative advantage in routine production *

Archanskaia L.[1], Van Biesebroeck J.[1] and Willmann G.[2]

[1]KU Leuven
[2]Universität Bielefeld

December 8, 2017

Abstract

We pin down a new mechanism behind comparative advantage by pointing out that countries differ in their ability to adjust to technological change. We take stock of the pattern extensively documented in the labor literature whereby more efficient machines displace workers from codifiable (routine) tasks. Our hypothesis is that labor reallocation across tasks is subject to frictions and that these frictions are country-specific. We incorporate task routineness into a canonical 2-by-2-by-2 Heckscher-Ohlin model. The key feature of our model is that factor endowments are determined by the equilibrium allocation of labor to routine and non routine tasks. Our model predicts that countries which facilitate labor reallocation across tasks become relatively abundant in non routine labor and specialize in goods that use non routine labor more intensively. We document that the ranking of countries with respect to the routine intensity of their exports is strongly connected to two institutional aspects: labor market institutions and behavioral norms in the workplace.

Keywords: comparative advantage, resource allocation, routineness

JEL codes: F11, F14, F15

*This paper has greatly benefited from helpful discussions with Jan de Loecker, Sašo Polanec, Ariell Reshef, Hylke Vandenbussche, and Frank Verboven as well as from the discussion by Chad Syverson at the CompNet 13th Annual Conference (2017). This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 649378. This project was carried out while Archanskaia was postdoctoral research fellow at KU Leuven (01/10/2013-15/01/2017).

Executive Summary

Classic theories of international trade generated predictions on the comparative advantage of countries from differences in factor endowments (Heckscher-Ohlin) or directly from productivity differences (Ricardo). More recent contributions have postulated that comparative advantage might also be generated endogenously from cross-country differences in institutions. We propose a variation of that approach in order to predict the specialization of countries in goods that are intensive (or not) in routine tasks.

We start from the production function pioneered by Autor et al. (2003) that models sectors as differing in their relative intensity of the nonroutine labor input versus an intermediate input. Crucially, this intermediate input is produced itself using routine labor or machines which may be perfect or imperfect substitutes in a CES aggregator. Our innovation is to make the ease of substitutability in the CES function a dimension along which countries differ.

We first provide some evidence that our nested production function is able to fit some features of the data. We estimate the production function using the EU KLEMS dataset for 25 countries and 30 industries, exploiting only the time dimension and allowing the structural parameters to vary across both industry and country dimensions. We obtain the best fit of the data if we let the parameter of the outer nest, which captures the relative importance of the nonroutine labor input, vary across sectors, while we let the parameter of the inner nest, which captures the ease of substitution between routine labor and capital in the production of the intermediate, vary across countries.

Next, we derive comparative advantage predictions from this production function and investigate which institutional characteristics of countries can support these predictions. We do this in a two-step procedure, borrowed from Costinot (2009). First, we estimate for each country how strong the correlation is between the sectoral composition of its net export bundle and the sectoral ranking of routine-intensity (a primitive of technology). Next, we investigate which institutional features are significant predictors of these correlation coefficients.

The first step yields intuitive patterns: countries that specialize the least in routine-intensive production are Japan, Switzerland, Germany, and Sweden, while countries that specialize the most in routine-intensive goods are Thailand, Italy, Canada, and China. It is interesting to note that these patterns are quite different from those obtained from traditional measures of skill-intensity. In the second step, we estimate that the institutional characteristics that co-vary positively with specialization in nonroutine-production are: rule of law, strong norms in the workforce (low absenteism, flexibility, responsibility,...), and high internal migration.

Finally, we provide some avenues to start thinking how the production function that we proposed can be built up from micro-foundations. The function has been used widely, especially in labor economics, but it has generally been treated as an exogenous primitive of the economy. We describe a few mechanisms where the adjustment of an economy to an exogenous increase in labor-substituting capital is facilitated by flexible labor market institutions, e.g. low severance pay, the fraction of the cost of retraining workers that is borne by society (government) rather than individual firms, high quality of formal schooling that imparts general (not firm-specific) skills, etc. We illustrate how a primitive parameter measuring high severance pay, for example, leads to low substitutability between factors in routine intermediate production. These mechanisms suggest directly a number of mechanisms that governments can exploit to influence their comparative advantage away from routine-intensive production.

1 Introduction

The classical theory of comparative advantage puts forward that differences in technology and factor endowments lead countries to specialize in the production of different goods. Recent developments in this literature put forward the role of worker attributes (human capital, skill dispersion) and of institutions (the ability to enforce contractual relationships) in shaping the pattern of trade. The available evidence supports the view that countries differ in many dimensions, and that all of these dimensions play a role in determining the pattern of trade.[1]

We seek to contribute by merging the comparative advantage literature with a prominent topic in the labor literature. We pin down a new mechanism behind comparative advantage by noticing that countries may differ in their ability to adjust to technological change. Our starting point is a well-documented pattern associated to the recent process of technological change.[2] The operationality of more efficient machines leads to the displacement of workers away from the relatively more codifiable ('more routine') tasks in which the new machines have a comparative advantage. The automation of routine tasks frees up labor to perform the less codifiable ('non routine') tasks. We find that countries that are better able to reallocate workers across tasks specialize in goods that require more intensive use of labor in the non routine tasks.

To make this point we incorporate task routineness into an otherwise canonical 2-country 2-good 2-factor Heckscher-Ohlin model. The two factors needed for the production of the two final goods are the routine and the non-routine factor. The key feature of our model is that the available quantities of these two factors are not given exogenously. Instead, these quantities are determined by the equilibrium allocation of labor to routine and non-routine tasks. We model the process of technological change as an increase in the capital endowment. As in Autor et al. (2003) and Autor and Dorn (2013), we posit that capital can only be used in routine tasks. An increase in the quantity of capital brings about a reduction in the relative cost of capital and an increase in the equilibrium capital intensity of routine production. Consequently, labor can be released from routine tasks and reallocated to non-routine tasks.[3]

[1] Chor (2010) shows that institutional characteristics matter at least as much as factor endowments. Bombardini et al. (2012) show that the level of human capital and the degree of skill dispersion are quantitatively similar.

[2] See in particular Autor et al. (2003), Acemoglu and Autor (2011), Goos et al. (2014), Harrigan et al. (2016).

[3] Two approaches have been used to model labor reallocation. Autor and Dorn (2013) posit that workers can only be reallocated from routine tasks in manufacturing to manual non-routine tasks in services while Autor et al. (2003) allow reallocation from routine to non-routine tasks in manufacturing. We follow the approach of Autor et al. (2003) while relaxing their assumption of perfect capital-labor substitutability in routine tasks.

Our hypothesis is that the reallocation of workers across tasks is subject to frictions, and that the intensity of these frictions is country-specific. We model the intensity of frictions associated to the process of labor reallocation as a change in the elasticity of substitution between capital and labor in routine production. We think of this assumption as a reduced form approach to capturing differences in labor market regulations across countries as well as differences in worker bargaining power and, more generally, in the intensity of frictions in the workplace. Specifically, we expect the elasticity of substitution to be decreasing in the magnitude of hiring, firing, and retraining costs associated to the adjustment of the workforce to the new machines.

Our model delivers the prediction that countries which adjust more smoothly to technological change - i.e. countries with a higher elasticity of substitution between capital and labor in routine production - free up more labor for non-routine tasks and become non-routine labor abundant. As in the canonical Heckscher-Ohlin model, the abundance of non-routine labor makes these countries relatively more efficient in producing goods that use the non-routine labor more intensively. Consequently, we get the prediction that countries which adjust more smoothly to technological change specialize in goods that are relatively non-routine intensive. This new mechanism of comparative advantage helps to explain why countries with similar factor endowments and similar technology may specialize in different goods.

We test the predictions of our model by following the approach in Costinot (2009). We work with bilateral trade data at the HS 2-digit level in 2000-2006. To reduce the number of zeros in the trade matrix, we restrict the sample to the 19 biggest exporters and the 34 biggest importers. In the first step of the estimation, we rank countries with respect to the routine intensity of their exports.[4] In the second step, we regress the ranking of countries with respect to the routine intensity of their exports on their ranking with respect to institutional characteristics that likely correlate with the ability to reallocate labor across tasks.

We find that the strictness of employment protection legislation (EPL) helps to explain differences in specialization across the countries of the European Union. Consistently with the predictions of our model, European countries with relatively strict EPL - and hence, lower capital-labor substitutability - specialize in goods that are relatively routine-intensive. Further, we find that the quality of the workforce as well as behavioral norms in the workplace help to explain differences in specialization across the 19 biggest world exporters. Consistently with the predictions of our model, countries in which the labor force is more able and more reliable

[4] The ranking of industries with respect to routine intensity is taken from Autor et al. (2003). We match their ranking across 140 census industries to the HS 2-digit classification.

specialize in goods that are relatively non routine-intensive.

Our work connects to three strands of the literature. Starting from the seminal work by Klump and De La Grandville (2000) who showed that the magnitude of the elasticity of substitution between capital and labor had substantial implications for growth, macroeconomists have seeked to estimate the magnitude of capital-labor substitutability and to uncover its determinants. We contribute to this literature by connecting the magnitude of capital-labor substitutability to the institutional characteristics of countries and by showing that differences in capital-labor substitutability play a role in determining countries' specialization in trade.

Our work also connects to the rapidly growing literature in labor economics that documents how increased automation and outsourcing of codifiable tasks led to job polarization in developed economies. This literature explicitly connects technological change to labor displacement from routine to non-routine tasks.[5] We contribute to this literature by showing that institutional characteristics play a role in determining the cost of worker reallocation across tasks. Further, we document that workers are expected to benefit relatively more from trade in countries that are able to adjust more smoothly to technological change.

Last but not least, we contribute to the trade literature that seeks to uncover new mechanisms behind comparative advantage. As pointed out by Nunn and Trefler (2014), this literature has extensively documented the importance of institutional characteristics. Our work also underscores the role of institutions. Our main contribution consists in pointing out that institutions may have a direct effect on the adjustment of the economy to technological change and, consequently, on the allocation of labor across tasks. We show that differences in measured factor abundance such as country-specific ratios of the skilled to the unskilled labor may be determined by the interaction of institutional characteristics with the process of technological change.

The rest of this paper is organized as follows. In section 2 we present the main features of the stylized model, derive the autarky equilibrium and discuss the predictions regarding the pattern of trade. In section 4 we discuss the estimation strategy and the results while section 3 describes the datasets that we use in the analysis. In section 5 we discuss one possible microfoundation of differences in capital-labor substitutability. Specifically, we show that an increase in the magnitude of adjustment costs leads to a reduction in measured capital-labor substitutability. We conclude in section 6.

[5] See in particular Autor et al. (2003), Acemoglu and Autor (2011), Goos et al. (2014), Harrigan et al. (2016).

2 Theory: the effect of σ on factor abundance

Our set-up maintains the structure of the canonical $2 \times 2 \times 2$ HO model whereby the pattern of trade is determined by the interaction of country-specific factor abundance and sector-specific factor intensity. The distinguishing feature of our set-up is that the quantities of factors available to produce the two final goods are endogenously determined by the optimal allocation of labor to routine and nonroutine tasks. We find that two countries, even if they (happen to) have the same endowments of capital and labor, still have an incentive to trade whenever they differ in the extent of K-L substitutability in routine production because the equilibrium labor allocation to tasks hinges on σ. The high-σ country is able to use the relatively scarce factor more efficiently, i.e. more labor moves into (out of) routine tasks when capital is scarce (abundant).

To make valid comparisons while working with two different CES functions requires choosing initial conditions, i.e. a point of normalization where countries allocate factors to tasks in the same way, and a pattern of factor accumulation. To keep things simple, we think of each point in time as a snapshot in which capital abundance in the economy is captured through a specific K-L ratio. We posit that the quantities of capital and labor are identical in the two countries at each point in time.[6] Thus, the state of the economy, as captured through the K-L ratio, is common to the two countries. The effects of the traditional HO channel of differences in endowments are well understood. This is why we abstract from differences in underlying endowments.

We demonstrate that as the two countries accumulate capital, they both reallocate labor from routine to nonroutine tasks. The key result for the incentive to trade is the different speed of adjustment. The high-σ country frees up more labor for nonroutine tasks and becomes nonroutine labor abundant. This result holds even though the high-σ country is relatively efficient in routine production, i.e. keeping factor quantities fixed, more output is obtained in routine production in the high-σ country.[7] To sum up: the labor reallocation effect dominates the efficiency effect and the high-σ country specializes in nonroutine intensive goods because the optimal allocation of labor to tasks makes it nonroutine labor abundant. The opposite pattern obtains if the K-L ratio is reduced: the high-σ country frees up more labor to do routine tasks and becomes routine labor (routine factor) abundant.

[6] Endogenizing capital accumulation would actually reinforce our results.

[7] This feature stems from the general mean property of the CES production function: the quantity of the routine intermediate M_i is strictly increasing in μ whenever the two countries allocate the same combination of inputs $\{K, L^m\}$ to its production and $K \neq L^m$ (Klump et al. (2012)).

Our general result on the relationship of K-L substitutability with factor abundance is that a higher σ mitigates resource scarcity, i.e. it maps into the relative abundance of the scarce factor needed in production of final goods. The corollary for the pattern of trade is that the high-σ country specializes in the final good that uses the relatively scarce factor more intensively. This result is a restatement, in the framework of our model, of the well-known Arrow et al. (1961) result, further studied in Klump and De La Grandville (2000), whereby economies with higher K-L substitutability are better able to mitigate the scarcity of labor and achieve higher welfare because they have higher incentives to accumulate capital. As in these papers, the magnitude of σ in our model captures the efficiency of resource allocation in the economy.

This section is organized as follows. First, we present the building blocks of the model and develop the intuition behind the key equilibrium relationships. Second, we discuss the choice of initial conditions and derive the general result on the mapping of K-L substitutability into factor abundance. Third, we derive the relationship between K-L substitutability and the pattern of trade and discuss FPE. We conclude by underlining the increasing divergence of labor market outcomes in the two countries as a consequence of opening up to trade.

2.1 The model

2.1.1 Basic set-up

The two countries are denoted $i \in \{A, B\}$. Factor endowments of capital $\bar{K}$ and labor $\bar{L}$ are common to the two countries. The two final goods are denoted $g \in \{1, 2\}$. The production factors used to produce the final goods are the nonroutine (abstract) labor L^a and the routine (intermediate) input M obtained from capital K and routine labor L^m, and the resource constraint on labor is $L^a + L^m \leq \bar{L}$.[8]

As is standard for the canonical HO model, the production function for final goods is Cobb-Douglas (time and firm subscripts are omitted to simplify notation):

$$Y_{ig} \quad = \quad z_g (L^a_{ig})^{1-\beta_g} M_{ig}^{\beta_g} \tag{1}$$

where z_g is a technology parameter, L^a_{ig} the quantity of abstract labor, M_{ig} the quantity of the routine input, and β_g its factor share. Note that factor shares β_g are common across countries. Without much loss of generality, we assume good 1 to be nonroutine intensive: $\beta_1 < \beta_2$.

As in the canonical HO model, it is sufficient to establish which country is nonroutine labor abundant to prove that under autarky this country produces relatively more output in the sector

[8] We discuss the transformation between L^a and L^m at a later point.

that uses nonroutine labor more intensively. However, the quantities of abstract labor L_i^a and of the routine intermediate M_i are now endogenously determined. Hence, the objective of the basic set-up is to determine the optimal allocation of labor to routine and nonroutine tasks.

Our focus is on K-L substitutability in routine production. So we keep things really simple for labor whereby one unit of raw labor gives one unit of labor for routine or abstract tasks, and the choice is reversible so one unit of routine (abstract) labor can be seemlessly converted into one unit of abstract (routine) labor.[9] For the production of the routine intermediate we follow Autor and Dorn (2013) posit a CES:

$$M_i \;=\; A_i \left[\alpha_i {K_i}^{\mu_i} + (1-\alpha_i)(L_i^m)^{\mu_i}\right]^{1/\mu_i} \tag{2}$$

where A_i and α_i are (respectively) the efficiency and distribution parameters of the CES, and $\mu_i = (\sigma_i - 1)/\sigma_i$ captures the extent of K-L substitutability in routine production.[10] Following Autor et al. (2003) and Autor and Dorn (2013) we posit that capital and routine labor are more substitutable than nonroutine labor and the routine input: $0 < \mu_i < 1 < \sigma_i, \forall i$.

Plugging (2) into (1), we obtain a two-tiered production function:

$$Y_{ig} \;=\; z_g (L_{ig}^a)^{1-\beta_g} \left\{ A_i \left[\alpha_i {K_{ig}}^{\mu_i} + (1-\alpha_i)(L_{ig}^m)^{\mu_i}\right]^{\frac{1}{\mu_i}} \right\}^{\beta_g} \tag{3}$$

Without loss of generality, we assume that country 1 has relatively high K-L substitutability in routine production: $\sigma_1 > \sigma_2$.

As is standard in many trade models, we assume identical, homothetic demand in both countries, and choose a Cobb-Douglas utility function: $U_i = \sum_g \theta_g \ln(Q_{ig})$. Consumers maximize this function, subject to the budget constraint $\sum_g P_{ig} Q_{ig} \le r_i \bar{K} + w_i \bar{L}$ where w_i is the wage and r_i the rental rate of capital. As is well known, this results in constant budget shares.

2.1.2 Solving the model

To solve the model we proceed as follows. Cost minimization by firms producing the routine input delivers conditional factor demands in intermediate good production. Cost minimization by firms producing the two final goods delivers conditional factor demands in final good production. By plugging the conditional factor demands into the respective objective functions, we obtain the unit cost functions for the routine input and for the two final goods. On the demand

[9] In our set-up σ absorbs all frictions associated to labor reallocation across tasks.Further, qualitative predictions are unchanged if we incorporate investment in human capital and task-specific wages in the model.

[10] The only deep parameter of the CES is σ. As explained in Klump et al. (2012), A_i and α_i are determined by the point of normalization and the magnitude of σ. Results are invariant to the point of normalization (see below).

side, the solution to the consumer problem determines expenditure allocation to the two final goods. We solve for the equilibrium factor price ratio by combining the supply-side FOCs and the constant budget shares on the demand side with market clearing conditions: capital and labor market clearing as well as final and intermediate goods' market clearing. The solution to the model delivers the optimal allocation of labor to routine and nonroutine tasks. We next discuss the main steps in solving the model and provide details in Appendix A.

