Comparative Advantage in (Non-)Routine Production*

Liza Archanskaia† Johannes Van Biesebroeck‡
Gerald Willmann§

June 2022

Abstract

We illustrate a new source of comparative advantage that stems from countries' different ability to adjust to technological change. In our model, workers in codifiable (routine) tasks can be substituted for more efficient machines, a process extensively documented in the labor literature. Our key hypothesis is that labor reallocation across tasks is subject to frictions, the importance of which varies by country. The arrival of capital-augmenting innovations triggers the movement of workers out of routine tasks. More flexible countries become relatively abundant in non-routine labor and increasingly specialize in producing goods that use non-routine labor more intensively. We document empirically that the ranking of countries with respect to the routine intensity of their exports is strongly related to labor market regulations and the organization of the workplace. This mechanism has the best explanatory power for intra-EU trade flows of all five mechanisms that we compare.

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

*This paper has benefited from helpful discussions with Jan de Loecker, Sašo Polanec, Ariell Reshef, Chad Syverson, Hylke Vandenbussche, and Frank Verboven. This project has received funding from the European Union's Horizon 2020 programme under grant agreement No. 649378, Methusalem project METH/15/004, and EOS project G0G4318N (EOS ID 30784531). The project was carried out while Archanskaia was postdoctoral research fellow at KU Leuven.

†KU Leuven, liza.archanskaia@kuleuven.be.

‡KU Leuven and CEPR, jo.vanbiesebroeck@kuleuven.be.

§Bielefeld University and IfW Kiel, gerald.willmann@uni-bielefeld.de.

1 Introduction

The labor literature has highlighted that workers perform tasks that differ in codifiability or routineness (Autor et al., 2003). Capital and computers are stronger substitutes for labor input in routine tasks than in abstract tasks. Yet, technology adoption is not a frictionless process (Bresnahan et al., 2002). As the economy becomes more capital intensive with the arrival of labor-saving technologies, workers continuously need to transition from more routine to more abstract tasks (Acemoglu and Restrepo, 2018). We show that an ability to facilitate such transitions gives countries a comparative advantage in industries that are intensive in non-routine tasks.

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 can also influence specialization. Trade specialization has been linked to skill dispersion (Bombardini et al., 2012), attitudes towards obedience (Campante and Chor, 2017), labor market flexibility (Cuñat and Melitz, 2012), and the strength of contract enforcement (Nunn, 2007). Chor (2010) finds that institutional differences matter as much as traditional factor endowments of human and physical capital in determining trade patterns.

Our contribution is to introduce an important feature of the production process that is highlighted in the labor literature into a trade model. We start from a well-documented pattern associated with the process of technological change: the continuous introduction of more efficient machines displaces workers in relatively more codifiable (routine) tasks where new machines are relatively more productive.[1] Such automation frees up labor to perform less codifiable (non-routine) tasks. While labor could be perfectly substitutable with the new machines, as in Autor et al. (2003), most studies assume a finite elasticity of substitution, which we interpret as the result of adjustment costs. The equilibrium allocation of labor to routine and non-routine tasks depends on the magnitude of these costs. We show that cross-country variation in the ability to adjust to new technologies and to reallocate workers between tasks induces specialization, and thus constitutes a novel source of comparative advantage.

Several studies have illustrated that flexible labor market institutions facilitate the speed and extent of adjustment to trade liberalization (Kambourov, 2009; Dix-Carneiro, 2014). Gains from trade are higher when workers can move more easily

[1] See in particular Autor et al. (2003), Acemoglu and Autor (2011), Goos et al. (2014), Harrigan et al. (2016) and Acemoglu and Restrepo (2018).

from import-competing to comparative advantage sectors. In our case, it is the adjustment flexibility itself—taken in the broad sense of all features that facilitate technology adoption and labor reallocation—that creates comparative advantage.

To illustrate this mechanism, we incorporate task routineness into an augmented $2 \times 2 \times 2$ Heckscher-Ohlin model. Final goods are produced with two factors: one routine and one non-routine. Importantly, these endowments are not given exogenously, but are determined by the equilibrium allocation of labor to routine and non-routine tasks. As in Autor et al. (2003) and Autor and Dorn (2013), capital can only be used in routine tasks. The flexibility of labor reallocation between tasks plays a crucial role in this economy because there is an ongoing process of technological change which we model as an increase in the capital endowment.[2] As more capital becomes available, its relative price falls and the capital intensity in routine input production rises. Consequently, labor can be released from routine tasks and reallocated to non-routine tasks.[3]

Acemoglu and Restrepo (2018) provide an explicit dynamic model where the continuous introduction of new capital or labor-saving technologies creates a permanent need for adjustment. We opt for a static model—where the process of capital deepening is exogenous and common across countries—to focus on the trade implications of differences in adjustment costs and the extent of labor reallocation. The novel ingredient in our model is that the reallocation of workers between tasks is subject to frictions, the importance of which varies by country.[4]

We model the flexibility of reallocations as a country-specific elasticity of substitution between capital and labor in routine production. This assumption can be considered as a reduced form way of capturing differences in labor market regulations, workplace organization, or other factors that make it less likely for workers to switch employers. We include a stylized model, where countries have identical production technology, but different real costs of changing jobs, to micro-found a country-specific elasticity of substitution parameter. We introduce the friction on the 'outgoing' labor side, but could also have introduced it on the 'incoming' capital side to capture cultural or institutional differences—such as behavioral norms in the

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

[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.

[4]The magnitude of adjustment costs influences the propensity to invest in and adopt new technologies (Bartelsman et al., 2016). We expect this channel—missing in our static set-up—to reinforce our results as a country with low adjustment costs would invest relatively more and reallocate even more labor to non-routine tasks.

workplace—that affect the costs of (labor-saving) technology adoption.

The model predicts that countries which adjust more flexibly to technological change—i.e., countries with a higher elasticity of substitution—free up more labor from 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. The arrival of more capital or capital-biased technological change triggers the process of labor reallocation and endogenously differentiates countries. This new source of comparative advantage helps explain why countries with similar capital-labor endowments and technology specialize in different goods.

We test the predictions on trade specialization using data on bilateral trade flows between 28 EU countries. As these countries have relatively similar factor endowments, the standard Heckscher-Ohlin model has only limited predictive power.[5] We use the same routine intensity measure as Autor et al. (2003) and Costinot et al. (2011) to distinguish between sectors. Following the two-step approach of Costinot (2009), we first show that the export bundles of these countries are quite distinct in terms of their relative routine intensity, and the ranking of countries in this dimension is quite intuitive. This dimension of specialization is almost orthogonal to the trade predictions obtained using other mechanisms in the literature. Using value-added trade as the dependent variable, instead of gross exports, leads to more pronounced differences between countries that are more stable over time. In particular, the pattern of specialization by routine intensity for value-added trade remains equally strong over the three annual cross-sections (2000, 2007, and 2014).

In a second step, we investigate whether the extent of countries' specialization in routine-intensive goods is correlated with institutional and regulatory features of the labor market that are expected to influence the ease of labor reallocation across tasks. The results indicate that the OECD's indicator for 'strictness of employment protection legislation' is an especially strong predictor. Countries with relatively strict regulations specialize in goods that are more routine intensive.[6]

To evaluate the predictive power of this novel specialization mechanism, we also perform a single-step analysis, regressing bilateral exports on multiple determinants of comparative advantage, i.e. interactions between country endowments and sectoral characteristics. The novel mechanism is represented by an interaction of sectoral routine intensity with country-level employment protection regulation, which

[5] Comparable results for a sample of the 50 largest exporters in the world are in Appendix F.

[6] In the more diverse sample of large global exporters, a low value on an index of 'workforce characteristics and organization', a subset of the broader 'quality of the workforce' indicator used by Costinot (2009), had the strongest predictive power for routine specialization.

we add to four similar interactions used to test for other comparative advantage mechanisms in the previous literature. We find the expected positive sign on our mechanism of interest in all three years. By the end of the sample period, the mechanism that we propose is a more informative predictor of intra-EU trade patterns than any of the Heckscher-Ohlin forces or other institutional mechanisms considered. The relative similarity of factor endowments and level of technology of these countries naturally limits the predictive power of more traditional sources of comparative advantage. We further show that the change from 2000 to 2014 in export specialization across sectors is strongly correlated with the level of labor market regulation, which relates even more directly to the theoretical predictions.

Our analysis contributes to the trade literature that seeks to uncover new mechanisms behind the pattern of specialization. Nunn and Trefler (2014) survey the theoretical and empirical literatures that consider domestic institutions as a source of comparative advantage, and we already mentioned the most relevant mechanisms. Labor market flexibility in particular has been shown by Cuñat and Melitz (2012) to induce specialization by conferring a comparative advantage in sectors where idiosyncratic shocks lead to high sales volatility. Our mechanism derives from the benefit that labor market flexibility confers in adjusting to pervasive capital-biased technological change. As capital deepening changes the equilibrium allocation of labor across tasks, a country's measured factor abundance may itself be influenced by the interaction of institutions with the process of technological change if workers employed in abstract tasks are counted as skilled workers.

Our analysis also speaks to the trade literature that links labor market flexibility to the magnitude of the gains from trade. Lower adjustment costs help countries reap the gains from trade liberalization (Dix-Carneiro, 2014). A novel implication of our model is that workers in the country with high capital-labor substitutability benefit relatively more from capital deepening in the open economy setting.

Our work is closely related to the rapidly growing literature in labor economics that documents how increased automation and outsourcing of codifiable tasks led to job polarization in developed economies. This literature explicitly links technological change to labor displacement from routine to non-routine tasks (Autor et al., 2003; Autor and Dorn, 2013; Bárány and Siegel, 2018). Costinot et al. (2011) further show that task heterogeneity influences the optimal organization of firms. They illustrate that an advantage of integrated firms in dealing with ex-post problems helps to explain multinational firms' preference for integration over outsourcing in sectors that are intensive in non-routine tasks.

We also build on the insights from the growth literature that connects capital-labor substitutability to capital accumulation (Klump and de la Grandville, 2000).

Stokey (1996) shows in a model with capital-skill complementarity that the incentive to accumulate capital is increasing in the substitutability of capital with unskilled labor. Bartelsman et al. (2016) document how labor markets flexibility determines the gains from capital deepening by increasing the expected gain from investment in disruptive technology. Our work explicitly connects the magnitude of adjustment costs to the perceived capital-labor substitutability. By embedding this mechanism in a trade model, we pin down the impact of labor market flexibility on the magnitude of workers' gains from trade in the context of capital deepening.

