Comparative Advantage in (Non-)Routine Production*

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Abstract

We illustrate a new source of comparative advantage that is generated by countries' differential ability to adjust to technological change. Our model introduces the substitution of workers in codifiable (routine) tasks with more efficient machines, a process extensively documented in the labor literature, into a canonical $2 \times 2 \times 2$ Heckscher-Ohlin model. Our key hypothesis is that labor reallocation across tasks is subject to frictions which importance varies by country. The arrival of capital-augmenting innovations generates comparative advantage as the 'produced' factor endowments—which are relevant for trade—are determined by the equilibrium allocation of labor to routine and non-routine tasks. Countries with flexible labor reallocation 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 related to labor market institutions and to behavioral norms in the workplace.

Keywords: Comparative advantage, resource allocation, routineness
JEL codes: F11, F14, F15

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1 Introduction

The classic theory of comparative advantage illustrates how differences in technology or factor endowments lead countries to specialize in the production of different goods. Recent developments in this literature highlight that differences in worker attributes and institutions, such as skill dispersion (Bombardini et al., 2012), labor market flexibility (Cuñat and Melitz, 2012), or strength of contract enforcement (Nunn, 2007), can also influence specialization. The evidence supports the view that all of these dimensions play a role in determining trade patterns. In particular, Chor (2010) finds that institutional characteristics matter at least as much as traditional factor endowments of human and physical capital.

Our contribution is to relate trade theory to a prominent topic in the labor literature. We introduce a new source of comparative advantage by noticing that countries may differ in their ability to adjust to new technologies. We start from a well-documented pattern associated with the process of technological change.[1] The continuous introduction of more efficient machines displaces workers in 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 less codifiable (non-routine) tasks. We show that countries which are better able to reallocate workers between tasks will adjust more smoothly to technological change and specialize in goods that require more intensive use of labor in non-routine tasks.

To illustrate this mechanism we incorporate task routineness into an otherwise canonical 2-country 2-good 2-factor Heckscher-Ohlin model. The final goods are produced with two factors: one routine and one non-routine. The available quantities of these two factors are not given exogenously, but are determined by the equilibrium allocation of labor to routine and non-routine tasks. The flexibility of labor reallocation matters in this economy because there is an ongoing process of technological change which we model as an increase in the capital endowment.[2] As in Autor et al. (2003) and Autor and Dorn (2013), capital can only be used in routine tasks. An increase in the amount of capital available leads to a reduction in its relative cost and an increase in the equilibrium capital intensity in the production

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

[2]The same results might also be obtained by modeling technological change as an increase in the capital productivity coefficient, but the normalization of the CES production function (below) greatly complicates that approach.

of the routine input. Consequently, labor can be released from routine tasks and reallocated to non-routine tasks.[3]

The novel ingredient in our model is that the reallocation of workers between tasks is subject to frictions which importance varies by country. We model this variation in intensity of labor reallocation frictions as a country-specific elasticity of substitution between capital and labor in routine production. This assumption can be considered a reduced form way of capturing differences across countries in labor market regulations, worker bargaining power, or other factors that make it less likely for workers to switch employer. Specifically, we expect the elasticity of substitution to be decreasing in the magnitude of hiring, firing, and retraining costs associated with the adjustment of the workforce to new machinery. We include a stylized model of this mechanism to micro-found the assumption of a country-specific elasticity of substitution parameter in the production function.

The model predicts that countries which adjust more smoothly to technological change—i.e. countries with a higher elasticity of substitution—free up more labor from non-routine tasks and become non-routine labor abundant. As in the canonical Heckscher-Ohlin model, the abundance of non-routine labor leads them to specialize in goods that are non-routine labor intensive. As a result, the arrival of more capital or capital-biased technological change that triggers a process of labor reallocation, will endogenously differentiate countries. This new source of comparative advantage could help explain why countries with similar factor endowments and similar technology and technological change specialize in different goods.

We test these predictions using bilateral trade data at the product level for three years: 1995, 2005, and 2015. To limit the number of zeros in the trade matrix, we perform the analysis on two samples. One contains the 43 most important traders in the world and lumps all other countries in ten regional blocks. The second sample is limited to EU member states where traditional sources of comparative advantage are likely to have low predictive power. We take the ranking of industries with respect to routine intensity from Autor et al. (2003) and aggregate the more detailed trade data to their 140 census industries.

The analysis follows the two-step empirical approach of Costinot (2009). In a first step, we uncover the routine intensity of each country's exports. In a second

[3] In Autor and Dorn (2013), workers performing routine tasks in manufacturing can only be reallocated to manual (non-routine) tasks in services. We follow the approach in Autor et al. (2003), where reallocation is possible between routine and non-routine tasks in manufacturing, but relax their assumption of perfect capital-labor substitutability in routine tasks.

step, we investigate to what extent this country-ranking is correlated with institutional or cultural characteristics that are plausibly correlated with the flexibility of labor reallocation across tasks. The results indicate that 'strictness of employment protection' legislation is a strong predictor for routine versus non-routine specialization across EU member states. Countries with relatively strict regulation—and hence, lower capital-labor substitutability—specialize in goods that are relatively routine intensive. In the more diverse sample of large global exporters, we find that two variables, namely 'quality of the workforce' and 'long-term orientation' predict such specialization. A final noteworthy finding is that the difference in routine versus non-routine specialization across countries has fallen over time, but this trend is much less pronounced for a value added based measure of trade that accounts for increased international fragmentation of production.

Our work connects to three strands of literature. Macroeconomists have estimated the magnitude of capital-labor substitutability and investigated implications on a number of outcomes. Klump and de la Grandville (2000) derive the implications for growth and Krusell et al. (2000) look at inequality. Stokey (1996) studies factor market integration and factor accumulation in an explicit dynamic model with a single sector. Given full factor price equalization, factor flows can also be interpreted as trade flows. 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 substitutability play a role in determining trade specialization.

Our work also builds on a rapidly growing literature in labor economics (mentioned earlier) that documents how increased automation and outsourcing of codifiable tasks led to job polarization in developed economies. This literature explicitly links technological change to labor displacement from routine to non-routine tasks, e.g. as in Autor et al. (2003) where capital and labor are perfectly substitutable in routine tasks and labor reallocation is within an industry.[4] We contribute by showing that institutional features 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.

We also contribute to the trade literature that seeks to uncover new mechanisms

[4]These authors show that most such reallocation within an industry happens within the same education group, i.e. it is not generally the case that non-routine workers are hired from a separate pool of workers.

behind comparative advantage. As pointed out in the survey paper of Nunn and Trefler (2014), this literature has already documented several important institutional characteristics. For example, Cuñat and Melitz (2012) illustrate that high labor market flexibility confers an advantage in sectors where idiosyncratic shocks lead to high sales volatility. Our main contribution is to point out that institutions, for example labor market flexibility, may have a direct effect on an economy's ability to adjust to a pervasive capital-biased technological change and, consequently, on the allocation of labor across tasks. As a result, differences in measured factor abundance, such as the ratios of skilled to unskilled labor, may themselves be determined by the interaction of country-specific institutions with the process of technological change.

The remainder of the paper is organized as follows. In section 2 we present the main features of the stylized model, derive the autarky equilibrium, and the predictions regarding trade patterns. Along the way we illustrate one possible microfoundation for country differences in capital-labor substitutability. Section 4 describes the empirical model we will estimate, 3 contains a description of the data used in the empirical analysis and Section 5 contains results. In Section 6 we summarize the conclusions.

2 Theory: the effect of σ on factor abundance

We follow the structure of the canonical $2 \times 2 \times 2$ Heckscher-Ohlin (HO) model where the pattern of trade is determined by the interaction of country-specific factor endowment and sector-specific factor intensity. The distinguishing feature of our set-up is that the endowments of the relevant production factors for the two final goods are endogenously determined ('produced') by the optimal allocation of labor to routine and non-routine tasks. Two countries with identical endowments of 'primitive' factors, capital and labor, can have an incentive to trade, simply because they differ in the substitutability of inputs in the production of a routine input that is used in both final good sectors. The elasticity of substitution parameter σ will determines the equilibrium allocation of labor to tasks. A country with higher σ will use a relatively scarce factor more efficiently. In our model, it makes labor move out of routine tasks more easily when capital becomes abundant.

To establish this result, we confront that a normalization is needed to make valid comparisons between different constant elasticity of substitution (CES) functions.

Moreover, given that we allow countries only to differ in the substitutability of inputs in production, we also need to introduce an exogenous change that triggers such substitution. To achieve both in a static set-up, we model an initial point of production that is attainable for all countries, regardless of their CES parameters; for simplicity we assume they initially produce the exact same output bundle. We then compare the relative change in output composition, or equivalently the change in allocation of production factors, when the capital endowment is increased.[5] At each point, all countries have identical factor endowments. We abstract from differences in the 'primitive' endowments, capital and labor, as those effects of the traditional HO channel are well understood. The different substitution possibilities lead to differences in 'produced' endowments, non-routine labor and a composite routine input, which are the input factors used in the production of final goods.

As countries accumulate capital, a reduced-form way of introducing capital-biased technological change, they reallocate labor from routine to non-routine tasks. A high-σ country frees up more labor for non-routine tasks and becomes non-routine labor abundant. This holds even though the high-σ country is relatively efficient in routine production, i.e. for the same input bundle it can produce more output in routine production.[6] As the labor reallocation effect dominates the efficiency effect, a country with higher σ will relatively specialize in non-routine intensive goods. Note that the opposite pattern obtains if the capital-labor ratio is reduced: a high-σ country frees up more labor to do routine tasks and becomes routine input abundant. Our maintained assumption is that a rising capital-labor ratio is a pervasive pattern of real-world technological change.

More generally, our finding implies that higher capital-labor substitutability mitigates resource scarcity. The corollary for the pattern of trade is that the high-σ country specializes in the final good that uses the relatively scarce factor—which we assume to be labor—more intensively. This is a restatement of the result in Arrow et al. (1961), studied in a growth context by Klump and de la Grandville (2000), that economies with higher labor substitution are better able to mitigate labor scarcity and achieve higher welfare because they have more incentive to accumulate capital. The magnitude of σ captures the efficiency of resource allocation in the economy when reallocation is needed, as in the adjustment to factor-biased

[5]Endogenizing capital accumulation is beyond the scope of this paper, but it is almost certain to reinforce our results.

[6]This is a feature of the CES production function: holding the input bundle constant, output is strictly increasing in σ (Klump et al., 2012).

technological growth.

In the remainder of this section, we first set up the model and develop the intuition behind the key equilibrium relationships. To motivate the assumption of heterogeneous σ, we provide a stylized model that illustrates how higher firing costs reduce equilibrium input substitution. Next, we discuss the choice of initial conditions and derive the mapping from capital-labor substitutability to factor abundance. Finally, we show the implications for the pattern of trade and discuss the lack of factor price equalization.

2.1 The model

2.1.1 Basic set-up

Denote two countries by $i \in \{A, B\}$; they have identical factor endowments of capital $\bar{K}$ and labor $\bar{L}$. Denote two final goods by $g \in \{1, 2\}$; they are produced with two factors, non-routine (abstract) labor L^a and a routine intermediate input M which is itself produced from capital K and routine labor L^m. The resource constraint on labor is $L^a + L^m \leq \bar{L}$.

As is standard in the canonical HO model, the production function for final goods is Cobb-Douglas:

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

where z_g is a productivity parameter and β_g the factor share of the routine input. Both parameters are common across countries. Let good 1 be non-routine intensive: i.e., $\beta_1 < \beta_2$.

Also standard is that countries have identical, homothetic demand over the two final goods. For simplicity, we also adopt a Cobb-Douglas utility function: $U_i = \sum_g \theta_g \ln(Q_{ig})$. Consumers maximize utility subject to the budget constraint $\sum_g P_{ig} Q_{ig} \leq r_i \bar{K} + w_i \bar{L}$, where w_i is the wage and r_i the rental rate of capital. This leads to constant budget shares.

In this set-up, the country that is non-routine labor abundant in autarky will produce relatively more output in sector 1, which uses non-routine labor more intensively. Given the same preferences, good 1 will be relatively cheap, giving that country a comparative advantage in it. The key element in our model is that the quantities of abstract labor and the routine input are endogenously determined, depending on the optimal allocation of labor to routine and non-routine tasks.

Given the focus on capital-labor substitutability in routine production, we simple assume that each unit of raw labor can directly produce routine or abstract tasks and this choice is reversible. In particular, one unit of routine labor can seamlessly be converted into one unit of abstract labor.[7] For the production of the routine intermediate, we adopt a CES production function:

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

where Z_i and α_i are the efficiency and distribution parameters, and $\mu_i = (\sigma_i - 1)/\sigma_i$ captures the ease of input substitutability.[8] We follow Autor et al. (2003) and Autor and Dorn (2013) and assume that capital and routine labor are more substitutable in routine production than is the case between non-routine labor and the routine input in the production of final goods: i.e., $\mu_i > 0$ or $\sigma_i > 1$ for both countries.

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

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

Let country A have relatively high input substitution in routine production: $\sigma_A > \sigma_B$.

2.1.2 Micro-foundation

The elasticity of substitution parameter in the production function is generally considered to be a representation of technology. Here we illustrate that countries with the same production technology, but with different institutions will adjust their input choices to a different extent when faced by the same exogenous shock. for how a labor market friction can give rise to variations in the elasticity of substitution, i.e. how substitutable capital and labor are in producing the routine input.

We view the illustration below as only one example of an institutional differ-

[7]The σ parameter reflects all frictions associated with labor reallocation across tasks. It would be feasible, but more complicated, to derive our predictions incorporating investment in human capital and task-specific wages.

[8]Importantly, the only free parameter is σ (or μ). As explained in Klump et al. (2012), Z_i and α_i are determined by the point of normalization (see below) and therefore we have also given them a subscript i.

ence between countries that can be represented by differences in the elasticity of substitution parameter. There are surely other differences that influence firms' responsiveness to exogenous shocks to relative prices in a similar manner. Examples are institutional barriers to labor mobility between regions or occupations or cultural differences regarding risk aversion or a short-term orientation in decision making.

Here, we consider a lay-off cost to be paid by any firm that seeks to reduce its workforce, for example in response to an increase in the relative price of labor. Note that this lay-off cost can be interpreted in more than one way, e.g. apart from its literal interpretation as a cost that the firm has to pay, it could be an obligation to provide for retraining. Differences between countries in the fraction of such costs that is borne by individual firms (and not by a public system) will have similar effects as cross-country variation in lay-off costs.

Given that ours is a real trade model, the cost has to be paid directly in terms of output of the firm. We then have:

$$\bar{y} + p\,C(L)\,\bar{y} \;=\; F(K,L),$$

where p is a cost shifter that we will use in the comparative statics, and $C(L)$ is the lay-off cost that satisfies $C(\bar{L}) = 0$, $C'(L) < 0$, and $C''(L) > 0$ for any $L < \bar{L}$.[9] In words, the cost kicks in when the firm starts to reduce labor below its initial level, the marginal cost is positive for lay-offs (negative changes in L), and the cost is convex, i.e. the marginal cost increases in the amount of workers the firms seeks to shed, which is a standard assumption.[10] Taking into account the lay-off cost, we have the following modified production function:

$$\bar{y} \;=\; \frac{F(K,L)}{1 + p\,C(L)}. \tag{4}$$

We now show the effect of changes in the lay-off cost friction on the elasticity of substitution for the modified production function. The latter is defined as

$$\sigma_{L,K} \;=\; \frac{d(L/K)}{dMRTS}\,\frac{MRTS}{L/K}.$$

[9]In the analysis of comparative advantage, we consider an increase in the capital stock which tends to increase the relative wage. Hence, the relative adjustment involves reducing labor.