On the supply side, we have three types of price-taking firms. The first type produces the routine intermediate input, the other two types produce the two final goods. We start with firms that produce the routine intermediate input. In our stylized model, the production function for this input is common to all firms engaged in routine production. Standard cost minimization for the CES function in (2) delivers conditional factor demands in routine production as well as the unit cost of the routine intermediate input which, due to perfect competition, is also its price (P_i^m). The unit cost function defined in terms of prices of factors used in routine production, i.e. the rental rate of capital (r_i) and the wage (w_i), is:

$$P_i^m \quad = \quad C(w_i, r_i; 1) = \frac{1}{A_i}\left[\alpha_i^{\frac{1}{1-\mu_i}} r_i^{-\frac{\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{-\frac{\mu_i}{1-\mu_i}}\right]^{\frac{\mu_i - 1}{\mu_i}} \tag{4}$$

The problem of the firms in final good production is also standard. Cost minimization for the CD function in (1) delivers conditional factor demands in final good production as well as the unit cost of each final good which, due to perfect competition, is also its price (P_{ig}). The unit cost function for each final good defined in terms of prices of factors used in final good production, i.e. the price of the routine input (P_i^m) and the wage (w_i), is:

$$P_{ig} \quad = \quad C_{ig}(w_i, P_i^m; 1) = \frac{w_i^{1-\beta_g} (P_i^m)^{\beta_g}}{z_g {\beta_g}^{\beta_g} (1-\beta_g)^{(1-\beta_g)}} \ , \ \forall g \in \{1, 2\} \tag{5}$$

The price vector is $\{r_i, w_i, P_i^m, P_{i1}, P_{i2}\}$. Just as in the canonical HO model, we can go back and forth between final goods' prices $\{P_{i1}, P_{i2}\}$ and mid-level factor prices $\{w_i, P_i^m\}$ or basic factor prices $\{w_i, r_i\}$. In particular, using (4), final good prices can be equivalently expressed as a function of prices of the 'primitive' factors (see equation (32) in the appendix). From here on we work with expressions defined in terms of prices of the primitive factors (labor and capital).

Since capital is used only in routine production, using market clearing for capital delivers the total quantity of the routine intermediate (M_i) as well as the quantity of labor allocated to routine tasks (L_i^m) as a function of the capital endowment and of factor prices (see respectively equation (39) and equation (36) in the appendix).

Labor market clearing delivers the total quantity of abstract labor (L_i^a) as a function of 'primitive' factor prices: $L_i^a = \bar{L} - L_i^m(w_i, r_i; \bar{K})$. Thus, optimal factor use in routine production together with market clearing for 'primitive' factors delivers relative factor supply, i.e. the ratio of 'produced' factors as a function of 'primitive' endowments and of the prices of the 'primitive' factors:

$$\frac{L_i^a}{M_i} = \frac{\bar{L} - L_i^m}{M_i} = \frac{\bar{L} - \left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\frac{1}{1-\mu_i}} \bar{K}}{A_i \alpha_i^{\frac{1}{\mu_i}} \bar{K} \left\{1 + \frac{w_i}{r_i}\left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\frac{1}{1-\mu_i}}\right\}^{\frac{1}{\mu_i}}} \tag{6}$$

On the demand side, we have assumed a Cobb-Douglas utility function. Hence, budget shares are constant, and denoting total expenditure by E, we can write:

$$\frac{P_{i1}Q_{i1}}{\theta_1} = \frac{P_{i2}Q_{i2}}{\theta_2} \tag{7}$$

Using the zero profit condition (5), we can rewrite (7) to express final good consumption Q_1/Q_2 as a function of factor prices and parameters $(P_i^m, w_i; \theta_g)$:

$$\frac{Q_{i1}}{Q_{i2}} = \left[\frac{w_i}{P_i^m}\right]^{\beta_1 - \beta_2} \left[\frac{\theta_1 z_1 \beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}}{\theta_2 z_2 \beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}}\right] \tag{8}$$

We then use final goods' market clearing to express the ratio on the LHS of (8) as a function of the 'produced' factors: $Q_{ig} = Y_{ig}(L_{ig}^a, M_{ig})$. Standard algebra thereafter delivers an expression for the ratio of 'produced' factors as a function of 'produced' factor prices, i.e. a relative factor demand equation.

Specifically, we plug the conditional factor demand for (respectively) abstract labor (the routine intermediate) in the LHS of (8) and rearrange to pin down the allocation of (respectively) abstract labor (the routine intermediate) to the two final goods as a function of parameters. Further rearranging allows to express the total quantity of each final good as a function of parameters, factor prices, and of the total use of (respectively) abstract labour (routine intermediate) in final good production. We obtain two expressions for each final good: the first one defines it as $Q_g(L_{ig}^a; P_i^m, w_i, \beta_g)$, and the second one defines it as $Q_g(M_{ig}; P_i^m, w_i, \beta_g)$. [11]

Equating these two expressions and rearranging delivers the familiar HO equation which connects relative factor abundance to relative factor prices in final good production. The only difference in our model is that of interpretation: the factors on the LHS are produced rather than exogenously given:

$$\frac{L_i^a}{M_i} = \frac{\sum_g \theta_g (1-\beta_g)}{\sum_g \theta_g \beta_g} \frac{P_i^m}{w_i} \tag{9}$$

[11] See equation (49) in Appendix A.

2.1.3 Solving for the relative factor price

We combine the relative factor supply equation (6) with the relative factor demand equation (9) to pin down the factor price ratio. Recall that the first relationship was expressed in terms of 'primitive' factor prices. We rewrite (9) in terms of 'primitive' factor prices by replacing P_i^m by its value in (4):

$$\frac{L_i^a}{M_i} = \frac{\sum_g \theta_g(1-\beta_g)}{\sum_g \theta_g \beta_g}\left[\frac{w_i}{r_i}A_i\alpha_i^{\frac{1}{\mu_i}}\right]^{-1}\left[1+\left(\frac{w_i}{r_i}\right)\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}\right]^{\frac{\mu_i-1}{\mu_i}} \tag{10}$$

Equating (6) with (10) and rearranging, we get an implicit solution for the equilibrium factor price ratio $\omega^* = (w_i/r_i)^*$ as a function of parameters and of 'primitive' factor endowments:[12]

$$F_i\left(\omega_i^*;\mu_i,\frac{\bar{L}}{\bar{K}},c,\alpha_i,A_i\right) = (\omega_i^*)^{-1}c+(1+c)\left[(\omega_i^*)^{-\frac{1}{1-\mu_i}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]-\frac{\bar{L}}{\bar{K}}=0 \tag{11}$$

where $c = (\sum_g \theta_g(1-\beta_g))/(\sum_g \theta_g\beta_g)$ summarizes information on factor use in final good production (β_g) and on preferences for final goods in consumption (θ_g).

It is immediate from (11) that the source of differences in the equilibrium factor price ratio across the two countries is K-L substitutability (μ_i).[13] To learn more about the impact of this parameter on the equilibrium factor price, we apply the implicit function theorem to $F_i(\cdot)$ whereby the partial derivative of the equilibrium factor price ratio with respect to μ is:

$$\frac{\partial(w_i/r_i)^*}{\partial\mu} = -\frac{\partial F_i(\cdot)/\partial\mu}{\partial F_i(\cdot)/\partial(w_i/r_i)^*} \tag{12}$$

The partial derivative of $F_i(\cdot)$ with respect to the factor price ratio is negative:

$$\frac{\partial F_i(\cdot)}{\partial(w_i/r_i)^*} = -\left[\left(\frac{w_i}{r_i}\right)^*\right]^{-2}\left[c+\frac{1+c}{1-\mu}\left[\left(\frac{w_i}{r_i}\right)^*\right]^{-\frac{\mu}{1-\mu}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu}}\right]<0 \tag{13}$$

It follows that the sign of $\partial(w_i/r_i)^*/\partial\mu$ is determined by the sign of $\partial F_i(\cdot)/\partial\mu$. Denoting the effective relative cost of labor by $\varpi_i = [w_i/(1-\alpha_i)]\,/\,[r_i/\alpha_i]$, we get:

$$\frac{\partial F_i(\cdot)}{\partial\mu} = -\frac{(1+c)}{(1-\mu)^2}\varpi_i^{-\frac{1}{1-\mu}}\ln\varpi_i \tag{14}$$

We learn that labor is relatively cheap in the high-μ country when the effective cost of labor is high ($\varpi_i > 1$). Further, labor is relatively expensive in the high-μ country when the effective

[12] We refer to section A.4.3 in the Appendix for details on these derivations and to section A.4.4 for the discussion on existence and uniqueness of the solution.

[13] Cross-country variation in α_i is driven by variation in μ_i (see below).

cost of labor is relatively low ($\varpi_i < 1$):

$$\begin{cases} \frac{\partial (w_i/r_i)^*}{\partial \mu} < 0, & \varpi_i > 1 \\ \frac{\partial (w_i/r_i)^*}{\partial \mu} = 0, & \varpi_i = 1 \\ \frac{\partial (w_i/r_i)^*}{\partial \mu} > 0, & \varpi_i < 1 \end{cases}$$

Further, we compute the derivative of the relative price with respect to the relative wage:

$$\frac{d(P_i^m/w_i)^*}{d(w_i/r_i)^*} = -\left\{\alpha_i \left[1 + \left[\left(\frac{w_i}{r_i}\right)^*\right]^{-\frac{\mu}{1-\mu}} \left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu}}\right]\right\}^{-\frac{1}{\mu}} A_i^{-1} \left[\frac{w_i}{r_i}\right]^{-2} < 0 \tag{15}$$

Combining this derivative with our previous result on the effect of μ on the equilibrium relative wage delivers the result that the relative price of the routine input is increasing in μ whenever labor is relatively expensive.

$$\begin{cases} \frac{d(P_i^m/w_i)^*}{d(w_i/r_i)^*} \frac{\partial (w_i/r_i)^*}{\partial \mu} < 0 & \varpi_i < 1 \\ \frac{d(P_i^m/w_i)^*}{d(w_i/r_i)^*} \frac{\partial (w_i/r_i)^*}{\partial \mu} = 0 & \varpi_i = 1 \\ \frac{d(P_i^m/w_i)^*}{d(w_i/r_i)^*} \frac{\partial (w_i/r_i)^*}{\partial \mu} > 0 & \varpi_i > 1 \end{cases}$$

Recall from (9) that it is sufficient to establish in which country the relative price of the routine input is relatively high in autarky to determine the pattern of specialization when the countries open up to trade. From the above expression, we learn that the high-μ country has a comparative advantage in the nonroutine intensive good whenever the effective cost of labor is relatively high ($\varpi_i > 1$) and a comparative disadvantage in this good whenever the effective cost of labor is relatively low ($\varpi_i < 1$).

These comparative statics hinge on the effective cost of labor which in turn depends on the magnitude of α_i. In general, α_i is a function of μ, so signing the effect of μ on the equilibrium factor price as a function of the effective cost of labor which itself is determined by μ is unsatisfactory. As we show below, by normalizing the CES function, we can break this circularity and pin down the effect of μ on the equilibrium factor price ratio as a function of endowments and of parameters.

2.2 The magnitude of σ and relative factor abundance

It remains to show formally how 'primitive' endowents are linked to the abundance of the 'produced' factors in equilibrium. Thus far, we have shown that the equilibrium factor price ratio determines the relative abundance of the produced factors and the pattern of comparative advantage. We have also shown that it is sufficient to sign the log of the effective cost of labor to pin down the relative abundance of the 'produced' factors. Finally, we have shown that the effective cost of labor ϖ_i hinges on the magnitude of σ. This is not sufficient: we still need to sign the log of the effective cost of labor as a function of the 'primitive' endowments. It turns out that we can pin down this final linkage by choosing initial conditions, i.e. the point of normalization of the CES production function.

2.2.1 Normalization of the CES: the choice of initial conditions

As shown by Klump et al. (2012), the normalization of the CES production function allows focusing on the structural effect of higher substitutability, i.e. the reduced incidence of decreasing marginal factor products.[14] By normalizing the CES production function, we are able to break the circularity of the problem outlined above - i.e. the impact of σ on the pattern of trade depends on the effective labor cost which in turn depends on σ to gain intuition on the way in which the optimal allocation of labor to routine and nonroutine tasks hinges on the magnitude of σ and on the endowments of the 'primitive' factors.

Specifically, by defining initial conditions, we can solve for the effective cost of labor ϖ as a function of endowments $\bar{K}/\bar{L}$ relatively to endowments at the point of normalization $\tilde{K}/\tilde{L}$, i.e. independently of the magnitude of σ. And given the effective cost of labor, we can determine the relative abundance of the produced factors $(L_1^a/M_1)/(L_2^a/M_2)$ or, equivalently, the relative price of the produced factors $(P_1^m/w_1)/(P_2^m/w_2)$ as a function of parameters $(\mu;\beta_g,\theta_g)$ and of endowments $(\bar{K}/\bar{L})$.

The normalization point is defined by the level of routine production $\tilde{M}$, the capital-routine labor ratio $\tilde{\kappa} = \tilde{K}/\tilde{L}^m$ and the marginal rate of substitution $\tilde{\omega} = \tilde{w}_i/\tilde{r}_i = [(1-\alpha_i)/\alpha_i]\,\tilde{\kappa}^{1-\mu_i}$ such that at this point the capital and labor allocation to routine production is independent of K-L substitutability (Klump et al. (2012); Klump and De La Grandville (2000)).

The normalized coefficient on capital α_i is:

$$\alpha_i(\mu) = \frac{\tilde{\kappa}^{1-\mu}}{\tilde{\kappa}^{1-\mu}+\tilde{\omega}} \tag{16}$$

Routine production at the point of normalization defines normalized productivity $A_i(\mu)$:

$$\tilde{M} = A_i(\mu)\left\{\alpha_i(\mu)\left(\tilde{K}\right)^{\mu} + [1-\alpha_i(\mu)]\left(\tilde{L}^m\right)^{\mu}\right\}^{1/\mu} \Leftrightarrow$$

$$A_i(\mu) = \frac{\tilde{M}}{\tilde{L}^m}\left[\frac{\tilde{\kappa}^{1-\mu}+\tilde{\omega}}{\tilde{\kappa}+\tilde{\omega}}\right]^{1/\mu} \tag{17}$$

[14] σ is decreasing in the cross-partial derivative of production with respect to capital and labor. See Appendix A.4.5 for details.

We then reformulate key relationships in terms of deviation from the point of normalization. Denoting optimal factor allocation in routine input production by $\kappa_i^* = \bar{K}/L_i^{m*}$, the FOC in routine production becomes:

$$\frac{\kappa_i^*}{\tilde{\kappa}} = \left[\frac{\omega_i^*}{\tilde{\omega}}\right]^{\frac{1}{1-\mu_i}} \tag{18}$$

Further, the function $F(\cdot)$ in (11) becomes:

$$F_i\left(\omega_i^*; \mu_i, \frac{\bar{L}}{\bar{K}}, c, \tilde{\kappa}\right) = (\omega_i^*)^{-1} c + \frac{1+c}{\tilde{\kappa}}\left[\frac{\omega_i^*}{\tilde{\omega}}\right]^{-\frac{1}{1-\mu_i}} - \frac{\bar{L}}{\bar{K}} = 0 \tag{19}$$

It is immediate from (19) that the equilibrium factor price ratio is independent of μ iff $\tilde{\omega} = \omega_i^*$. And it is immediate from (18) that optimal factor allocation to routine production mimicks the allocation at the point of normalization $L_i^{m*}/\bar{K} = \tilde{L}_i^m/\tilde{K}$ whenever the equilibrium factor price ratio is μ-independent.

There exists one particular normalization of the CES production function for which the effective cost of labor ϖ_i equals 1 at the point of normalization. From (16), the effective factor price ratio is $\varpi_i(\mu) = \tilde{\kappa}^{1-\mu}\left[\omega_i^*/\tilde{\omega}\right]$. Choosing $\tilde{\kappa} = 1$ at the point of normalization entails $\alpha_i = \alpha = (1+\tilde{\omega})^{-1}$ and $A_i = A$.[15] We plug these values into the existence condition (see A.4.4 for details) to pin down the set of choices for initial endowments that are consistent with this normalization: $\tilde{L}/\tilde{K} > (1+c)$. We obtain the wage that for a given choice of endowments at the point of normalization equalizes the relative cost of labor in the two countries: $\tilde{\omega}_i(\tilde{L}, \tilde{K}; c) = c\left[(\tilde{L}/\tilde{K}) - (1+c)\right]^{-1} = \tilde{\omega}$.

More generally, we can choose any $\kappa \neq 1$ at the point of normalization whereby $\varpi_i = 1$ when $\omega_i^* = \tilde{\omega}\tilde{\kappa}^{\mu_i - 1}$ and $\varpi_i \neq 1$ at the point of normalization defined by $\omega_i^* = \tilde{\omega}$. It is immediate that in the general case, the distribution (α_i) and productivity (A_i) terms are country-specific. We plug these values into the existence condition to pin down the set of feasible choices for initial endowments: $\tilde{L}/\tilde{K} > (1+c)/\tilde{\kappa}$. We obtain the wage that equalizes the relative wage in the two countries for a given choice of endowments at the point of normalization: $\tilde{\omega}(\tilde{L}, \tilde{K}; c) = c\left[(\tilde{L}/\tilde{K}) - (1+c)/\tilde{\kappa}\right]^{-1}$.[16] We readily check that the relative price of the routine input is equalized in the two countries at the point of normalization.

2.2.2 Main result: σ mitigates relative factor scarcity

We now investigate how the wage-rental rate ratio ω_i^* (the relative wage) changes when factor endowments deviate from the point of normalization. It is immediate from (**??**) that a

[15] For simplicity, we can always normalize $A = 1$ by defining $\tilde{M} = \tilde{L}^m = \tilde{K}$.

[16] Equivalently, $\tilde{\omega} = c\tilde{K}\left[\tilde{L} - (1+c)\tilde{L}^m\right]^{-1}$.

shock to endowments that leaves relative endowments unchanged ($\bar{K}/\bar{L} = \tilde{K}/\tilde{L}$) leaves the relative wage unchanged and independent of μ. Thus, a proportional shock to factor endowments situates routine production on the ray from the origin to the point of normalization in the K-L_i^m plane, with factor allocation and factor prices independent of μ.