The remainder of the paper is organized as follows. In Section 2 we present the main features of the stylized model and provide a possible micro-foundation for differences in capital-labor substitutability between countries. Next we derive the autarky equilibrium and the predictions regarding trade patterns. Section 3 describes the data and Section 4, the empirical model. Section 5 provides the estimation results that link trade patterns, in terms of (non-)routine specialization, to country characteristics. In Section 6 we draw some conclusions from the analysis.

2 The model

Our objective is to analyze in the simplest possible way the trade implications of differences in the ease of factor reallocation. We introduce this through heterogeneity of the substitution parameter σ in a production function for the routine input which has been used extensively in the labor literature (Acemoglu and Autor, 2011). It is intended to capture a variety of adjustment frictions, e.g. firing costs, risk aversion, etc. in a reduced form way. Before solving the model, we provide a simple way to micro-found differences in σ.

At the level of final output production, our model is structured as 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 endowments and sector-specific factor intensities. Its distinguishing feature is that the endowments of the two factors necessary for the production of the final goods, namely non-routine tasks and a routine intermediate, are endogenously determined ('produced') by the optimal allocation of labor to routine and non-routine tasks, with capital dedicated entirely to the production of the routine intermediate. We show that in this set-up two countries with identical endowments of the 'primitive' factors, i.e. capital and labor, can have an incentive to trade, simply because they differ in the substitutability of capital and labor in the production of the routine intermediate. A key prediction of our model is that the country with a relatively high elasticity of substitution parameter σ in routine intermediate production becomes non-routine labor abundant - as the two countries accumulate capital - because it frees up more labor to do non-routine tasks. Consequently, it acquires a comparative advantage in the final good industry that uses non-routine labor more intensively. The novel driving force for trade in our framework lies in the varying friction for labor reallocation across tasks.

The comparative statics analysis considers how countries with different σ parameters adjust differentially to an exogenous increase in the capital stock that triggers capital-labor substitution and the reallocation of labor. To study this in a static model, we measure the change from an initial point of production where the equilibrium allocation is identical in the two countries. Because the σ parameter not only changes the curvature but also the intercept of the CES production function, a normalization is needed to essure that the same production plan is attainable if we make only the σ parameter country specific.

In the following sub-sections we derive the trade implications in six steps: (1) the augmented Heckscher-Ohlin set-up, (2) a micro-foundation for σ differences in the production function, (3) solving for the equilibrium allocations and production, (4) normalizing the CES-component in the production function, (5) the pattern of specialization, and (6) implications of opening up to trade.

2.1 Set-up

Denote two countries by $i \in \{A, B\}$; they have identical factor endowments of capital $\bar{K}$ and labor $\bar{L}$.[7] 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 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 consumers in both countries have identical, homothetic demand over the two final goods. For simplicity, we adopt a Cobb-Douglas utility function: $U_i = \sum_g \theta_g \ln(Q_{ig})$. Consumers maximize utility subject to the budget

[7] We abstract from traditional endowment differences that are well understood to focus on the mechanism we wish to explore. In the empirical analysis we control for traditional endowment differences.

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. It leads to constant budget shares for both final goods.

Given the focus on capital-labor substitutability in routine production, we simply assume that each unit of raw labor can directly produce either routine or abstract tasks and that this choice is reversible. In particular, one unit of routine labor can seamlessly be converted into one unit of abstract labor. We explicitly choose not to focus solely on the difficulty for routine workers to acquire the necessary skills to perform abstract tasks. We are interested in any type of reallocation friction that makes capital-labor substitution less than infinite, such that a labor-saving machine cannot instantaneously replace all workers in routine production.[8]

We adopt a CES production function for the routine intermediate:

$$M_i = Z \left[\alpha (K_i)^{\frac{\sigma_i - 1}{\sigma_i}} + (1 - \alpha)(L_i^m)^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i - 1}}, \tag{2}$$

where Z and α are the efficiency and distribution parameters, and σ_i captures the ease of factor substitutability.[9] We follow Autor et al. (2003) and Autor and Dorn (2013) and assume that capital and routine labor are more substitutable in routine production ($\sigma_i > 1$) than are non-routine labor and the routine input in the production of final goods, the latter being a Cobb-Douglas production function. Without loss of generality, let country A have the relatively higher factor substitution in routine production such that $\sigma_A > \sigma_B > 1$.

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

$$Y_{ig} = z_g \left(L_{ig}^a\right)^{1-\beta_g} \left\{ Z \left[\alpha (K_{ig})^{\frac{\sigma_i - 1}{\sigma_i}} + (1 - \alpha)(L_{ig}^m)^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i - 1}} \right\}^{\beta_g}. \tag{3}$$

In Appendix A we discuss estimates of a nested production function of the form of (3). The analysis uses the KLEMS dataset that has country-sector-year observations and measures abstract and routine labor input by the number of high or low-skilled employees, which is not ideal, but can serve as an approximation. To evaluate the appropriateness of our assumptions, we initially allow for country-sector specific β and σ parameters, exploiting only time variation in the estimation. An ANOVA analysis indicates that country dummies have the most explanatory power

[8]Redeploying routine labor to abstract tasks could require a human capital investment, but we do not model this explicitly, as it would lead to task-specific wages. The σ parameter is a reduced form way of representing various frictions associated with labor reallocation across tasks.

[9]We follow the convention in recent work with the CES production function, namely that Z and α parameters are common across countries. For two countries with the same endowments but different σ_i parameters to have the same Z and α parameters requires a particular normalization (see for example Klump et al. (2012)). We discuss the normalization in Section 2.4.

for the elasticity of substitution estimates $\hat{\sigma}$, while sector dummies have more explanatory power for the output elasticity of the routine intermediate estimates $\hat{\beta}$. It suggests that our assumption on the country respectively sector-specificity of these two parameters is broadly consistent with the observed variation between outputs and inputs in the KLEMS data.

2.2 Micro-foundation for differences in σ

The elasticity of substitution parameter σ in a CES production function is generally considered to be a representation of technology. Here we show that countries with the same production technology, but with different (labor market) institutions adjust their input choices to a different extent when hit by the same exogenous shock. This micro-foundation illustrates how a labor market friction can give rise to variation in the *measured* elasticity of substitution, i.e., how easy it is in practice to substitute between 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 switching jobs a cost ranging from 1.4 to 2.7 times the average annual wage.[10] 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.[11] While adjustment costs are indeed likely to vary in importance across workers, we will here focus on institutional characteristics that introduce a *country-specific* component in the adjustment cost.

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. Given that ours is a real trade model, the lay-off cost has to be paid directly in terms of output of the firm. It means that

$$y + p\,C(L)\,y \quad = \quad F(K, L), \tag{4}$$

where p is a country-specific cost shifter that we use in the comparative statics to vary the importance of this friction. $C(L)$ is the lay-off cost that satisfies $C(L_0) = 0$, $C'(L) < 0$, and $C''(L) > 0$ for any $L < L_0$.[12] In words, the cost kicks in when the firm reduces labor input below its initial level L_0, the marginal cost is positive for lay-

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

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

[12] 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 input.

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.[13] Combining technology and institutions leads to the following modified production function:

$$y = \frac{F(K, L)}{1 + p\,C(L)}. \tag{5}$$

We view the real lay-off cost in (4) as representative for a variety of institutional differences between countries that can be modelled in a reduced form way by a heterogeneous elasticity of substitution parameter. In addition to a lay-off cost per se, the cost parameter can be interpreted in alternative ways. It can stand, for example, for a legal obligation by the former employer to provide retraining to workers who are dismissed. Cross-country differences in the fraction of such costs borne by individual firms, and not by a public system, have similar effects as variation in severance pay. Another interpretation is as equilibrium compensation to workers for the risk involved in job transitions.[14] Due to mobility barriers between regions and sectors or due to transitory unemployment spells, many dismissed workers will experience a period of lower earnings with variation across countries in its duration and the amount of income lost.

Going beyond differences in transition costs, the equilibrium compensation accompanying dismissals can also vary if workers differ in their risk aversion. They will regard the risk of not finding an equally well paid job in the non-routine sector differently, and hence their certainty equivalent of switching to the other sector will differ. We therefore regard the set-up in (4) as representing a wider class of models where adjustments in total labor input to exogenous shocks involve real costs.

Similarly, institutional or cultural differences can introduce costs associated with adjustments in the capital stock, e.g. as firms invest in new technology. Augmenting the capital stock might increase its productivity with a probability close to, but short of one. If decision-makers differ across countries in risk aversion, or in the extent to which they take a long-term perspective in investment decisions, the benefit of increasing the capital stock will be assessed differently. If the new production plan involves a change in the capital stock, such a mechanism would also give rise to a

[13]Small employment reductions can often be accommodated relatively easily by not replacing retiring workers or by natural job attrition, and thus incur smaller than proportional costs.

[14]Bewley (2009) provides evidence that compensation for dismissals in the United States tends to be much higher than legally required. Many managers discuss existing practices as equilibrium compensation for job transition costs that dismissed employees are likely to incur.

modified, country-specific production function, of a form similar to (5):

$$y = \frac{F(K,L)}{1 - \tilde{p}\,\tilde{C}(K)},$$

We now show the effect of a difference in the lay-off cost friction p on the elasticity of substitution for the modified production function (5). The latter is defined as

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

We derive in Appendix B for the special case of perfect substitution between inputs in the underlying production function, i.e., for $F(K,L) = K + L$, that $\sigma_{L,K}$ for the modified production function is finite if $p\,C'' > 0$. Moreover, the derivative of $\sigma_{L,K}$ with respect to the cost shifter p equals

$$\frac{\partial \sigma_{L,K}}{\partial p} = \frac{-pC'(L)y - 1}{L} + \frac{-pC'(L)y - 1 + 2(pC'(L)y)^2}{K}. \tag{6}$$

The first term is negative as long as $-pC'(L)y < 1$, 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 $-pC'(L)y \in (-1, 1/2)$; 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, 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—which measures the importance of the friction—on the elasticity of substitution. In other words, a more severe friction reduces the optimal (from the firm's perspective) substitution of capital for labor.

The above mechanism links labor market frictions in the form of a convex lay-off cost to lower *effective* substitutability of capital and labor. 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 perform better in the steady state as workers are more productive, but following structural shocks they experience a longer and more costly transition period. 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 and document that countries with relatively high switching costs also adjust more slowly to trade shocks.

2.3 Solving the model

After providing a motivation for the CES production function, with a country-specific elasticity of substitution between capital and labor in routine intermediate production, we solve the model by finding the relative supply and demand of the two 'produced' factors, the routine intermediate and the non-routine tasks. The solution to the model delivers the optimal allocation of labor to routine and non-routine tasks, determining the relative abundance of the non-routine factor. We show here the main steps to solve the model and provide further details in Appendix C.