[10]Small employment reductions can often be accommodated relatively easily by not replacing retirements or by natural job attrition. If the costs represent retraining rather than firing costs, it is also natural that they increase with the number of job changes.

Since the lay-off cost is specified as a function of labor, we first need to relate changes in L/K to changes in L. To do so, observe that staying on the isoquant of the modified production function (4) implies:

$$dK \;=\; \frac{\bar{y}\, p\, C'(L) - MP_L}{MP_K}\, dL.$$

In addition, we have

$$d(L/K) \;=\; \frac{1}{K}\, dL - \frac{L}{K^2}\, dK,$$

and substituting for dK then yields

$$d(L/K) \;=\; \left(\frac{1}{K} + \frac{L}{K^2} \frac{MP_L}{MP_K} - \frac{L}{K^2} \frac{p\, C\, F'(L)\, \bar{y}}{MP_K} \right) dL \tag{5}$$

We are now in a position to consider the elasticity of substitution, and to conduct comparative statics with respect to the parameter p that measures the importance of the labor market friction. In general, the marginal rate of technical substitution for our modified production function takes the form:

$$MRTS \;=\; \frac{MP_K}{MP_L - p\, C'(L)\, \bar{y}}.$$

Differentiating with respect to L/K gives:

$$\frac{dMRTS}{d(L/K)} \;=\; \frac{\frac{dMP_K}{d(L/K)}}{MP_L - p\, C'(L)\, \bar{y}} - \frac{MP_K \left(\frac{dMP_L}{d(L/K)} - p\, C''(L)\, \bar{y}\, \frac{dL}{d(L/K)} \right)}{(MP_L - p\, C'(L)\, \bar{y})^2} \tag{6}$$

In order to simplify the analysis, consider the case of perfect substitutes, i.e. $F(K, L) = K + L$, which implies that both MP_K and MP_L equal one. Absent any labor market friction, the $MRTS$ in this case is one, its derivative with respect to L/K zero, and the elasticity of substitution infinite. This is clearly a limiting case, but it serves as a useful starting point as we show that introducing a labor market friction will reduce the elasticity of substitution in this case.

In the presence of a friction, the derivative of the marginal rate of substitution (6) in this case simplifies to:

$$\frac{p\, C''(L)\, K^2}{\left(1 - p\, C'(L)\, \bar{y}\right)^2}.$$

Note that because of the (strictly) convex cost, this derivative is (strictly) positive – the lower the factor input ratio L/K, the lower the derivative or slope of the isoquant. Based on this derivative, the elasticity of substitution takes the form:

$$\sigma_{L,K} \;=\; \frac{\left(1 - p\,C'(L)\,\bar{y}\right)^2/L + \left(1 - p\,C'\,(L)\,\bar{y}\right)^3/K}{p\,C''(L)\,\bar{y}}. \tag{7}$$

Differentiating with respect to the cost shifter p we obtain:

$$\frac{\partial\sigma_{L,K}}{\partial p} \;=\; \frac{-pC'(L)\bar{y} - 1}{L} + \frac{-pC'(L)\bar{y} - 1 + 2(pC'(L)\bar{y})^2}{K} \tag{8}$$

The first term is negative as long as $-pC'(L)\bar{y} < 1$, or the marginal friction does not exceed the marginal product of labor, which must be satisfied for the adjustment to be optimal. The second term is a polynomial of order two which is negative for $-pC'(L)\bar{y} \in (-1, 1/2)$; that is, the marginal friction does not exceed half the marginal product of labor. Since the terms are weighted by $1/L$ and $1/K$ respectively, note that this constraint is relaxed at higher K and lower L. As long as the friction is not excessive, we thus find a negative effect of the cost shifter p, that increases the importance of the friction, on the elasticity of substitution. In other words, a more severe friction reduces optimal (from the firm's perspective) substitution of capital for labor in producing the routine input.

The above mechanism links labor market frictions in the form of a convex layoff cost to lower substitutability of capital and labor. Several recent papers have documented large and highly heterogeneous adjustment costs when workers switch occupations. Dix-Carneiro (2014) finds for the median Brazilian worker who switches jobs a cost ranging from 1.4 to 2.7 times the average annual wage.[11] Autor et al. (2014) even find that adjustment costs may be prohibitively high for less skilled and older workers and shocks can lead to a permanent exit from the labor force.[12]

While adjustment cost are likely to vary in importance across workers, our focus is on institutional characteristics that determine a country-specific component of adjustment costs. Several papers have suggested that more stringent labor market regulation reduces the speed of adjustment of an economy to structural change. For example, Wasmer (2006) shows that countries with more rigid labor markets

[11] Artuç et al. (2010) report even higher costs for the median U.S. worker, but they have less detailed controls for worker characteristics.

[12] Pierce and Schott (2016) report that one third of workers who lost employment in U.S. manufacturing as a consequence of import competition from China transition to inactivity.

perform better in the steady state as workers are more productive, but transition periods following structural shocks are longer and more costly. Comparing the adjustment to trade liberalization in Mexico and Chile, Kambourov (2009) shows that high firing costs in Mexico slowed down the process of worker reallocation to comparative advantage activities. 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.

Bartelsman et al. (2016) further connect the stringency of employment protection legislation (EPL) to reduced incentives for investment in risky technology. By increasing the cost of downsizing or exiting, it is akin to a distortive tax on risky investment. They show that industries characterized by a greater dispersion in labor productivity also use ICT more intensively and argue that it reflects the recent process of technological change which corresponded to such high-risk high-return technology. Consistent with their predictions, countries with more stringent labor market regulations specialized in less ICT-intensive industries.

We have shown theoretically, that higher labor market frictions can be represented by a lower substitutability of capital and labor in the production function. In Appendix A we show estimates for a production function of the form (3) using the KLEMS data that has country-sector-year observations. We allow the β as well as the μ parameters to be country-sector specific, exploiting only time variation in the estimation. An ANOVA analysis on the resulting estimates indicates that country dummies have the largest explanatory power for the elasticity of substitution μ, while sector dummies have more explanatory power for the β parameter that determines capital and skilled labor elasticities. These results suggest that our assumptions on the country or sector specificity of the two parameters is not wildly at odds with the relationship between observed outputs and inputs in the KLEMS data.

2.1.3 Solving the model

After this detour, we solve the model by finding the relative supply and demand of the two 'produced' factors, the routine input and abstract labor. The solution to the model delivers the optimal allocation of labor to routine and non-routine tasks. We show the main steps to solve the model here and provide further details in Appendix B.

On the supply side, we have three types of price-taking firms, producing the routine intermediate input and both final goods. The cost and thus the input choices must be the same for the routine inputs used in both final goods. Cost minimization of the CES production function in (2) gives conditional factor demands for capital and routine labor. Substituting them in the production function and then in the objective function gives the unit cost of the routine input in terms of factor prices. Given the assumption of perfect competition, this also equals the price of the routine input:

$$P_i^m \;=\; C(w_i, r_i) \;=\; \frac{1}{Z_i}\left[\alpha_i^{\frac{1}{1-\mu_i}} r_i^{-\frac{\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{-\frac{\mu_i}{1-\mu_i}}\right]^{\frac{\mu_i-1}{\mu_i}}. \tag{9}$$

Cost minimization of the Cobb-Douglas production function in (1) leads to a straightforward expression of unit costs of the final goods, and thus prices P_{ig}, again as a function of the relevant factor prices, i.e. the price of the routine input and the wage rate:

$$P_{ig} \;=\; C_{ig}(w_i, P_i^m) \;=\; \frac{1}{z_g}\left(\frac{w_i}{1-\beta_g}\right)^{1-\beta_g}\left(\frac{P_i^m}{\beta_g}\right)^{\beta_g}, \quad \forall g \in \{1, 2\}. \tag{10}$$

By combining (9) and (10), we can express the final goods price ratio in terms of the 'primitive' factor price ratio w_i/r_i, as in the canonical HO model (equation (B5) in the Appendix).

Note that capital can only be used in routine production. From the capital demand in routine production, we can find the optimal quantity of the routine input, and thus how much labor to allocate to routine tasks, as a function of the capital endowment and the relative factor price ratio.

Labor market clearing then gives the total quantity of abstract labor as a function of the labor endowment and factor prices: $L_i^a = \bar{L} - L_i^m(w_i, r_i; \bar{K})$. Optimal factor use in routine production together with market clearing for labor and capital determines the relative supply of produced factors, which is the relevant factor ratio for the two final goods sectors. We express the ratio of produced factors as a function of primitive endowments and the prices of the primitive factors as follows:

$$\frac{L_i^a}{M_i} \;=\; \frac{\frac{\bar{L}}{\bar{K}} - \left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\frac{1}{1-\mu_i}}}{Z_i \alpha_i^{\frac{1}{\mu_i}}\left\{1 + \frac{w_i}{r_i}\left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\frac{1}{1-\mu_i}}\right\}^{\frac{1}{\mu_i}}} \tag{11}$$

We now turn to the demand side to derive an expression for the relative demand for produced factors. We have assumed a Cobb-Douglas utility function that implies constant budget shares. Substituting the expressions for final goods prices (10), we find an expression for relative final good consumption as a function of factor prices:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{\theta_1 z_1 \beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}}{\theta_2 z_2 \beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}} \left(\frac{w_i}{P_i^m}\right)^{\beta_1-\beta_2} \tag{12}$$

Using the production function and market clearing for final goods, we can express the output ratio in (12) in terms of the allocation of the 'produced' factors to both sectors:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{Y_{i1}}{Y_{i2}} = \frac{z_1 {L_{i1}^a}^{1-\beta_1} {M_{i1}}^{\beta_1}}{z_2 {L_{i2}^a}^{1-\beta_2} {M_{i2}}^{\beta_2}}. \tag{13}$$

Plugging in the first order conditions of the final good producers and of the consumers, we find that the allocation of production factors to both sectors depends only on the preference and technology parameters.[13] As a result, the relative factor demand takes the following simple and familiar form:

$$\frac{L_i^a}{M_i} = \frac{\sum_g \theta_g(1-\beta_g)}{\sum_g \theta_g \beta_g} \frac{P_i^m}{w_i} \tag{14}$$

This is the familiar HO equation that connects relative factor abundance to relative factor prices in final good production. The only difference in our model is in terms of interpretation, i.e. the production factors in this equation are produced rather than exogenously given.

We combine the relative factor supply equation (11) with the relative factor demand equation (14) to pin down the equilibrium factor price ratio. Because the second relationship is expressed in terms of produced factor prices, we still need to use (9) to eliminate P_i^M. Equating the two expressions, 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. We can write this expression as

$$F_i\left(\omega_i^*\right) = \frac{c}{\omega_i^*} + (1+c)\left(\frac{\alpha_i\ \omega_i^*}{1-\alpha_i}\right)^{\frac{1}{1-\mu_i}} - \frac{\bar{L}}{\bar{K}} = 0 \tag{15}$$

[13] The simple form of these expressions is a result of the Cobb-Douglas functional form for both preferences and the production function that leads to constant expenditure shares for consumers and constant cost shares for producers.

where $c = (\sum_g \theta_g(1-\beta_g))/(\sum_g \theta_g\beta_g)$ summarizes information on factor use in final good production and consumers' preferences over final goods.

2.2 Normalizing the CES function

To investigate the pattern of trade, we derive the comparative statics of the relative factor price ratio with respect to the parameter of interest, the substitutability between capital and labor. However, as we illustrate in Appendix C, deriving comparative statics predictions using the CES function (2) leads to a circularity. The impact of σ on the pattern of trade depends on the effective labor cost, defined as $\varpi_i = [w_i/(1-\alpha_i)] \,/\, [r_i/\alpha_i]$, which depends itself on σ_i (through α_i).

We have already mentioned that a high σ has two opposing effects. It makes routine production more efficient, but it also makes it easier to reallocate labor from routine to non-routine tasks, for example in response to capital-biased technological change. Klump et al. (2012) have shown that normalizing the CES production function makes it possible to focus on the structural effect of higher substitutability.[14] Fundamentally, a high σ parameter implies that the marginal product of a production factor declines more slowly if the amount of that factor increases. By normalizing we will be able to compare the extent of adjustment in high-σ and low-σ countries, starting from the same initial situation.

The rationale behind the normalization of the CES production function stems from its key defining property, namely $\sigma = d\ln(K/L)/d\ln(F_k/F_l)$ is constant. This definition can be re-written as a second-order differential equation of $F(K,L)$. When this equation is solved to find F, it introduces two integration constants. These are fixed by the following two boundary conditions: (1) Each of the CES production functions that we consider, which vary in σ, needs to be able to deliver a particular production plan, a combination of output and inputs; (2) The initial allocation is cost minimizing, i.e. the isoquant is tangent to a given relative factor price ratio.

The boundary conditions follow from the elasticity of substitution implicitly being defined as a point elasticity, i.e. related to a particular point on a particular isoquant. If a CES isoquant has to go through one particular point, the choices of its integration constants will depend on σ and cannot be chosen freely. The elasticity of substitution is the only structural parameter and together with the boundary

[14] De La Grandville (1989) shows that the substitution effect can always be written as a σ-multiple of the income effect.

conditions it determines the other parameters. Hence our notation $Z_i = Z(\sigma_i)$ and $\alpha_i = \alpha(\sigma_i)$.

Comparative statics in σ that do not adjust the integration constants, i.e. keep Z and α constant, compare production functions that cannot produce the same initial production plan or are not tangent to the same initial factor price ratio. Two solutions are possible. One could take the full derivative of σ, explicitly incorporating the dependency of the other CES parameters on σ.[15] Alternatively, one can normalize the CES by making it go through an initial point (with M_0, K_0, L_0^m) and be tangent to the initial factor price ratio (or equivalently, have a capital share π_0). This approach eliminates all parameters other than σ from the CES production function and it is the one that we follow.

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 $\tilde{K}_0/\tilde{L}_0$, but independently of σ. The impact on the effective cost of labor determines the relative abundance of the produced factors or the relative price of the produced factors between the country countries, and thus the pattern of trade.