Consequently, we focus on endowment shocks that modify the capital-labor ratio in the economy relatively to the point of normalization. Without loss of generality, we keep the labor endowment fixed $\bar{L} = \tilde{L}$ and consider shocks to the stock of capital: $\bar{K} \neq \tilde{K}$. As previously, we apply the implicit function theorem to $F(\cdot)$ in (19) to get:

$$\frac{\partial \omega_i^*}{\partial K} = -\frac{\partial F_i(\cdot)/\partial K}{\partial F_i(\cdot)/\partial \omega_i^*} > 0 \tag{20}$$

An increase (decrease) in the capital stock unambiguously increases (decreases) the relative wage. Consequently, the relative wage exceeds the relative wage at the point of normalization whenever the stock of capital exceeds the stock of capital at the point of normalization:

$$\begin{cases} \frac{\omega_i^*}{\tilde{\omega}} > 1, & \bar{K} > \tilde{K} \\ \frac{\omega_i^*}{\tilde{\omega}} = 1, & \bar{K} = \tilde{K} \\ \frac{\omega_i^*}{\tilde{\omega}} < 1, & \bar{K} < \tilde{K} \end{cases}$$

Further, the sign of $\partial(\omega_i)^*/\partial\mu$ is still determined by the sign of $\partial F_i(\cdot)/\partial\mu$ because $\partial F(\cdot)/\partial \omega_i^* < 0$. The latter is determined by the equilibrium relative wage relatively to the relative wage at the point of normalization:

$$\frac{\partial F_i(\cdot)}{\partial \mu} \quad = \quad -\ln\left(\frac{\omega_i^*}{\tilde{\omega}}\right)\frac{(1+c)}{\tilde{\kappa}(1-\mu)^2}\left[\frac{\omega_i^*}{\tilde{\omega}}\right]^{-\frac{1}{1-\mu}} \tag{21}$$

It follows that labor is relatively cheap in the high-μ country when the cost of labor increases relatively to the point of normalization. Further, labor is relatively expensive in the high-μ country when the cost of labor decreases relatively to the point of normalization:

$$\begin{cases} \frac{\partial \omega_i^*}{\partial \mu} < 0, & \left(\frac{\omega_i^*}{\tilde{\omega}}\right) > 1 \;\Leftrightarrow\; \bar{K} > \tilde{K} \\ \frac{\partial \omega_i^*}{\partial \mu} = 0, & \left(\frac{\omega_i^*}{\tilde{\omega}}\right) = 1 \;\Leftrightarrow\; \bar{K} = \tilde{K} \\ \frac{\partial \omega_i^*}{\partial \mu} > 0, & \left(\frac{\omega_i^*}{\tilde{\omega}}\right) < 1 \;\Leftrightarrow\; \bar{K} < \tilde{K} \end{cases}$$

Thus, a higher μ dampens the effect of any shock to factor endowments on the equilibrium relative wage.[17] If the shock to the stock of capital is positive, labor becomes more expensive

[17] Any given change in capital intensity leads to a smaller change in the marginal product of labor in the high-μ country because μ is inversely related to the cross-partial derivative of output with respect to K and L.

than at the point of normalization in both countries, but less so in the high-μ country: $\tilde{\omega} < \omega_1^* < \omega_2^*$. If the shock to the stock of capital is negative, labor becomes less expensive than at the point of normalization in both countries, but less so in the high-μ country: $\tilde{\omega} > \omega_1^* > \omega_2^*$.

Combining this result with our previous finding that $d(P_i^m/w_i)/d\omega_i < 0$, the relative price of the routine input is increasing (decreasing) in μ whenever the stock of capital increases (decreases) relatively to the point of normalization:

$$\begin{cases} \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial \omega_i^*}{\partial \mu} < 0, & \bar{K} < \tilde{K} \quad \Leftrightarrow \frac{d(L^a/M)}{d\mu} < 0 \\ \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial \omega_i^*}{\partial \mu} = 0, & \bar{K} = \tilde{K} \quad \Leftrightarrow \frac{d(L^a/M)}{d\mu} = 0 \\ \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial \omega_i^*}{\partial \mu} > 0, & \bar{K} > \tilde{K} \quad \Leftrightarrow \frac{d(L^a/M)}{d\mu} > 0 \end{cases}$$

The intuition behind this result is as follows. When labor is relatively expensive (scarce), the routine input is relatively expensive in the high-μ country because labor in this country is cheap relatively to labor in the low-μ country. The direct effect of the lower wage on the P_i^m/w_i ratio exceeds the indirect effect through which lower labor cost contributes to reduce the price of the routine input. Similarly, when capital is relatively expensive (scarce), the routine input is relatively cheap in the high-μ country because capital in this country is cheap relatively to capital in the low-μ country. The direct effect of the relatively high wage on the P_i^m/w_i ratio exceeds its indirect effect through which higher labor cost contributes to increase the price of the routine input.

Recall from (9) that it is sufficient to establish in which country the relative price of the routine input is relatively high in autarky to determine relative 'produced' factor abundance. It follows that under capital deepening, the high-μ country is relatively nonroutine labor abundant: $(L_1^a/M_1)^* > (L_2^a/M_2)^*$. Conversely, under labor deepening, the high-μ country is relatively routine abundant: $(L_1^a/M_1)^* < (L_2^a/M_2)^*$. Comparative statics highlight that higher K-L substitutability helps the economy to use its relatively scarce 'primitive' factor relatively more efficiently where 'primitive' factor scarcity is defined in terms of deviation from the point of normalization.

2.3 The magnitude of σ and the pattern of trade

2.3.1 The pattern of specialization

We are now in a position to establish the main result. In our model, the quantities of the 'primitive' factors are common to the two countries, and it is the optimal allocation of labor to routine and nonroutine tasks which pins down the equilibrium quantities of the 'produced' factors, i.e. the relative abundance of the abstract labor and of the routine input. Further, in our model, these equilibrium quantities are determined by the equilibrium wage-rental rate ratio, i.e. the relative wage that clears labor and capital markets while also clearing the final goods' market and verifying the FOCs in intermediate and final good production. Finally, as we show above, we need to fix initial endowments in order to pin down the effect of σ on the relative wage.

As we seek to nail down the static effect of σ on factor allocation to tasks, we limit ourselves to a thought experiment in which capital is "dropped" on the two countries in the same proportion. Endogenizing capital accumulation is left for future work.[18] Instead, we focus on showing how differences in K-L substitutability for countries with similar endowments may create an incentive to trade. By solving the model we establish that in the case of capital deepening, at any point in time, the equilibrium ratio $(L_t^a/M_t)^*$ is increasing in σ. As capital is accumulated, the high-σ country becomes relatively nonroutine labor abundant.

We can apply the standard reasoning of the HO model to determine the direction of trade. The high-μ country becomes nonroutine labor abundant under capital deepening whereby it has a comparative advantage in the nonroutine intensive good. Conversely, the high-μ country becomes routine abundant under labor deepening whereby it has a comparative disadvantage in the nonroutine intensive good. The dampening effect of higher K-L substitutability in absorbing any given shock to 'primitive' factor endowments leads the high-μ country to specialize in the nonroutine intensive final good when labor becomes relatively scarce and to specialize in the routine intensive final good when labor becomes relatively abundant.

We obtain an adjusted HO prediction: when factors are produced rather than exogenously given, the high-σ country specializes in the good which uses more intensively the 'produced' factor which requires relatively more of the relatively scarce 'primitive' factor, with the scarcity of the primitive factor defined in terms of deviation from the point of normalization and the intensity of use of the 'produced' factor defined in the canonical HO way.

2.3.2 The implications of opening up to trade

Opening up to trade amplifies differences in labor allocation to routine and non-routine tasks that were observed in autarky. The intuition is the following. Differences in capital-

[18] We find that the return to capital is relatively high in the high-σ country under capital deepening, so it may have a higher incentive to accumulate capital. This process would lead to a further release of labor from routine tasks, further increasing the relative abundance of the nonroutine labor in the high-σ country but also reducing the wedge in the relative factor price in autarky.

labor substitutability in the two countries lead to a wedge in the MPL/MPK ratio in the autarky equilibrium which leads to a wedge in the relative autarky price of the two final goods. When the relative wage increases, the cost of labor allocated to non-routine tasks increases by more than the cost of the routine input because the latter uses both capital and labor. Consequently, the final good that requires more labor in non-routine tasks is relatively cheap in the country with the relatively low MPL/MPK ratio.

Trade equalizes the relative price of the two final goods by increasing the relative price of the good that was relatively cheap in autarky. The MPL/MPK ratio decreases in the country where it was relatively high, and it increases in the country where it was relatively low. The capital endowment is fixed by assumption. It follows that the only way to reduce (increase) the MPL/MPK ratio is to move labor into (out of) routine input production. Thus, the country that had a relatively high MPL/MPK ratio and, consequently, a relatively low price of the routine-intensive good, allocates more labor to routine input production. At the same time, the country that had a relatively low MPL/MPK ratio allocates more labor to non-routine tasks.

Two additional results associated to the pattern of trade are discussed in the appendix. Firstly, we show in Appendix A.5 that as in the canonical HO model, opening up to trade leads to factor price equalization for the prices of the 'produced' factors (P^m/w) (through equalization of the prices of the two final goods). However, in general, it does not lead to 'primitive' factor price equalization.

Secondly, we show that the equalization of final good prices is obtained through further divergence in the capital intensity of routine production in the two countries. Specifically, under capital deepening, the only way in which the P^m/w ratio can increase in the high-μ country is by increasing the relative wage ω. The latter can only occur if we move labor out of routine production in the high-μ country. Symmetrically, under labor deepening, the relative wage ω must increase in the low-μ country. The latter can only occur if we move labor out of routine production in the low-μ country.

Hence, the country with a comparative advantage in the nonroutine intensive good is characterized by relatively high capital intensity in routine production in autarky, and this gap in the capital intensity of routine production further increases when the countries open up to trade.

3 Data

We perform three distinct empirical analyses which are each based on a different dataset.

First, we estimate production functions at the country-sector level to provide support for the assumptions regarding the parameter heterogeneity of the model. We use the 2009 release of the EU KLEMS database that is described in O'Mahony and Timmer (2009). It contains information on output, capital and labor use for 25 countries, 30 sectors, and 25 years. We rely on observed schooling levels to distinguish between abstract and routine labor input: routine labor is equated with employment of workers with a low schooling level and abstract labor with the two higher schooling levels, middle and high.[19] Real output and an index of capital services are reported directly in the database.

Second, we estimate for each country the extent that its export bundle is specialized towards routine-intensive products. Bilateral exports are reported in the UN Comtrade database and we use the latest BACI harmonized version; Gaulier and Zignago (2010) describe an earlier release. Our sample covers three years—1995, 2005, and 2015—but we average exports over two adjacent years to smooth out annual fluctuations.[20] Products are observed at the 6-digit detail of the Harmonized System (HS) and mapped into 4-digit NAICS sectors using a concordance available on the UN Comtrade web site.

We construct two separate samples, based on two different groups of exporters. In the 'full sample' we retain bilateral exports that originate from the 43 largest exporters in the world, while in the 'EU sample' we only keep the 27 current EU members states (combining Belgium and Luxembourg). On the import-side we keep trade flows towards those 54 destinations separate (16 countries enter in both samples) and we aggregate the remaining countries, which together account for less than 10% of total trade, into 10 regional blocs. In the EU sample, we only keep exports to the other EU member states.

The key explanatory variable in the second analysis is the routine task intensity by sector, as represented by the parameter β_g in the model. We use the ranking of routine intensity constructed by Autor et al. (2003) for 77 U.S. industries also at the 4-digit NAICS level. It is a weighted average of the routine task intensity by occupation using the employment shares of occupations in each industry in 1977 as weights. By using employment shares that pre-date the recent process of automation, the ranking is expected to capture sectors' technological features that determine routine intensity.[21]

[19] There is a strong negative correlation between the skill intensity and the routine intensity of occupations, especially within manufacturing sectors.

[20] For 1995 and 2005 we use the average export flows for 1995-1996 and 2005-2006, but given that 2015 is the last year included in the dataset we average with the preceding year: 2014-2015.

[21] Autor et al. (2003) show that routine intensive industries, measured this way, replaced labor with machines and increased demand for nonroutine labor at above-average rates.

Third, we investigate which country-level characteristics or endowments have predictive power for the specialization in routine-intensive sectors. According to the model, these would be factors that determine the ease of substituting between capital and labor in production. As a general measure of a country's institutional quality, we consider the widely used 'rule-of-law' index published as part of the World Bank Governance Indicators database.[22] Following the labor literature, we consider the role of formal labor market institutions, as measured by the stringency of employment protection legislation (EPL). This index is constructed by the OECD and discussed in Nicoletti et al. (2000). We also use a broad index of labor quality, the 'ability to perform' measure also used in Costinot (2009) and developed by a private firm, *Business Environment Risk Intelligence*. It is a synthetic index of worker attributes that combines behavioral norms in the workforce, such as work ethic, with the quality of human capital, and physical characteristics such as healthiness.

Two additional characteristics are intended to capture the substitution elasticity more directly. 'Internal mobility', measured as the fraction of the population residing in a different region than their place of birth, is a coarse measure of workforce mobility, a type of flexibility in another dimension.[23] If workers tend to substitute easily between geographic locations, they might show similar flexibility substituting between sectors or occupations. Finally, we construct a measure for cultural traits that would pre-dispose workers to move between sectors if opportunities present themselves. From the six dimensions of national culture introduced by **?**, we take the average of the two most suitable in our context: long-term orientation and the inverse of uncertainty avoidance.

Where possible, we use the values of these five country characteristics for the same year as the trade flows. Most variables, e.g. the rule-of-law index, change only slightly over time and the cultural traits do not have any time variation. This stability is not unexpected and is consistent with our interpretation of these measures as exogenously given, relatively immutable country characteristics that help determine sectoral specialization.

4 Results

Our empirical strategy follows the two-step approach of Costinot (2009). In the first step, we estimate for each country the extent of revealed comparative advantage in sectors that are

22 Available online at http://info.worldbank.org/governance/wgi/index.

23 This information is taken from OECD's 'Labor Market Statistics' database.

intensive in routine tasks. In the second step, we regress the obtained ranking on country characteristics that are likely to be correlated with the ease of labor reallocation across tasks. Before we turn to these two steps, we first show some stylized facts to illustrate the reasonableness of the maintained assumptions in the production function of our model.

4.1 Stylized facts

The production function technology (3) incorporates heterogeneity along two dimensions. First, it assumes that sectors differ in the relative intensity they use abstract labor and the routine input aggregate, which is captured by the parameter β_g. The assumption that industries can be ranked according to their routine intensity has been adopted widely since the seminal work of Autor et al. (2003) who pioneered measures of the task content of occupations. The sectoral intensity is measured by weighting the routine task intensity of occupations by the composition of the workforce of each sector.

The second dimension of heterogeneity in the production function is cross-country variation in the ease of substitution between (routine) labor and capital in the production of the routine input, which is represented by the parameter μ_i. Existing studies have assumed or estimated different rates of substitution between inputs in the production of the routine input aggregate. For example, Autor et al. (2003) and Acemoglu and Restrepo (2016) assume perfect substitutability ($\mu = 1$, or equivalently $\sigma = \infty$), Autor and Dorn (2013) assume $\mu \in (0,1)$ such that $\sigma > 1$, while Goos et al. (2014) estimate an elasticity between the tasks required to generate industry output that is less than unity.[24] Importantly, each of these studies looks at a single country and assumes a constant value for the elasticity of substitution.

Before we turn to the comparative advantage predictions of our model, we evaluate whether the assumptions of sectoral heterogeneity in β_g and cross-country heterogeneity in σ_i are consistent with the data. We estimate a separate production function for each country-sector combination exploiting only variation over time. Following Klump et al. (2012), we use the explicitly normalized version of the embedded CES function to guarantee that the estimated parameters have an unambiguous structural interpretation.[25] This is also convenient given that the flow of real capital services is measured as a time index. Omitting the country-sector subscripts on the

[24] Goos et al. (2014) impose a capital-labor substitutability equal to one in the production of each task.
[25] We force the β coefficient to lie between 0 and 0.6 and the μ coefficient between $-\infty$ and 1.

variables and parameters, we estimate the following equation,

$$Y_t = A\left[L_t^a\right]^{1-\beta}\left[(1-\pi_0)\left(\frac{L_t^m}{L_0^m}\right)^{\mu}+\pi_0\left(\frac{K_t}{K_0}\right)^{\mu}\right]^{\beta/\mu}, \tag{22}$$

to recover two coefficients, β and μ, for each country-sector pair. There is substantial variation in the estimated parameters. The median elasticity of substitution in routine production is 1.75, but the interquartile range is $(0.3, 20)$. The median routine intensity is 0.81 and the interquartile range is $(0.05, 0.40)$.

We next investigate which dimension, country or sector, has the most explanatory power for the variation in the production function parameters. In the top panel of Table 1, we first show such an analysis using two input factor ratios that can be observed without any estimation.

The share of abstract labor in total employment is directly influenced by the β coefficient that indicates the relative routine intensity of the sector. The μ parameter plays only an indirect role. Regressing this variable on a full set of country and sector-fixed effects shows that the sector dummies have the most explanatory power. They capture 54.2% of the total sum of squares against only 28.5% for the country dummies. Note that we would not expect the country dimension to have no explanatory power. Even if the β coefficients are identical across countries, sectoral specialization (for example driven by the mechanism in our model) would still generate variation in the employment ratio across countries. Moreover, the three skill levels are defined somewhat differently by country, which is apparent from the large variation across countries in the average share of the skilled workforce over all sectors.

In contrast, the capital to routine labor ratio does not depend on the β coefficient. This ratio has increased over time almost everywhere, but for a given change in the factor price ratio (which is controlled for by year-fixed effects), its variation is a function of the elasticity of substitution which is determined by the μ parameter. The results indicate that the country dummies explain a lot more of the variation than sector-fixed effects.

[Include Table 1 approximately here]

In panel (b) of Table 1, we confirm these results with a similar exercise directly explaining variation in the estimated production function coefficients. The β coefficient is mostly explained by the sector dummies, while the μ coefficient varies mostly across countries. In the latter case, the fraction of the sum of squares that is explained by either set of fixed effects is relatively similar, but there are many fewer countries than sectors and the F-statistic shown on the right (which takes the degrees of freedom into account) is almost twice as high for the country dummies. If we follow the approach in the literature and constrain the routine intensity β to be an industry-characteristic common to all countries, the contrast becomes even larger. In that case the country-fixed effects explain four times as much of the variation in the μ_{ig} estimates.

4.2 Revealed comparative advantage of countries in terms of routine intensity

The first step in evaluating the predictions of our model is to recover the nature of specialization of different countries. The results will reveal that routine intensity is a strong predictor of the observed pattern of trade. We estimate the following equation

$$\ln X_{gij} \quad = \quad \tau_{ij} + \tau_{gj} + \gamma_i r_g + \varepsilon_{gij}. \tag{23}$$

The dependent variable measures bilateral exports from exporter i to importer j in sector g. The comparative advantage in the routine dimension is captured by the country-specific coefficient γ_i that interacts the sectoral intensity in routine tasks r_g that is country-invariant. A high (positive) value for γ_i would indicate that the composition of the export bundle of country i is correlated positively with the the routine-intensity of those sectors.

Equation (23) includes a pair of interaction fixed effects to control for alternative explanations of trade volumes. The bilateral exporter-importer fixed effects τ_{ij} absorb gravity effects, including both country characteristics, e.g. size or multilateral resistance, as well as any form of bilateral proximity or country-ties. The destination-sector fixed effects τ_{gj} capture variation in import barriers, preferences, or business cycles in importing countries. We do not exploit the time dimension, but estimate equation (23) separately for the three years we consider. This allows both sets of fixed effects and the γ_i coefficients to vary entirely flexibly over time.

Figure 1 shows the point estimates for all 43 countries included in the full sample for the 2005 trade flows. The included fixed effects implicitly normalize the γ_i estimates to average zero over the entire sample.[26] Given that the sample is almost balanced over exporters, by construction half of the countries show a positive point estimate. The results only have a relative interpretation: a country with a higher estimate is relatively more specialized in routine-intensive sectors.

[26] Because of the two sets of fixed effects we include, which include both the i and g dimension, one of the country-specific γ_i coefficients cannot be estimated and is implicitly normalized to zero. The point estimates shown in Figure 1 are explicitly normalized to have a sample average of zero.

[Include Figure 1 approximately here]

The countries in the top panel of Figure 1 tend to specialize more in non-routine-intensive products. This pattern is most pronounced for Finland, Sweden, and Ireland and also the next group of countries is intuitive: Singapore, Japan, Germany, Switzerland and the United States. At the other end of the spectrum, shown at the right-side of the bottom panel, we find countries that specialize relatively more in routine-intensive products. Here we find more developing or emerging economies, first Peru and Sri Lanka, followed by Argentina and Chile. The next country, New Zealand, is well-known to specialize in primary products, and it is followed by Turkey which is an assembly hub for EU-bound exports.