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 optimal input combinations must be the same for routine inputs used in either final goods sector. 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:

$$P_i^m \;=\; C(w_i, r_i) \;=\; \frac{1}{Z}\left[\alpha^{\sigma_i} r_i^{1-\sigma_i} + (1-\alpha)^{\sigma_i}\, w_i^{1-\sigma_i}\right]^{\frac{1}{1-\sigma_i}}. \tag{7}$$

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:

$$P_{ig} \;=\; C_{ig}(w_i, P_i^m) \;=\; \frac{1}{z_g}\left(\frac{w_i}{1-\beta_g}\right)^{1-\beta_g}\left(\frac{P_i^m}{\beta_g}\right)^{\beta_g}, \quad \forall g \in \{1,2\}. \tag{8}$$

By combining (7) and (8), we can express the final goods prices in terms of w_i and r_i, see equation (C5) in the Appendix. Hence, we can express the price ratio P_{i1}/P_{i2} in terms of the 'primitive' factor price ratio w_i/r_i, as in the canonical HO model.

Next, note that capital can only be used in routine production. The capital demand in routine production, i.e., the first-order condition for K, provides an expression for the optimal quantity of the routine intermediate as a function of the capital endowment and the relative factor price ratio. The production function of the routine intermediate then determines how much labor to allocate to routine tasks.

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 the two produced factors, which is the relevant factor ratio available to the two final goods sectors taken together. The ratio of produced factors can then be expressed as a function of primitive endowments and the prices of the primitive factors as follows:

$$\frac{L_i^a}{M_i} = \frac{\frac{\bar{L}}{\bar{K}} - \left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\sigma_i}}{Z\alpha_i^{\frac{\sigma_i}{\sigma_i-1}}\left\{1 + \frac{w_i}{r_i}\left[\frac{w_i/(1-\alpha_i)}{r_i/\alpha_i}\right]^{-\sigma_i}\right\}^{\frac{\sigma_i}{\sigma_i-1}}} \tag{9}$$

We now turn to the demand side of the economy 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 (8), we find an expression for relative final good consumption as a function of the produced factor prices:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{\theta_1 z_1 \beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}}{\theta_2 z_2 \beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}} \left(\frac{w_i}{P_i^m}\right)^{\beta_1-\beta_2} \tag{10}$$

Using the production function and market clearing for final goods, we can express the output ratio in (10) in terms of the allocation of the produced factors to both sectors:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{Y_{i1}}{Y_{i2}} = \frac{z_1 {L_{i1}^a}^{1-\beta_1} {M_{i1}}^{\beta_1}}{z_2 {L_{i2}^a}^{1-\beta_2} {M_{i2}}^{\beta_2}}. \tag{11}$$

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.[15] As a result, the relative factor demand takes the following simple form:

$$\frac{L_i^a}{M_i} = \frac{\sum_g \theta_g(1-\beta_g)}{\sum_g \theta_g \beta_g} \frac{P_i^m}{w_i} \tag{12}$$

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, namely, the production factors in this equation are produced rather than exogenously given.

We combine the relative factor supply equation (9) with the relative factor de-

[15] 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.

mand equation (12) 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 (7) 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

$$F_i\left(\omega_i^*\right) \;=\; \frac{c}{\omega_i^*} + (1+c)\left(\frac{\alpha}{1-\alpha}\,\omega_i^*\right)^{-\sigma_i} - \frac{\bar{L}}{\bar{K}} \;=\; 0, \tag{13}$$

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.

It is straightforward to establish existence and uniqueness of the equilibrium real wage. The function $F_i(\omega_i)$ attains a positive value for the lowest value in the domain, $\lim_{\omega_i \to 0} F_i\left(\omega_i\right) = +\infty$, and a negative value for the highest value, $\lim_{\omega_i \to \infty} F_i\left(\omega_i\right) = -\bar{L}/\bar{K}$. As the function is continuous, it must equal zero for at least one positive, but finite value of ω_i.

Moreover, the function is monotonically decreasing in ω_i as the derivative

$$\frac{\partial F(\omega_i)}{\partial \omega_i} \;=\; -c\,\omega_i^{-2} - \sigma_i(1+c)\left(\frac{\alpha}{1-\alpha}\right)^{1-\sigma_i} \omega_i^{-\sigma_i - 1} \;<\; 0 \tag{14}$$

is negative for all positive real wage rates, which guarantees that the solution is unique. This forms the basis for the comparative statics that follow, as we do not need to worry about factor intensity reversals.

2.4 Normalizing the CES function

Before we can derive comparative statics of how the σ parameter influences the equilibrium allocation and international trade, it is necessary to normalize the CES function (2). This is because a high σ has two different effects. First, it facilitates producing with a more unequal K/L^m input ratio. With a higher σ parameter, the marginal product of a production factor declines more slowly if the amount of that factor increases. The second effect of a higher σ parameter is to make routine production more efficient overall. The output of intermediate M is increasing in σ for any given bundle of production factors.

Our objective is to study how countries that start from the same initial situation can develop a comparative advantage as they adjust to the same external shock, for example in response to an increase in the capital stock. The substitution effect is the one of interest, as it directly influences how much labor will be reallocated from routine to non-routine tasks. The second, efficiency effect is more of a nuisance, as it is a structural feature of the CES production function, but not the mechanism we are primarily interested in. The normalization of the CES eliminates the efficiency effect at the starting point (i.e. for initial capital and labor endowments), ensuring that countries with different σ parameters are initially producing the same output bundle.

Klump et al. (2012) have shown that normalizing the CES production function makes it possible to focus on the structural effect of higher substitutability.[16] The rationale behind the normalization follows from the defining property of a CES production function, namely that $\sigma = d\ln(K/L)/d\ln(F_k/F_l)$ is constant. The elasticity of substitution is defined as a point elasticity, valid for a particular point on a particular isoquant. It is fundamentally a second-order differential equation of $F(K, L)$. Solving this equation to find F introduces two constants of integration. Both are fixed once the following two boundary conditions are imposed on the resulting CES production function: (1) It must be able to produce an initial production plan, a combination of output and inputs; (2) The initial allocation must be cost minimizing, i.e., the isoquant is tangent to the initial relative factor price ratio.

If a CES isoquant has to go through one particular point, its constants of integration will depend on σ and cannot be chosen freely. The elasticity of substitution σ_i is the only structural parameter for country i; together with the boundary conditions it determines the other two parameters, $Z_i = Z(\sigma_i)$ and $\alpha_i = \alpha(\sigma_i)$.

To implement the normalization, we reformulate two key relationships that we derived earlier in terms of deviations from an initial production plan. That way, we can investigate how countries with a different σ adjust differentially to an external shock, starting from the same point of normalization. Denote the optimal factor allocation in routine input production by $\kappa_i^* = \bar{K}/(L_i^m)^*$ and indicate quantities and prices at the point of normalization with a subscript 0. The normalized first order condition in routine production, equation (C1) in the Appendix, then becomes

$$\frac{\kappa_i^*}{\kappa_0} = \left(\frac{\omega_i^*}{\omega_0}\right)^{\sigma_i}. \tag{15}$$

Equation (15) illustrates the key property of a CES production function: the sensitivity of relative factor use to a change in relative factor prices is increasing in σ_i. If labor becomes more expensive than at the point of normalization, routine production will become more capital intensive and this change will be especially strong in the high-σ country. Or inversely, a given change in the capital-labor ratio will lead to a smaller change in the relative factor price ratio in the high-σ country.

[16] de la Grandville (1989) shows that the substitution effect can always be written as a σ-multiple of the efficiency effect.

Substituting (15) back in the original first order condition, we find that α varies with σ_i and equals $\alpha(\sigma_i) = \frac{\kappa_0^{1/\sigma_i}}{\kappa_0^{1/\sigma_i}+\omega_0}$. From the routine production function at the point of normalization, we can solve for the productivity term Z_i as $Z(\sigma_i) = \frac{M_0}{L_0^m}\left(\frac{\kappa_0^{1/\sigma_i}+\omega_0}{\kappa_0+\omega_0}\right)^{\frac{\sigma_i-1}{\sigma_i}}$. As mentioned, a country-specific σ_i parameter will in general require country-specific Z_i and α_i parameters in order to make the same initial production plan feasible. Using this expression for α_i, the function $F(\cdot)$ in (13) becomes

$$F_i\left(\omega_i^*; \sigma_i, \frac{\bar{L}}{\bar{K}}, c, \kappa_0\right) = \frac{c}{\omega_i^*} + \frac{1+c}{\kappa_0}\left[\frac{\omega_i^*}{\omega_0}\right]^{-\sigma_i} - \frac{\bar{L}}{\bar{K}} = 0. \quad (16)$$

As is common in the literature, we imposed identical Z and α coefficients in the CES production function of the routine intermediate (2) for all countries. This choice implies a particular initial allocation of labor to routine production, such that the quantity of the routine intermediate produced at the point of normalization is independent of the elasticity of substitution, given the initial total endowment of capital $\bar{K}_0$ and labor $\bar{L}_0$. It is straightforward to see from (13) or (16) that the same equilibrium factor price will obtain if $\omega_0\,\alpha/(1-\alpha) = 1$ or equivalently if $w_0/(1-\alpha) = r_0/\alpha$, irrespective of the σ_i parameter. In that case, cost minimization in routine production implies that $\kappa_0 \equiv \bar{K}_0/L_0^m = 1$.[17] The assumption of Z and α common to the two countries constrains the initial endowments to verify $\bar{K}_0/\bar{L}_0 < 1$.

2.5 Pattern of specialization

We now show how the relative wage ω_i^* changes when factor endowments deviate from the point of normalization. Consider a change in the stock of capital $\bar{K} \gtrless \bar{K}_0$, holding the labor endowment fixed at $\bar{L} = \bar{L}_0$. We apply the implicit function theorem to $F_i(\cdot)$ in (16) and find that[18]

$$\frac{\partial \omega_i^*}{\partial K} = -\frac{\partial F_i(\cdot)/\partial K}{\partial F_i(\cdot)/\partial \omega_i^*} > 0. \quad (17)$$

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

$$\bar{K} \gtreqless \bar{K}_0 \Rightarrow \frac{\omega_i^*}{\omega_0} \gtreqless 1. \quad (18)$$

[17] In that point of normalization, $\alpha_i = 1/(1+\omega_0)$ and $Z_i = M_0/L_0^m$, and both do not vary with σ_i.

[18] The derivative in the numerator is positive for our production function. The derivative in the denominator is negative for all wage rates, see equation (14).