The normalization point is defined by a level of routine production M_0, a capital-routine labor ratio $\kappa_0 = K_0/L_0^m$ and a relative wage rate $\omega_0 = (w/r)_0$ that satisfies $\omega_0 = (1-\alpha_i)/\alpha_i\, \kappa_0^{1-\mu_i}$, which is the first order conditions in routine production, equation (B1). It makes the choice of labor to allocate to routine tasks independent of the capital-labor substitutability. The normalization points defines the normalized capital coefficient as

$$\alpha(\mu) \quad = \quad \frac{\kappa_0^{1-\mu}}{\kappa_0^{1-\mu} + \omega_0}. \tag{16}$$

Rewriting the routine production at the point of normalization defines normalized productivity as

$$M_0 = Z(\mu)\left[\alpha(\mu)(K_0)^{\mu} + (1-\alpha(\mu))(L_0^m)^{\mu}\right]^{\frac{1}{\mu}} \quad \Leftrightarrow \quad Z(\mu) = \frac{M_0}{L_0^m}\left(\frac{\kappa_0^{1-\mu}+\omega_0}{\kappa_0+\omega_0}\right)^{\frac{1}{\mu}} \tag{17}$$

We can now reformulate key relationships in terms of deviation from the point of normalization. That way, we can investigate how countries with different σ adjust

[15] Klump et al. (2012) show this dependency for one particular parameterization and set of boundary conditions in equations (15) and (16).

differentially to a capital-labor ratio that differs from the ratio in the normalization point. In particular, the function $F(\cdot)$ in (15) becomes

$$F_i\left(\omega_i^*;\mu_i,\frac{\bar{L}}{\bar{K}},c,\kappa_0\right) = \frac{c}{\omega_i^*}+\frac{1+c}{\kappa_0}\left[\frac{\omega_i^*}{\omega_0}\right]^{-\frac{1}{1-\mu_i}}-\frac{\bar{L}}{\bar{K}} = 0 \tag{18}$$

Denoting optimal factor allocation in routine input production by $\kappa_i^* = \bar{K}/(L_i^m)^*$, the first order condition in routine production (B1) becomes:

$$\frac{\kappa_i^*}{\kappa_0} = \left(\frac{\omega_i^*}{\omega_0}\right)^{\frac{1}{1-\mu_i}} \tag{19}$$

This illustrates the key property of the CES production function: the sensitivity of relative factor use to a change in relative factor prices is increasing in μ (σ). Hence, the same exogenous change in the capital-labor ratio will lead to a smaller change in the relative factor price ratio in a high-σ country. If labor becomes more expensive than in the point of normalization, routine production will become relatively more capital intensive in the high-σ country.

It is immediate from (18) that the equilibrium factor price ratio will be independent of μ if $\omega_i^* = \omega_0$. In this case, the optimal allocation of labor to routine production will also be the same as in the point of normalization.

NOT CLEAR WHAT IS HAPPENING NEXT: WHY NEEDED?

Given that we can choose the point of normalization of the CES production function as we see fit, we can choose it such that the effective cost of labor ϖ_0 equals one at the point of normalization, which immediately implies that $\kappa_0 = 1$ as well. In that case, $\alpha_i = 1/(1+\omega_0) = \alpha$ and it does not vary with σ. We can always pick values for the routine output and its inputs such that $Z_i = Z$ is constant as well. Plugging these values into the existence condition (see Appendix B.7 for details) gives the set of choices for initial endowments that are consistent with this normalization, namely $L_0/K_0 > (1+c)$. The wage that for a given choice of endowments at the point of normalization equalizes the relative cost of labor in the two countries is given by $\omega_i = c/[(L_0/K_0)-(1+c)] = \omega_0$ and is also independent of σ.

EVEN MORE UNCLEAR: choosing $\varpi_0 = 1$ seems to directly imply $\kappa_0 = 1$ by (B1)

More generally, we can choose any $\kappa_0 \neq 1$ whereby $\varpi_0 = 1$ when $\omega_i^* = \omega_0\kappa_0^{\mu_i-1}$

and $\varpi_i \neq 1$ at the point of normalization defined by $\omega_i^* = \omega_0$. In the general case, the distribution and productivity parameters, α_i and Z_i, will be country-specific. Plugging these values into the existence condition we again find the set of feasible choices for initial endowments: $L_0/K_0 > (1+c)/\kappa_0$. We obtain the wage that equalizes the relative wage in the two countries for a given choice of endowments at the point of normalization: $\omega_0(L_0, K_0; c) = c/[(L_0/K_0) - (1+c)/\kappa_0]$. We can readily check that the relative price of the routine input is equalized in the two countries at the point of normalization.

2.3 The magnitude of σ and the pattern of trade

2.3.1 σ mitigates relative factor scarcity

We now investigate how the relative wage ω_i^* changes when factor endowments deviate from the point of normalization. A change that leaves relative endowments unchanged, i.e. $\bar{K}/\bar{L} = K_0/L_0$, leaves the relative wage unchanged and will not change the allocation of labor to routine tasks, the only choice in the model that really depends on the σ parameter.

We therefore focus on a change in endowments that modifies the capital-labor ratio in the economy relatively to the point of normalization. Consider an change in the stock of capital $\bar{K} \gtrless K_0$ with no change in the labor endowment $\bar{L} = L_0$. We apply the implicit function theorem to $F_i(\cdot)$ in (18) to find that

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

The relative wage unambiguously rises and will exceed its value at the point of normalization whenever the stock of capital exceeds its initial level:

$$\bar{K} \gtreqqless K_0 \Rightarrow \frac{\omega_i^*}{\omega_0} \gtreqqless 1. \tag{21}$$

To learn how σ influences specialization, we apply the implicit function theorem one more time to

$$\frac{\partial \omega_i^*}{\partial \mu} = -\frac{\partial F_i(\cdot)/\partial \mu}{\partial F_i(\cdot)/\partial \omega_i^*}. \tag{22}$$

We already established that the denominator is negative. Hence, the sign of this expression is determined by the sign of the numerator,

$$\frac{\partial F_i(\cdot)}{\partial \mu} \quad = \quad -\ln\left(\frac{\omega_i^*}{\omega_0}\right)\frac{(1+c)}{\kappa_0(1-\mu)^2}\left[\frac{\omega_i^*}{\omega_0}\right]^{-\frac{1}{1-\mu}}, \tag{23}$$

which depends on the equilibrium relative wage relative to the relative wage at the point of normalization.

It follows that when the price of labor increases relatively to the point of normalization, e.g. following an increase in the capital stock, labor will be relatively cheap in the high-σ country in the new equilibrium.

$$\begin{cases} \frac{\partial \omega_i^*}{\partial \mu} < 0 & \Leftrightarrow \quad \bar{K} > K_0 \ \text{ or } \ \left(\frac{\omega_i^*}{\omega_0}\right) > 1 \\ \frac{\partial \omega_i^*}{\partial \mu} = 0 & \Leftrightarrow \quad \bar{K} = K_0 \ \text{ or } \ \left(\frac{\omega_i^*}{\omega_0}\right) = 1 \\ \frac{\partial \omega_i^*}{\partial \mu} > 0 & \Leftrightarrow \quad \bar{K} < K_0 \ \text{ or } \ \left(\frac{\omega_i^*}{\omega_0}\right) < 1 \end{cases} \tag{24}$$

A higher μ dampens the effect of a shock to factor endowments on the equilibrium relative wage.[16] When the relative wage increases, it increases relatively less in the high-σ country (A): $\omega_0 < \omega_A^* < \omega_B^*$.

Recall from (14) 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 is intuitive and straightforward to show (see Appendix C) that $d(P_i^m/w_i)/d\omega_i < 0$. In combination with the results in (24) it implies that the relative price of the routine input is increasing in μ whenever the stock of capital increases relatively to the point of normalization and vice versa:

$$\begin{cases} \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial \omega_i^*}{\partial \mu} > 0 & \& \quad \frac{d(L^a/M)}{d\mu} > 0 \quad \Leftrightarrow \quad \bar{K} > K_0 \\ \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial \omega_i^*}{\partial \mu} = 0 & \& \quad \frac{d(L^a/M)}{d\mu} = 0 \quad \Leftrightarrow \quad \bar{K} = K_0 \\ \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial \omega_i^*}{\partial \mu} < 0 & \& \quad \frac{d(L^a/M)}{d\mu} < 0 \quad \Leftrightarrow \quad \bar{K} < K_0 \end{cases} \tag{25}$$

The intuition is as follows. When labor is relatively scarce it will be expensive and the routine input relatively cheap everywhere. These price changes, which are needed to clear all factor markets after a capital injection, are especially pronounced in the low-σ country making the routine input relatively more expensive in the high-σ country. It follows that under capital deepening, the high-σ country

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

(A) is relatively non-routine labor abundant: $(L^a/M)^*_A > (L^a_/M)^*_B$. More flexible substitution between capital and labor helps the economy to use more efficiently the 'primitive' production factor that has become more scarce, where scarcity is defined relative to the point of normalization.

Note that after the adjustment, the capital intensity in routine input production will be higher in the high-σ country. Hence, when countries accumulate capital, the high-μ country tends to specialize in non-routine production.

2.3.2 The pattern of specialization

Establishing the main result is now straightforward. In our model, the two countries have identical endowments of primitive factors and it is the optimal allocation of labor to routine and non-routine tasks that determines the equilibrium quantities of the produced factors, abstract labor and routine input. The equilibrium is fully determined by the relative factor price ratio that clears labor and capital markets, satisfies the first order conditions in all three sectors, and implies unit prices that clear the final goods' markets. We have shown that to compare the relative wage in countries with a different σ parameter in their production function, it is necessary to compare its differential adjustment to the same type of exogenous shock that requires a labor reallocation.

We want to determine the 'static' effect of σ on the allocation of labor to tasks. We accomplish this by comparing how countries with different σ adjust when faced with the same exogenous increase in capital. Endogenizing capital accumulation is left for future work.[17] Here, we only highlight that differences in the substitutability of capital and labor can create an incentive to trade for countries with identical endowments. We have established that in response to capital deepening, the equilibrium ratio $(L^a_t/M_t)^*$ is increasing in σ. As capital accumulates, the high-σ country becomes relatively non-routine labor abundant.[18]

The direction of trade then follows from the standard reasoning of the HO model.

[17] We find that the return to capital falls by less in the high-σ country under capital deepening, giving it *ceteris paribus* higher incentives 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. Stokey (1996) performs a related exercise, but in a one-sector model.

[18] Or more precisely, the ratio of non-routine labor to routine input will be relatively higher in the high-σ country in a situation where the capital to labor ratio has increased relative to an initial benchmark.

The high-σ country becomes non-routine labor abundant under capital deepening and acquires a comparative advantage in the non-routine intensive good. Higher substitutability dampens the necessary factor price change that is needed to absorb a shock to factor endowments. It leads the high-σ country to specialize in the non-routine intensive final good when labor becomes relatively scarce and the price of abstract labor increases relative to the price of the routine input.

We obtain an adjusted HO prediction. When the relevant production factors for the two final good sectors are produced rather than exogenously given, the high-σ country specializes in the good that uses more intensively the produced factor that requires relatively more of the relatively scarce primitive factor. Relative scarcity (of the primitive factor) is defined in terms of deviation from the point of normalization, while the relative intensity of use (of the produced factor) is technologically determined, in the canonical HO way.

2.3.3 Implications of opening up to trade

Opening up to trade further amplifies differences between countries in the allocation of labor to routine and non-routine tasks observed in autarky. Differences in input substitutability in the two countries creates a wedge between their marginal product ratios (MP_{L^m}/MP_K) in the autarky equilibrium and thus a wedge between their relative final good prices. As capital accumulation increases the relative wage, it also increases the wage to routine input price ratio and thus the relative price of the final good that is intensive in non-routine tasks. These price changes are most pronounced in the low-σ country, which makes the non-routine intensive good relatively cheap in the other country, which has s relatively low MP_{L^m}/MP_K ratio.

Trade equalizes the relative final good price in the two countries by increasing the relative price of the good that was relatively cheap in autarky. The same happens for the MP_{L^m}/MP_K ratio. As the capital endowment is fixed by assumption, the only way this can happen is by moving labor into or out of routine input production. Thus, the country that had a relatively low MP_{L^m}/MP_K ratio and, consequently, a relatively high price of the routine-intensive good, allocates more labor to non-routine tasks.

Two additional results associated to the pattern of trade are discussed in more detail in Appendix D. First, as in the canonical HO model, opening up to trade equalizes the final good prices and leads to factor price equalization for the prices of the produced factors P^m/w. However, this does not lead to factor price equalization for the price ratio of primitive factors w/r. In our model, the two countries have different production technologies due to institutional or cultural differences that affect the flexibility of input substitution.

Second, equalization of final good prices is obtained through further divergence in the capital intensity of routine production in the two countries. Specifically, with capital deepening, the only way that the P^m/w ratio can increase in the high-σ country is by increasing its relative wage $(w/r)_A/(w/r)_B$. This requires a movement of labor out of routine production in the high-σ country. Hence, the country where capital deepening leads to a comparative advantage in the non-routine intensive good is characterized by relatively high capital intensity in routine production in autarky, and its relative capital intensity further increases when the countries open up to trade. The relative wage difference will be lower than in autarky, but not be eliminated entirely.

TO ADD: which workers gain most from capital deepening?

3 Data

The empirical analysis is based on three types of data. Bilateral export flows at the product level are used to construct the dependent variable. The explanatory variables are interactions of industry-level indicators of input intensity, in particular the routine-intensity, and country-level indicators of the corresponding endowments, including both factor endowments and quality of institutions.

Bilateral exports

Bilateral exports are reported in the UN Comtrade database and we use the 2017 release of the BACI harmonized version. Gaulier and Zignago (2010) describe an earlier release. The model predicts the cross-sectional export specialization, but we keep three years in the sample—1995, 2005, and 2015—to investigate whether the fit of the model has improved or deteriorated over the last two decades. We average exports over two adjacent years to smooth out annual fluctuations.[19] Products are observed at the 6-digit detail of the Harmonized System (HS) and mapped into 4-digit NAICS sectors using the concordance constructed by Pierce and Schott (2012).

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

We construct two separate samples that are limited to two different groups of exporters. In the 'large exporters sample' we keep bilateral exports that originate from the 50 largest exporters in the world (excluding fossil fuels). On the import-side, we keep trade flows towards those same 50 destinations separate and aggregate the remaining countries, which together account for less than 10% of global trade, into 10 separate regional blocs. In the 'EU sample', we keep only exports from the 28 EU members states, Belgium and Luxembourg are combined, and use the same set of countries on the import side.

Industry-level input intensity

The key explanatory variable is the routine task intensity by industry, which was 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 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 intended to capture sectors' technological features that determine routine intensity.[20]

As control variables, we include additional industry characteristics that represent other dimensions of the production technology. Physical capital and human capital intensity are included to capture the effects of the traditional HO mechanism. Following Nunn (2007) and Chor (2010), we measure these by the U.S.' values for the real capital stock per employee and the ratio of non-production workers to total employment from the NBER-CES database.

We further include two characteristics that capture industries' reliance on domestic institutions. External capital dependence, which was introduced by Rajan and Zingales (1998), is measured as the fraction of total capital expenditures not financed by internal cash flow. This is calculated at the firm level in the Compustat database. The median value within each ISIC 2-digit industry is assigned to the corresponding 4-digit NAICS industries.[21] Finally, the fraction of differentiated inputs in total input expenditure, using the liberal definition, is taken directly from Nunn (2007).

[20] 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.

[21] We calculate the indicator for twenty different 2-digit ISIC manufacturing industries, which are, on average, assigned to four 4-digit NAICS industries.

Country-level endowments

We follow the literature regarding endowments that are expected to give countries a comparative advantage along the four dimensions of factor intensity that we control for. Physical and human capital endowments are constructed from the *Penn World Tables*.[22] The physical capital stock is measured using constant national prices and converted into USD at current exchange rates. To obtain a capital-labor ratio, we divide by the number of employees multiplied by the average annual hours worked. Human capital is proxied by average years of schooling.