A remarkably pattern are the large difference in specialization between some countries that share similar levels of development. Finland and Sweden have much lower (more negative) point estimates than Norway or Denmark, and the contrast between Germany or France and Italy or Spain is also very large. The same holds in the other continents: in Latin America, Mexico and Costa Rica are much less specialized towards routine-intensive products than Chile; in Asia, Malaysia much less than Thailand.

[Include Figure 2 approximately here]

In Figure 2 we plot the results obtained using the 1995 trade data against the results for 2015. For almost all countries, the 2005 estimates were intermediate to those extremes. Over the 20 year period spanned by these estimates, countries' specialization in the routine-intensity dimension is very stable. Deviations from the 45-degree line are minimal. The export bundles of Finland, Germany, Italy and Argentina became slightly more routine intensive and the reverse evolution is apparent for many Asian countries: especially for Taiwan, Korea, Hong Kong and Thailand. The preponderance of countries between the 45-degree line and the X-axis suggests that there is some mild convergence. Countries specializing in non-routine-intensive products in 1995, on the left side of the graph, lost some of this specialization, with Singapore a lone exception. Countries initially specializing in routine-intensive products, on the right, also show a somewhat less extreme specialization in 2015, with Costa Rica the clearest example of this trend towards diminished specialization and Argentina showing a reverse evolution.

[Include Figure 3 approximately here]

Finally, in Figure 3 we show comparable estimates for the sample of EU countries and only including intra-EU trade in the dependent variable. The relative ranking of countries is broadly consistent with Figure 1, suggesting that the overall export bundle of most countries is highly correlated with their intra-EU export bundle. This is almost by construction as the intra-EU share of exports tends to be very high for most member states. One difference is that based solely on within-EU trade the United Kingdom specializes more than Germany in non-routine-intensive products, while the reverse is true if extra-EU trade is included. The reverse is true for the Czech Republic: it shows greater specialization on non-routine-intensive products in its intra-EU trade than for total trade.

Comparing the estimates for the three years in Figure 3 reveals that the convergence between countries is broad-based within the EU. The point estimates for 1995 (in yellow) show much larger differences than for 2015 (in red). Most countries see their γ_i coefficient shrink towards zero. Exceptions are Slovakia, Malta, and Slovenia which become less specialized in routine-intensive products and Belgium, Denmark, Croatia, and Spain which become more specialized.

While there is a clear negative correlation between GDP per capita and specialization, it is by no means perfect. In particular, Italy sees a much stronger and Slovakia a much weaker specialization in routine-intensive products than would be predicted by their level of development. We next try to see which observable differences between countries help explain these differences in specialization.

4.3 Country characteristics that explain specialization

The next step in our analysis is to connect the estimated routine intensity of exports to country characteristics. The objective is to uncover whether observables that are plausible proxies for the ease with which countries reallocate labor across tasks, i.e. the σ parameter in our model, have the predicted correlation with export specialization. We collected information on five institutional or cultural differences between countries that we expect to be related to the magnitude of adjustment costs incurred by firms and workers in such reallocation process.

We regress $\hat{\gamma}_i$, the countries' ranking by routine intensity reported in Figures 1 to 3, on each of the institutional dimensions I_i:

$$\hat{\gamma}_i \quad = \quad \delta_0 + \delta_1 I_i + \delta_2 \,\text{GDP/capita}_i + \varepsilon_i. \tag{24}$$

We include GDP per capita to control for the level of development. The coefficient of interest is δ_1, which we expect to be negative for most dimensions as we defined the explanatory variables to have a predicted positive correlation with σ. Only for the stringency of employment protection legislation do we expect a negative sign as this increases adjustment costs for labor reallocations.

The results in Table 2 use the estimates for 2005 on the full sample. Not surprisingly, GDP per capita is always negatively related to the extent of specializing in products that are routine intensive. As countries develop, they specialize away from routine-intensive tasks. We report standardized β coefficients to make the absolute magnitudes of the point estimates of different variables comparable. The first coefficient in column (1) implies that a one standard deviation increase in the log of GDP per capita is associated with a reduction in the dependent variable of -0.619. This is approximately one seventh of a standard deviation of the dependent variable and corresponds, for example, to the difference between Germany and the United States in Fig. 1.

Less expected is the insignificant coefficient on the rule-of-law variable. However, this is due to the extremely high correlation with GDP per capita, showing a partial correlation coefficient of 0.84 on our sample of 43 countries. If we omit the control variable, the coefficient on rule-of-law becomes -0.512 and significant at the 1% level. The same pattern is true for the estimates obtained on the EU sample. With GDP per capita included, the rule-of-law coefficient is -0.384 and not statistically different from zero, while omitting the control variable it becomes -0.670 with a t-statistic of 4.5. These results underscore that interpreting the effects of rule-of-law certainly warrant some caution.

The results in columns (2) and (3) show that two other variables do have explanatory power even when we control for the level of development. Countries that have a high workforce quality tend to specialize in sectors that are not intensive in routine tasks. This variable captures a variety of workforce features such as worker behavior, e.g. punctuality, workplace norms, e.g. taking responsibility, human capital, and good health. On its own it explains fully 44% of total variation in the dependent variable. The second significant variable, the Hofstede/national culture index, has a smaller effect in absolute value, but is estimated more precisely. Countries where workers are less risk average and have a more long-term orientation tend to specialize to a less extent in routine-intensive tasks.

The other two variables, the extent of internal migration and strictness of employment protection, have effects of the predicted sign, but are not statistically significant. The number of observations for which we observe these variables is also much smaller, but the lack of significance is less a result of higher standard errors than of smaller coefficient estimates (in absolute value).

In Table 3 we report results using the nature of export specialization estimated on the EU sample as dependent variable. If only GDP per capita is included, the coefficient is -0.66 and estimated highly significantly. However, adding a second country characteristic in the regression renders the effect statistically insignificant in almost all cases.

The only other dimension that has predictive power when the control variable for the level of development is included is the strictness of employment protection. The coefficients on the rule-of-law and Hofstede/culture are similar as in Table 2, but on the smaller sample these effects become insignificant. In contrast, the labor market institutions are highly predictive. Countries that enacted laws and regulations to make firing workers more costly and to restrict temporary employment are strongly specialized in routine-intensive tasks. It is noteworthy that this effect only shows up in Table 3 where we compare across EU countries that are relatively similar in several other dimensions. Note that these results should not be interpreted causally. While EPL might have caused or contributed to the trade specialization, as in our model, it is equally possible that labor regulations were enacted in response to sectoral specialization.

We conducted two robustness checks that generated highly consistent results.[27] Because the dependent variable has no clear cardinal interpretation, we also ran the regressions using the following transformation: $\ln(\hat{\gamma}_i - \hat{\gamma}_{min})$. The interpretation of the coefficients is then in terms of percentage change in γ, which has been shifted up to be positive before taking logarithms. The estimated β coefficients always have the same signs as in Tables 2 and 3 and are remarkably similar in magnitude. A much more flexible approach is to treat the dependent variable as an ordinal variable and estimated an ordered probit or ordered logit model. The point estimates are not comparable anymore, but the signs always remained the same and many of the t-statistics even increased.

[Here?] We have shown that EU countries with more flexible labor markets and countries in the full sample with high workforce ability or suitable culture have a revealed comparative advantage in sectors that use nonroutine labor more intensively. These findings motivate the microfoundations for country-level differences in the elasticity of substitution between capital and labor that we develop in the final section of the paper.

[27] All results available upon request.

5 Microfoundation of variation in K-L substitutability

We provide the theoretical underpinning of our results by connecting institutional characteristics that predict countries' specialization according to the sectoral ranking of routine intensity to differences in K-L substitutability. Indeed, the elasticity of substitution between capital and labor is generally thought to be a technology parameter. By allowing countries to differ in production technologies we 'cook up' an incentive to trade without proving that the specialization pattern can be reconducted to the institutional characteristics that we investigate in our regressions or interpreted as picking up the magnitude of barriers to labor mobility.

In this section we demonstrate that two countries with the same underlying technology but different institutional set-ups look 'as if' they had different technologies, i.e. we show that a reduced form approach to modelling barriers in labor reallocation across tasks is to allow for differences in capital-labor substitutability. In so doing, we address the legitimate concern that the connection we uncover between countries' specialization according to the sectoral ranking of routine intensity and specific institutional characteristics may have no linkage to the underlying elasticity of substitution between capital and labor.

We start by reporting the main findings of the recent literature on the linkages between the institutional characteristics of the labor market and the adjustment of the economy to structural change. We then summarize our approach to microfounding differences in K-L substitutability across countries.

5.1 Labor market institutions and adjustment to structural change

An important stream of the recent labor literature documents that adjustment costs associated to the reallocation of workers across occupations are non-negligible for the median worker and strongly heterogeneous across workers. Dix-Carneiro (2014) finds that the median cost of switching jobs for Brazilian workers amounts to 1.4-2.7 times the average annual wage.[28] Dix-Carneiro (2014) shows that cost variability across workers is attributable to skills, age, initial specialization, and experience accumulated in the job. For the U.S. market, Autor et al. (2014) find that adjustment costs may be prohibitively high for the less skilled and the less young and lead to their permanent exit from the labor force.[29]

[28] The seminal paper by Artuç et al. (2010) reports higher median costs but has a coarser approach to capturing differences in worker characteristics.

[29] Pierce and Schott (2016) report that 1/3 of workers who lost employment in U.S. manufacturing as a consequence of import competition from China transition to inactivity while 1/3 switches to services.

A key insight of this literature is that the cost of switching occupations is not fully determined by the cost of looking for a job or of moving to a new location. Rather, the bulk of the adjustment cost is attributable to the loss of firm- or occupation-specific human capital. Working with (respectively) Brazilian and U.S. data, Dix-Carneiro (2014) and Autor et al. (2014) explain the positive relationship between the magnitude of the adjustment cost and the distance from the initial to the final occupations by the loss of non-transferable human capital. For the Danish market, Ashournia (2015) documents that the loss of industry-specific human capital constitutes a substantial fraction of reallocation costs.

Although we acknowledge the importance of adjustment cost variability across workers, our focus is on institutional characteristics that determine the country-specific component of adjustment costs common to all workers. Specifically, we seek to quantify the contribution of institutional determinants of reallocation costs to the pattern of trade. We put forward two candidate institutional characteristics which may result in different average levels of transferable skills in the labor force and, subsequently, different per worker magnitudes of retraining costs: the quality of the educational system and the flexibility of labor market institutions (LMIs).

It is immediate that a less efficient educational system may result in a lower level of general human capital. As shown by Wasmer (2006), stringent labor market regulations may also result in a lower level of general human capital. Stringent LMIs are captured through high firing costs in Wasmer (2006). Their direct effect is to increase the cost of labor adjustment on the firm side and to reduce the separation rate in the economy. The increase in the expected duration of employment gives an incentive to workers to accumulate specific human capital endogenously increasing the cost of switching occupations on the worker side. This indirect effect leads to relatively high retraining costs and low job turnover.

Several papers put forward that stringent LMIs reduce the speed of adjustment of the economy to structural change. Wasmer (2006) demonstrates that economies with rigid LMIs perform relatively better in the steady state because workers are more productive in their jobs but have prolonged and costly transition periods. Kambourov (2009) shows that high firing costs slow down the process of worker reallocation to comparative advantage activities in an economy that opens up to trade and result in a sizeable reduction of the gains from trade.[30] Artuç et al. (2015) estimate the magnitude of switching costs for workers in a set of countries and document that countries with relatively high switching costs adjust more slowly to trade shocks.

[30] Coşar (2013) finds that active (passive) labor market policies speed up (slow down) labor reallocation.

Several other papers argue that LMIs co-determine the pattern of specialization. Tang (2012) derives the comparative advantage implications of reinforced worker incentives to accumulate firm-specific human capital.[31] Tang (2012)'s model predicts that stringent LMIs confer a comparative advantage in sectors that require intensive use of specific human capital. Tang (2012) measures the sectoral intensity of specific human capital use by estimating the sectoral return to tenure. Connecting the pattern of trade to the obtained sectoral ranking, Tang (2012) finds that countries with rigid LMIs export more in sectors with higher returns to tenure.

Even closer to our research focus are the papers by Cuñat and Melitz (2012) and Bartelsman et al. (2016) who look at the impact of stringent LMIs from the perspective of the firm. Cuñat and Melitz (2012) show that higher costs of labor adjustment confer a relative cost disadvantage in volatile sectors, with volatility defined in terms of the variance of firm-specific productivity shocks.[32] Bartelsman et al. (2016) connect the stringency of LMIs to reduced incentives to invest in risky technology by showing that EPL is akin to a distortive tax on risky investment.[33] The authors show that industries characterized by a greater degree of dispersion in labor productivity are also characterized by more intensive ICT usage and argue that the recent process of technological change through innovations in ICT corresponded to such high-risk high-return technology. Consistently with the predictions of the model, Bartelsman et al. (2016) document that countries with more stringent labor market regulations adopted ICT less intensively in the mid-1990s and specialized in less ICT-intensive industries.

5.2 σ is reconductible to the magnitude of labor adjustment costs

Overall, the literature summarized in the previous subsection suggests there is a linkage between labor market institutions, the set of skills that workers choose to acquire, the type of investment that firms choose to implement, and the equilibrium allocation of resources to different sectors of the economy. Our contribution to this line of work consists in explicitly connecting the level of labor adjustment costs to the magnitude of the parameter that captures capital-labor substitutability in the canonical CES production function.

Consider the definition of capital-labor substitutability: σ captures the percentage increase in the capital-labor ratio that follows a one percent increase in the relative cost of labor. We put forward that there may be a country-specific wedge between the underlying technological

[31] Acharya et al. (2013) argues that higher EPL induces workers to engage in higher risk innovative projects.
[32] Cuñat and Melitz (2012) proxy sectoral volatility with the standard deviation of firm-specific growth rates.
[33] EPL increases the cost of downsizing (exit) and reduces the expected return to investment in risky technology.

parameter common to all countries that captures how firms would adjust the capital-labor ratio in the absence of labor adjustment costs and the measured capital-labor substitutability that captures how firms effectively adjust the capital-labor ratio. A given shock to the relative price of labor translates into a smaller change of the capital-labor ratio when there is a cost for the firm of adjusting the labor input. Countries characterized by relatively high labor adjustment costs have a relatively low sensitivity to changes in the relative cost of labor.

The line of argument is as follows. We start from the production function in the seminal paper of Autor et al. (2003). Capital and routine labor are perfect substitutes while capital and abstract labor are imperfect substitutes. The justification for perfect substitutability in the routine tasks is that once the machine exists, both labor and the machine have the capability to accomplish the routine task (example: count coins), but their efficiency in the task may differ.

We consider some initial allocation of labor to routine and non-routine tasks for some initial state of technology. We then compute the change in the labor input in the routine task that takes place following a positive shock to the efficiency of capital while keeping wages fixed.

The full effect of the technological shock would be to get rid of all labor in the routine task if labor productivity were the same for all units employed in the routine task and there were no adjustment costs incurred by the firm in laying off workers. In reality, the effect of this technological shock on the capital-labor ratio in routine production will be reduced because of labor adjustment costs incurred by the firm such as severance payments. The labor input is reduced by less because each unit of labor replaced with capital is associated to a severance payment, and these payments are likely to be a convex function of the number of laid-off workers. Severance payments increase the effective cost of the more efficient capital and reduce the sensitivity of the capital-labor ratio to changes in the relative factor price.

Measured capital-labor substitutability is decreasing in the degree of convexity of the severance payment function. An intuitive way of justifying the convexity of the severance payment function is to consider that workers are heterogeneous in the retraining costs required to reallocate them from the routine to the noroutine tasks. As more workers are laid off, the retraining cost per worker is increasing at an increasing speed. Thus, technological upgrading shifts labor out of a subset of routine tasks but labor eviction from such tasks is gradual because routine workers differ in the amount of training they require to perform the nonroutine task, and the institutional set-up that defines which agents bear this retraining cost determines the magnitude of labor market frictions that slow down the process of labor reallocation.

The final building block is to spell out how countries differ. One simple way of generating differences in the convexity of the retraining cost function is to consider intrinsic differences in the quality of schooling. Countries with higher level and lower variance of initially acquired human capital will have lower level and variance of re-training needs. Another way of generating differences in labor adjustment costs across countries is to consider that certain countries provide more generous financial support to employers who bear the re-training costs. In the latter case, even if the underlying convexity of the retraining cost function is common to the two countries, the effective convexity is lower in the country in which the government participates in retraining more intensively.

6 Conclusion

In this paper, we pin down a new mechanism behind comparative advantage by pointing out that countries may differ in their ability to adjust to technological change.

We take stock of the pattern extensively documented in the labor literature whereby more efficient machines displace workers from codifiable (routine) tasks. Our hypothesis is that labor reallocation across tasks is subject to frictions and that these frictions are country-specific. We incorporate task routineness into a canonical 2-by-2-by-2 Heckscher-Ohlin model. The key feature of our model is that factor endowments are determined by the equilibrium allocation of labor to routine and non routine tasks. Our model predicts that countries which facilitate labor reallocation across tasks become relatively abundant in non routine labor and specialize in goods that use non routine labor more intensively.

We document that the ranking of countries with respect to the routine intensity of their exports is strongly connected to two institutional aspects: labor market institutions and behavioral norms in the workplace. We proceed to develop microfoundations (in a non-formal way) which help to explain why the parameter that captures capital-labor substitutability and is generally perceived as an exogenous characteristic of the production technology may in fact be determined by the institutional environment.

Specifically, we show that any type of institutional characteristic which increases the cost of adjusting the labor input - such as the rigidity of labor market institutions or the lack of efficiency of the public administration in implementing active labor market policies - may increase the shadow cost of switching to more productive capital. Any given change in the relative cost of labor will result in a smaller change in the relative capital-labor ratio in routine production in a highly frictional environment and result in a lower perceived capital-labor substitutability in routine production.

Our results pin down a new linkage between institutions and the pattern of trade while showing that specific institutional characteristics facilitate the adjustment of the economy to the process of structural change. Our results have strong policy implications because they illustrate that governments have a key role to play in ensuring that the process of labor reallocation from tasks that are substitutable with machines to tasks that are complementary with machines proceeds quickly and smoothly. Indeed, workers are shown to benefit relatively more from the process of technological change and from trade integration in institutional environments that succeed in reducing the costs of labor reallocation across tasks.

References

Acemoglu, D. and D. H. Autor (2011). Skills, tasks and technologies: Implications for employment and earnings. In O. Ashenfelter and D. E. Card (Eds.), *Handbook of Labor Economics*. Amsterdam: Elsevier B.V.

Acemoglu, D. and P. Restrepo (2016). The race between machine and man: Implications of technology for growth, factor shares and employment. NBER Working Paper No. 22252.

Acharya, V., R. Baghai, and K. Subramanian (2013). Labor laws and innovation. *Journal of Law and Economics 56*, 997–1037.