The direction of change does not depend on σ_i, but the magnitude of the change does. Even though the high-σ country experiences a relative productivity boost in the intermediate goods sector, it moves more routine production workers to non-routine tasks in order to equalize the return to labor in routine and non-routine tasks following the shock to the capital endowment. The differential adjustment of the capital intensity in the production of the routine intermediate in the two countries determines the relative abundance of the produced factors and the relative price of final goods.

We next determine how the new equilibrium allocation depends on σ_i as both countries adjust away from the point of normalization where both countries produce the same equilibrium production plan. As their input allocations become different when they move away from the initial situation in response to an increase in the capital stock, a different relative specialization of two economies emerges. We apply the implicit function theorem to (16) one more time and find

$$\frac{\partial \omega_i^*}{\partial \sigma} \quad = \quad -\frac{\partial F_i(\cdot)/\partial \sigma}{\partial F_i(\cdot)/\partial \omega_i^*}.$$

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

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

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, which will happen following an increase in the capital stock, labor will be relatively cheap in the high-σ country in the new equilibrium. Hence,

$$\begin{cases} \frac{\partial \omega_i^*}{\partial \sigma} < 0 & \Leftrightarrow \quad \bar{K} > K_0 \ \text{ or } \ \omega_i^* > \omega_0 \\ \frac{\partial \omega_i^*}{\partial \sigma} = 0 & \Leftrightarrow \quad \bar{K} = K_0 \ \text{ or } \ \omega_i^* = \omega_0 \\ \frac{\partial \omega_i^*}{\partial \sigma} > 0 & \Leftrightarrow \quad \bar{K} < K_0 \ \text{ or } \ \omega_i^* < \omega_0. \end{cases} \tag{19}$$

A higher σ dampens the effect of a change in factor endowments on the equilibrium relative wage. The relative wage increases, but it increases relatively less in the high-σ country A: $\omega_0 < \omega_A^* < \omega_B^*$.

Recall from (12) that it is sufficient to establish in which country the relative price of the routine intermediate is relatively high in autarky to determine relative abundance of 'produced' factors. It is intuitive and straightforward to show that

$d(P_i^m/w_i)/d\omega_i < 0$.[19] In combination with the results in (19), it implies that the relative price of the routine input is increasing in σ for all capital stocks that exceed the level at the point of normalization and vice versa:

$$\begin{cases} \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial\omega_i^*}{\partial\sigma} > 0 & \& \quad \frac{d(L^a/M)}{d\sigma} > 0 \quad \Leftrightarrow \quad \bar{K} > K_0 \\ \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial\omega_i^*}{\partial\sigma} = 0 & \& \quad \frac{d(L^a/M)}{d\sigma} = 0 \quad \Leftrightarrow \quad \bar{K} = K_0 \\ \frac{d(P_i^m/w_i)^*}{d\omega_i^*}\frac{\partial\omega_i^*}{\partial\sigma} < 0 & \& \quad \frac{d(L^a/M)}{d\sigma} < 0 \quad \Leftrightarrow \quad \bar{K} < K_0 \end{cases} \tag{20}$$

The intuition is as follows. When labor becomes more scarce than in the normalization point, it will be expensive and the routine input relatively cheap. The price changes are needed to clear both factor markets after a capital injection, but they are especially pronounced in the low-σ country. It makes labor relatively more expensive in the low-σ country and the routine intermediate expensive in the high-σ country. It follows that after capital deepening, the high-σ country A becomes relatively abundant in non-routine labor: $(L^a/M)^*_A > (L^a/M)^*_B$. More flexible substitution between capital and labor helps the economy to use more efficiently the 'primitive' production factor that has become more scarce (labor), where scarcity is defined relative to the point of normalization.

As countries accumulate capital, which we interpret as a reduced-form representation of capital-biased technological change, they reallocate labor from routine to non-routine tasks.[20] The high-σ country frees up more labor for non-routine tasks and becomes non-routine labor abundant, implying that it will specialize, at least relatively, in the production of the final good that intensively uses the non-routine input. This result is obtained even though the high-σ country is more efficient in the production of the routine intermediate, i.e. with the same input bundle it produces more output in routine production.[21]

The intuition behind this key prediction of our model is that the higher elasticity parameter implies less of a productivity penalty in routine production for an unbalanced factor ratio, meaning that a bigger shift of labor out of routine tasks in the high-σ country is associated with a smaller change in the relative price of labor ω. In the new equilibrium, capital intensity in routine production will be higher in both countries, but it increases especially in the high-σ country.

[19]From equation (7) we can derive $\frac{d(P_i^m/w_i)^*}{d\omega_i^*} = \frac{-\alpha^{\frac{\sigma}{\sigma-1}}}{Z(\omega^*)^2}\left[1+(\omega^*)^{1-\sigma}\left(\frac{1-\alpha}{\alpha}\right)^{\sigma}\right]^{\frac{\sigma}{\sigma-1}} < 0.$

[20]Note that the opposite pattern obtains if the capital-labor ratio is reduced from the initial point of normalization: a high-σ country frees up more labor to do routine tasks and becomes routine input abundant. When we turn to the trade predictions, our maintained assumption is that a rising capital-labor ratio is a pervasive pattern of real-world technological change. Hence, the empirically relevant case is the one where labor is becoming more and more scarce.

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

2.6 Implications of opening up to trade

We now investigate the effect of substitutability between capital and labor in routine production on the pattern of comparative advantage. To accomplish this in a static model, we compare how countries with different σ parameters adjust to the same exogenous shock. In particular, we consider an increase in the capital stock which requires a reallocation of labor to achieve a new equilibrium. In order to focus on this effect, we abstract from other channels of comparative advantage, that are well understood, and assume that both countries have identical endowments of primitive factors, capital and labor, at all times. It is the optimal allocation of labor to routine or non-routine tasks that determines the available quantities of produced factors, abstract labor and routine intermediates, that are used in the two final goods sectors. The equilibrium is fully determined by the relative factor price ratio that clears labor and capital markets.

After a capital injection, the difference in substitutability creates an incentive to trade, even for countries with identical endowments that initially produce the same output bundle. The pattern of comparative advantage that arises can be determined from the comparative statics of the relative factor price ratio with respect to σ. We need to work with the normalized CES function here because—as illustrated in Appendix D—without the normalization we would encounter a circularity: The impact of σ on the pattern of trade depends on the effective labor cost, i.e., whether w_i/r_i exceeds $(1-\alpha_i)/\alpha_i$ or not, while α_i depends on σ itself.

Given the pattern of specialization in autarky, establishing the main result is straightforward. We have already shown that in response to capital deepening, the equilibrium $(L_i^a/M_i)^*$ ratio is increasing in σ. As capital accumulates and labor becomes more scarce, the high-σ country becomes relatively abstract labor abundant (compared to the low-σ country). Higher substitutability dampens the necessary factor price change that is needed to absorb a shock to factor endowments. Capital deepening raises the relative wage in both countries, but less so in the high-σ country which adjusts more in quantities and less in prices.

The direction of trade then follows from the usual reasoning in the HO model. Both countries acquire a comparative advantage in the good that is intensive in their abundant factor. We obtain an adjusted HO prediction in this case, as the relevant production factors for the two final good sectors are not exogenously given, but produced through the equilibrium labor allocation. After a capital increase, the high-σ country specializes in the good intensive in abstract labor. More generally, the high-σ country specializes in the good that uses more intensively the produced factor that itself requires relatively more of the relatively scarce primitive factor. In this condition, the 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 determined by technology, in the canonical HO way.

Three implications of the free trade equilibrium are worth highlighting. First, equalization of final good prices is obtained through further divergence between countries of the capital intensity in routine production. In the autarky equilibrium, capital accumulation creates a wedge between the marginal product ratios (MP_{L^m}/MP_K) for the two countries that differ in input substitutability. In turn, this leads to a wedge in the relative produced factor prices (w/P^m) and thus a wedge in the relative final good prices in the two countries.[22] Once they open up to trade, the only way that the wage to routine input price ratio can increase in the high-σ country is by increasing its relative real wage ω_A/ω_B. This requires a movement of labor out of routine production.[23] Hence, the high-σ 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 this relative capital intensity increases further when the countries open up to trade.

Second, opening up to trade equalizes the final good prices and implies factor price equalization for w/P^m, the relative price ratio for the produced factors, as it would in the canonical HO model. However, factor price equalization is not obtained for the primitive factors. The gap in the relative price of the primitive factors w/r will be smaller than in autarky, but not eliminated entirely. This can be seen from equation (7) which shows that the price for the routine input is a CES price index of the two primitive factor prices. Hence, the relationship between w/P^m and w/r depends on the σ_i parameter. When the first ratio equalizes between countries, the second in general will not whenever the elasticities of substitution differ. In our model, there is no factor price equalization for the primitive factors because - as shown in Section 2.2 - institutional or cultural differences that affect the flexibility of input substitution translate into the use of different production technologies in the two countries. This result is reminiscent of the absence of factor price equalization in the Ricardian model. These patterns are shown formally in Appendix E.

Third, we already discussed that capital deepening raises real wages, but less so in the high-σ country. At the same time, there is an efficiency effect associated with σ in the CES function: holding the other parameters (α and Z) fixed, increasing the production factors raised output M more with higher σ. As a result, capital deepening produces higher total benefits in the high-σ country, but compared to the

[22]The high-σ country will have a lower relative wage, MP_{L^m}/MP_K ratio, wage to routine input price ratio, and a lower relative price for the final good that is intensive in non-routine tasks.

[23]The relative wage rate will equal labor's marginal productivity in routine production and this is increasing in capital intensity.

low-σ country they flow more to capital owners and less to workers. The standard HO finding that gains from trade flow disproportionately to the scarce factor still applies and this favors workers in the high-σ country. As a result, we cannot tell in general in which country workers gain most from capital deepening, but we know that workers gain relatively more in the high-σ country under free trade than under autarky.

The main mechanism at work in our model illustrates how higher factor substitutability helps to mitigate resource scarcity. By imposing a smaller productivity penalty for an unbalanced factor ratio in routine production, it enables the high-σ country to use its relatively scarce factor, i.e. labor, more efficiently, by redeploying it to tasks which cannot yet be accomplished with capital. The high-σ country achieves a more efficient resource allocation in adjusting to factor-biased technological growth. 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 assumed 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 capital-labor substitution are better able to mitigate labor scarcity and achieve higher welfare because they have a stronger incentive to accumulate capital. Endogenizing capital accumulation is left for future work, but it is likely to reinforce our results.[24]

3 Data

As is standard since Bowen et al. (1987) and Debaere (2003), our empirical analysis is based on three types of data. The dependent variable is bilateral export flows at the product level. The explanatory variables are interactions of industry-level indicators of input intensity, in particular, in our case, the routine-intensity, and country-level indicators of the corresponding endowments, including factor endowments and quality of institutions.