Two dimensions of institutional quality, financial development and rule of law, are conducive to industries with, respectively, a high external capital dependency and a high fraction of differentiated inputs. Financial development is measured by the amount of credit extended by banks and non-bank financial intermediaries to the private sector, normalized by GDP. This is taken from the most recent version of the World Bank's *Financial Development and Structure Dataset*.[23] The ability and effectiveness of contract enforcement is proxied by the 'rule-of-law' index published as part of the *World Bank Governance Indicators database*.[24]

We keep time-varying information on endowments for the same three years as the export flows—1995, 2005, and 2015—and similarly use two-year averages to smooth out annual fluctuations.

No existing literature establishes which country-level endowments give a comparative advantage in (non-)routine intensive production. We will investigate for a number of observable characteristics whether they have predictive power for the routine specialization that we estimate in a first stage. According to our theory, these would be factors that determine the ease of substituting between capital and labor in production.

We include GDP per capita (taken from the Penn World Tables) as a general control for development and also consider whether the widely used rule of law indicator predicts routine specialization.

Following the labor literature, we consider the role of formal labor market institutions, as measured by the stringency of employment protection legislation (EPL).

[22] The 9.1 version was downloaded from `https://www.rug.nl/ggdc/productivity/pwt/`.

[23] The July 2018 version was downloaded from `https://www.worldbank.org/en/publication/gfdr/data/financial-structure-database/`.

[24] Available online at `https://info.worldbank.org/governance/wgi/`.

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.

The degree of internal mobility measures the prevalence of adjustment in a geographic dimension. It is measured as the fraction of the population residing in a different region than their place of birth, a coarse measure of workforce mobility.[25] If workers tend to substitute easily between geographic locations, they might show similar flexibility substituting between sectors or occupations. Finally, we consider two cultural traits that could pre-dispose workers to move between sectors if opportunities present themselves. From the six dimensions of national culture introduced by Hofstede (1980), we consider 'long-term orientation' and 'uncertainty avoidance' most suitable in our context.

Where possible, we use the values of the 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 Empirical model

Our empirical strategy follows the two-step approach of Costinot (2009). In a first step, we estimate for each country the extent of revealed comparative advantage in sectors that are intensive in routine tasks. In a second step, we regress the obtained ranking on country characteristics that are likely to be correlated with the ease of labor reallocation across tasks. In a final analysis, once we have determined which endowments or institutions are conducive to (non-)routine production, we show results for a single step analysis, including the interaction between routine intensity and the relevant country characteristic.

The first step in evaluating the predictions of our model is to recover the direc-

[25] This information is taken from OECD's *Labor Market Statistics* database.

tion of export specialization of each country with respect to routine intensity. We estimate the following equation

$$\ln X_{ijg} \;\; = \;\; \gamma_i \, r_g + \sum_{t \in k,h,f,c} \gamma_t \, I_i^t \, t_g + \tau_{ij} + \tau_{jg} + \epsilon_{ijg}. \qquad (26)$$

The dependent variable is bilateral exports from exporter i to importer j in industry g. The comparative advantage in the routine dimension is captured by the country-specific coefficient γ_i that interacts with the sectoral intensity in routine tasks r_g a country-invariant measure of sectoral technology. 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 (26) 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 exporter and importer country characteristics, e.g. size or multilateral resistance, as well as any form of bilateral trade friction, e.g. proximity or historical ties. The destination-sector fixed effects τ_{jg} capture variation in import barriers, preferences, or business cycles in importing countries. We do not exploit the time dimension, but estimate equation (26) 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.

To control for other mechanisms that can explain the exporter-sector specialization, we include four interaction terms between a sector-specific technology dimension (t_g) and a country-specific endowment (I_i^t). The four terms are for physical (k) and human capital (h) intensity times endowment, the traditional HO mechanisms, as well as external capital dependence of the industry times financial development of the country (f), and importance of differentiated inputs times the quality of contract-enforcing institutions (c).

The second step in our analysis is to connect the estimated routine intensity of exports to one or more country characteristics. We wish to uncover whether observables that are plausible proxies for the country-specific ease of reallocating labor across tasks (the σ parameter in our model) have the predicted correlation with export specialization. We regress $\hat{\gamma}_{it}$, the countries' ranking by routine intensity estimated using specification (26) by year, on each of the institutional dimensions

I^r_{it}:

$$\hat{\gamma}_{it} \quad = \quad \delta_0 + \delta_1 \, \text{GDP/capita}_{it} + \delta_r \, I^r_{it} + \gamma_t + \epsilon_i, \tag{27}$$

for $r \in \{1, ..., 6\}$.

We include GDP per capita to control for the level of development and time fixed effects. The coefficient of interest is δ_r, which we expect to be negative for dimensions that are expected to have a positive correlation with σ, i.e. rule of law, quality to perform, long-term orientation, and internal mobility. For country characteristics with an expected negative correlation with σ, i.e. the stringency of employment protection legislation and uncertainty avoidance, we expect a negative sign as they are likely to impede labor reallocation.

In a final analysis, we perform the estimation in a single step:

$$\ln X_{ijg} \quad = \quad \gamma_r \, I^r_i \, r_g + \sum_{t \in k,h,f,c} \gamma_t \, I^t_i \, t_g + \tau_{ij} + \tau_{jg} + \epsilon_{ijg}. \tag{28}$$

Compared to specification (26), we replaced the country-specific coefficient γ_i with $\gamma_r \, I^r_i$, inserting one of the country endowments found to predict routine specialization in specification (27). This specification is estimated separately by year and for time-varying endowments and institutions (I^r_i and I^t_i) we use the appropriate year.

5 Results

5.1 Step 1: Revealed comparative advantage in routine tasks

We estimate each country's specialization in routine versus non-routine tasks using specification (26) and plot the γ_i point estimates. Figure 1 shows the estimates for the sample of 50 largest exporters and Figure 2 the estimates on the EU sample. Tables A.2 and A.3 in the Appendix show each country's point estimates for the two samples.

Before estimation, we standardize all variables by subtracting the mean and dividing by the standard deviation over the respective sample. As a result, the magnitudes of the coefficients are in terms of standard deviations: How many standard deviations do export flows change on average when the routine-intensity indicator is one standard deviation higher? Note, however, that this interpretation is only approximate due to the included fixed effects (which all need to be held constant when evaluating the effect of a change in routine-intensity).

Due to the included fixed effects, the γ_i estimates are also normalized to average zero over the entire sample.[26] A negative coefficient only implies that the country specializes less in routine-intensive industries than the average country in the sample. Given that the sample is almost balanced over exporters, by construction half of the countries show positive and the other half negative point estimates.

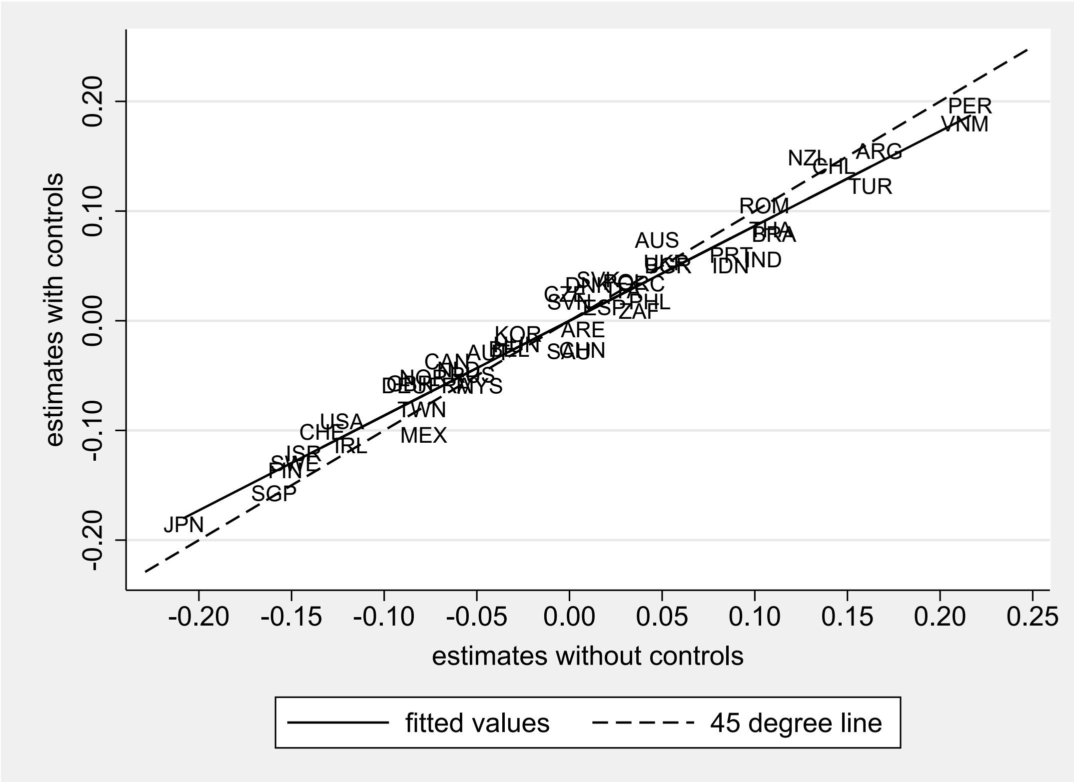
The top panel shows the country-average of the three estimates obtained using separate regressions for each of the three years. The estimates without the $I_i^t\, t_g$ interaction controls are on the horizontal axis and the corresponding estimates including the controls are on the vertical axis. The countries towards the left of the graph, in particular Japan, Singapore, Finland, Sweden, and Israel, tend to specialize more in non-routine intensive products. Also the next cluster of countries is intuitive, with Ireland, Switzerland, and the United States. At the other end of the spectrum (on the right), we find countries with a revealed comparative advantage in routine-intensive industries. Here we find more developing or emerging economies, first Peru and Vietnam, followed by Argentina and Chile. Exports of New Zealand, which is well-known to specialize in primary products, and Turkey, which is an assembly hub for EU-bound exports, are also highly routine-intensive.

It is intuitive that the results with controls on the vertical axis are lower in absolute value than the results without controls. The estimates on the left tend to lie above the 45-degree line, while on the right they tend to lie below the dashed line. The solid line shows more formally that on average the results change towards zero if controls are included. The adjustment is most notable for poorer countries with lower capital endowments or lower institutional quality than their most important trading partners, such as Mexico, India, and Turkey. Overall, however, the pattern of routine specialization is relatively unaffected by the inclusion of the four sets of interaction controls that capture alternative explanations for the countries' export specialization.

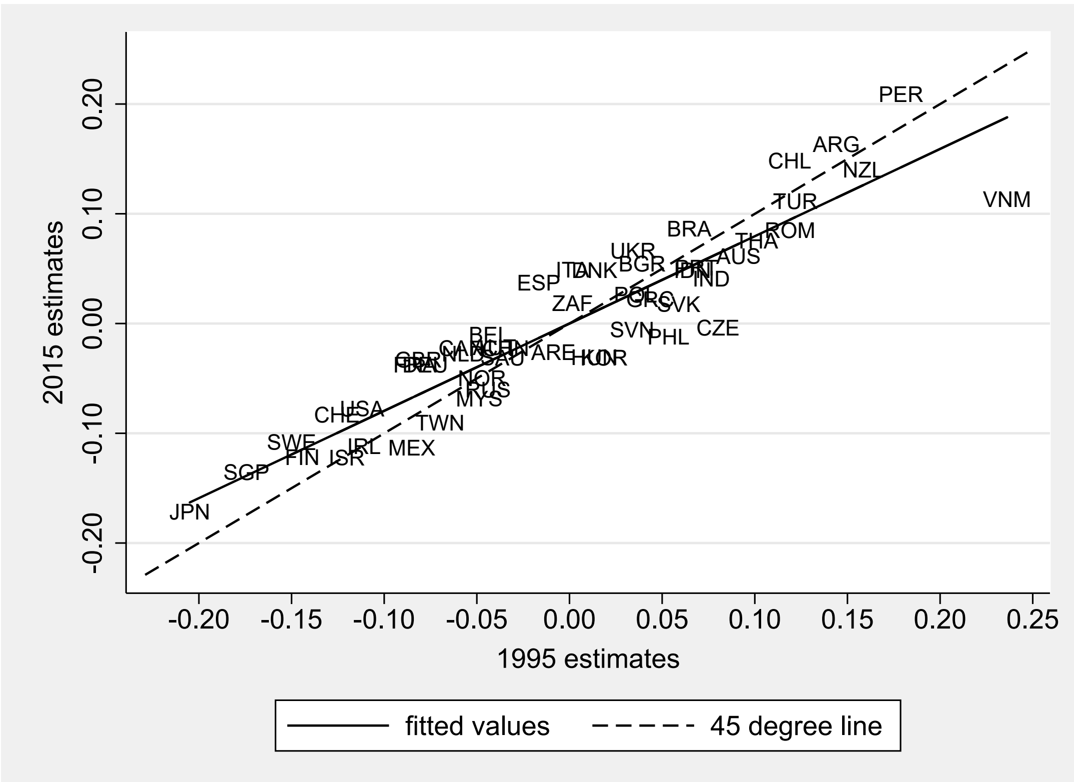
One more notable pattern is the large difference in specialization between some countries that share similar levels of development. Finland and Sweden have much lower (more negative) point estimates than Norway or Denmark. The contrast

[26] Because of the two sets of fixed effects, 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 in the figures are explicitly normalized to have an average of zero over the different countries.

Figure 1: (Non-)Routine export specialization in sample of 50 largest exporters



(a) Estimates with and without Heckscher-Olin interaction terms



(b) Estimates for 1995 versus 2015 (with controls) between France and Italy or between Spain and Portugal is also very large. The same holds in the other continents: in Latin America, Mexico is much less specialized in routine-intensive industries than Argentina or Chile; in Asia, Malaysia much less than Thailand.