Arrow, K. J., H. B. Chenery, B. S. Minhas, and R. M. Solow (1961). Capital-labor substitution and economic efficiency. *Review of Economics and Statistics 43*(3), 225–247.

Artuç, E., S. Chaudhuri, and J. McLaren (2010). Trade shocks and labor adjustment: A structural empirical approach. *American Economic Review 100*(3), 1008–1045.

Artuç, E., D. Lederman, and G. Porto (2015). A mapping of labor mobility costs in the developing world. *Journal of International Economics 95*, 28–41.

Ashournia, D. (2015). Labour market effects of international trade when mobility is costly. Oxford University Department of Economics Discussion Paper No. 751.

Autor, D. H. and D. Dorn (2013). The growth of low-skill service jobs and the polarization of the US labor market. *American Economic Review 103*(5), 1553–1597.

Autor, D. H., D. Dorn, G. H. Hanson, and J. Song (2014). Trade adjustment: Worker-level evidence. *The Quarterly Journal of Economics 129*(4), 1799–1860.

Autor, D. H., F. Levy, and R. J. Murnane (2003). The skill content of recent technological change: An empirical exploration. *The Quarterly Journal of Economics 118*(4), 1279–1333.

Bartelsman, E., P. Gautier, and J. De Wind (2016). Employment protection, technology choice, and worker allocation. *International Economic Review 57*(3).

Bombardini, M., G. Gallipoli, and G. Pupato (2012). Skill dispersion and trade flows. *American Economic Review 102*(5), 2327–2348.

Chor, D. (2010). Unpacking sources of comparative advantage: A quantitative approach. *Journal of International Economics 82*, 152–167.

Coşar, K. (2013). Adjusting to trade liberalization: Reallocation and labor market policies. *mimeo*.

Costinot, A. (2009). On the origins of comparative advantage. *Journal of International Economics 77*, 255–264.

Cuñat, A. and M. Melitz (2012). Volatility, labor market flexibility, and the pattern of comparative advantage. *Journal of the European Economic Association 10*, 225–254.

Dix-Carneiro, R. (2014). Trade liberalization and labor market dynamics. *Econometrica 82*(3), 825–855.

Gaulier, G. and S. Zignago (2010). BACI: International trade database at the product-level. the 1994-2007 version. CEPII Working Paper No. 2010-23.

Goos, M., A. Manning, and A. Salomons (2014). Explaining job polarization: Routine-biased technological change and offshoring. *American Economic Review 104*(8), 2509–2526.

Harrigan, J., A. Reshef, and F. Toubal (2016). The March of the Techies: Technology, Trade, and Job Polarization in France. NBER Working Paper series No. 22110.

Kambourov, G. (2009). Labor market regulations and the sectoral reallocation of workers: the case of trade reforms. *Review of Economic Studies 76*(4), 1321–1358.

Klump, R. and O. De La Grandville (2000). Economic growth and the elasticity of substitution: Two theorems and some suggestions. *The American Economic Review 90*(1), 282–291.

Klump, R., P. McAdam, and A. Willman (2012). The normalized CES production function: Theory and empirics. *Journal of Economic Surveys 26*(5), 769–799.

Nicoletti, G., S. Scarpetta, and O. Boylaud (2000). Summary indicators of product market regulation with an extension to employment protection legislation. OECD Economics Department Working Papers No. 226.

Nunn, N. and D. Trefler (2014). Domestic institutions as a source of comparative advantage. In G. Gopinath, E. Helpman, and K. Rogoff (Eds.), *Handbook of International Economics*, Volume 4. North Holland.

O'Mahony, M. and M. P. Timmer (2009). Output, input and productivity measures at the industry level: The EU KLEMS database. *Economic Journal 119*(538), F374–F403.

Pierce, J. R. and P. Schott (2016). The surprisingly swift decline of US manufacturing employment. *American Economic Review 106*(7), 1632–1662.

Tang, H. (2012). Labor market institutions, firm-specific skills, and trade patterns. *Journal of International Economics 87*, 337–351.

Wasmer, E. (2006). General versus specific skills in labor markets with search frictions and firing costs. *The Quarterly Journal of Economics 96*(3), 811–831.

Appendices

A Solving the model: step-by-step

We have three types of price-taking firms: the first type produces the routine intermediate input, the other two types produce the two final goods.

A.1 Routine production

A.1.1 The problem of the firm in routine production

The production function of the atomistic firm in routine production is:

$$M_{if} \;\; = \;\; A_i \left[\alpha_i (K_{if})^{\mu_i} + (1-\alpha_i)(L_{if}^m)^{\mu_i}\right]^{1/\mu_i} \tag{25}$$

Denote w_i the wage and r_i the cost of capital. The cost minimization problem of the firm is:

$$\begin{cases} \text{Min } \; w_i L_{if}^m + r_i K_{if} \\ s.t. \;\; M_{if} \leq A_i \left[\alpha_i (K_{if})^{\mu_i} + (1-\alpha_i)(L_{if}^m)^{\mu_i}\right]^{1/\mu_i} \end{cases}$$

The first order conditions define relative factor demand as a function of the factor price ratio:

$$\frac{L_{if}^m}{K_{if}} \;\; = \;\; \left[\frac{w_i}{r_i}\frac{\alpha_i}{1-\alpha_i}\right]^{-\frac{1}{1-\mu_i}} \tag{26}$$

We rearrange this expression to solve for each of the factors and plug it into the production function to obtain conditional factor demands:

$$K_{if} = \frac{M_{if}}{A_i}\left[\alpha_i + (1-\alpha_i)\left(\frac{w_i}{r_i}\frac{\alpha_i}{(1-\alpha_i)}\right)^{\frac{\mu_i}{\mu_i-1}}\right]^{-\frac{1}{\mu_i}} = \frac{M_{if}}{A_i}\left[\alpha_i\right]^{-\frac{1}{\mu_i}}\left[1+\left(\frac{w_i}{r_i}\right)^{\frac{\mu_i}{\mu_i-1}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}$$

$$L_{if}^m = \frac{M_{if}}{A_i}\left[(1-\alpha_i) + \alpha_i\left(\frac{w_i}{r_i}\frac{\alpha_i}{(1-\alpha_i)}\right)^{\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}} = \frac{M_{if}}{A_i}\left[1-\alpha_i\right]^{-\frac{1}{\mu_i}}\left[1+\left(\frac{w_i}{r_i}\right)^{\frac{\mu_i}{1-\mu_i}}\left(\frac{\alpha_i}{1-\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}$$

We rearrange each of the expressions in square brackets. In the capital equation we factor out $\alpha_i^{-\frac{1}{1-\mu_i}} r_i^{\frac{\mu_i}{1-\mu_i}}$. In the routine labor equation we factor out $(1-\alpha_i)^{-\frac{1}{1-\mu_i}} w_i^{\frac{\mu_i}{1-\mu_i}}$.

For capital, we get:

$$\begin{aligned} K_{if}\left(M_{if}; w_i, r_i\right) &= \frac{M_{if}}{A_i}\left[\alpha_i\right]^{-\frac{1}{\mu_i}}\left[\alpha_i^{-\frac{1}{1-\mu_i}} r_i^{\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}\left[\alpha_i^{\frac{1}{1-\mu_i}} r_i^{-\frac{\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{\frac{-\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}} \\ &= \frac{M_{if}}{A_i}\left[\frac{\alpha_i}{r_i}\right]^{\frac{1}{1-\mu_i}}\left[\alpha_i^{\frac{1}{1-\mu_i}} r_i^{-\frac{\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{\frac{-\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}} \end{aligned} \tag{27}$$

For routine labor, we get:

$$L_{if}^{m}\left(M_{if};w_i,r_i\right)=\frac{M_{if}}{A_i}\left[1-\alpha_i\right]^{-\frac{1}{\mu_i}}\left[(1-\alpha_i)^{-\frac{1}{1-\mu_i}}w_i^{\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}\left[\alpha_i^{\frac{1}{1-\mu_i}}r_i^{-\frac{\mu_i}{1-\mu_i}}+(1-\alpha_i)^{\frac{1}{1-\mu_i}}w_i^{\frac{-\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}$$

$$=\frac{M_{if}}{A_i}\left[\frac{1-\alpha_i}{w_i}\right]^{\frac{1}{1-\mu_i}}\left[\alpha_i^{\frac{1}{1-\mu_i}}r_i^{-\frac{\mu_i}{1-\mu_i}}+(1-\alpha_i)^{\frac{1}{1-\mu_i}}w_i^{\frac{-\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}} \tag{28}$$

We obtain the cost function by plugging the conditional factor demands in the objective function. Dividing through by the quantity of the routine intermediate M_{if} delivers the unit cost function which is also the price of the intermediate input P_i^m:

$$C(w_i,r_i;1)=\frac{1}{A_i}\left[\alpha_i^{\frac{1}{1-\mu_i}}r_i^{-\frac{\mu_i}{1-\mu_i}}+(1-\alpha_i)^{\frac{1}{1-\mu_i}}w_i^{-\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}\left[(1-\alpha_i)^{\frac{1}{1-\mu_i}}w_i^{1-\frac{1}{1-\mu_i}}+\alpha_i^{\frac{1}{1-\mu_i}}r_i^{1-\frac{1}{1-\mu_i}}\right]$$

$$C(w_i,r_i;1)=\frac{1}{A_i}\left[\alpha_i^{\frac{1}{1-\mu_i}}r_i^{-\frac{\mu_i}{1-\mu_i}}+(1-\alpha_i)^{\frac{1}{1-\mu_i}}w_i^{-\frac{\mu_i}{1-\mu_i}}\right]^{\frac{\mu_i-1}{\mu_i}}=P_i^m \tag{29}$$

A.2 Final good production

The problem of the firms in final good production is standard Heckscher-Ohlin. Costs are minimized in production of the final good g by choosing M_{ig} and L_{ig}^a subject to the technological constraint $Y_{ig}\le z_g {L_{ig}^a}^{1-\beta_g} {M_{ig}}^{\beta_g}$ taking factor prices P_i^m and w_i as given.

The cost minimization problem of the firm is:

$$\begin{cases}\text{Min } w_i L_{igf}^a+P_i^m M_{igf}\\ s.t.\ Y_{igf}\le z_g\left(L_{igf}^a\right)^{1-\beta_g}\left(M_{igf}\right)^{\beta_g}\end{cases}$$

The FOC defines relative factor demand as a function of the factor price ratio:

$$\frac{L_{igf}^a}{M_{igf}}=\frac{1-\beta_g}{\beta_g}\frac{P_i^m}{w_i} \tag{30}$$

We rearrange this expression to solve for each of the factors and plug the result into the production function to get conditional factor demands:

$$L_{igf}^a=\frac{Y_{igf}}{z_g}\left[\frac{w_i}{P_i^m}\right]^{-\beta_g}\left[\frac{1-\beta_g}{\beta_g}\right]^{\beta_g}$$

$$M_{igf}=\frac{Y_{igf}}{z_g}\left[\frac{w_i}{P_i^m}\right]^{1-\beta_g}\left[\frac{\beta_g}{1-\beta_g}\right]^{1-\beta_g}$$

Plugging the conditional factor demands into the cost of production and dividing through by the quantity produced gives the unit cost function which, given the zero profit condition, is also the price of the final good:

$$C_{ig}(w_i,P_i^m;1)\ =\ \frac{w_i^{1-\beta_g}\,(P_i^m)^{\beta_g}}{z_g{\beta_g}^{\beta_g}(1-\beta_g)^{(1-\beta_g)}}=P_{ig} \tag{31}$$

By replacing the price of the routine intermediate by the unit cost in routine production, we express the price of each final good in terms of the wage and of the rental rate of capital:

$$P_{ig} = \frac{w_i}{z_g \beta_g{}^{\beta_g} (1-\beta_g)^{(1-\beta_g)}} \left[\frac{A_i \alpha_i^{\frac{1}{\mu_i}} w_i}{r_i} \right]^{-\beta_g} \left[1 + \left[\frac{(1-\alpha_i)}{\alpha_i} \right]^{\frac{1}{1-\mu_i}} \left(\frac{w_i}{r_i} \right)^{\frac{-\mu_i}{1-\mu_i}} \right]^{\frac{-\beta_g(1-\mu_i)}{\mu_i}} \tag{32}$$

A.3 The demand side

We take a standard Cobb-Douglas utility function for the two final goods: $U_i = \sum_g \theta_g \ln(Q_{ig})$. The budget constraint is $\sum_g P_{ig} Q_{ig} \leq r_i \bar{K} + w_i \bar{L}$. The solution to the consumer problem gives an expression of total expenditure on one good as a function of relative income shares of each good and expenditure on the other good:

$$P_{i2} Q_{i2} = \frac{\theta_2}{\theta_1} P_{i1} Q_{i1} \tag{33}$$

Using (32), the above expression can be written as a function of the wage and of the price of the routine intermediate:

$$\frac{Q_{i1}}{Q_{i2}} = \left(\frac{w_i}{P_i^m} \right)^{\beta_1 - \beta_2} \frac{\theta_1 z_1 \beta_1^{\beta_1} (1-\beta_1)^{1-\beta_1}}{\theta_2 z_2 \beta_2^{\beta_2} (1-\beta_2)^{1-\beta_2}} \tag{34}$$

A.4 Equilibrium

A.4.1 Equilibrium conditions

To determine the equilibrium, we start with resource constraints for capital and labor. Capital is only used in routine production. It is immediate from (27) that total capital use in the economy is determined by the production of the routine intermediate M_i. Denoting by F the set of firms in routine production, capital market clearing delivers the total quantity of the routine intermediate as well as the total demand for labor in its production.

$$\bar{K} = \sum_F K_{if} = \left\{ \sum_F M_{if} = M_i \right\} A_i^{-1} \alpha_i^{\frac{-1}{\mu_i}} \left\{ 1 + \left[\frac{w_i}{r_i} \right]^{\frac{-\mu_i}{1-\mu_i}} \left[\frac{1-\alpha_i}{\alpha_i} \right]^{\frac{1}{1-\mu_i}} \right\}^{\frac{-1}{\mu_i}} \tag{35}$$

Total routine labor use is:

$$L_i^m = \sum_F L_{if}^m = \left\{ \sum_F M_{if} \right\} A_i^{-1} (1-\alpha_i)^{\frac{-1}{\mu_i}} \left\{ 1 + \left[\frac{w_i}{r_i} \right]^{\frac{\mu_i}{1-\mu_i}} \left[\frac{1-\alpha_i}{\alpha_i} \right]^{\frac{-1}{1-\mu_i}} \right\}^{\frac{-1}{\mu_i}}$$

Plugging (35) in the above expression and rearranging we get back the FOC on optimal capital-labor use in routine production:

$$L_i^m = \bar{K}\left[\frac{1-\alpha_i}{\alpha_i}\right]^{\frac{1}{1-\mu_i}}\left[\frac{w_i}{r_i}\right]^{\frac{-1}{1-\mu_i}} \tag{36}$$

Using the CES price index (29), we can also write the total use of labor in routine production as a function of its price and of the price of the routine intermediate:

$$L_i^m = \left(\frac{\alpha}{1-\alpha}\right)^{1/\mu}\bar{K}\left[\left(\frac{P_i^m}{w_i}\right)^{-\frac{\mu_i}{(1-\mu_i)}}(1-\alpha)^{-\frac{1}{(1-\mu_i)}}A_i^{-\frac{\mu_i}{(1-\mu_i)}}-1\right]^{-\frac{1}{\mu_i}} \tag{37}$$

Total supply of the routine intermediate is written as a function of its price and of the wage:

$$M_i = A_i\alpha_i^{\frac{1}{\mu_i}}\bar{K}\left[1-\left(\frac{P_i^m}{w_i}\right)^{\frac{\mu_i}{1-\mu_i}}(1-\alpha_i)^{\frac{1}{1-\mu_i}}A_i^{\frac{\mu_i}{1-\mu_i}}\right]^{\frac{-1}{\mu_i}} \tag{38}$$

Equivalently, the supply of the routine intermediate can be written as a function of the wage and of the rate of return on capital:

$$M_i = A_i\alpha_i^{\frac{1}{\mu_i}}\bar{K}\left\{1+\left[\frac{w_i}{r_i}\right]^{\frac{-\mu_i}{1-\mu_i}}\left[\frac{1-\alpha_i}{\alpha_i}\right]^{\frac{1}{1-\mu_i}}\right\}^{\frac{1}{\mu_i}} \tag{39}$$

To clear the labor market, we combine conditional factor demands for abstract labor in final good production with total labor demand in routine production (37):

$$\bar{L} = L_i^a + L_i^m =$$

$$\sum_g \frac{Y_{ig}}{z_g}\left[\frac{w_i/(1-\beta_g)}{P_i^m/\beta_g}\right]^{-\beta_g} + \left(\frac{\alpha_i}{1-\alpha_i}\right)^{1/\mu_i}\bar{K}\left[\left(\frac{P_i^m}{w_i}\right)^{\frac{-\mu_i}{1-\mu_i}}(1-\alpha_i)^{-\frac{1}{1-\mu_i}}A_i^{\frac{-\mu_i}{1-\mu_i}}-1\right]^{-\frac{1}{\mu_i}}$$

Labor market clearing delivers the first equilibrium condition:

$$\sum_g \frac{Y_{ig}}{z_g}\left[\frac{w_i/(1-\beta_g)}{P_i^m/\beta_g}\right]^{-\beta_g} = \bar{L} - \left(\frac{\alpha_i}{1-\alpha_i}\right)^{1/\mu_i}\bar{K}\left[\left(\frac{P_i^m}{w_i}\right)^{\frac{-\mu_i}{1-\mu_i}}(1-\alpha_i)^{-\frac{1}{1-\mu_i}}A_i^{\frac{-\mu_i}{1-\mu_i}}-1\right]^{-\frac{1}{\mu_i}} \tag{40}$$

Market clearing for the routine intermediate delivers the second equilibrium condition:

$$A_i\alpha_i^{\frac{1}{\mu_i}}\bar{K}\left[1-\left(\frac{P_i^m}{w_i}\right)^{\frac{\mu_i}{1-\mu_i}}(1-\alpha_i)^{\frac{1}{1-\mu_i}}A_i^{\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}} = \sum_g \frac{Y_{ig}}{z_g}\left[\frac{w_i/(1-\beta_g)}{P_i^m/\beta_g}\right]^{1-\beta_g}$$

Market clearing in the two final goods gives $Y_{ig} = Q_{ig}$. Plugging these equalities into (34) gives the third equilibrium relationship between the quantities of the two final goods and the prices of labor and of the routine intermediate:

$$\frac{Y_{i1}}{Y_{i2}} = \left(\frac{w_i}{P_i^m}\right)^{\beta_1-\beta_2}\frac{\theta_1 z_1\beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}}{\theta_2 z_2\beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}} \tag{41}$$

Finally, we can use the budget constraint to express the quantities of the two final goods as a function of prices of labor and of the routine intermediate:

$$\sum_g Y_{ig}P_{ig} = \sum_g \frac{Y_{ig}}{z_g}\frac{w_i}{(1-\beta_g)}\left[\frac{w_i/(1-\beta_g)}{P_i^m/\beta_g}\right]^{-\beta_g} = w_i\bar{L} + r_i\bar{K}$$

Using (29), we solve for r_i as a function of P_i^m and w_i:

$$\sum_g \frac{Y_{ig}}{z_g}\frac{w_i}{(1-\beta_g)}\left[\frac{w_i/(1-\beta_g)}{P_i^m/\beta_g}\right]^{-\beta_g} = w_i\bar{L} + P_i^m A_i \alpha_i^{\frac{1}{\mu_i}}\bar{K}\left[1-\left(\frac{P_i^m}{w_i}\right)^{\frac{\mu_i}{1-\mu_i}}(1-\alpha_i)^{\frac{1}{1-\mu_i}}A^{\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}} \tag{42}$$

A.4.2 Two equilibrium relationships: relative factor supply and relative factor demand

A simple approach to solving the model is to notice that the equilibrium conditions can be summarized in two equilibrium relationships: relative factor supply and relative factor demand of the produced factors (L_i^a/M_i). The first expression for L_i^a/M_i is obtained from the solution to the lower tier problem together with the resource constraints: this is the relative factor supply. The second expression for L_i^a/M_i is obtained from the solution to the upper tier problem together with final goods' market clearing conditions: this is the relative factor demand.