Bilateral exports

We take bilateral export information from two data sources. First, we use product-level trade flows from the UN Comtrade database, in the form of the 2017 BACI harmonized version, an earlier release is described in Gaulier and Zignago (2010).

[24] 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 abstract labor in the high-σ country but also reducing the wedge in the autarky factor prices. Stokey (1996) performs a related exercise, but in a one-sector model where no trade is possible.

Using a concordance constructed by Pierce and Schott (2012), we aggregate bilateral trade flows from the 6-digit product detail of the Harmonized System (HS) to 4-digit NAICS sectors, the level at which we observe the industry-level routine intensity.

Second, we also use value-added trade as dependent variable. Due to integration of production processes across borders, the gross export flows in the official statistics only imperfectly capture 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. This trade measure further avoids the so-called 'Rotterdam effect' in Europe, where trade is shipped through a port in another country.

For this analysis we rely on the sectoral information in the *World Input-Output Database* (WIOD).[25] We follow Los et al. (2016) and construct 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 partner were removed from the world economy, leaving all other sources of demand and input-output relationships unaffected. A disadvantage of this data source is the lower industry detail, as we only observe 17 sectors that produce tradable products.

In both datasets, we keep exports from the 28 EU countries—Belgium and Luxembourg are combined—and use the same set of countries on the import side. We keep three years in the sample—1995, 2005, and 2015 for gross exports from BACI, and 2000, 2007, and 2014 for value-added trade from the WIOD—to investigate how the cross-sectional export specialization has evolved over the last two decades. We average exports over two adjacent years to smooth out annual fluctuations.

Industry-level input intensity

The key explanatory variable is the routine task intensity by industry, which is represented by the parameter β_g in the model. We use the ranking constructed by Autor et al. (2003) for 77 US industries at the 4-digit NAICS level. It is a weighted average of the routine task intensity by occupation using as weights the employment shares of occupations in each industry in 1977. 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.[26]

An alternative country-specific measure is developed by Marcolin et al. (2016) for 20 countries, among which 15 EU member states. We calculated an EU index as the weighted average of the national indices and found that it had a high correlation

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

[26] 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.

of 0.77 with the original US index. The bilateral correlations between the indices of different member states and the EU index average 0.66 (standard deviation of 0.09), which is barely higher than the average correlation with the US index, at 0.62. Hence, we use the US routine-intensity measure throughout, also on the global sample for which we report alternative estimates in Appendix F, in line with the practice for the control variables.

As control variables, we include industry characteristics that represent other dimensions of the production technology. Physical 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 US' 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, 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. Finally, the fraction of differentiated inputs in total input expenditure (using the liberal definition) is taken directly from Nunn (2007).

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*.[27] 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*.[28] The ability and effectiveness of contract enforcement is proxied by the 'rule of law' index published

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

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

as part of the *World Bank Governance Indicators database*.[29]

As a measure of country-differences that give a comparative advantage in routine-intensive production, we use several measures of labor market regulation. According to our theory, these should be factors that either determine the ease of substituting between capital and labor in the production of the routine intermediate or determine the ease of labor reallocation between routine and non-routine tasks.

First, we consider the role of formal labor market institutions, as measured by the stringency of employment protection legislation (EPL). This index is constructed by the OECD and discussed in Nicoletti et al. (2000). A similar index to measure worker protection was constructed by Botero et al. (2004) based on data on employment, collective relations, and social security laws as of 1997 in a sample of 85 countries. A third index is based on information from *Business Environment Risk Intelligence*, which was previously used in Costinot (2009). This firm compiles a synthetic index of national 'workforce quality' combining three dimensions which are in turn each constructed from five variables. We take the average of only two dimensions, 'Workforce Characteristics' and 'Workforce Organization and Practices', and omit the 'Workforce Performance' dimension as it captures human and physical capital features that are already included in our alternative HO dimensions. The resulting variable measures behavioral norms of the workforce, worker-management collaboration, and organizational flexibility.[30]

Finally, the degree of internal migration 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.[31] If workers tend to move easily between locations, they might display a similar flexibility substituting between sectors or occupations.

Where possible, we use time-varying information on endowments for the same three years as the export flows. Similarly as we did for exports, we use two-year averages to smooth out annual fluctuations. Most endowment variables change only slightly over time and the second labor market index does 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.

---

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

[30] The 'Workforce Characteristics Index' comprises (i) work ethic, (ii) absenteeism, (iii) attention span, (iv) class, ethnic, and religious factors in the workplace, and (v) availability of trained manpower. The 'Workforce Organization and Practices Index' measures (i) hiring & firing flexibility, (ii) adherence to collective bargaining, (iii) workforce participation in corporate decision making, (iv) workforce militancy, and (v) union corruption.

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

In the second step estimation, we include GDP per capita (taken from the Penn World Tables) as a general control for development.

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

$$\ln X_{ijg} = \gamma_i r_g + \sum_{t \in k,h,f,c} \gamma_t I_i^t t_g + \tau_{ij} + \tau_{jg} + \epsilon_{ijg}. \tag{21}$$

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 routine task intensity r_g, a country-invariant measure of sectoral technology. A high (positive) value for γ_i indicates that the composition of country i's export bundle is correlated positively with the routine-intensity of those sectors.

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 the two traditional HO mechanisms, physical (k) and human capital (h) intensity times endowment, 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).

Equation (21) 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 (21) separately for the three years that we consider. This allows both sets of fixed effects and the γ_i coefficients to vary entirely flexibly over time.

The second step in our analysis is to connect the estimated routine intensity of exports to country characteristics. We wish to find out 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 (21) by year, on the various candidate institutional dimensions I^r_{it}:

$$\hat{\gamma}_{it} \quad = \quad \delta_0 + \delta_1 \, \text{GDP/capita}_{it} + \delta_r \, I^r_{it} + \gamma_t + \epsilon_i, \tag{22}$$

for $r \in \{1, ..., 4\}$.

We include GDP per capita to control for the level of development as well a time fixed effects. Note as well, equation (21) that generates the dependent variable includes controls for alternative HO mechanisms, e.g. human capital abundance, external capital dependency, etc. The coefficient of interest is δ_r. For the two indices measuring the stringency of employment protection legislation, we expect a negative correlation with σ and thus a positive sign on δ_r as they are likely to induce specialization in routine-intensive sectors. In contrast, we expect a negative sign for dimensions that have a positive correlation with σ, i.e., the third labor market index capturing workforce organization and internal migration.

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

$$\ln X_{ijg} \quad = \quad \gamma_r \, I^1_i \, r_g + \sum_{t \, \in \, k,h,f,c} \gamma_t \, I^t_i \, t_g + \tau_{ij} + \tau_{jg} + \epsilon_{ijg}. \tag{23}$$

Compared to specification (21), we replaced the country-specific coefficient γ_i with $\gamma_r \, I^1_i$, inserting the index of employment protection expected to predict routine specialization. This specification is estimated separately by year. Both specifications (21) and (23) are estimated using both value-added trade and gross exports as the dependent variable.

We also estimate specification (23) using change in exports, $\Delta \ln X_{ijg}$, as dependent variable. The theory predicts that the level of the labor market regulation I^1_i should explain the change in comparative advantage as capital accumulates over time. For physical and human capital intensities we use the change in endowments, ΔI^k_i and ΔI^h_i, but for the other two institutional controls, I^f_i and I^c_i, we report results using both the level or the change interacted with the corresponding time-invariant industry intensity.

5 Results

5.1 Step 1: Revealed comparative advantage in routine-intensive industries

We estimate each country's specialization in routine versus non-routine-intensive industries using specification (21). Before estimation, we standardize all variables by subtracting the mean and dividing by the standard deviation over the full sample. As a result, the magnitudes of the coefficients measure how many standard deviations exports change on average when the routine-intensity indicator is one standard deviation higher.[32]

The included fixed effects implicitly normalize the γ_i estimates to average zero over the entire sample.[33] A negative coefficient only implies that the country specializes less in routine-intensive industries than the average country. Given that the sample is almost balanced over exporters, by construction half of the countries show positive and the other half negative point estimates.

Figure 1 shows the estimates of γ_i for all EU countries based on gross exports, which allows for the greatest sector detail.[34] Statistics shown are the country-average of the 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, in particular Finland, Ireland and Sweden, tend to specialize in non-routine-intensive products. At the other end of the spectrum (on the right), are countries with a revealed comparative advantage in routine-intensive industries. Here we find Eastern European countries, like Romania and Bulgaria, but also Portugal.

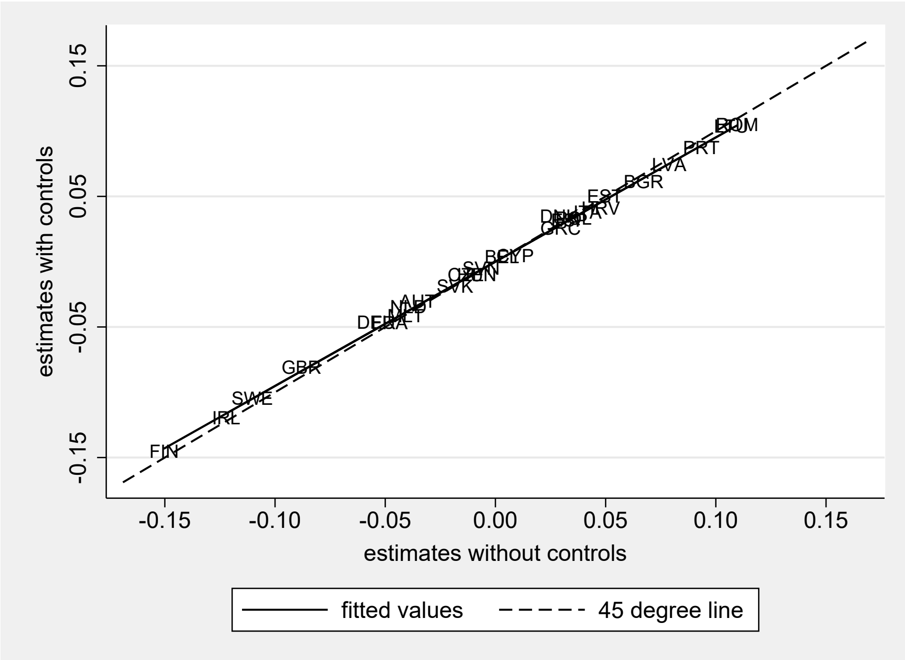
It is remarkable how invariant the estimates are to the inclusion of the four sets of interaction controls that capture alternative explanations for the pattern of sectoral specialization. Results are almost identical with or without; the fitted (solid) line

[32] This interpretation is only approximate due to the fixed effects, which implicitly need to be held constant when evaluating the effect of a change in routine intensity.