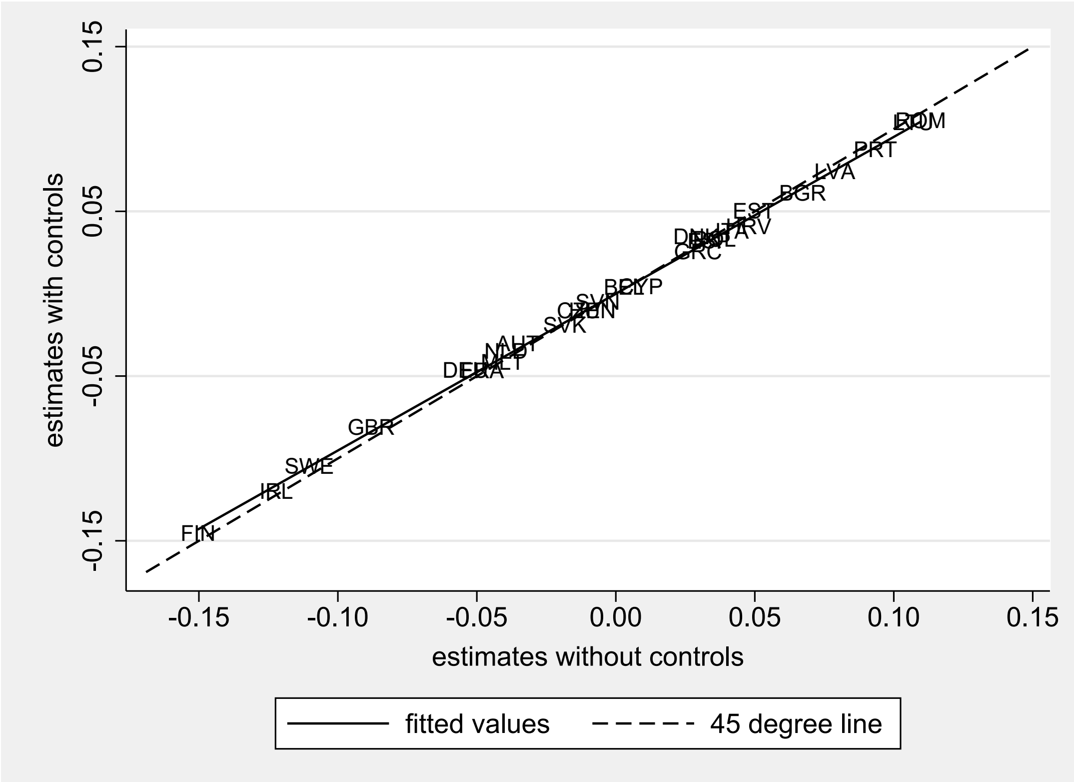
The bottom panel of Figure 1 plots the point estimates for 2015 (on the vertical axis) against the corresponding estimates for 1995 (on the horizontal axis) including the HO interaction controls in both years.[27]. Over this twenty year period, countries' specialization by routine-intensity is relatively stable. Large deviations from the 45-degree line are rare. The two largest changes are for Vietnam and the Czech Republic which both oriented away from the routine-intensive sectors. Spain, the United Kingdom and Italy are among the countries with the largest change in the opposite direction, towards routine-intensive industries. The flattening of the solid line suggests that in 2015 the routine intensity of a sector has somewhat less predictive power for a country's exports compared to 1995.

In Figure 2 we show comparable estimates for the sample of EU countries, including only 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 not surprising as the intra-EU share of exports tends to be very high for most member states. The two countries that move up in the ranking the most when we look solely at intra-EU trade are the United Kingdom and Slovakia. In the full sample, the United Kingdom, France, and Germany are rather specialized in non-routine industries in 1995, each with a coefficient of around -0.08 (at rank 10 to 12). For all three countries this specialization diminishes by 2015 as the coefficient estimates rises to around -0.035 by 2015 (at rank 14 to 16). Limited to EU trade, we see the same evolution for France and Germany and they each drop 3 places in the ranking among EU countries. The United Kingdom almost maintains its specialization and its rank.

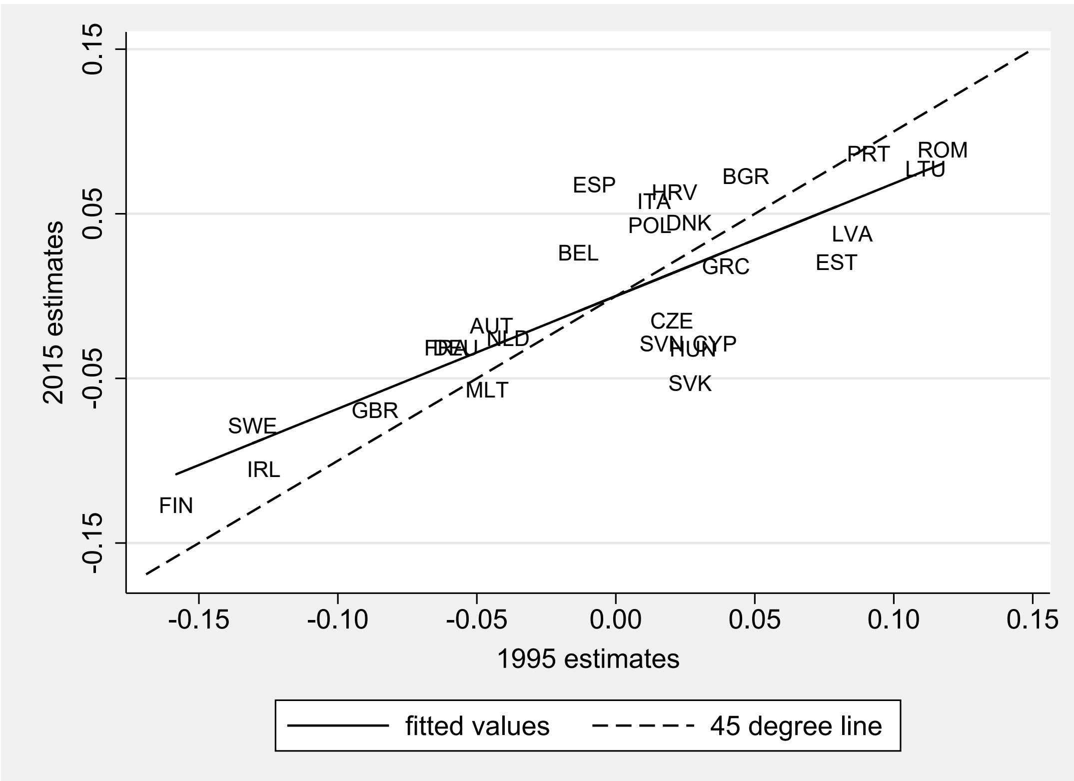
As is the case of France and Germany, a few other older member states go down quite a bit in the ranking. Belgium, Italy, and Spain had negative or in the case of Italy a very low positive coefficient in 1995, but by 2015 they all three show a clear revealed comparative advantage in routine-intensive industries. Given that we only uncover a relative specialization, the reverse pattern must hold for some other countries. Among EU countries that appear in both samples, Slovakia is at

[27]For almost all countries, the 2005 estimates are intermediate, as shown in Table A.2.

Figure 2: (Non-)Routine export specialization among EU member states



(a) Estimates with and without Heckscher-Olin interaction terms



(b) Estimates for 1995 versus 2015 (with controls) rank 18 (or fourth last) in the full sample, but in fifth place in the EU sample. It indicates that its intra-EU exports are systematically different from its extra-EU exports. Moreover, especially for intra-EU trades its specialization has shifted notably towards non-routine industries with the point estimate falling from 0.027 to -0.053. Other countries with a sharp decline in coefficient are Cyprus, Hungary, Estonia, and Slovenia.

The two panels of Figure 2 are also very revealing. The bottom panel shows a convergence in export orientation. Countries with negative coefficients in 1995 are systematically above the 45-degree line in 2015 and the reverse is true for countries with positive coefficients in 1995. Most countries see their γ_i coefficient shrink towards zero. As a result, routine-intensity has less predictive power for countries' export bundle in 2015 than in 1995. This can also be gauged from the decline in the standard deviation across the point estimates in Table A.3 from 0.072 to 0.060. However, in the middle of the graph we see two clusters of countries with relatively similar export orientation in 1995, but with a different evolution in the next 2 decades. Spain, Belgium, and Italy, as mentioned already, but also Croatia and Poland move towards specialization in routine-intensive industries. Slovakia, Hungary, Cyprus, Slovenia, and the Czech Republic change in the opposite direction.

The top panel compares the estimates with and without HO control interactions. It is remarkably how invariant the estimates are to these controls. Results are almost identical with or without and the fitted line lies almost on top of the dashed 45-degree line. It implies that routine-intensity has predictive power for trade flows that is orthogonal to the most important endowment or institution-based explanations in the literature.

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.

5.2 Step 2: Country characteristics that predict (non-)routine specialization

To learn which country characteristics are correlated with the pattern of routine versus non-routine specialization that was recovered in step 1, we report the estimates

Table 1 Country determinants for routine versus non-routine export specialization

	Dependent variable is the country-specific extent of specialization in routine-intensive industries estimated in the first stage						
	(1a)	(2a)	(3a)	(4a)	(5a)	(6a)	(7a)
(a) Sample of 50 largest exporters							
log(GDP/capita)	-0.541***	-0.061	-0.667***	-0.603***	-0.621***	-0.662***	-0.091
	(.120)	(.127)	(.118)	(.075)	(.072)	(.121)	(.163)
Rule of law	-0.081						0.122
	(.108)						(.119)
Ability to perform		-0.721***					-0.590***
		(.115)					(.119)
Strictness of EPL			0.053				
			(.091)				
Uncertainty avoidance				0.202***			0.137*
				(.067)			(.077)
Long-term orientation					-0.294***		-0.324***
					(.065)		(.065)
Internal migration						-0.172*	
						(.092)	
Observations	150	120	102	150	150	90	120
Adjusted R2	0.285	0.425	0.257	0.324	0.371	0.265	0.525

	(1b)	(2b)	(3b)	(4b)	(5b)	(6b)	(7b)
(b) Sample of EU member states							
log(GDP/capita)	-0.542**	-0.174	-0.788***	-0.790***	-0.884***	-0.516***	-0.454
	(.218)	(.313)	(.139)	(.121)	(.120)	(.184)	(.225)
Rule of law	-0.313*						-0.229
	(.160)						(.172)
Ability to perform		-0.450**					
		(.207)					
Strictness of EPL			0.358***				0.289***
			(.099)				(.105)
Uncertainty avoidance				0.226**			0.158
				(.089)			(.119)
Long-term orientation					0.063		0.027
					(.088)		(.097)
Internal migration						-0.358***	
						(.123)	
Observations	81	48	63	81	81	54	63
Adjusted R2	0.437	0.242	0.414	0.455	0.412	0.267	0.443

Note: The dependent variable is the country-specific estimates of routine-specialization in exports (the point estimates reported in Tables A.2 and A.3). EPL stands for employment protection legislation. Regressions include year fixed effects. The reported statistics are standardized beta-coefficients which measure effects in standard errors. Standard errors are in brackets. ***, **, * indicate statistical significance at the 1%, 5%, 10% level.

of specification (27) in Table 1. Each of the six country characteristics is introduced separately in columns 1–6 and simultaneously in column 7. In the last regression we omit the two characteristics with most missing observations to preserve the sample size. The reported estimates are standardized β coefficients to make the absolute magnitudes of the point estimates of different variables comparable.

GDP per capita is always included as a control variable because countries at different levels of development are likely to have different institutional quality and industrial structure. Given that most country characteristics we consider are correlated with the level of development, they are all likely to have some predictive power, but it would be difficult to interpret them. Not surprisingly, GDP per capita is always negatively related to the extent of specializing in routine-intensive industries.

More surprising is the insignificant coefficient on the rule-of-law variable in the top panel, for the sample of large exporters. To some extent, this is due to the high correlation with GDP per capita, showing a partial correlation coefficient of 0.61. Without the control variable, the coefficient on rule-of-law becomes -0.455 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 coefficient on rule-of-law is -0.313 and barely significantly different from zero. Without the control variable it becomes -0.670 with a t-statistic of 4.5. These results highlight that interpreting the effects of rule-of-law warrants some caution.

The other columns in panel (a) suggest that four of the five observables have predictive power, even when we control for the level of development. Countries with a high workforce quality are especially likely 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. It explains fully 44% of the variation in the dependent variable. However, it is even more strongly correlated with GDP per capita than rule-of-law, showing a partial correlation statistic of 0.75 overall and even 0.88 in 1995.

More interestingly, the two dimensions of national culture are correlated with export specialization in the direction predicted by the theory. Countries where workers are more risk averse or have a more short-term orientation tend to specialize relatively more in routine-intensive tasks. It is plausible that both of these features are inversely related to the σ coefficient in the model that governs the capital-labor substitution. The extent to which countries adjust their production structure when more productive capital is introduced is likely to be lower when workers and managers are highly risk averse and have no long-term outlook.

In the micro-foundation of our production function, we showed that firing restrictions naturally have such an effect. The strictness of employment protection legislation (EPL) has the predicted positive sign on both samples, but it is only a significant predictor of export specialization on the EU sample with countries that are relatively similar in most other dimensions. Among EU countries, EPL is the most robust predictor of export specialization when different dimensions are included simultaneously. Countries that enacted laws and regulations to make firing workers more costly and to restrict temporary employment tend to specialize in more routine-intensive tasks. 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.

The last variable, the extent of internal migration, has the predicted negative sign in both samples, but it is only observed for a subset of countries. Unfortunately, it is only observed for two thirds of the countries in the sample and it is unlikely to have the same interpretation in large and small countries.

Because the dependent variable has no clear cardinal interpretation, we also implemented a more flexible estimation approach as a robustness check. We can treat the dependent variable as an ordinal variable and estimate specification (27) as an ordered probit model. It makes the point estimates not comparable and harder to interpret, but the signs for the different country characteristics are always unchanged. In this case, it is preferable to estimate separate models by year, rather than pooling and controlling for time fixed-effects, but most of the t-statistics did not decline much even on samples only one third the size.[28]

5.3 Single-step estimation

Now that we have a sense which attributes make a country specialize in routine-intensive industries, we can include an interaction between the routineness indicator r_g and the preferred country 'endowment' I_i^r directly in the initial regression. Based on the results on the EU sample, we interact r_g with the EPL measure. The results

[28] Results available upon request.

Table 2 Relative importance of different Heckscher-Ohlin mechanisms

	Dependent variable is the country-specific extent of specialization in routine-intensive industries estimated in the first stage					
	1995		2005		2015	
	(1a)	(2a)	(3a)	(4a)	(5a)	(6a)
<u>(a) Sample of 50 largest exporters</u>						
Routineness	0.139***		0.115***		0.115***	
* employment protection regulation	(.011)		(.010)		(.009)	
Routineness		0.224***		0.217***		0.189***
* culture		(.009)		(.008)		(.007)
Capital-intensity	0.004	0.038***	0.0004	0.032***	0.003	0.036***
* K/L ratio for entire economy	(.004)	(.004)	(.004)	(.003)	(.004)	(.003)
Human capital-intensity	0.424***	0.358***	0.450***	0.369***	0.478***	0.426***
* School enrollment	(.012)	(.008)	(.011)	(.008)	(.012)	(.009)
Differentiated input share	0.046***	0.111***	-0.002	0.089***	-0.005	0.068***
* rule of law	(.005)	(.004)	(.004)	(.003)	(.004)	(.003)
External capital dependency	-0.025***	-0.037***	0.004	-0.014***	0.020***	0.001
* financial development	(.003)	(.002)	(.003)	(.002)	(.003)	(.002)
Observations	160,694	219,894	177,821	253,409	183,935	265,276

	(1b)	(2b)	(3b)	(4b)	(5b)	(6b)
<u>(b) Sample of EU member states</u>						
Routineness	0.169***		0.202***		0.162***	
* employment protection regulation	(.019)		(.018)		(.017)	
Routineness		0.098***		0.099***		0.111***
* culture		(.017)		(.016)		(.014)
Capital-intensity	0.002	0.001	-0.012	0.016**	-0.008	0.025***
* K/L ratio for entire economy	(.009)	(.008)	(.009)	(.007)	(.008)	(.007)
Human capital-intensity	0.236***	0.198***	0.185***	0.164***	0.180***	0.039
* School enrollment	(.025)	(.025)	(.024)	(.024)	(.024)	(.024)
Differentiated input share	0.157***	0.159***	0.055***	0.098***	0.041***	0.060***
* rule of law	(.010)	(.008)	(.008)	(.007)	(.007)	(.006)
External capital dependency	-0.042***	-0.049***	-0.018***	-0.025***	-0.001	0.003
* financial development	(.005)	(.005)	(.005)	(.005)	(.006)	(.004)
Observations	40,899	48,988	43,962	54,561	44,977	56,556

Note: Dependent variable is the log of bilateral exports at the industry level. Explanatory variables are the interactions between industry-level intensities and country-level endowments. "Culture" is the average between uncertainty avoidance and short-term orientation. All regressions include destination-industry and origin-destination fixed effects. The dependent and explanatory variables are standardized Z-variables such that the effects are measures in standard deviations. Standard errors in brackets. ***, **, * indicate statistical significance at the 1%, 5%, 10% level.

on the large exporters sample highlighted the importance of national culture and we interact r_g with the average of uncertainty avoidance and short-term orientation. Results in Table 2 are shown separately for the two samples and each of the three years.