The first expression for the ratio L_i^a/M_i is obtained by using labor market clearing ($\bar{L}-L_i^m$) together with capital market clearing which determines the total quantity of labor allocated to routine tasks (L_i^m in (36)) and the total quantity of the routine intermediate (M_i in (39)):

$$\frac{L_i^a}{M_i} = \frac{\bar{L}-L_i^m}{M_i} = \frac{\bar{L}-\left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\frac{1}{1-\mu_i}}\bar{K}}{A_i\alpha_i^{\frac{1}{\mu_i}}\bar{K}\left\{1+\frac{w_i}{r_i}\left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\frac{1}{1-\mu_i}}\right\}^{\frac{1}{\mu_i}}} \tag{43}$$

Equivalently, we can use (37) and (38) to write this expression as a function of the wage and of the price of the routine intermediate:

$$\frac{L_i^a}{M_i} = \frac{\bar{L}-\left[\frac{\alpha_i}{1-\alpha_i}\right]^{1/\mu_i}\left[\left(\frac{P_i^m}{w_i}\right)^{-\frac{\mu_i}{(1-\mu_i)}}(1-\alpha_i)^{-\frac{1}{(1-\mu_i)}}A_i^{-\frac{\mu_i}{(1-\mu_i)}}-1\right]^{-\frac{1}{\mu_i}}\bar{K}}{A_i\alpha_i^{\frac{1}{\mu_i}}\bar{K}\left[1-\left(\frac{P_i^m}{w_i}\right)^{\frac{\mu_i}{1-\mu_i}}(1-\alpha_i)^{\frac{1}{1-\mu_i}}A_i^{\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}} \tag{44}$$

We get the second expression of the ratio of abstract labor to the routine intermediate by combining optimal factor allocation in final goods' production together with goods' market clearing. First, we use goods' market clearing $Q_{ig} = Y_{ig}$ together with (1) to express final good consumption Q_1/Q_2 as a function of factors used in the production of final goods (L_{ig}^a, M_{ig}):

$$\frac{Q_{i1}}{Q_{i2}} = \frac{Y_{i1}}{Y_{i2}} = \frac{z_1 {L_{i1}^a}^{1-\beta_1}{M_{i1}}^{\beta_1}}{z_2 {L_{i2}^a}^{1-\beta_2}{M_{i2}}^{\beta_2}}$$

Second, we use the FOC in final goods production (30) which determines the optimal factor ratio L_i^a/M_i as a function of factor prices and parameters $(P_i^m, w_i; \beta_g)$ to express Q_1/Q_2 as a function of a single production factor:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{z_1 {L_{i1}^a}^{1-\beta_1}\left[L_{i1}^a(\beta_1/(1-\beta_1))(w_i/P_i^m)\right]^{\beta_1}}{z_2 {L_{i2}^a}^{1-\beta_2}\left[L_{i2}^a(\beta_2/(1-\beta_2))(w_i/P_i^m)\right]^{\beta_2}} = \left[\frac{w_i}{P_i^m}\right]^{\beta_1-\beta_2} \frac{z_1 L_{i1}^a\left[\beta_1/(1-\beta_1)\right]^{\beta_1}}{z_2 L_{i2}^a\left[\beta_2/(1-\beta_2)\right]^{\beta_2}} \tag{45}$$

$$\frac{Q_{i1}}{Q_{i2}} = \frac{z_1\left[M_{i1}\left[(1-\beta_1)/\beta_1\right](P_i^m/w_i)\right]^{1-\beta_1} {M_{i1}}^{\beta_1}}{z_2\left[M_{i2}\left[(1-\beta_2)/\beta_2\right](P_i^m/w_i)\right]^{1-\beta_2} {M_{i2}}^{\beta_2}} = \left[\frac{w_i}{P_i^m}\right]^{\beta_1-\beta_2} \frac{z_1 M_{i1}\left[(1-\beta_1)/(\beta_1)\right]^{1-\beta_1}}{z_2 M_{i2}\left[(1-\beta_2)/(\beta_2)\right]^{1-\beta_2}} \tag{46}$$

Third, we equate (45) (respectively, (46)) with (8) and rearrange to pin down the allocation of abstract labor (respectively, routine intermediate) to the two final goods as a function of parameters (β_g, θ_g):

$$\frac{L_{i1}^a}{L_{i2}^a} = \frac{\theta_1(1-\beta_1)}{\theta_2(1-\beta_2)} \quad ; \quad \frac{M_{i1}}{M_{i2}} = \frac{\theta_1\beta_1}{\theta_2\beta_2} \tag{47}$$

Total factor use in final good production (L_i^a, M_i) is the sum of factor allocation across final goods. Plugging $L_{i2}^a = L_i^a - L_{i1}^a$ and $M_{i2} = M_i - M_{i2}$ in (47) and rearranging, we get:

$$L_{i1}^a = \frac{\theta_1(1-\beta_1)}{\sum_g \theta_g(1-\beta_g)} L_i^a \quad ; \quad M_{i1} = \frac{\theta_1\beta_1}{\sum_g \theta_g\beta_g} M_i \tag{48}$$

The fourth step consists in expressing the consumption of one of the final goods (here we illustrate with Q_1) as a function of total factor use in final good production (L_i^a, M_i). We have already used the production function (1) and optimal factor allocation in final good production (30) to write $Q_1(L_{i1}^a; P_i^m, w_i, \beta_g)$ and $Q_1(M_{i1}; P_i^m, w_i, \beta_g)$. It is immediate from (48) that we can write $Q_1(L_i^a; P_i^m, w_i, \beta_g, \theta_g)$ and $Q_1(M_i; P_i^m, w_i, \beta_g, \theta_g)$:

$$\begin{aligned}
\frac{Q_{i1}}{z_1} &= \frac{\theta_1(1-\beta_1)}{\sum_g \theta_g(1-\beta_g)} L_i^a \left[\frac{\beta_1}{1-\beta_1}\right]^{\beta_1}\left[\frac{w_i}{P_i^m}\right]^{\beta_1} \\
\frac{Q_{i1}}{z_1} &= \frac{\theta_1(\beta_1)}{\sum_g \theta_g\beta_g} M_i \left[\frac{1-\beta_1}{\beta_1}\right]^{1-\beta_1}\left[\frac{w_i}{P_i^m}\right]^{-(1-\beta_1)}
\end{aligned} \tag{49}$$

Equating these two expressions and rearranging delivers the familiar HO equation which connects relative factor abundance to relative factor prices. The only difference in our model is that of interpretation: the factors on the LHS are produced rather than exogenously given:

$$\frac{L_i^a}{M_i} = \frac{\sum_g \theta_g(1-\beta_g)}{\sum_g \theta_g\beta_g}\frac{P_i^m}{w_i} \tag{50}$$

We denote $c = \frac{\sum_g \theta_g(1-\beta_g)}{\sum_g \theta_g\beta_g}$ and replace the price of the routine intermediate P_i^m by its value in (29) to get:

$$\frac{L_i^a}{M_i} = c\left[\frac{w_i}{r_i}A_i\alpha_i^{\frac{1}{\mu_i}}\right]^{-1}\left[1+\left(\frac{w_i}{r_i}\right)\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}\right]^{\frac{\mu_i-1}{\mu_i}} \tag{51}$$

A.4.3 The equilibrium factor price ratio

We solve for the equilibrium factor price ratio by equating (51) with (43).[34]

$$\left(\frac{w_i}{r_i}\right)^{-1} c\left[1+\left(\frac{w_i}{r_i}\right)\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}\right]^{\frac{\mu_i-1}{\mu_i}} = \frac{\left[\frac{\bar{L}}{\bar{K}}-\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}\right]}{\left[1+\left(\frac{w_i}{r_i}\right)\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}\right]^{\frac{1}{\mu_i}}}$$

Rearranging and simplifying gives:

$$\left(\frac{w_i}{r_i}\right)^{-1} c\left[1+\left(\frac{w_i}{r_i}\right)\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}\right] = \left[\frac{\bar{L}}{\bar{K}}-\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}\right]$$

$$\left(\frac{w_i}{r_i}\right)^{-1} c+c\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}} = \frac{\bar{L}}{\bar{K}}-\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}$$

We obtain an implicit solution for the equilibrium factor price ratio $\omega_i^* = (w_i/r_i)^*$:

$$\omega_i^* = c\left[\frac{\bar{L}}{\bar{K}}-(1+c)\left[\frac{1-\alpha_i}{\alpha_i}\right]^{\frac{1}{1-\mu_i}}(\omega_i^*)^{\frac{-1}{1-\mu_i}}\right]^{-1} \tag{52}$$

A.4.4 Evidence on existence and uniqueness of the solution

To establish existence and uniqueness of the solution, we define $F_i(\cdot)$:

$$F_i\left(\omega_i^*;\mu_i,\frac{\bar{L}}{\bar{K}},c,\alpha_i,A_i\right) = (\omega_i^*)^{-1}c+(1+c)\left[(\omega_i^*)^{-\frac{1}{1-\mu_i}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]-\frac{\bar{L}}{\bar{K}}=0 \tag{53}$$

Without loss of generality, we focus on cases where σ_i is an integer. We eliminate negative exponents by factoring out $(\omega_i^*)^{-\frac{1}{1-\mu_i}}$ and use $\sigma_i=(1-\mu_i)^{-1}$ and $\sigma_i-1=\mu_i/(1-\mu_i)$ to show that the solution is the root of the polynomial of degree σ_i:

$$\begin{aligned} F_i\left(\omega_i;\mu_i,\frac{\bar{L}}{\bar{K}},c,\alpha_i,A_i\right) &= -\frac{\bar{L}}{\bar{K}}(\omega_i^*)^{\frac{1}{1-\mu_i}}+c\,(\omega_i^*)^{\frac{\mu_i}{1-\mu_i}}+(1+c)\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}=0 \\ \Leftrightarrow\ \frac{\bar{L}}{\bar{K}}(\omega_i^*)^{\sigma_i}-c\,(\omega_i)^{\sigma_i-1}-(1+c)\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\sigma_i} &= 0 \end{aligned} \tag{54}$$

The derivative with respect to ω_i^* is:

$$\frac{\partial F(\cdot)}{\partial\omega_i^*} = -\sigma_i(\omega_i^*)^{\sigma_i-1}\frac{\bar{L}}{\bar{K}}+c(\sigma_i-1)(\omega_i^*)^{\sigma_i-2} = -\sigma_i(\omega_i^*)^{\sigma_i-1}\left[\frac{\bar{L}}{\bar{K}}-c(\omega_i^*)^{-1}\right]-c\,(\omega_i^*)^{\sigma_i-2}$$

[34] Equivalently, we could equate (50) with (44) to solve for P_i^m/w_i.

A sufficient condition for this derivative to be negative is to verify $\left[\bar{L}/\bar{K}-c(\omega_i^*)^{-1}\right]\geq 0$ or, equivalently, $\omega_i^*\geq c\bar{K}/\bar{L}$. By assumption, $\sigma_i\in(1,\infty)$. The function $F(\cdot)$ is monotonically decreasing in ω_i^*, it is positive for $\omega_i^*\to 0$ and negative for $\omega_i^*\to\infty$. We conclude that whenever $\omega_i^*\geq c\bar{K}/\bar{L}$, there exists a positive solution, and it gives rise to a finite real root ω_i^* that is the unique solution of this polynomial in each country.

The degree of the polynomial is country specific, and the solution to any polynomial in terms of its coefficients is degree-specific. Nevertheless, given the uniqueness of the solution, we can always express the solution of the polynomial in country 1 as a function of the solution in country 2: $\omega_1^*=\omega_2^*/\nu$.

As we showed above, the polynomial in (11) has a unique positive root ω_i^* whenever the relative price of capital is not 'too high' $(r_i/w_i)^*\leq c^{-1}(\bar{L}/\bar{K})$. To investigate whether this inequality always holds, we start from some initial endowments for which it is satisfied and characterize the magnitude of the change in the factor price ratio and in the relative endowment following a positive shock to $\bar{L}/\bar{K}$.[35] Differentiating both sides with respect to $\bar{L}/\bar{K}$, we get:

$$\left[\frac{\partial\left(\frac{r_i}{w_i}\right)^*}{\partial\left(\frac{\bar{L}}{\bar{K}}\right)}\right]d\left(\frac{\bar{L}}{\bar{K}}\right)=\frac{1}{1+\sigma_i\left[\frac{w_i^*\bar{L}}{r_i^*\bar{K}}-1\right]}d\left(\frac{\bar{L}}{\bar{K}}\right)\leq\frac{1}{c}d\left(\frac{\bar{L}}{\bar{K}}\right)\;\Leftrightarrow\; c\leq 1+\sigma_i\left[\frac{w_i^*\bar{L}}{r_i^*\bar{K}}-1\right] \quad (55)$$

As long as the above inequality holds, the change in the factor price ratio is smaller than the change in relative factor endowments, and the initial inequality continues to hold. The magnitude of c depends on factor shares in production of final goods and on the shares of these final goods in consumption. For simplicity, we assume that $c=1$.[36] It is immediate that the initial inequality can be rearranged as $1\leq w_i^*\bar{L}/r_i^*\bar{K}$ whereby (55) is verified. It follows that the polynomial has a unique positive solution for any $\bar{L}'/\bar{K}'\geq\bar{L}/\bar{K}$, i.e. both labor and capital continue to be used in routine input production as labor becomes more and more abundant.

The intuition is the following. An increase in the labor endowment translates into an increase in the relative cost of capital (55). Notwithstanding this increase in the cost of capital, it remains optimal to use the full amount of capital in routine input production. Indeed, (26) indicates that by increasing the amount of capital used in production we always decrease the relative cost of capital and free up labor for non-routine tasks. By freeing up labor from routine tasks, we always increase the total quantity of final goods that can be produced, thereby making the

[35] One such initial endowment point is simply $\bar{L}/\bar{K}=1$.

[36] $c=1$ if the two goods carry equal weight in consumption ($\theta_1=\theta_2=.5$) and $\beta_1+\beta_2=1$. The result also holds if $c>1$ since $c-1\leq\sigma_i(d)$ where $d>c-1$. However, as preferences are tilted away from the nonroutine intensive good ($c<1$), the result may cease to hold.

consumer better off.

Next, we consider the change in relative endowments and in the relative factor price ratio following a positive shock to $(\bar{K}/\bar{L})$. For the initial endowments, the inequality $(w_i/r_i)^* \geq c(\bar{K}/\bar{L})$ is verified. Differentiating both sides with respect to $\bar{K}/\bar{L}$, we get:

$$\left[\frac{\partial\left(\frac{w_i}{r_i}\right)^*}{\partial\left(\frac{\bar{K}}{\bar{L}}\right)}\right] = \frac{\left(\frac{w_i^*\bar{L}}{r_i^*\bar{K}}\right)^2}{c + \frac{1}{1-\mu_i}\left\{(1+c)\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\left[\left(\frac{w_i}{r_i}\right)^*\right]^{-\frac{\mu_i}{1-\mu_i}}\right\}} \geq c \tag{56}$$

From the polynomial we know that the expression in the curly brackets of (56) is equal to $[w_i\bar{L}/r_i\bar{K} - c]$. Rearranging and simplifying the above expression, we get:

$$\left[\frac{\partial\left(\frac{w_i}{r_i}\right)^*}{\partial\left(\frac{\bar{K}}{\bar{L}}\right)}\right] = \frac{(1-\mu_i)\left(\frac{w_i^*\bar{L}}{r_i^*\bar{K}}\right)^2}{\frac{w_i^*\bar{L}}{r_i^*\bar{K}} - \mu_i c} \geq c \tag{57}$$

Again we set $c = 1$, and simplify the above expression to get:

$$\frac{(1-\mu_i)\left(\frac{w_i^*\bar{L}}{r_i^*\bar{K}}\right)^2}{\frac{w_i^*\bar{L}}{r_i^*\bar{K}} - \mu_i} \geq 1 \;\Leftrightarrow\; \frac{w_i^*\bar{L}}{r_i^*\bar{K}} \geq \frac{\mu_i}{1-\mu_i} \tag{58}$$

As long as the above inequality holds, the change in the factor price ratio exceeds the change in relative factor endowments, and the initial inequality always holds. The above inequality is necessarily verified if $\mu_i \leq .5$. However, the inequality may be violated for $\mu_i > .5$ whereby the initial inequality may be violated for high enough μ and sufficiently abundant capital. The intuition is straightforward. As capital endowment increases, the use of labor in routine tasks becomes more and more expensive. If μ is sufficiently high, we may reach a situation where capital becomes sufficiently cheap to fully replace labor in routine tasks.

If one or both countries stop using labor in routine input production, its price becomes $P_i^m = r_i\bar{K}/M_i$ where $M_i = A_i\alpha_i^{1/\mu_i}\bar{K}$ whereby $P_i^m = r_i/A_i\alpha_i^{1/\mu_i}$. If this approach to production is cost-minimizing, it must be that the price of the routine input is lower without using labor:

$$\frac{r_i}{A_i\alpha_i^{1/\mu_i}} \leq \frac{r_i}{A_i\alpha_i^{1/\mu_i}}\left[1 + \frac{w_i}{r_i}\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{-\frac{1}{1-\mu_i}}\right]^{\frac{\mu_i-1}{\mu_i}} \Leftrightarrow$$

$$\left[1 + \left(\frac{w_i}{r_i}\right)^{-\frac{\mu_i}{1-\mu_i}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]^{\frac{-(1-\mu_i)}{\mu_i}} \geq 1 \tag{59}$$

The LHS of (59) is strictly smaller than 1 as long as w_i/r_i is finite. The LHS converges to 1 when $w_i/r_i \to \infty$. We conclude that when capital endowment becomes sufficiently abundant and $\mu > .5$, the weight of labor in routine input production becomes negligible. In the latter case, $L_i^a \to \bar{L}'$, $M_i \to A_i \alpha_i^{1/\mu_i} \bar{K}'$, and $P_i^m = r_i / A_i \alpha_i^{1/\mu_i}$ whereby (50) becomes:

$$\frac{L_i^{a*}}{M_i^*} = c\frac{P_i^m}{w_i} \quad \Leftrightarrow \quad \frac{\bar{L}'}{\bar{K}'} = c\frac{r_i}{w_i} \quad \Leftrightarrow \quad \omega_i^* = c\frac{\bar{K}'}{\bar{L}'} \tag{60}$$

This situation must occur in the high-μ country before the low-μ country because the equilibrium factor price ratio $\omega_1^*(\mu_1) < \omega_2^*(\mu_2)$ when capital endowment increases relatively to the point of normalization. It follows that $\frac{\bar{K}'}{\bar{L}'}$ for which $\omega_1^*(\mu_1) \to c\frac{\bar{K}'}{\bar{L}'}$ has $\omega_2^*(\mu_2) > c\frac{\bar{K}'}{\bar{L}'}$. As the relative wage is lower in the high-μ country, this country continues to have a relatively lower autarky price for the non-routine intensive final good.