[33] 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 normalized to zero. The point estimates in the figures are re-normalized to have an average of zero over the different countries.

[34] Table F.1 and Table F.2 in the Appendix report the point estimates and standard errors for the estimates using both gross exports and value-added trade as dependent variables. Figures F.1 to F.3 show corresponding results on the sample of the 50 largest global exporters.

Figure 1: (Non-)Routine export specialization among EU member states



Note: Estimates on the horizontal axis control for industry-country interaction terms that represent other sources of comparative advantage. Estimates on the vertical axis are based only on the routineness index and fixed effects. The specification is estimated separately for three years using gross exports as dependent variable and the three country-estimates are averaged.

lies almost on top of the dashed 45-degree line. It implies that the predictive power of routine intensity for trade flows is orthogonal to the most important endowment or institution-based explanations in the literature.

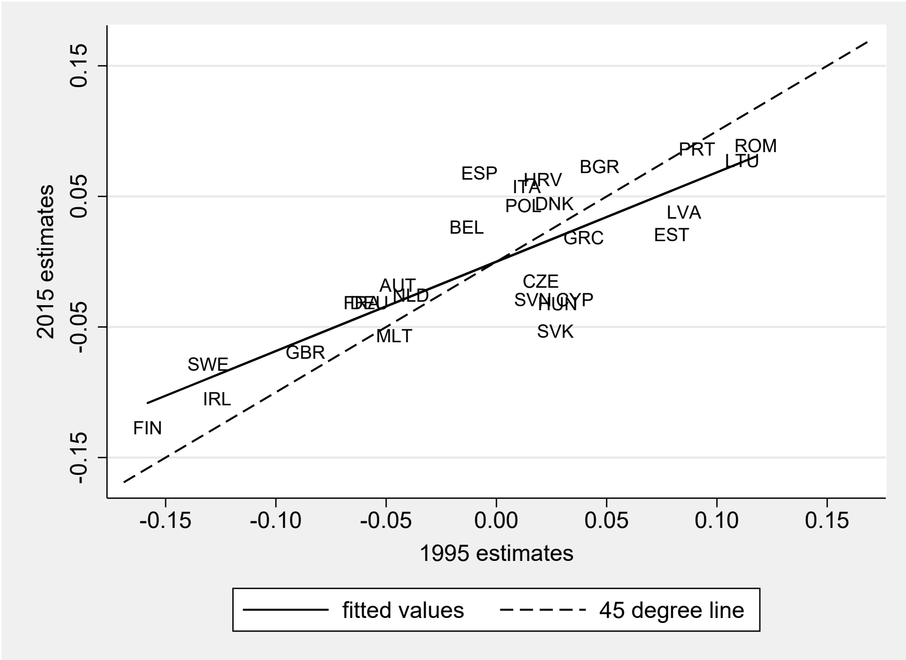
Another notable pattern is the relatively large difference in specialization between some countries that are similar in GDP per capita. Finland and Sweden have much lower (more negative) point estimates than Denmark. The contrast between France and Italy is also quite large.

Figure 2 shows how routine specialization has evolved over time, always including the interaction controls. The top panel shows results for gross exports as dependent variable, and the bottom panel for value-added trade. In both cases, the point estimates for the most recent year, 2015 or 2014, are on the vertical axis, with the corresponding estimates for 1995 or 2000 on the horizontal axis.[35]

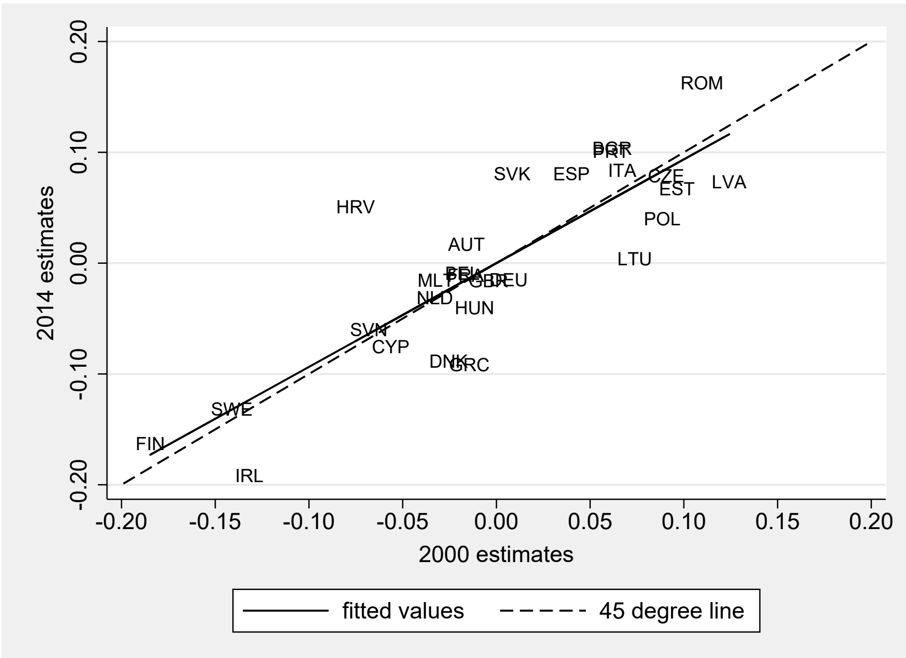
The top panel, for gross exports, shows a convergence in export orientation. Countries with negative coefficients in 1995 are systematically above the 45-degree line in 2015 and the reverse is true for countries with positive coefficients in 1995. Most countries see their γ_i coefficient shrink towards zero. It implies that routine-

[35]For almost all countries, the estimates in 2005 or 2007 are intermediate.

Figure 2: Change in (non-)routine export specialization over time



(a) Estimates using gross exports



(b) Estimates using value-added trade

Note: Estimates in the top panel are based on the BACI data and 76 industries. Estimates in the bottom panel are based on the WIOD data and 17 industries.

intensity has less predictive power for countries' export bundle in 2015 than in 1995.

In the middle of the graph we see two clusters of countries with relatively similar export orientation in 1995, but a different evolution in the next 2 decades. Spain, Belgium, and Italy, but also Croatia and Poland increasingly specialize in routine-intensive industries. In contrast, Slovakia, Hungary, Cyprus, Slovenia, and the Czech Republic changed in the opposite direction.

The bottom panel of Figure 2 shows similar estimates but using value-added trade as dependent variable. While the results differ somewhat for some countries, discussed further below, an important difference is that the estimates are highly stable over time using this type of trade flow. The fitted (solid) line lies almost on top of the 45-degree line. It suggests that the convergence in the top panel does not so much result from a changing specialization, but is due to gross export becoming an increasingly inaccurate gauge of specialization.

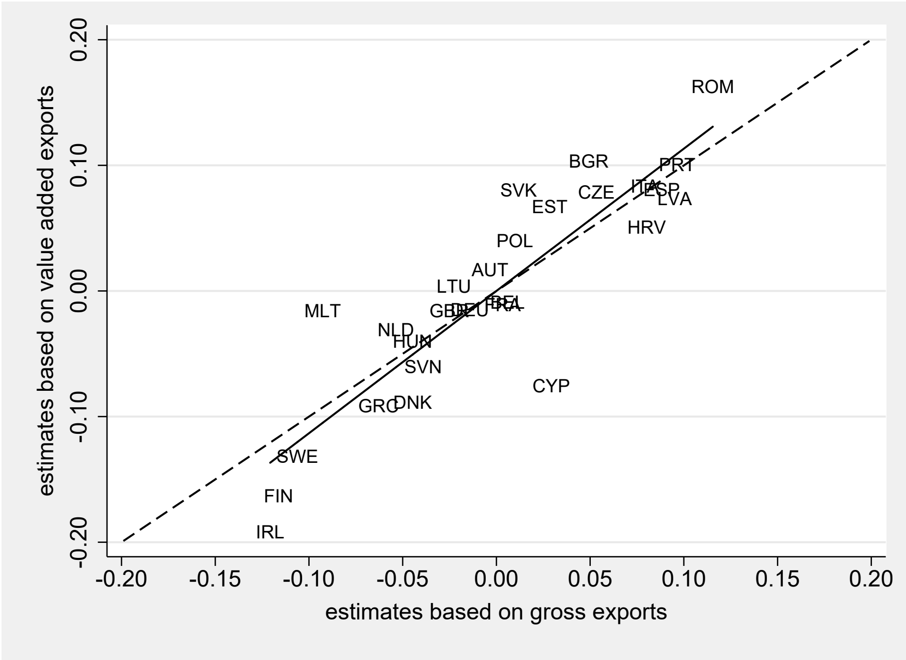
The emergence of a large Slovak automotive industry illustrates this nicely. That industry is highly non-routine intensive, but at the same time sources a lot of intermediates from other sectors making it more than twice as important for trade in gross exports than in value-added trade. As several assembly plants opened up in Slovakia after 1995, its point estimate in the top panel declined from 0.027 to -0.053, suggesting a shift in specialization towards non-routine industries. However, the opposite pattern appears using the trade in value added data (in the bottom panel).

While the overall extent of routine specialization remained similar, a number of countries saw a notable change in their relative position. Countries farthest above the 45-degree line, in particular Croatia, Slovakia, and Romania, become more specialized in routine-intensive industries. Countries farthest below the line, such as Ireland, Greece, or Lithuania, specialized away from routine-intensive industries. Importantly, while a number of Eastern European countries specialized more in routine-intensive industries over time, there are as many cases where we see an opposite evolution. Similarly, a few traditional EU member states become more routine-intensive, like Austria and Spain, but others evolve in the opposite direction, like Denmark and Greece.

The two panels in Figure 2 use different data sources and the gross export information uses much more industry detail. The results in Figure 3 compare the extent of routine specialization based on both dependent variables on the identical sample in 2014. The relative ranking of countries is broadly consistent for the two measures. In particular, the 3 countries least and the 5 countries most specialized in routine-intensive products are the same for both dependent variables. The largest difference in the ranking for the two measures is for Cyprus, which is right in the middle based on gross exports, but fourth-least routine intensive based on value-added trade.

Even though there are some deviations from the 45-degree line, the overall ranking of countries is very similar. The partial correlation of the two sets of estimates

Figure 3: (Non-)routine export specialization for two different export measures



Note: Estimates using the BACI data for 2014 in both cases.

is 0.91 and the Spearman rank correlation is 0.89. The steep fitted (solid) line indicates that routine specialization is more pronounced using the value-added trade measure.