On the large exporters sample, human capital is by far the most important determinant of countries' export specialization. Capital intensity and the ability to enforce contracts for differentiated inputs also show the predicted positive sign in most specifications, but their predictive power is much lower. The combination of routine task intensiveness and the national culture indicator is remarkably important as well. It is easily the second most important predictor. Even routineness interacted with EPL turns out to be a strong predictor of export specialization, even on the sample of large exporters.

On the sample of EU countries, results are rather similar. Both mechanisms that we have introduced show the expected sign and point estimates are remarkably large. The interaction of routine intensity and EPL predicts export specialization equally well as human capital. Culture is not as important as on the broader sample of panel (a), but it still shows a robust and strong effect. Especially in the last year of the sample, when EU countries have probably converged in economic structure and institutions, the interaction of culture and routine-intensity has become the most important predictor.

5.4 Results using value added trade

As a final robustness check, we investigate whether the results differ using value added trade rather than gross exports as dependent variable. Due to integration of production processes across borders, the gross export flows in the official statistics are often not representative of the underlying exchange of value added. Given that our model abstracts away from trade in intermediate goods, it is more representative of value added trade.

For this analysis we rely on the sectoral information in the *World Input-Output Database* (WIOD).[29] We follow Los et al. (2016) who illustrate how to construct a measure of value added trade from the input-output table using an intuitive "hypothetical extraction" method. It takes the difference between observed GDP in a country and what would have resulted if final demand from a single trading part-

[29] We used the latest release, for 2016, which can be downloaded from `http://www.wiod.org/`.

ner were removed from the world economy, leaving all other sources of demand and input-output relationships unaffected.

This analysis is of course limited to the level of detail in the WIOD. It contains 43 countries and 56 sectors in total, but for comparability with the earlier results, we only use a subset of this. We only use the information in 2014, the latest year in the WIOD, and estimate specification (26) on two samples. The intersection between the WIOD and the 50 largest exporters that we studied before is a first sample of 36 countries. On the import side we include information from the 'rest-of-the-world' aggregate and we combine the imports from 7 small EU countries. As before, the second sample consists of the same 27 EU member states and we again restrict it to intra-EU trade. Of the 56 sectors, only 17 are in manufacturing, for which we observe the routineness indicator which we need to aggregate to this level.

In Figure E.1 in the Appendix we compare for both samples two sets of estimates obtained on the WIOD data. On the horizontal axis are results using gross exports as dependent variable. These estimates differ somewhat from those reported in Figures 1 and 2 due to the different country sample and industry detail. Overall, the ranking of countries is very similar with a partial correlation of more than 0.8. On the horizontal axis we show the corresponding country-coefficients obtained using the value added trade dependent variable.

Most countries are fairly close to the 45-degree line and the broad ranking is maintained. A few countries, in particular Denmark, the United States, and Taiwan, are found to specialize more in non-routine products based on the value added trade measure. Especially in the case of Denmark, this moves the country closer to the position of the other Scandinavian countries and also the other two changes are plausible.

On the EU sample, in the bottom panel, deviations from the 45-degree line appear to be somewhat larger. But also in this case is the relationship between the two estimates very strong. The partial correlation between the measure displayed on the two axes is 0.91 and the spearman rank correlation is equally large at 0.89. Using the value added measure does not change the earlier conclusions materially.

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 micro-foundations (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.

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Appendix A Support for parameter assumptions

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.[30] Real output and an index of capital services are reported directly in the database.

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.[31] Importantly, each of these studies looks at a single country and assumes a constant value for the elasticity of substitution.

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

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

[31] Goos et al. (2014) impose a capital-labor substitutability equal to one in the production of each task.

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.[32] 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 variables and parameters, we estimate the following equation,

$$Y_t \;=\; A\left[\,L_t^a\,\right]^{1-\beta}\left[(1-\pi_0)\left(\frac{L_t^m}{L_0^m}\right)^{\mu}+\pi_0\left(\frac{K_t}{K_0}\right)^{\mu}\right]^{\beta/\mu}, \qquad \text{(A1)}$$

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 A.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.

[32]We force the β coefficient to lie between 0 and 0.6 and the μ coefficient between $-\infty$ and 1.

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

	Sum of squares: level (and share)				F-statistic (and p-value)		
	Dep. Var.	Sector (33)	Country (20)	Year (25)	Sector	Country	Year
(a) Observable variables							
$\left(\frac{L^a}{L^a+L^m}\right)^{(i)}$	9.98	5.41	2.84		62.03	53.69	
	(100%)	(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
	(100%)	(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)	
$\mu_{ig}{}^{(ii)}$	1636	191	217		1.03	1.93	
		(11.7%)	(13.3%)		(0.43)	(0.01)	

(i) The dependent variable is the average abstract labor share over the period
(ii) Only includes country-sector observations with $\hat{\sigma}_{ig} < 20$

In panel (b) of Table A.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.

Appendix B Solving the model: step-by-step

The model features three types of price-taking firms: one type produces the routine intermediate input, the other types produce the two final goods. We solve the model by deriving the cost-minimizing input choices for a representative firm of each of the three types.

B.1 Routine production

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

$$M_{if} = Z_i \left[\alpha_i (K_{if})^{\mu_i} + (1-\alpha_i)(L^m_{if})^{\mu_i}\right]^{\frac{1}{\mu_i}} \tag{2}$$

with w_i the wage and r_i the cost of capital. Its cost minimization problem is:

$$\begin{cases} \min\limits_{L^m,\, K} \; w_i L^m_{if} + r_i K_{if} \\ \text{s.t.} \;\; M_{if} \;\le\; Z_i \left[\alpha_i (K_{if})^{\mu_i} + (1-\alpha_i)(L^m_{if})^{\mu_i}\right]^{\frac{1}{\mu_i}} \end{cases}$$

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

$$\frac{L^m_{if}}{K_{if}} = \left[\frac{w_i}{r_i}\,\frac{\alpha_i}{1-\alpha_i}\right]^{-\frac{1}{1-\mu_i}}. \tag{B1}$$

We use this expression with the production function to write the conditional factor demands as a function of output M_{if} and the factor price ratio:

$$K_{if} = \frac{M_{if}}{Z_i}\left[\frac{r_i}{\alpha_i}\right]^{-\frac{1}{1-\mu_i}}\left[\alpha_i^{\frac{1}{1-\mu_i}} r_i^{-\frac{\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{-\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}} \tag{B2}$$

$$L^m_{if} = \frac{M_{if}}{Z_i}\left[\frac{w_i}{1-\alpha_i}\right]^{-\frac{1}{1-\mu_i}}\left[\alpha_i^{\frac{1}{1-\mu_i}} r_i^{-\frac{\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{-\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}. \tag{B3}$$

We then obtain the cost function for intermediate input producers by substituting these conditional factor demands in the objective function. Dividing through by the routine intermediate quantity M_{if} gives the unit cost, which equals the intermediate input price

$$P^m_i = C(w_i, r_i) = \frac{1}{Z_i}\left[\alpha_i^{\frac{1}{1-\mu_i}} r_i^{-\frac{\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{-\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1-\mu_i}{\mu_i}}. \tag{9}$$

B.2 Final good production

The production function of a firm producing final good g is:

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

with factor prices P^m_i and w_i as given. Its cost minimization problem is

$$\begin{cases} \min\limits_{L^a,\, M} \; w_i L^a_{igf} + P^m_i M_{igf} \\ \text{s.t.} \;\; Y_{igf} \;\le\; z_g \left(L^a_{igf}\right)^{1-\beta_g} (M_{igf})^{\beta_g} \end{cases}$$

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

$$\frac{L^a_{igf}}{M_{igf}} \;=\; \frac{1-\beta_g}{\beta_g} \, \frac{P^m_i}{w_i}. \tag{B4}$$

Again, plugging this expression in the production function, we can write the conditional factor demands as a function of output Y_{igf} and the factor price ratio:

$$\begin{aligned} L^a_{igf} &= \frac{Y_{igf}}{z_g} \left[\frac{w_i}{P^m_i} \, \frac{\beta_g}{1-\beta_g} \right]^{-\beta_g} \\ M_{igf} &= \frac{Y_{igf}}{z_g} \left[\frac{w_i}{P^m_i} \, \frac{\beta_g}{1-\beta_g} \right]^{1-\beta_g} \end{aligned}$$

We obtain the cost of production by substituting these conditional factor demands in the objective function. Dividing through by the final good quantity gives the unit cost, which is also the final good price:

$$P_{ig} \;=\; C_{ig}(w_i, P^m_i) \;=\; \frac{1}{z_g} \left(\frac{w_i}{1-\beta_g} \right)^{1-\beta_g} \left(\frac{P^m_i}{\beta_g} \right)^{\beta_g}, \qquad \forall g \in \{1, 2\}. \tag{10}$$

By replacing the price of the routine intermediate in (10) by its function of primitive factor prices (9), we express the price of each final good in terms of the primitive factor prices, the wage and rental rate of capital:

$$P_{ig} \;=\; \frac{1}{z_g \, Z_i^{\beta_g}} \left[\frac{w_i}{1-\beta_g} \right]^{1-\beta_g} \frac{1}{\beta_g^{\beta_g}} \left[\alpha_i^{\frac{1}{1-\mu_i}} r^{\frac{-\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{\frac{-\mu_i}{1-\mu_i}} \right]^{-\frac{(1-\mu_i)}{\mu_i} \beta_g} \tag{B5}$$

B.3 Relative supply of 'produced' factors

We next use the resource constraints for capital and labor. Capital market clearing is straightforward because capital can only be used in routine production: $\sum_f K_{if} = \bar{K}$. We can rewrite the capital demand in routine production, equation (B3), as

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

From this we find the optimal quantity of the routine input M_i, and thus how much labor to allocate to routine tasks, as a function of the capital endowment and the relative factor price ratio by summing across all firms

$$\sum_f M_{if} = M_i = Z_i\,\bar{K}\,\alpha_i^{\frac{1}{\mu_i}}\left[1+\frac{w_i}{r_i}\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{-\frac{1}{1-\mu_i}}\right]^{\frac{1}{\mu_i}}.$$

Labor market clearing then gives the total quantity of abstract labor as a function of the labor endowment and factor prices: $L_i^a = \bar{L} - \sum_f L_{if}^m(w_i, r_i; K_{if})$. The appropriate expression for L_{if}^m is given directly by the ratio of first order conditions in routine production (B1).

Optimal factor use in routine production together with market clearing for labor and capital determines the relative supply of the produced factors. We express it as a function of primitive endowments and the prices of the primitive factors as follows:

$$\frac{L_i^a}{M_i} = \frac{\bar{L}-L_i^m}{M_i} = \frac{\bar{L}-\left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\frac{1}{1-\mu_i}}\bar{K}}{Z_i\bar{K}\alpha_i^{\frac{1}{\mu_i}}\left\{1+\frac{w_i}{r_i}\left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\frac{1}{1-\mu_i}}\right\}^{\frac{1}{\mu_i}}} \tag{11}$$

Equivalently, we could use (9) to write the relative factor supply as a function of the wage and of the price of the routine input:

$$\frac{L_i^a}{M_i} = \frac{\bar{L}-\left[\frac{\alpha_i}{1-\alpha_i}\right]^{\frac{1}{\mu_i}}\left[\left(\frac{P_i^m}{w_i}\right)^{-\frac{\mu_i}{(1-\mu_i)}}(1-\alpha_i)^{-\frac{1}{(1-\mu_i)}}Z_i^{-\frac{\mu_i}{(1-\mu_i)}}-1\right]^{-\frac{1}{\mu_i}}\bar{K}}{Z_i\bar{K}\alpha_i^{\frac{1}{\mu_i}}\left[1-\left(\frac{P_i^m}{w_i}\right)^{\frac{\mu_i}{1-\mu_i}}(1-\alpha_i)^{\frac{1}{1-\mu_i}}Z_i^{\frac{\mu_i}{1-\mu_i}}\right]^{-\frac{1}{\mu_i}}} \tag{B6}$$

B.4 The demand side

We have assumed a standard Cobb-Douglas utility function to represent preferences over 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 ratio of the consumer's two first order conditions 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:

$$P_{i2}Q_{i2} = \frac{\theta_2}{\theta_1} P_{i1}Q_{i1} \tag{B7}$$

By substitution in the final good prices (10), we can re-write this expression as a function of the wage rate and the price of the routine input:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{\theta_1 z_1 \beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}}{\theta_2 z_2 \beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}} \left(\frac{w_i}{P_i^m}\right)^{\beta_1-\beta_2} \tag{12}$$

Alternatively, we can also write this expression as a function of the primitive factor prices by using equation (B5) instead to eliminate the final good prices:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{\theta_1 z_1 \beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}}{\theta_2 z_2 \beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}} (Z_i w_i)^{\beta_1-\beta_2} \left[\alpha_i^{\frac{1}{1-\mu_i}} r^{\frac{-\mu_i}{1-\mu_i}} + (1-\alpha_i)^{\frac{1}{1-\mu_i}} w_i^{\frac{-\mu_i}{1-\mu_i}}\right]^{-\frac{(1-\mu_i)}{\mu_i}(\beta_2-\beta_1)} \tag{B8}$$

B.5 Relative demand for 'produced' factors

We now combine optimal factor allocation in the production of both final goods with goods market clearing. We start from the market clearing condition $Q_{ig} = Y_{ig}$ and the upper nest of the production function (1) to express relative demand for the two goods as a function of the factors used in their production:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{Y_{i1}}{Y_{i2}} = \frac{z_1 L_{i1}^{a\;1-\beta_1} M_{i1}{}^{\beta_1}}{z_2 L_{i2}^{a\;1-\beta_2} M_{i2}{}^{\beta_2}}. \tag{13}$$

Using the first order conditions in final goods production (B4), we can eliminate one of the production factors from both the numerator and the denominator and replace it by a function of the other factor and the relative factor price. We do this for both factors:

$$
\begin{aligned}
\frac{Q_{i1}}{Q_{i2}} &= \left[\frac{w_i}{P_i^m}\right]^{\beta_1-\beta_2} \frac{z_1 L_{i1}^a\left[\beta_1/(1-\beta_1)\right]^{\beta_1}}{z_2 L_{i2}^a\left[\beta_2/(1-\beta_2)\right]^{\beta_2}} \\
\frac{Q_{i1}}{Q_{i2}} &= \left[\frac{w_i}{P_i^m}\right]^{\beta_1-\beta_2} \frac{z_1 M_{i1}\left[(1-\beta_1)/\beta_1\right]^{1-\beta_1}}{z_2 M_{i2}\left[(1-\beta_2)/\beta_2\right]^{1-\beta_2}}.
\end{aligned}
$$

We then equate both of these expressions to (12), the ratio of first order conditions from the consumers' problem, where the final goods prices have already been replaced by the factor prices. The two resulting expressions determine the allocation of abstract labor and the routine input to the two final goods sectors:

$$
\frac{L_{i1}^a}{L_{i2}^a} = \frac{\theta_1(1-\beta_1)}{\theta_2(1-\beta_2)} \quad ; \quad \frac{M_{i1}}{M_{i2}} = \frac{\theta_1\beta_1}{\theta_2\beta_2}. \tag{B9}
$$

Given the Cobb-Douglas functional form assumptions on both the preferences and technology, this allocation depends solely on preference and production function parameters β_g and θ_g.