If $\mu_2 > .5$ and the capital endowment continues to increase, the low-μ country also reaches the point where only capital is used in routine input production. Beyond this threshold, differences in capital-labor substitutability cease to be a source of comparative advantage.

To sum up, we have a unique positive solution to the polynomial for any factor endowments if $\mu_i \leq .5$, and the pattern of specialization described in the core of the paper always holds. Whenever both μ_1 and μ_2 are strictly bigger than .5, there exists a threshold at which the relative capital endowment is sufficiently high for labor to become negligible in routine input production. In the latter case, our mechanism ceases to be a source of comparative advantage.

A.4.5 Normalization of the CES production function

Klump et al. (2012) explain the rationale behind the normalization of the CES production function. Here we briefly summarize their argument. The CES is defined as the production function that possesses the following property: $\sigma = d\ln(K/L)/d\ln(F_k/F_l)$ is constant. This definition can be re-written as a second-order differential equation of $F(K,L)$. When one solves this second-order differential equation for F, one introduces 2 integration constants which are fixed by some boundary conditions.

The key point is that the elasticity of substitution is implicitly defined as a point elasticity, i.e. it is related to a particular point on a particular isoquant. But if the isoquant has to go through one particular point, the choices of the integration constants will depend on σ. Hence, the elasticity of substitution is the only structural parameter of the production structure. The properties of the boundary conditions, e.g. the capital share at the benchmark, will also influence the other parameters (together with σ).

Comparative statics in σ that do not adjust the integration constants compare situations where the isoquants for the initial and the final CES cannot be tangent at the benchmark point while the definition of σ requires that they have the same factor proportions and the same marginal rate of technical substitution at the benchmark point. One could take the full derivative of σ, incorporating the change in the other parameters explicitly. Alternatively, one can normalize the CES by making it go through an initial point (with Y_0, K_0, L_0 and a capital share π_0) and thus getting rid of all parameters other than σ. The normalization allows focusing on the structural effect of higher substitutability, e.g. the reduced incidence of decreasing marginal factor products.[37]

A.5 Opening up to trade

A.5.1 The pattern of trade

The price of the final good is:

$$P_{ig} = \frac{w_i^{1-\beta_g} P_i^{m\beta_g}}{z_g \beta_g^{\beta_g} (1-\beta_g)^{1-\beta_g}}$$

We replace P_i^m by its value and rearrange the expression to get:

$$P_{ig} = \frac{w_i \left(\frac{w_i}{r_i}\right)^{-\beta_g} \alpha_i^{-\frac{\beta_g}{\mu_i}} \left[1 + \left(\frac{w_i}{r_i}\right)^{-\frac{\mu_i}{1-\mu_i}} \left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]^{-\frac{\beta_g(1-\mu_i)}{\mu_i}}}{A_i^{\beta_g} z_g \beta_g^{\beta_g} (1-\beta_g)^{1-\beta_g}}$$

The relative price of the two final goods is:

$$\frac{P_{i1}}{P_{i2}} = \frac{z_2 \beta_2^{\beta_2} (1-\beta_2)^{1-\beta_2}}{z_1 \beta_1^{\beta_1} (1-\beta_1)^{1-\beta_1} \alpha_i^{\frac{\beta_1-\beta_2}{\mu_i}} \left(\frac{w_i}{r_i}\right)^{\beta_1-\beta_2} A_i^{\beta_1-\beta_2} \left[1 + \left(\frac{w_i}{r_i}\right)^{-\frac{\mu_i}{1-\mu_i}} \left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]^{\frac{(\beta_1-\beta_2)(1-\mu_i)}{\mu_i}}}$$

To simplify the expression, we use the normalization $\tilde{\kappa} = 1$ whereby $A_i = 1$ and $\alpha_i = (1+\tilde{\omega})^{-1}$ and further group all the country-invariant terms under the constant B. We have:

$$\frac{P_{i1}}{P_{i2}} = B(1+\tilde{\omega})^{\frac{\beta_1-\beta_2}{\mu_i}} \left\{ \omega_i \left[1 + \omega_i \left(\frac{\omega_i}{\tilde{\omega}}\right)^{-\frac{1}{1-\mu_i}}\right]^{\frac{(1-\mu_i)}{\mu_i}} \right\}^{\beta_2-\beta_1}$$

Introducing ω_i into square brackets we get:

$$\frac{P_{i1}}{P_{i2}} = B(1+\tilde{\omega})^{\frac{\beta_1-\beta_2}{\mu_i}} \left[\omega_i^{\frac{\mu_i}{1-\mu_i}} + \tilde{\omega}^{\frac{1}{1-\mu_i}}\right]^{\frac{(\beta_2-\beta_1)(1-\mu_i)}{\mu_i}}$$

[37] σ is decreasing in the cross-partial derivative of production with respect to capital and labor.

The derivative of the relative price wrt the relative wage ω_i is positive if good 1 is non-routine abundant ($\beta_1 < \beta_2$). Next, consider the relative price of the two final goods for the two countries:

$$\frac{P_{11}/P_{12}}{P_{21}/P_{22}} = (1+\tilde{\omega})^{\frac{(\mu_1-\mu_2)(\beta_2-\beta_1)}{\mu_1\mu_2}} \left[\omega_1^{\frac{\mu_1}{1-\mu_1}} + \tilde{\omega}^{\frac{1}{1-\mu_1}}\right]^{\frac{(\beta_2-\beta_1)(1-\mu_1)}{\mu_1}} \left[\omega_2^{\frac{\mu_2}{1-\mu_2}} + \tilde{\omega}^{\frac{1}{1-\mu_2}}\right]^{\frac{(\beta_1-\beta_2)(1-\mu_2)}{\mu_2}}$$

We use $\omega_2/\omega_1 = \nu$ to write:

$$\frac{P_{11}/P_{12}}{P_{21}/P_{22}} = (1+\tilde{\omega})^{\frac{(\mu_1-\mu_2)(\beta_2-\beta_1)}{\mu_1\mu_2}} \left[(\omega_2/\nu)^{\frac{\mu_1}{1-\mu_1}} + \tilde{\omega}^{\frac{1}{1-\mu_1}}\right]^{\frac{(\beta_2-\beta_1)(1-\mu_1)}{\mu_1}} \left[\omega_2^{\frac{\mu_2}{1-\mu_2}} + \tilde{\omega}^{\frac{1}{1-\mu_2}}\right]^{\frac{(\beta_1-\beta_2)(1-\mu_2)}{\mu_2}}$$

The above expression illustrates that any change in the relative price ratio can be studied as a function of the wedge in the relative wage of country 2 and country 1. It is immediate that the relative price of the non-routine intensive good is decreasing in ν.

Suppose $\nu > 1$ in autarky (case of capital deepening). To equate the relative price of the non-routine intensive good in both countries, ν must be reduced whereby ω_1 must go up. The latter can only occur if we move labor out of routine input production in country 1. Hence, country 1 specializes in the non-routine intensive good when the relative autarky price of this good is lower in country 1. Suppose $\nu < 1$ in autarky. To equate the relative price of the non-routine intensive good in both countries, ν must increase whereby ω_2 must go up. The latter can only occur if we move labor out of routine input production in country 2. Hence, country 2 specializes in the non-routine intensive good when the relative autarky price of this good is lower in country 2.

A.5.2 Free Trade Equilibrium

The free trade equilibrium is a vector of allocations for consumers ($\hat{Q}_{ig}, i, g = 1,2$), allocations for the firm ($\hat{K}_{ig}$, $\hat{L}^m_{ig}$, $\hat{L}^a_{ig}$, $\hat{M}_{ig}, i, g = 1,2$), and prices ($\hat{w}_i$, $\hat{r}_i$, $\hat{P}^m_i$, $\hat{P}_g, i, g = 1,2$) such that given prices consumer's allocation maximizes utility, and firms' allocations solve the cost minimization problem in each country, goods and factor markets clear: $\sum_i \hat{Q}_{ig} = \sum_i \hat{Y}_{ig}, g = 1,2$; $\sum_g \hat{K}_{ig} = \bar{K}, i = 1,2$; $\sum_g \hat{L}^a_{ig} + \hat{L}^m_{ig} = \bar{L}, i = 1,2$; $\sum_g \hat{M}_{ig} = \hat{M}_i, i = 1,2$.

Whenever both final goods are produced in both countries, firms' allocations satisfy:
$\beta_g P_g z_g M_{ig}^{\beta_g - 1} {L^a_{ig}}^{1-\beta_g} = P^m_i$ and $(1-\beta_g) P_g z_g M_{ig}^{\beta_g} {L^a_{ig}}^{-\beta_g} = w_i$. Further, from the ZPC, the price of each final good in each country is $P_{ig} = {P^m_i}^{\beta_g} {w_i}^{1-\beta_g}/Z$ where $Z = z_g \beta_g^{\beta_g}(1-\beta_g)^{1-\beta_g}$. Prices are equalized through trade whereby: $(P^m_1/P^m_2)^{\beta_g} = (w_2/w_1)^{1-\beta_g}$. We solve for P^m_1/P^m_2 in one sector and plug the solution in the expression for the other sector to get:

$$\left(\frac{w_2}{w_1}\right)^{\frac{1-\beta_2}{\beta_2}} = \left(\frac{w_2}{w_1}\right)^{\frac{1-\beta_1}{\beta_1}}, \beta_2 \neq \beta_1 \;\Leftrightarrow\; w_2 \;=\; w_1 \tag{61}$$

As in the canonical HO model, trade leads to factor price equalization: the cost of labor and the cost of the routine input are equalized through trade. The feature specific to our model is that in general opening up to trade does not result in capital cost equalization. To see why, we combine the unit cost function in routine production with the FPE prediction of P^m/w equalization: $P^m = A_i^{-1}\left[\alpha_i^{\sigma_i} r_i^{1-\sigma_i} + (1-\alpha_i)^{\sigma_i} w^{1-\sigma_i}\right]^{\frac{1}{1-\sigma_i}}$. We use the normalization $\tilde{\kappa}=1$ whereby $A_i = 1$ and $\alpha_i = (1+\tilde{\omega})^{-1}$ to simplify this expression and to solve for r_i in each country:

$$\begin{cases} r_1 = \left[(1+\tilde{\omega})^{\sigma_1} P^{m\,1-\sigma_1} - \tilde{\omega}^{\sigma_1} w^{1-\sigma_1}\right]^{\frac{1}{1-\sigma_1}} \\ r_2 = \left[(1+\tilde{\omega})^{\sigma_2} P^{m\,1-\sigma_2} - \tilde{\omega}^{\sigma_2} w^{1-\sigma_2}\right]^{\frac{1}{1-\sigma_2}} \end{cases}$$

The two expressions only differ by μ whereby in general $r_1 \neq r_2$.[38] Below we show that $r_1 = r_2$ iff $w/r_1 = w/r_2 = \tilde{\omega}$.

We connect the equilibrium relative price of the routine input and of labor to the allocation of resources to routine and non-routine tasks. Firm cost minimization in final goods' production delivers $\beta_g P_g z_g M_{ig}^{\beta_g}(L_{ig}^a)^{1-\beta_g} = P^m M_{ig}$ and $(1-\beta_g) P_g z_g M_{ig}^{\beta_g}(L_{ig}^a)^{1-\beta_g} = wL_{ig}^a$. Rearranging these two expressions and summing across countries delivers:

$$\begin{cases} P_g Y_{ig} = P^m M_{ig}/\beta_g \;\Leftrightarrow\; \sum_i Y_{ig} = \frac{P^m}{P_g \beta_g} \sum_i M_{ig} \\ P_g Y_{ig} = wL_{ig}^a/(1-\beta_g) \;\Leftrightarrow\; \sum_i Y_{ig} = \frac{w}{P_g(1-\beta_g)} \sum_i L_{ig}^a \end{cases}$$

First order conditions of the consumer problem in each country give:

$$\begin{cases} \theta_1 = \lambda_i P_1 Q_{i1} \\ \theta_2 = \lambda_i P_2 Q_{i2} \end{cases}$$

Summing the FOCs for each good in the two countries gives: $\theta_g/\lambda_1 + \theta_g/\lambda_2 = P_g(\sum_i Q_{ig})$. From goods' market clearing $\sum_i Q_{ig} = \sum_i Y_{ig}$. Plugging in the two expressions of $\sum_i Y_{ig}$ we get:

$$\begin{cases} \sum_i \frac{\theta_g}{\lambda_i} = \frac{P^m}{\beta_g} \sum_i M_{ig} \;\Leftrightarrow\; \sum_i \frac{1}{\lambda_i} \sum_g \beta_g \theta_g = P^m \sum_g \sum_i M_{ig} \;\Leftrightarrow\; \sum_i \frac{1}{\lambda_i} = P^m \frac{M_1^* + M_2^*}{\sum_g \beta_g \theta_g} \\ \sum_i \frac{\theta_g}{\lambda_i} = \frac{w}{(1-\beta_g)} \sum_i L_{ig}^a \;\Leftrightarrow\; \sum_i \frac{1}{\lambda_i} \sum_g (1-\beta_g)\theta_g = P^m \sum_g \sum_i L_{ig}^a \;\Leftrightarrow\; \sum_i \frac{1}{\lambda_i} = w \frac{L_1^{a*} + L_2^{a*}}{\sum_g (1-\beta_g)\theta_g} \end{cases}$$

Combining the above expressions delivers:

$$\frac{L_1^{a*} + L_2^{a*}}{M_1^* + M_2^*} = c\frac{P^m}{w} \tag{62}$$

Notice that the expression on the RHS can be written in two ways, depending on whether we use the expression of the price index in country 1 or in country 2. Replacing P^m by its value

[38] Expressions are more cumbersome if the general normalization $\kappa \neq 1$ is used, but the conclusion is unchanged.

in each of the two countries gives:

$$A_1^{-1}\left[\alpha_1^{\frac{1}{1-\mu_1}}\left(\frac{w}{r_1}\right)^{\frac{\mu_1}{1-\mu_1}}+(1-\alpha_1)^{\frac{1}{1-\mu_1}}\right]^{-\frac{1-\mu_1}{\mu_1}} = A_2^{-1}\left[\alpha_2^{\frac{1}{1-\mu_2}}\left(\frac{w}{r_2}\right)^{\frac{\mu_2}{1-\mu_2}}+(1-\alpha_2)^{\frac{1}{1-\mu_2}}\right]^{-\frac{1-\mu_2}{\mu_2}}$$

We use the normalization $\tilde{\kappa}=1$ whereby $A_i=1$ and $\alpha_i=(1+\tilde{\omega})^{-1}$ to get:

$$(1+\tilde{\omega})^{\frac{1}{\mu_1}}\left[\left(\frac{w}{r_1}\right)^{\frac{\mu_1}{1-\mu_1}}+\tilde{\omega}^{\frac{1}{1-\mu_1}}\right]^{-\frac{1-\mu_1}{\mu_1}} = (1+\tilde{\omega})^{\frac{1}{\mu_2}}\left[\left(\frac{w}{r_2}\right)^{\frac{\mu_2}{1-\mu_2}}+\tilde{\omega}^{\frac{1}{1-\mu_2}}\right]^{-\frac{1-\mu_2}{\mu_2}} \tag{63}$$

It is easy to check that setting $w/r_1=w/r_2=\tilde{\omega}$ solves (63). As expected, at the point of normalization, resource allocation and equilibrium relative factor prices are the same in both countries. In all other cases we can solve for the equilibrium factor price ratio in one country as a function of the factor price ratio in the other country:

$$\frac{w}{r_1}=\left\{(1+\tilde{\omega})^{\frac{\mu_2-\mu_1}{\mu_2(1-\mu_1)}}\left[\left(\frac{w}{r_2}\right)^{\frac{\mu_2}{1-\mu_2}}+\tilde{\omega}^{\frac{1}{1-\mu_2}}\right]^{\frac{\mu_1(1-\mu_2)}{\mu_2(1-\mu_1)}}-\tilde{\omega}^{\frac{1}{1-\mu_1}}\right\}^{\frac{1-\mu_1}{\mu_1}}$$

$$\omega_1^*=\left\{(1+\tilde{\omega})^{\frac{\sigma_2-\sigma_1}{\sigma_2-1}}\left[\left(\frac{w}{r_2}\right)^{\sigma_2-1}+\tilde{\omega}^{\sigma_2}\right]^{\frac{\sigma_1-1}{\sigma_2-1}}-\tilde{\omega}^{\sigma_1}\right\}^{\frac{1}{\sigma_1-1}} \tag{64}$$

$$\frac{w}{r_2}=\left\{(1+\tilde{\omega})^{\frac{\mu_1-\mu_2}{\mu_1(1-\mu_2)}}\left[\left(\frac{w}{r_1}\right)^{\frac{\mu_1}{1-\mu_1}}+\tilde{\omega}^{\frac{1}{1-\mu_1}}\right]^{\frac{\mu_2(1-\mu_1)}{\mu_1(1-\mu_2)}}-\tilde{\omega}^{\frac{1}{1-\mu_2}}\right\}^{\frac{1-\mu_2}{\mu_2}}$$

$$\omega_2^*=\left\{(1+\tilde{\omega})^{\frac{\sigma_1-\sigma_2}{\sigma_1-1}}\left[\left(\frac{w}{r_1}\right)^{\sigma_1-1}+\tilde{\omega}^{\sigma_1}\right]^{\frac{\sigma_2-1}{\sigma_1-1}}-\tilde{\omega}^{\sigma_2}\right\}^{\frac{1}{\sigma_2-1}} \tag{65}$$

Next, we work with the LHS of (62). We use firm cost minimization in routine production together with factor market clearing to rewrite the LHS as a function of the equilibrium factor price ratio and factor endowments. Capital market clearing delivers:

$$M_i^*=A_i\alpha_i^{1/\mu_i}\bar{K}\left[1+(\omega_i^*)^{-\frac{\mu_i}{1-\mu_i}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]^{1/\mu_i} \tag{66}$$

Labor market clearing delivers $L_i^{a*}=\bar{L}-L_i^{m*}$ while cost minimization in routine input production and the total capital stock determine labor allocation to routine tasks:

$$L_i^{m*}(M_i^*)=(\omega_i^*)^{-\frac{1}{1-\mu_i}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\bar{K} \tag{67}$$

We simplify (66) and (67) with the normalization $\tilde{\kappa} = 1$ and rearrange to get:

$$\frac{L_1^{a*}+L_2^{a*}}{M_1^*+M_2^*} = \frac{2\frac{\bar{L}}{\bar{K}} - \left(\frac{\omega_1^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_1}} - \left(\frac{\omega_2^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_2}}}{(1+\tilde{\varpi})^{\frac{-1}{\mu_1}}\left\{1+\omega_1^*\left(\frac{\omega_1^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_1}}\right\}^{1/\mu_1} + (1+\tilde{\varpi})^{\frac{-1}{\mu_2}}\left\{1+\omega_2^*\left(\frac{\omega_2^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_2}}\right\}^{1/\mu_2}} \tag{68}$$

We solve for the price ratio in each country by plugging the expressions for the LHS and the RHS into (62) and plugging the expression of the factor price ratio as a function of the factor price ratio in the other country. To simplify notation, we define $\Omega_i = (\omega_i^*)^{\frac{\mu_i}{1-\mu_i}} + \tilde{\varpi}^{\frac{1}{1-\mu_i}}$.