The predictive power of the routineness indicator for export specialization only falls over time when the dependent variable is gross exports and not for value-added trade. The standard deviation across countries of the estimated $\hat{\gamma}_i$ coefficients based on gross exports is one fifth lower in 2015 than in 1995 on the BACI data. Estimated on the less detailed WIOD data, the standard deviation is one tenth lower in 2014 than in 2000. In contrast, using the identical sample, the standard deviation of the estimates based on value-added trade increases by 6%.

While there is a negative correlation between GDP per capita and specialization, this relationship is highly imperfect. For example, Italy sees a much stronger and Slovenia a much weaker specialization in routine-intensive sectors than would be predicted by their level of development. We next evaluate which observable differences between countries help explain differences in the routine-intensity of their exports.

Table 1: Country determinants for (non-)routine export specialization

	Gross exports (76 sectors)				Value added trade (17 sectors)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(GDP/capita)	-0.784***	-0.923***	-0.594**	-0.594**	-0.813***	-0.845***	-0.376	-0.483***
	(.144)	(.124)	(.276)	(.276)	(.145)	(.129)	(.250)	(.168)
Strictness of employment protection legislation	0.355***				0.262**			
	(.100)				(.103)			
Labor market legislation (Botero et al., 2004)		0.119				0.064		
		(.090)				(.097)		
Workforce characteristics and organization			-0.111				-0.418**	
			(.181)				(.167)	
Internal migration				-0.358***				-0.483***
				(.105)				(.112)
Observations	63	72	48	54	63	72	48	54
Adjusted R2	0.398	0.422	0.166	0.267	0.366	0.353	0.312	0.312

Note: Dependent variables are the country-specific estimates of routine specialization in exports (the point estimates reported in Tables F.1 and F.2 in the Appendix). Regressions include year-fixed effects. Reported statistics are standardized β-coefficients which measure effects in standard errors. ***, **, * indicate statistical significance at the 1%, 5%, 10% level.

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

To learn which country characteristics correlate with the pattern of routine versus non-routine specialization recovered in step 1, we report the estimates of specification (22) in Table 1. Each of the four country characteristics is introduced separately. The reported estimates are standardized β-coefficients to make the absolute magnitudes of coefficients on the different variables comparable. We run a panel regression, pooling the estimates for the three years.

GDP per capita is always included as a control variable because countries with a different level of development are likely to have different institutional quality and industrial structure. Not surprisingly, it is always negatively related to the extent of specialization in routine-intensive industries.

The strictness of employment protection legislation (EPL) has the predicted positive sign using either type of trade flow. This variable happens to show almost no correlation with GDP per capita, but still varies widely across EU countries that are relatively similar in most other dimensions. The second variable measures the rigidity of labor market legislation more broadly. It also shows positive point estimates, but they are not statistically significant. Countries that regulate the labor market more tightly and that make it harder for firms to fire workers tend to specialize in routine-intensive industries. In the micro-foundation of our production function, we showed that firing restrictions tend to lower the elasticity of substitution between labor and capital and indirectly between routine and abstract tasks. These results are thus in line with the predictions of our model.

The third variable combines a variety of workforce features and norms, such as good work ethic and low absenteeism, as well as organizational features, such as hiring & firing flexibility and worker-management collaboration in decision making. It is coded such that a high value indicates a high workforce quality. The results indicate that it is negatively related to routine specialization, especially for the estimates based on value-added trade.

The last variable, the extent of internal migration, has the predicted negative sign in both samples. It is plausible that countries with a lot of internal geographic mobility also have norms or institutions that facilitate movement of workers between tasks. To the extent that it will be reflected in a higher σ parameter in the model, it is consistent with the comparative advantage predictions.

One must be careful in attributing a causal interpretation to these results. While in our model we consider a set-up in which cultural or institutional differences are given exogenously, in practice labor regulations may have been enacted in response to either structural characteristics of the economy or in response to - for example - social tensions associated to trade shocks. As we do not take a stance on the exogeneity of the observed EPL regime, we stop short of giving a causal interpretation to our results.

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 (22) as an ordered probit model. This follows the spirit of the rank comparisons in Bowen et al. (1987). It makes the point estimates harder to interpret, but the signs for the different country characteristics are always unchanged. In this case, it is preferable to estimate separate specifications for each year, rather than pooling and including time fixed-effects, but most of the t-statistics did not decline much even on samples only one third the size.[36]

5.3 Single-step estimation

The second step results provide an idea which attributes make countries specialize in routine-intensive industries. Now we include an interaction between the routineness indicator r_g and the preferred country 'endowment' I_i^r directly in the initial

[36]Results available upon request.

Table 2: Relative importance of different mechanisms for comparative advantage

	Value added trade (17 sectors)				
	level of exports			change in exports	
	2000	2007	2014	2000 to 2014	
	(1)	(2)	(3)	(4)	(5)
Routineness	0.148***	0.271***	0.295***	0.181***	0.176***
* EPL (level)	(.031)	(.035)	(.036)	(.059)	(.059)
Differentiated input share	0.051***	0.109***	0.087***	-0.123***	
* Rule of law (level)	(.014)	(.015)	(.014)	(.023)	
Differentiated input share					-0.100***
* Rule of law (change)					(.018)
External capital dependency	-0.051***	-0.041***	0.020*	0.081***	
* Financial development (level)	(.007)	(.009)	(.010)	(.018)	
External capital dependency					0.015*
* Financial development (change)					(.009)
Capital-intensity	0.031**	0.022	-0.065***		
* K/L ratio (level)	(.014)	(.016)	(.016)		
Capital-intensity				0.162***	0.176**
* K/L ratio (change)				(.021)	(.021)
Human capital-intensity	0.251***	0.056	-0.041		
* School enrollment (level)	(.035)	(.041)	(.045)		
Human capital-intensity				-0.018	-0.001
* School enrollment (change)				(.036)	(.036)
Observations	9,639	9,639	9,639	9,639	9,639

regression. Based on the results in Table 1 we interact r_g with the EPL measure. Results in Table 2 are shown first in levels, separately by year, and using the change in exports from 2000 to 2014 in the last two columns.

The interaction of sectoral routine-intensity and national EPL shows the expected positive sign. As before, we normalized all variables by their standard deviation such that the absolute magnitudes are comparable across the different interactions and over time. In 2000, four of the five mechanisms show a positive coefficient, indicating that they have some explanatory power for countries' export specialization. The specialization of countries with a high human capital endowment in industries with high human capital intensity is the strongest mechanism, but its predictive power has diminished starkly in recent years. In contrast, the coefficient on the interaction between routineness and EPL has doubled in magnitude from 2000 to 2014. From 2007 onwards, this mechanism has by far the strongest predictive power for export specialization of the five mechanisms that we consider. The same evolution is apparent in the sample of the largest global exporters, reported in Table F.4 in the Appendix. Only on this broader sample, the human capital mechanism still retains a predictive power that is almost equally large.

One way to interpret the theoretical prediction is that the accumulation of capital that has been ongoing for decades, even centuries, must have created a comparative advantage in non-routine-intensive tasks in countries with low EPL. Taking a more literal interpretation of the theory, we can investigate whether the routine-EPL interaction term is correlated with a change in export specialization towards routine-intensive industries. This is exactly what the results in columns (4) and (5) establish. Countries with a high EPL in 2000, significantly changed their revealed comparative advantage towards routine-intensive industries in the next 14 years.

It is intuitive to interact the physical and human capital intensity of each sector with the change in respective capital endowments in each country. For physical capital, this mechanism is also very potent. Countries that experience a strong capital growth increasingly specialize in capital-intensive industries. However, this is not the case for human capital. Changes in human capital endowments tend to be driven by changes in GDP per capita and they show no relationship with the evolution of a country's export specialization.

Finally, for the two other institutional mechanisms it is not clearcut whether to use the level or change in the institutional indicators. In the case of our theory, there is an explicit link between the level of σ, here proxied by EPL, and the change in comparative advantage. The alternative mechanisms tend to relate the (relative) level of the institution to the level of exports. However, measuring changes in these institutional indicators over time is challenging and observed changes risk being dominated by measurement error. In any case, both levels and changes give similar results. They are supportive for the financial development mechanism, but not for the differentiated goods contracting mechanism.

6 Conclusion

We pin down a novel mechanism behind comparative advantage that is based on countries' differential ability to adjust to capital accumulation and labor-saving technological change. We build on a pattern extensively documented in the labor literature, whereby more efficient machines displace workers from codifiable (routine) tasks. We then introduce the hypothesis that the reallocation of labor across tasks is subject to frictions, the importance of which differs by country. We incorporate task routineness and labor reallocation frictions into an augmented $2 \times 2 \times 2$ Heckscher-Ohlin model, where labor needs to be allocated to routine and non-routine tasks. The key feature of our model is that the factor endowments necessary for the production of the two final goods, namely the quantity of the routine intermediate as well as the quantity of labor available for non-routine tasks, are determined endogenously. The optimal allocation of labor to routine and non-routine tasks, conditional on the total amount of capital available in the economy, determines the relative abundance of the non-routine factor in each country in equilibrium.

We provide a microfoundation that helps explain why the parameter that captures capital-labor substitutability—which 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 that increases a firm's cost of adjusting the labor input, such as the rigidity of labor market institutions or the lack of publicly-financed active labor market policies, may increase the shadow cost of switching to more productive capital. Hence, it will result in a lower perceived capital-labor substitutability in routine production.

The key theoretical prediction of our model is that with capital deepening, countries with flexible reallocation of labor become relatively abundant in non-routine labor. As a result, they specialize in goods that use non-routine labor more intensively.

We follow the two-step approach of Costinot (2009) to test this prediction in the data. We first estimate the revealed comparative advantage of each country in exports of routine versus non-routine-intensive industries. Next, we relate these estimates to country-level characteristics of labor market institutions and regulations that may influence the ease of adjustment to new technology.

For a sample of relatively similar EU countries, we document significant differences in the pattern of revealed comparative advantage in terms of the routine-intensity of their exports. Countries with the most strict employment protection legislation tend to have an export bundle tilted towards routine-intensive industries. An alternative index of high-quality 'workforce characteristics and organization' predicts export specialization in non-routine-intensive industries.

To account for the increased importance of global value chains, we also use value-added trade data from the World Input-Output Database to verify the robustness of these findings. The estimated measures of comparative advantage are found to correlate highly with our baseline findings. Importantly, while the explanatory power of routineness for gross exports declines over time, this is not the case for value-added trade. That is, the channel we have put forward in this paper retains its explanatory power, when we take into account the increased trade in intermediate products.