Factor market clearing for abstract labor and the routine input across their use in the two final good sectors implies $L_{i2}^a = L_i^a - L_{i1}^a$ and $M_{i2} = M_i - M_{i2}$. Substituting in (B9) and rearranging, we find

$$
L_{i1}^a = \frac{\theta_1(1-\beta_1)}{\sum_g \theta_g(1-\beta_g)} L_i^a \quad ; \quad M_{i1} = \frac{\theta_1\beta_1}{\sum_g \theta_g\beta_g} M_i. \tag{B10}
$$

Next, we take the ratio of the two factor demands (B10) for sector 1 and equate it to the first order condition ratio (B4). After rearranging, we find the familiar HO equation that 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:

$$
\frac{L_i^a}{M_i} = \frac{\sum_g \theta_g(1-\beta_g)}{\sum_g \theta_g\beta_g} \frac{P_i^m}{w_i} \tag{14}
$$

We denote $c = \frac{\sum_g \theta_g(1-\beta_g)}{\sum_g \theta_g\beta_g}$ and replace the price of the routine input by its value in (9) to find the relative factor demand in terms of the primitive factor prices

$$
\frac{L_i^a}{M_i} = c\left[\frac{w_i}{r_i} Z_i \alpha_i^{\frac{1}{\mu_i}}\right]^{-1} \left[1 + \left(\frac{w_i}{r_i}\right)\left(\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right)^{\frac{-1}{1-\mu_i}}\right]^{\frac{\mu_i-1}{\mu_i}}. \tag{B11}
$$

B.6 The equilibrium factor price ratio

The final step is to solve for the equilibrium factor price ratio by equating the relative factor supply and demand. We have derived expressions for both equations in terms of the primitive factor prices—(11) and (B11)—and in terms of the produced factor prices—(B6) and (14). We follow the first approach and find

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

Rearranging and simplifying gives an implicit solution for the equilibrium factor price ratio $\omega_i^* = (w_i/r_i)^*$:

$$\omega_i^* = c\left[\frac{\bar{L}}{\bar{K}}-(1+c)\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}(\omega_i^*)^{\frac{-1}{1-\mu_i}}\right]^{-1} \tag{B12}$$

B.7 Existence and uniqueness

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

$$F_i\left(\omega_i^*;\mu_i,\frac{\bar{L}}{\bar{K}},c,\alpha_i,A_i\right) = (\omega_i^*)^{-1}c+(1+c)\left[(\omega_i^*)^{-\frac{1}{1-\mu_i}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\right]-\frac{\bar{L}}{\bar{K}} = 0 \tag{B13}$$

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:

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

$$\Leftrightarrow \frac{\bar{L}}{\bar{K}}(\omega_i^*)^{\sigma_i}-c\,(\omega_i)^{\sigma_i-1}-(1+c)\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\sigma_i} = 0 \tag{B14}$$

The derivative with respect to ω_i^* is:

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

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 (15) 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 $\bar{L}/\bar{K}$.[33] Differentiating both sides with respect to $\bar{L}/\bar{K}$, we get:

$$\left[\frac{\partial\left(\frac{r_i}{w_i}\right)^*}{\partial\left(\frac{\bar{L}}{\bar{K}}\right)}\right] d\left(\frac{\bar{L}}{\bar{K}}\right) = \frac{1}{1+\sigma_i\left[\frac{w_i^*\bar{L}}{r_i^*\bar{K}}-1\right]} d\left(\frac{\bar{L}}{\bar{K}}\right) \leq \frac{1}{c} d\left(\frac{\bar{L}}{\bar{K}}\right) \quad \Leftrightarrow \quad c \leq 1+\sigma_i\left[\frac{w_i^*\bar{L}}{r_i^*\bar{K}}-1\right] \tag{B15}$$

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 $c = 1$.[34] It is immediate that the initial inequality can be rearranged as $1 \leq w_i^*\bar{L}/r_i^*\bar{K}$ whereby (B15) 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 (B15). Notwithstanding this increase in the cost of capital, it remains optimal to use the full amount of capital in routine input production. Indeed, (B1) indicates that by increasing the amount of capital used in production we always decrease the relative cost of capital and free up labor

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

[34] $c = 1$ 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.

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 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:

$$\left[\frac{\partial\left(\frac{w_i}{r_i}\right)^*}{\partial\left(\frac{\bar{K}}{\bar{L}}\right)}\right] = \frac{\left(\frac{w_i^*\bar{L}}{r_i^*\bar{K}}\right)^2}{c + \frac{1}{1-\mu_i}\left\{(1+c)\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu_i}}\left[\left(\frac{w_i}{r_i}\right)^*\right]^{-\frac{\mu_i}{1-\mu_i}}\right\}} \geq c \tag{B16}$$

From the polynomial we know that the expression in the curly brackets of (B16) is equal to $\left[w_i\bar{L}/r_i\bar{K} - c\right]$. Rearranging and simplifying the above expression, we get:

$$\left[\frac{\partial\left(\frac{w_i}{r_i}\right)^*}{\partial\left(\frac{\bar{K}}{\bar{L}}\right)}\right] = \frac{(1-\mu_i)\left(\frac{w_i^*\bar{L}}{r_i^*\bar{K}}\right)^2}{\frac{w_i^*\bar{L}}{r_i^*\bar{K}} - \mu_i c} \geq c \tag{B17}$$

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

$$\frac{(1-\mu_i)\left(\frac{w_i^*\bar{L}}{r_i^*\bar{K}}\right)^2}{\frac{w_i^*\bar{L}}{r_i^*\bar{K}} - \mu_i} \geq 1 \quad \Leftrightarrow \quad \frac{w_i^*\bar{L}}{r_i^*\bar{K}} \geq \frac{\mu_i}{1-\mu_i} \tag{B18}$$

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:

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

$$\left[1 + \left(\frac{w_i}{r_i} \right)^{-\frac{\mu_i}{1-\mu_i}} \left(\frac{1-\alpha_i}{\alpha_i} \right)^{\frac{1}{1-\mu_i}} \right]^{\frac{-(1-\mu_i)}{\mu_i}} \geq 1 \tag{B19}$$

The LHS of (B19) 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 (14) becomes:

$$\frac{L_i^{a*}}{M_i^*} = c \frac{P_i^m}{w_i} \quad \Leftrightarrow \quad \frac{\bar{L}'}{\bar{K}'} = c \frac{r_i}{w_i} \quad \Leftrightarrow \quad \omega_i^* = c \frac{\bar{K}'}{\bar{L}'} \tag{B20}$$

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.

Appendix C Comparative advantage without normalization

We imposed that the two countries shared the same preferences, production technology and endowments. As a result, equation (15) that determines the equilibrium factor price ratio differs between countries only through the capital-labor substitutability (μ_i).[35] To learn about the impact of this parameter on the equilibrium factor price ratio, we apply the implicit function theorem to $F_i(\cdot)$. The partial derivative of the equilibrium factor price ratio with respect to μ is[36]

$$\frac{\partial(w_i/r_i)^*}{\partial\mu} = -\frac{\partial F_i(\cdot)/\partial\mu}{\partial F_i(\cdot)/\partial(w_i/r_i)^*} \tag{C1}$$

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

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

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 find that

$$\frac{\partial F_i(\cdot)}{\partial\mu} = -\frac{(1+c)}{(1-\mu)^2}\varpi_i^{-\frac{1}{1-\mu}}\ln\varpi_i \tag{C2}$$

Labor will be relatively cheap in the high-σ country, i.e. $\partial\omega^*/\partial\mu_i > 1$, when the effective cost of labor is high, i.e. when $\varpi_i > 1$. Labor will be relatively expensive in that same country when the effective cost of labor is relatively low. In sum,

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

Put differently, when capital is abundant and labor is expensive, the high-σ country will have a lower real wage than the low-σ country. Note this is a ratio-of-ratios. The *relative* real wage is lower in the high-σ country.

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

[36] Given that $\mu = 1 - 1/\sigma$, it holds that $\partial X/\partial\mu = \partial X/\partial\sigma^2 * 1/\sigma^2$, such that any derivative has the same sign with respect to μ or σ.

To provide further intuition, we compute the derivative of the relative price of produced factors with respect to the relative wage:

$$\frac{d(P_i^m/w_i)^*}{d(w_i/r_i)^*} = -\left\{\alpha_i\left[1+\left[\left(\frac{w_i}{r_i}\right)^*\right]^{-\frac{\mu}{1-\mu}}\left(\frac{1-\alpha_i}{\alpha_i}\right)^{\frac{1}{1-\mu}}\right]\right\}^{-\frac{1}{\mu}} A_i^{-1}\left[\frac{w_i}{r_i}\right]^{-2} < 0 \quad \text{(C3)}$$

In combination with the effect of μ on the equilibrium relative wage, we find 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 (14) 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-σ country has a comparative advantage in the non-routine intensive good whenever the effective cost of labor is relatively high ($\varpi_i > 1$) and a comparative advantage in the routine intensive good whenever the effective cost of labor is relatively low.

A complication with these comparative statics insights is that they hinge on the effective cost of labor. Recall that ϖ_i depends in turn on α_i which is itself a function of μ. It is unsatisfactory that the sign of the effect of μ on the equilibrium factor price depends on the effective cost of labor which is itself determined by μ. To break this circularity and pin down the effect of μ on the equilibrium factor price ratio as a function of only endowments and parameters, it is necessary to normalize the CES function.

Appendix D Opening up to trade

D.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:

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

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.

D.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:
$\beta_g P_g z_g M_{ig}^{\beta_g-1} L^{a\ 1-\beta_g}_{ig} = P^m_i$ and $(1-\beta_g) P_g z_g M_{ig}^{\beta_g} L^{a\ -\beta_g}_{ig} = w_i$. Further, from the ZPC, the price of each final good in each country is $P_{ig} = P_i^{m\beta_g} w_i^{1-\beta_g}/Z$ 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 ex-

pression for the other sector to get:

$$\left(\frac{w_2}{w_1}\right)^{\frac{1-\beta_2}{\beta_2}} = \left(\frac{w_2}{w_1}\right)^{\frac{1-\beta_1}{\beta_1}}, \beta_2 \neq \beta_1 \quad \Leftrightarrow \quad w_2 \quad = \quad w_1 \tag{D1}$$

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:

$$\begin{cases} r_1 = \left[(1+\tilde{\omega})^{\sigma_1} P^{m1-\sigma_1} - \tilde{\omega}^{\sigma_1} w^{1-\sigma_1}\right]^{\frac{1}{1-\sigma_1}} \\ r_2 = \left[(1+\tilde{\omega})^{\sigma_2} P^{m1-\sigma_2} - \tilde{\omega}^{\sigma_2} w^{1-\sigma_2}\right]^{\frac{1}{1-\sigma_2}} \end{cases}$$

The two expressions only differ by μ whereby in general $r_1 \neq r_2$.[37] 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 $(1-\beta_g) P_g z_g M_{ig}^{\beta_g}(L_{ig}^a)^{1-\beta_g} = w L_{ig}^a$. Rearranging these two expressions and summing across countries delivers:

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

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:

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

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

Combining the above expressions delivers:

$$\frac{L_1^{a*} + L_2^{a*}}{M_1^* + M_2^*} = c\frac{P^m}{w} \tag{D2}$$

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 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:

$$(1+\tilde{\omega})^{\frac{1}{\mu_1}}\left[\left(\frac{w}{r_1}\right)^{\frac{\mu_1}{1-\mu_1}} + \tilde{\omega}^{\frac{1}{1-\mu_1}}\right]^{-\frac{1-\mu_1}{\mu_1}} = (1+\tilde{\omega})^{\frac{1}{\mu_2}}\left[\left(\frac{w}{r_2}\right)^{\frac{\mu_2}{1-\mu_2}} + \tilde{\omega}^{\frac{1}{1-\mu_2}}\right]^{-\frac{1-\mu_2}{\mu_2}} \tag{D3}$$

It is easy to check that setting $w/r_1 = w/r_2 = \tilde{\omega}$ solves (D3). 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:

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

$$\omega_1^* = \left\{(1+\tilde{\omega})^{\frac{\sigma_2-\sigma_1}{\sigma_2-1}}\left[\left(\frac{w}{r_2}\right)^{\sigma_2-1} + \tilde{\omega}^{\sigma_2}\right]^{\frac{\sigma_1-1}{\sigma_2-1}} - \tilde{\omega}^{\sigma_1}\right\}^{\frac{1}{\sigma_1-1}} \tag{D4}$$

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

$$\omega_2^* = \left\{ (1+\tilde{\omega})^{\frac{\sigma_1-\sigma_2}{\sigma_1-1}} \left[\left(\frac{w}{r_1}\right)^{\sigma_1-1} + \tilde{\omega}^{\sigma_1} \right]^{\frac{\sigma_2-1}{\sigma_1-1}} - \tilde{\omega}^{\sigma_2} \right\}^{\frac{1}{\sigma_2-1}} \tag{D5}$$

Next, we work with the LHS of (D2). 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:

$$M_i^* = A_i \alpha_i^{1/\mu_i} \bar{K} \left[1 + (\omega_i^*)^{-\frac{\mu_i}{1-\mu_i}} \left(\frac{1-\alpha_i}{\alpha_i} \right)^{\frac{1}{1-\mu_i}} \right]^{1/\mu_i} \tag{D6}$$

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:

$$L_i^{m*}(M_i^*) = (\omega_i^*)^{-\frac{1}{1-\mu_i}} \left(\frac{1-\alpha_i}{\alpha_i} \right)^{\frac{1}{1-\mu_i}} \bar{K} \tag{D7}$$

We simplify (D6) and (D7) with the normalization $\tilde{\kappa} = 1$ and rearrange to get:

$$\frac{L_1^{a*} + L_2^{a*}}{M_1^* + M_2^*} = \frac{2\frac{\bar{L}}{\bar{K}} - \left(\frac{\omega_1^*}{\tilde{\omega}}\right)^{\frac{-1}{1-\mu_1}} - \left(\frac{\omega_2^*}{\tilde{\omega}}\right)^{\frac{-1}{1-\mu_2}}}{(1+\tilde{\omega})^{\frac{-1}{\mu_1}} \left\{ 1 + \omega_1^* \left(\frac{\omega_1^*}{\tilde{\omega}}\right)^{\frac{-1}{1-\mu_1}} \right\}^{1/\mu_1} + (1+\tilde{\omega})^{\frac{-1}{\mu_2}} \left\{ 1 + \omega_2^* \left(\frac{\omega_2^*}{\tilde{\omega}}\right)^{\frac{-1}{1-\mu_2}} \right\}^{1/\mu_2}} \tag{D8}$$

We solve for the price ratio in each country by plugging the expressions for the LHS and the RHS into (D2) 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 $\Omega_i = (\omega_i^*)^{\frac{\mu_i}{1-\mu_i}} + \tilde{\omega}^{\frac{1}{1-\mu_i}}$.