For the high-μ country we get:

$$\frac{2\frac{\bar{L}}{\bar{K}} - \left(\frac{\omega_1^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_1}} - \tilde{\varpi}^{\frac{1}{1-\mu_2}}\left[(1+\tilde{\varpi})^{\frac{\mu_1-\mu_2}{\mu_1(1-\mu_2)}}\Omega_1^{\frac{\mu_2(1-\mu_1)}{\mu_1(1-\mu_2)}} - \tilde{\varpi}^{\frac{1}{1-\mu_2}}\right]^{\frac{-1}{\mu_2}}}{(1+\tilde{\varpi})^{\frac{-1}{\mu_1}}\left[1+\omega_1^*\left(\frac{\omega_1^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_1}}\right]^{\frac{1}{\mu_1}} + (1+\tilde{\varpi})^{\frac{-(1-\mu_1)}{\mu_1(1-\mu_2)}}\Omega_1^{\frac{(1-\mu_1)}{\mu_1(1-\mu_2)}}\left[(1+\tilde{\varpi})^{\frac{\mu_1-\mu_2}{\mu_1(1-\mu_2)}}\Omega_1^{\frac{\mu_2(1-\mu_1)}{\mu_1(1-\mu_2)}} - \tilde{\varpi}^{\frac{1}{1-\mu_2}}\right]^{\frac{-1}{\mu_2}}}$$
$$= c(1+\tilde{\varpi})^{\frac{1}{\mu_1}}\Omega_1^{\frac{-(1-\mu_1)}{\mu_1}}$$

For the low-μ country we get:

$$\frac{2\frac{\bar{L}}{\bar{K}} - \left(\frac{\omega_2^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_2}} - \tilde{\varpi}^{\frac{1}{1-\mu_1}}\left[(1+\tilde{\varpi})^{\frac{\mu_2-\mu_1}{\mu_2(1-\mu_1)}}\Omega_2^{\frac{\mu_1(1-\mu_2)}{\mu_2(1-\mu_1)}} - \tilde{\varpi}^{\frac{1}{1-\mu_1}}\right]^{\frac{-1}{\mu_1}}}{(1+\tilde{\varpi})^{\frac{-1}{\mu_2}}\left[1+\omega_2^*\left(\frac{\omega_2^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_2}}\right]^{\frac{1}{\mu_2}} + (1+\tilde{\varpi})^{\frac{-(1-\mu_2)}{\mu_2(1-\mu_1)}}\Omega_2^{\frac{(1-\mu_2)}{\mu_2(1-\mu_1)}}\left[(1+\tilde{\varpi})^{\frac{\mu_2-\mu_1}{\mu_2(1-\mu_1)}}\Omega_2^{\frac{\mu_1(1-\mu_2)}{\mu_2(1-\mu_1)}} - \tilde{\varpi}^{\frac{1}{1-\mu_1}}\right]^{\frac{-1}{\mu_1}}}$$
$$= c(1+\tilde{\varpi})^{\frac{1}{\mu_2}}\Omega_2^{\frac{-(1-\mu_2)}{\mu_2}}$$

Rearranging and simplifying this expression, the implicit solution for the high-μ country is:

$$F_1(\omega_1;\mu_1,\mu_2,\frac{\bar{L}}{\bar{K}},c) = c\,(\omega_1^*)^{-1} + (c+1)\left(\frac{\omega_1^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_1}} - 2\frac{\bar{L}}{\bar{K}} + \frac{\left[c(1+\tilde{\varpi})^{\frac{\mu_1-\mu_2}{\mu_1(1-\mu_2)}}\Omega_1^{\frac{\mu_2(1-\mu_1)}{\mu_1(1-\mu_2)}} + \tilde{\varpi}^{\frac{1}{1-\mu_2}}\right]}{\left[(1+\tilde{\varpi})^{\frac{\mu_1-\mu_2}{\mu_1(1-\mu_2)}}\Omega_1^{\frac{\mu_2(1-\mu_1)}{\mu_1(1-\mu_2)}} - \tilde{\varpi}^{\frac{1}{1-\mu_2}}\right]^{\frac{1}{\mu_2}}} = 0$$

Rearranging and simplifying this expression, the implicit solution for the low-μ country is:

$$F_2(\omega_2;\mu_1,\mu_2,\frac{\bar{L}}{\bar{K}},c) = c\,(\omega_2^*)^{-1} + (c+1)\left(\frac{\omega_2^*}{\tilde{\varpi}}\right)^{\frac{-1}{1-\mu_2}} - 2\frac{\bar{L}}{\bar{K}} + \frac{\left[c(1+\tilde{\varpi})^{\frac{\mu_2-\mu_1}{\mu_2(1-\mu_1)}}\Omega_2^{\frac{\mu_1(1-\mu_2)}{\mu_2(1-\mu_1)}} + \tilde{\varpi}^{\frac{1}{1-\mu_1}}\right]}{\left[(1+\tilde{\varpi})^{\frac{\mu_2-\mu_1}{\mu_2(1-\mu_1)}}\Omega_2^{\frac{\mu_1(1-\mu_2)}{\mu_2(1-\mu_1)}} - \tilde{\varpi}^{\frac{1}{1-\mu_1}}\right]^{\frac{1}{\mu_1}}} = 0$$

The first two terms replicate the analogous expression for the autarky equilibrium (11) while the third term now takes into account factor endowments in both countries. The fourth term is specific to the FTE: it accounts for the difference in capital-labor substitutability.

We can rewrite these expressions as a function of σ. In the high-σ country we get:

$$F_1(\cdot) = c\left(\omega_1^*\right)^{-1} + (c+1)\left(\frac{\omega_1^*}{\tilde{\omega}}\right)^{-\sigma_1} - 2\frac{\bar{L}}{\bar{K}} + \frac{\left[c(1+\tilde{\omega})^{\frac{\sigma_1-\sigma_2}{\sigma_1-1}}\left[(\omega_1^*)^{\sigma_1-1}+\tilde{\omega}^{\sigma_1}\right]^{\frac{\sigma_2-1}{\sigma_1-1}}+\tilde{\omega}^{\sigma_2}\right]}{\left[(1+\tilde{\omega})^{\frac{\sigma_1-\sigma_2}{\sigma_1-1}}\left[(\omega_1^*)^{\sigma_1-1}+\tilde{\omega}^{\sigma_1}\right]^{\frac{\sigma_2-1}{\sigma_1-1}}-\tilde{\omega}^{\sigma_2}\right]^{\frac{\sigma_2}{\sigma_2-1}}} = 0$$

In the low-σ country we get:

$$F_2(\cdot) = c\left(\omega_2^*\right)^{-1} + (c+1)\left(\frac{\omega_2^*}{\tilde{\omega}}\right)^{-\sigma_2} - 2\frac{\bar{L}}{\bar{K}} + \frac{\left[c(1+\tilde{\omega})^{\frac{\sigma_2-\sigma_1}{\sigma_2-1}}\left[(\omega_2^*)^{\sigma_2-1}+\tilde{\omega}^{\sigma_2}\right]^{\frac{\sigma_1-1}{\sigma_2-1}}+\tilde{\omega}^{\sigma_1}\right]}{\left[(1+\tilde{\omega})^{\frac{\sigma_2-\sigma_1}{\sigma_2-1}}\left[(\omega_2^*)^{\sigma_2-1}+\tilde{\omega}^{\sigma_2}\right]^{\frac{\sigma_1-1}{\sigma_2-1}}-\tilde{\omega}^{\sigma_1}\right]^{\frac{\sigma_1}{\sigma_1-1}}} = 0$$

Table 1: ANOVA analysis of input ratios and production function parameters

	Sum of squares: level (and share)				F-statistic (and p-value)		
	dependent variable	Sector (33)	Country (20)	Year (25)	Sector (33)	Country (20)	Year (25)
(a) Observable variable							
$\left(\frac{L^a}{L^a + L^m}\right)$ [i]	9.98	5.41	2.84		62.03	53.69	
		(54.2%)	(28.5%)		0.00	0.00	
$\ln\left(\frac{K}{L^m}\right)$	3843	466	789	1118	114.73	320.63	363.49
		(12.1%)	(20.5%)	(29.1%)	0.00	0.00	0.00
(b) Estimated parameters							
β_{ig}	25.52	5.30	2.67		6.03	5.01	
		(20.8%)	(10.5%)		0.00	0.00	
μ_{ig} [ii]	1636	191	217		1.03	1.93	
		(11.7%)	(13.3%)		0.43	0.01	

Notes: [i] The dependent variable is the average abstract labor share over the period

[ii] Only includes country-sector observations with $\sigma_{ig} < 20$

Table 2: Country characteristics that explain export specialization within the full sample

	Dependent variable is the country-specific extent of specialization in routine-intensive sectors estimated in the first stage				
	(1)	(2)	(3)	(4)	(5)
log(GDP/capita)	-0.619***	-0.168	-0.482***	-0.553***	-0.372*
	(2.7)	(0.8)	(4.0)	(3.3)	(1.7)
Rule of law	0.009				
	(0.1)				
Quality of the workforce		-0.538***			
		(2.6)			
Hofstede/culture			-0.375***		
			(3.1)		
Internal migration				-0.195	
				(1.2)	
Strictness of employment protection					0.149
					(0.7)
Observations	43	43	42	26	26
Adjusted R2	0.343	0.440	0.438	0.301	0.153

Note: Higher value of the dependent variable indicates a larger share of exports is in sectors with a large fraction of the workforce in routine-intensive occupations. The reported statistics are standardized 'beta-coefficients', which measure effects in standard errors, and t-statistics in brackets. ***, **, * indicate statistical significance at the 1%, 5%, 10% level.

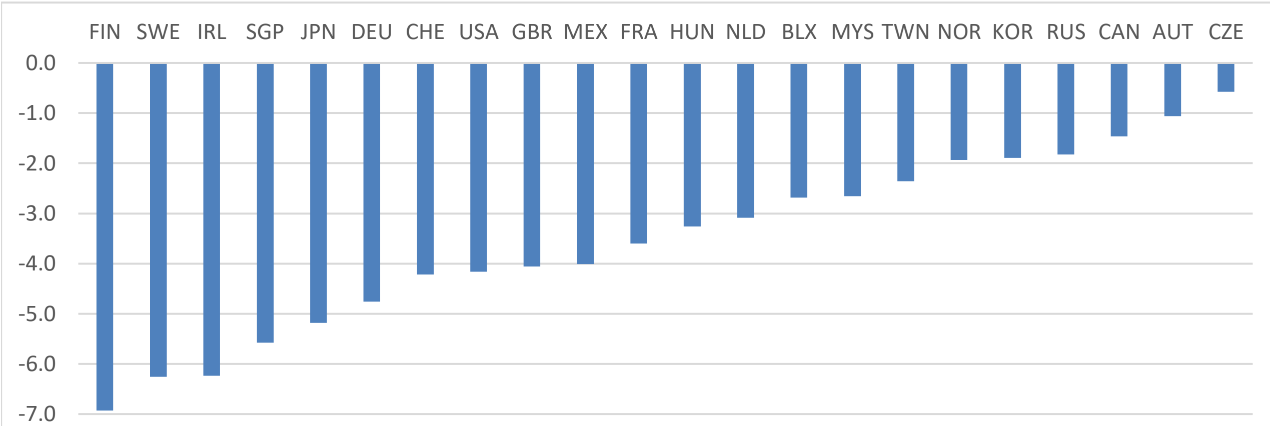
Table 3: Country characteristics that explain export specialization within the EU sample

	Dependent variable is the country-specific extent of specialization in routine-intensive sectors estimated in the first stage				
	(1)	(2)	(3)	(4)	(5)
log(GDP/capita)	-0.330	0.027	-0.632***	-0.264	-0.317*
	(1.1)	(0.1)	(4.1)	(1.2)	(1.8)
Rule of law	-0.384				
	(1.3)				
Quality of the workforce		-0.569			
		(1.3)			
Hofstede/culture			-0.190		
			(1.2)		
Internal migration				-0.365	
				(1.6)	
Strictness of employment protection					0.607***
					(3.4)
Observations	27	16	26	18	18
Adjusted R2	0.433	0.190	0.428	0.176	0.452

Note: Higher value of the dependent variable indicates a larger share of exports is in sectors with a large fraction of the workforce in routine-intensive occupations. The reported statistics are standardized 'beta-coefficients', which measure effects in standard errors, and t-statistics in brackets. ***, **, * indicate statistical significance at the 1%, 5%, 10% level.

Figure 1: Country trade patterns in the full sample for 2005

(a) Countries with relative comparative advantage towards non-routine intensive sectors



(b) Countries with relative comparative advantage towards routine-intensive sectors

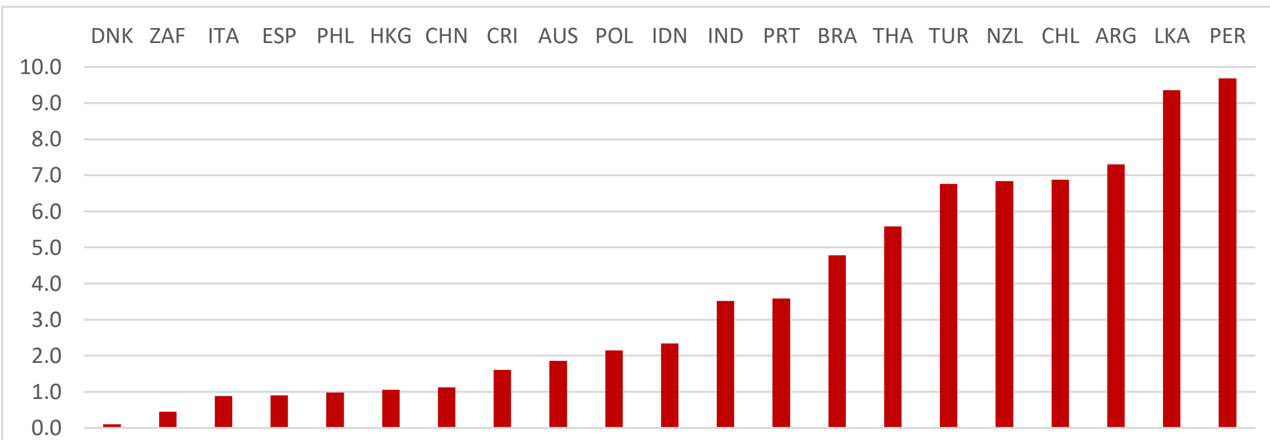


Figure 2: Evolution in countries' revealed comparative advantage in full sample, 1995 versus 2015

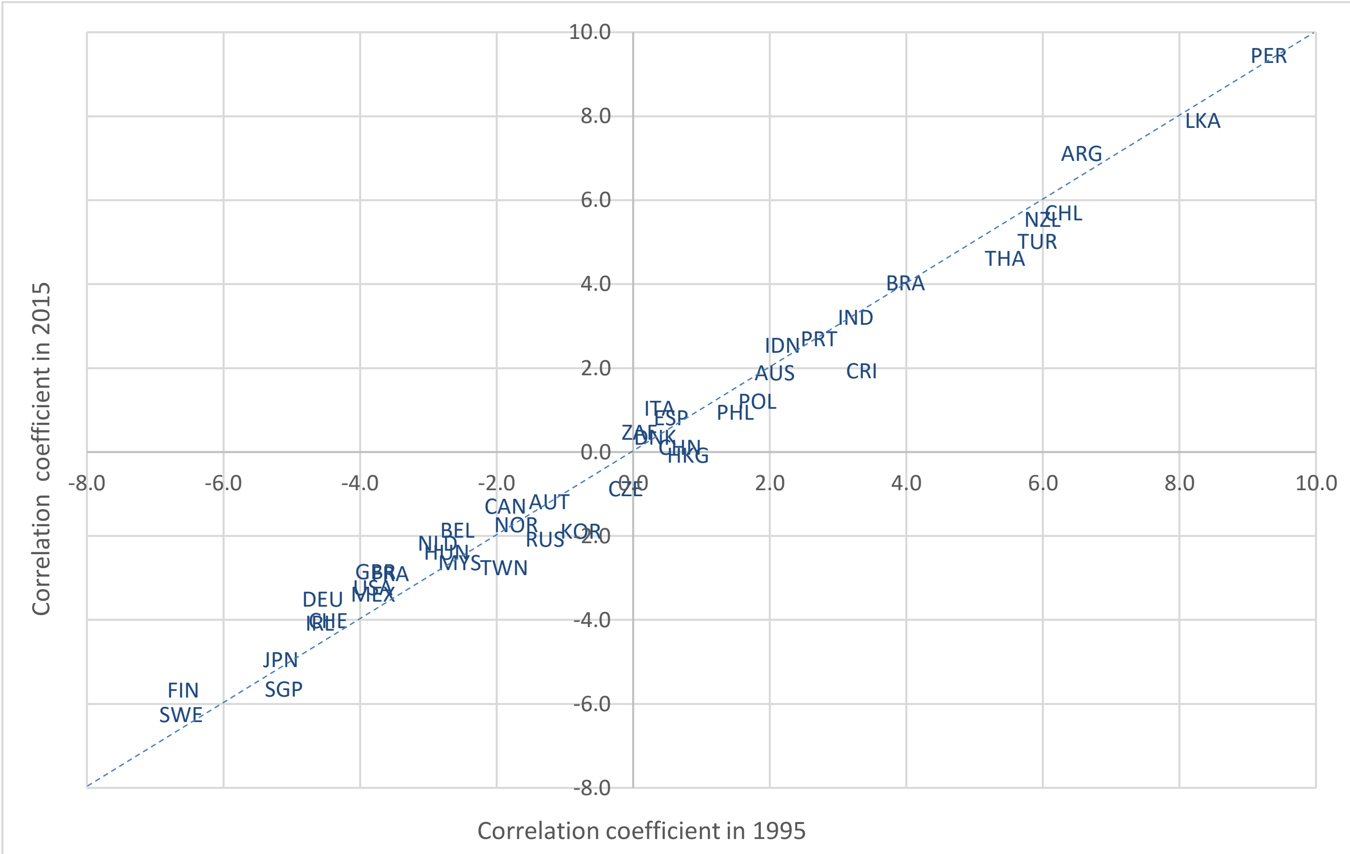


Figure 3: Revealed comparative advantage, with evolution over time, in the EU sample