For the high-μ country we get:

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

$$= c(1+\tilde{\omega})^{\frac{1}{\mu_1}}\,\Omega_1^{\frac{-(1-\mu_1)}{\mu_1}}$$

For the low-μ country we get:

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

$$= c(1+\tilde{\omega})^{\frac{1}{\mu_2}}\,\Omega_2^{\frac{-(1-\mu_2)}{\mu_2}}$$

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

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

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

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

The first two terms replicate the analogous expression for the autarky equilibrium (15) 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:

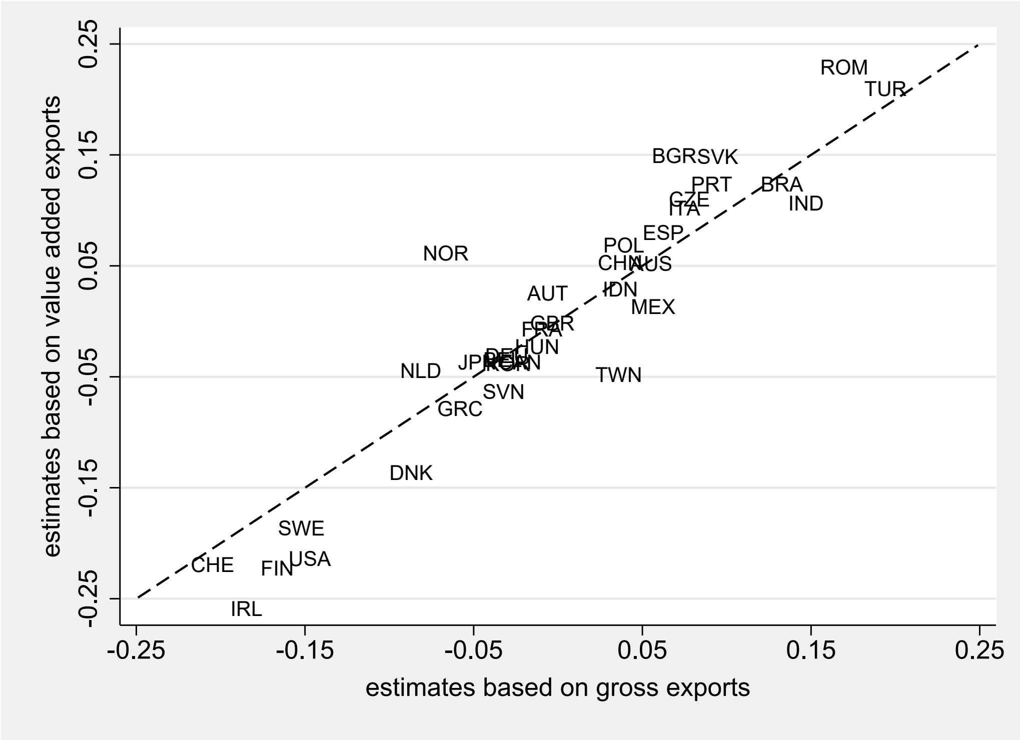
$$F_1(\cdot) = c\,(\omega_1^*)^{-1} + (c+1)\left(\frac{\omega_1^*}{\tilde{\omega}}\right)^{-\sigma_1} - 2\frac{\bar{L}}{\bar{K}} + \frac{\left[c(1+\tilde{\omega})^{\frac{\sigma_1-\sigma_2}{\sigma_1-1}}\left[(\omega_1^*)^{\sigma_1-1}+\tilde{\omega}^{\sigma_1}\right]^{\frac{\sigma_2-1}{\sigma_1-1}}+\tilde{\omega}^{\sigma_2}\right]}{\left[(1+\tilde{\omega})^{\frac{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

In the low-σ country we get:

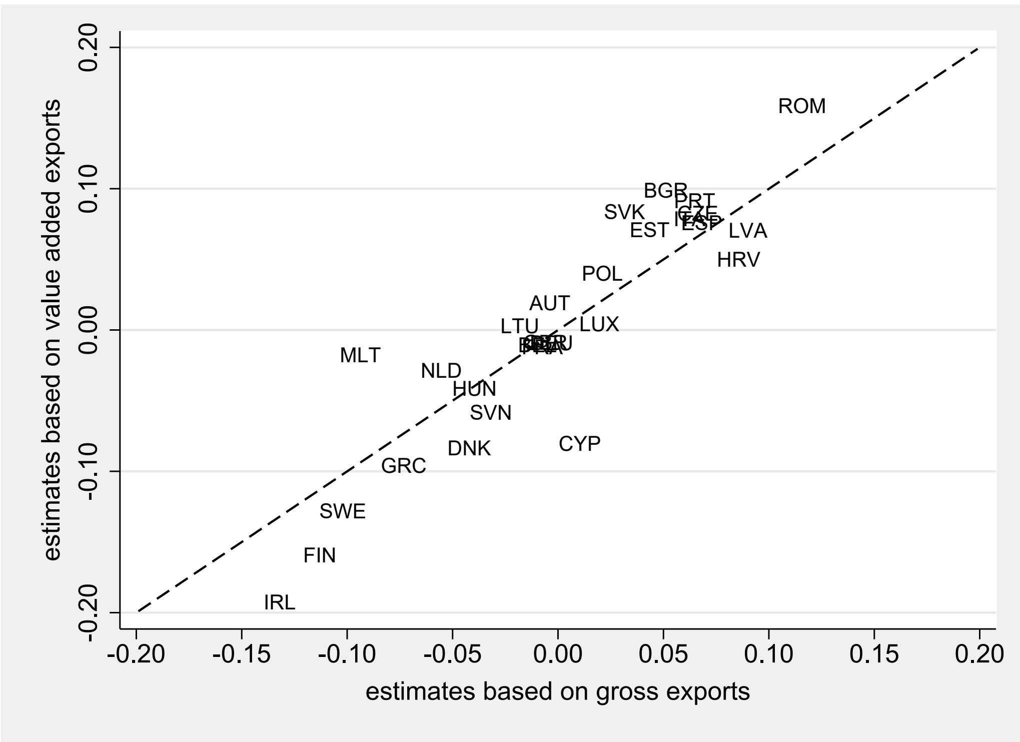
$$F_2(\cdot) = c\,(\omega_2^*)^{-1} + (c+1)\left(\frac{\omega_2^*}{\tilde{\omega}}\right)^{-\sigma_2} - 2\frac{\bar{L}}{\bar{K}} + \frac{\left[c(1+\tilde{\omega})^{\frac{\sigma_2-\sigma_1}{\sigma_2-1}}\left[(\omega_2^*)^{\sigma_2-1}+\tilde{\omega}^{\sigma_2}\right]^{\frac{\sigma_1-1}{\sigma_2-1}}+\tilde{\omega}^{\sigma_1}\right]}{\left[(1+\tilde{\omega})^{\frac{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

Appendix E Results based on value added trade

Figure E.1: (Non-)Routine export specialization based on value added trade



(a) Large exporters (36 countries)



(b) EU member states

Table A.2 Routine versus non-routine export specialization in sample of 50 largest exporters

	1995		2005		2015	
	Coef.	**St.Dev.**	**Coef.**	**St.Dev.**	**Coef.**	**St.Dev.**
JPN	-0.205	(.012)	-0.181	(.011)	-0.172	(.010)
SGP	-0.174	(.012)	-0.163	(.011)	-0.136	(.010)
FIN	-0.144	(.012)	-0.145	(.011)	-0.122	(.010)
SWE	-0.150	(.012)	-0.132	(.011)	-0.109	(.010)
ISR	-0.120	(.013)	-0.121	(.011)	-0.123	(.010)
IRL	-0.111	(.012)	-0.118	(.011)	-0.112	(.010)
MEX	-0.085	(.013)	-0.115	(.011)	-0.114	(.010)
CHE	-0.126	(.012)	-0.096	(.011)	-0.084	(.010)
USA	-0.112	(.012)	-0.086	(.011)	-0.078	(.010)
TWN	-0.070	(.012)	-0.083	(.011)	-0.091	(.010)
MYS	-0.049	(.012)	-0.062	(.011)	-0.069	(.010)
FRA	-0.083	(.012)	-0.057	(.011)	-0.038	(.010)
DEU	-0.078	(.012)	-0.062	(.011)	-0.038	(.010)
GBR	-0.082	(.012)	-0.057	(.011)	-0.033	(.010)
NOR	-0.047	(.012)	-0.059	(.011)	-0.050	(.010)
RUS	-0.044	(.013)	-0.044	(.011)	-0.061	(.010)
NLD	-0.057	(.012)	-0.049	(.011)	-0.028	(.010)
CAN	-0.058	(.012)	-0.032	(.011)	-0.023	(.010)
AUT	-0.040	(.012)	-0.025	(.011)	-0.022	(.010)
SAU	-0.036	(.014)	-0.017	(.012)	-0.031	(.011)
CHN	-0.034	(.012)	-0.023	(.011)	-0.023	(.010)
BEL	-0.043	(.012)	-0.024	(.011)	-0.010	(.010)
HUN	0.014	(.013)	-0.048	(.011)	-0.031	(.010)
KOR	0.019	(.012)	-0.024	(.011)	-0.032	(.010)
ARE	-0.009	(.014)	0.010	(.011)	-0.026	(.010)
ZAF	0.002	-	0.006	-	0.018	-
ESP	-0.017	(.012)	0.016	(.011)	0.037	(.010)
SVN	0.034	(.014)	0.023	(.011)	-0.006	(.010)
PHL	0.054	(.013)	0.011	(.011)	-0.012	(.010)
CZE	0.080	(.013)	-0.003	(.011)	-0.004	(.010)
ITA	0.002	(.012)	0.031	(.011)	0.049	(.010)
DNK	0.014	(.012)	0.035	(.011)	0.049	(.010)
GRC	0.044	(.013)	0.036	(.011)	0.022	(.010)
POL	0.036	(.013)	0.043	(.011)	0.026	(.010)
SVK	0.059	(.014)	0.036	(.011)	0.017	(.010)
IDN	0.066	(.013)	0.035	(.011)	0.049	(.010)
BGR	0.039	(.014)	0.057	(.011)	0.054	(.010)
UKR	0.034	(.014)	0.058	(.011)	0.066	(.010)
IND	0.077	(.012)	0.049	(.011)	0.041	(.010)
PRT	0.069	(.013)	0.060	(.011)	0.051	(.010)
AUS	0.091	(.012)	0.067	(.011)	0.061	(.010)
BRA	0.065	(.012)	0.086	(.011)	0.086	(.010)
THA	0.101	(.012)	0.072	(.011)	0.075	(.010)
ROM	0.119	(.014)	0.111	(.011)	0.085	(.010)
TUR	0.122	(.013)	0.134	(.011)	0.111	(.010)
CHL	0.119	(.014)	0.156	(.012)	0.148	(.011)
NZL	0.159	(.013)	0.147	(.011)	0.140	(.010)
ARG	0.144	(.013)	0.156	(.011)	0.163	(.010)
VNM	0.236	(.016)	0.189	(.011)	0.113	(.010)
PER	0.179	(.016)	0.200	(.012)	0.209	(.011)
No. of obs.	219,894		253,409		265,276	

Note: Dependent variable is the log of bilateral exports at the industry level. Explanatory variables are the interactions between country dummies and the routineness indicator, normalized by the sample average (ZAF is the excluded country). Control variables (not reported) are four interactions between country-endowments and industry-intensities, as well as destination-industry and origin-destination fixed effects. The indicator and dependent variable are standardized Z-variables such that the effects are measures in standard deviations. Countries are sorted by the average of the estimates over years.

Table A.3 Routine versus non-routine export specialization among EU member states

	1995		2005		2015	
	Coef.	St.Dev.	Coef.	St.Dev.	Coef.	St.Dev.
FIN	-0.158	(.016)	-0.151	(.015)	-0.127	(.013)
IRL	-0.127	(.016)	-0.128	(.015)	-0.105	(.013)
SWE	-0.131	-	-0.104	-	-0.079	-
GBR	-0.087	(.016)	-0.087	(.015)	-0.070	(.013)
FRA	-0.061	(.016)	-0.048	(.015)	-0.032	(.013)
DEU	-0.058	(.016)	-0.050	(.015)	-0.031	(.013)
MLT	-0.046	(.021)	-0.021	(.017)	-0.057	(.015)
NLD	-0.039	(.016)	-0.040	(.015)	-0.026	(.013)
AUT	-0.045	(.016)	-0.028	(.015)	-0.018	(.013)
SVK	0.027	(.017)	-0.031	(.015)	-0.053	(.014)
HUN	0.028	(.016)	-0.026	(.015)	-0.032	(.013)
CZE	0.020	(.016)	-0.036	(.015)	-0.015	(.013)
SVN	0.017	(.017)	-0.003	(.015)	-0.029	(.013)
BEL	-0.013	(.016)	-0.001	(.015)	0.026	(.013)
CYP	0.036	(.019)	0.007	(.016)	-0.029	(.014)
GRC	0.040	(.017)	0.019	(.015)	0.018	(.013)
ESP	-0.008	(.016)	0.036	(.015)	0.068	(.013)
POL	0.012	(.016)	0.044	(.015)	0.043	(.013)
DNK	0.026	(.016)	0.034	(.015)	0.044	(.013)
ITA	0.014	(.016)	0.043	(.015)	0.058	(.013)
HRV	0.021	(.018)	0.039	(.015)	0.063	(.014)
EST	0.080	(.018)	0.051	(.015)	0.021	(.014)
BGR	0.047	(.017)	0.064	(.015)	0.073	(.013)
LVA	0.085	(.019)	0.100	(.015)	0.038	(.014)
PRT	0.091	(.017)	0.085	(.015)	0.086	(.014)
LTU	0.112	(.018)	0.123	(.015)	0.077	(.013)
ROM	0.118	(.017)	0.109	(.015)	0.089	(.014)
No. of obs.	48,988		54,561		56,556	

Note: Dependent variable is the log of bilateral exports at the industry level. Explanatory variables are the interactions between country dummies and the routineness indicator, normalized by the sample average (SWE is the excluded country). Control variables (not reported) are four interactions between country-endowments and industry-intensities, as well as destination-industry and origin-destination fixed effects. The indicator and dependent variable are standardized Z-variables such that the effects are measures in standard deviations. Countries are sorted by the average of the estimates over the four years.