To compare the predictive power of our new mechanism relative to other endowment-based (Heckscher-Ohlin) or other institutional mechanisms, we also evaluate predictions in a single step. The interaction of the sectoral indicator of routine-intensity and the country-level employment legislation indicator has a strong and increasing predictive power for revealed comparative advantage. In fact, towards the end of the sample period it has the best predictive power of all five mechanisms that we consider to explain intra-EU trade.

Results are similar in a broader sample of the 50 largest exporters. In this bigger sample of countries, human capital endowments are an equally good predictor of specialization, i.e. in industries that use human capital more intensively.

Our results have important policy implications. They illustrate that governments can play a key role to ensure that the process of labor reallocation from tasks that are substitutable with machines to tasks that are complementary with machines proceeds quickly and smoothly. Indeed, workers are shown to benefit relatively more from the process of technological change and from trade integration in institutional environments that succeed in reducing the costs of labor reallocation across tasks.

References

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

Acemoglu, D. and P. Restrepo (2018). The race between machine and man: Implications of technology for growth, factor shares and employment. *American Economic Review 108*(6), 1488–1542.

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

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

Artuç, E., D. Lederman, and G. Porto (2015). A mapping of labor mobility costs in the developing world. *Journal of International Economics 95*(1), 28–41.

Autor, D. H. and D. Dorn (2013). The growth of low-skill service jobs and the polarization of the US labor market. *American Economic Review 103*(5), 1553–97.

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

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

Bárány, Z. L. and C. Siegel (2018). Job polarization and structural change. *American Economic Journal: Macroeconomics 10*(1), 57–89.

Bartelsman, E., P. Gautier, and J. De Wind (2016). Employment protection, technology choice, and worker allocation. *International Economic Review 57*(3), 787–825.

Bewley, T. F. (2009). *Why Wages Don't Fall during a Recession*. Cambridge: Harvard University Press.

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

Botero, J. C., S. Djankov, R. La Porta, F. L. de Silanes, and A. Shleifer (2004). The regulation of labor. *Quarterly Journal of Economics 119*(4), 1339–1382.

Bowen, H. P., E. E. Leamer, and L. Sveikauskas (1987). Multicountry, multifactor tests of the factor abundance theory. *American Economic Review 77*(5), 791–809.

Bresnahan, T. F., E. Brynjolfsson, and L. M. Hitt (2002). Information technology, workplace organization, and the demand for skilled labor: Firm-level evidence. *Quarterly Journal of Economics 117*(1), 339–376.

Campante, F. R. and D. Chor (2017). "just do your job": Obedience, routine tasks, and the pattern of specialization. ERIA Discussion Paper No. DP-2016-35.

Chor, D. (2010). Unpacking sources of comparative advantage: A quantitative approach. *Journal of International Economics 82*(2), 152–167.

Costinot, A. (2009). On the origins of comparative advantage. *Journal of International Economics 77*(2), 255–264.

Costinot, A., L. Oldenski, and J. Rauch (2011). Adaptation and the boundary of multinational firms. *Review of Economics and Statistics 93*(1), 298–308.

Cuñat, A. and M. Melitz (2012). Volatility, labor market flexibility, and the pattern of comparative advantage. *Journal of the European Economic Association 10*(2), 225–254.

de la Grandville, O. (1989). In quest of the slutsky diamond. *American Economic Review 79*(3), 468–481.

Debaere, P. (2003). Relative factor abundance and trade. *Journal of Political Economy 111*(3), 589–610.

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

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

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

Harrigan, J., A. Reshef, and F. Toubal (2016). The march of the techies: Technology, trade, and job polarization in France, 1994-2007. NBER Working Paper No. 22110.

Kambourov, G. (2009). Labor market regulations and the sectoral reallocation of workers: The case of trade reforms. *Review of Economic Studies 76*(4), 1321–58.

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

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

Los, B., M. P. Timmer, and G. J. de Vries (2016). Tracing value-added and double counting in gross exports: Comment. *American Economic Review 106*(7), 1958–66.

Marcolin, L., S. Miroudot, and M. Squicciarini (2016). The routine content of occupations: New cross-country measures based on PIAAC. OECD Science, Technology and Industry Working Paper No. 2016/02.

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

Nunn, N. (2007). Relationship-specificity, incomplete contracts, and the pattern of trade. *Quarterly Journal of Economics 122*(2), 569–600.

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

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

Pierce, J. R. and P. K. Schott (2012). A concordance between ten-digit U.S. Harmonized System codes and SIC/NAICS product classes and industries. *Journal of Economic and Social Measurement 37*(1-2), 61–96.

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

Rajan, R. G. and L. Zingales (1998). Financial dependence and growth. *American Economic Review 88*(3), 559–586.

Stokey, N. L. (1996). Free trade, factor returns, and factor accumulation. *Journal of Economic Growth 1*, 421–447.

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

Appendix A Support for parameter assumptions

We estimate a separate production function for each country-sector to provide support for the assumed parameter heterogeneity in 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. While not ideal, 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.[37] Real output and an index of capital services are reported directly in the database.

The production function technology in equation (3) incorporates heterogeneity along two dimensions. First, it assumes that sectors differ in the relative intensity they use abstract labor and the routine input intermediate, 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. A sectoral measure of routine intensity is constructed 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 intermediate, which is represented by the parameter σ_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 (2018) assume perfect substitutability ($\sigma = +\infty$), Autor and Dorn (2013) assume $\sigma > 1$, while Goos et al. (2014) estimate the elasticity of substitution between the tasks required to generate industry output and find a value slightly below one.[38] 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 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

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

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

unambiguous structural interpretation.[39] 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,

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

to recover two coefficients, β and σ, for each country-sector pair. There is a lot of heterogeneity in the estimated parameters. The median elasticity of substitution ($\hat{\sigma}$) in routine production is 1.75, but the interquartile range is $(0.3, 20)$. The median routine intensity ($\hat{\beta}$) is 0.19 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 either production function parameter. In the top panel of Table A.1, we first show a reduced-form 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 captures the relative routine intensity of the sector. The σ 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 explain 54.2% of the total sum of squares against only 28.5% for the country dummies. Note that even if the β parameter was the same for all countries, we would still expect the country dimension to have some explanatory power. Sectoral specialization by country (for example driven by the mechanism in our model) would still generate variation in the average employment ratio across countries.[40]

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, i.e. of the σ parameter. The results in Table A.1 indicate that the country dummies explain a lot more of the variation in this ratio than sector-fixed effects.

Finally, in panel (b) of Table A.1, we confirm these results with a similar exercise, but now directly explaining variation in the two estimated production function coefficients. The β coefficient is predicted better by the sector dummies, while the σ 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,

[39] We force the β coefficient to lie between 0 and 0.6 and the σ coefficient between 0 and $+\infty$.

[40] Moreover, the three skill levels are defined based on the country-specific schooling levels, which itself introduces some cross-country variation in the average share of the skilled workforce over all sectors.

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[i]							
$\left(\frac{L^a}{L^a+L^m}\right)$	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							
$\hat{\beta}_{ig}$	25.52	5.30	2.67		6.03	5.01	
		(20.8%)	(10.5%)		(0.00)	(0.00)	
$\hat{\sigma}_{ig}$[ii]	1636	191	217		1.03	1.93	
		(11.7%)	(13.3%)		(0.43)	(0.01)	

[i] The average input shares over the period are used

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

but there are many fewer countries than sectors and the F-statistic—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 $\hat{\sigma}_{ig}$ estimates.

Appendix B Derivative of $\sigma_{L,K}$ with respect to the lay-off friction

Here, we show the effect of a change in the lay-off cost friction p on the elasticity of substitution of the modified production function $y = F(K, L)/(1 + pC(L))$.

The elasticity is defined as

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

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 (5) implies:

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

In addition, we have

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

and substituting for dK then yields

$$d(L/K) = \left(\frac{1}{K} + \frac{L}{K^2}\frac{MP_L}{MP_K} - \frac{L}{K^2}\frac{p\,C\,F'(L)\,y}{MP_K}\right) dL. \quad \text{(B1)}$$

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:

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

Differentiating with respect to L/K gives:

$$\frac{dMRTS}{d(L/K)} = \frac{\frac{dMP_K}{d(L/K)}}{MP_L - p\,C'(L)\,y} - \frac{MP_K\left(\frac{dMP_L}{d(L/K)} - p\,C''(L)\,y\,\frac{dL}{d(L/K)}\right)}{(MP_L - p\,C'(L)\,y)^2} \quad \text{(B2)}$$

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 illustration that introducing a labor market friction will reduce the elasticity of substitution even in this case.

In the presence of a friction, the derivative of the marginal rate of substitution (B2) in this case simplifies to:

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

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:

$$\sigma_{L,K} = \frac{\left(1 - p\,C'(L)\,y\right)^2/L + \left(1 - p\,C'\left(L\right)\bar{y}\right)^3/K}{p\,C''(L)\,y}. \tag{B3}$$

Appendix C Solving the model: step-by-step

The model features three types of price-taking firms: one type produces the routine intermediate, the other two 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.

C.1 Routine production

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

$$M_{if} \;=\; Z\left[\alpha (K_{if})^{\frac{\sigma_i-1}{\sigma_i}} + (1-\alpha)(L^m_{if})^{\frac{\sigma_i-1}{\sigma_i}}\right]^{\frac{\sigma_i}{\sigma_i-1}} \tag{2}$$

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

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

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

$$\frac{L^m_{if}}{K_{if}} \;=\; \left[\frac{w_i}{r_i}\,\frac{\alpha}{1-\alpha}\right]^{-\sigma_i}. \tag{C1}$$

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:

$$K_{if} \;=\; \frac{M_{if}}{Z}\left[\frac{r_i}{\alpha}\right]^{-\sigma_i}\left[\alpha^{\sigma_i} r_i^{1-\sigma_i} + (1-\alpha)^{\sigma_i} w_i^{1-\sigma_i}\right]^{-\frac{\sigma_i}{\sigma_i-1}} \tag{C2}$$

$$L^m_{if} \;=\; \frac{M_{if}}{Z}\left[\frac{w_i}{1-\alpha}\right]^{1-\sigma_i}\left[\alpha^{\sigma_i} r_i^{-\sigma_i} + (1-\alpha)^{\sigma_i} w_i^{1-\sigma_i}\right]^{-\frac{\sigma_i}{\sigma_i-1}}. \tag{C3}$$

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

$$P^m_i \;=\; C(w_i, r_i) \;=\; \frac{1}{Z}\left[\alpha^{\sigma_i} r_i^{1-\sigma_i} + (1-\alpha)^{\sigma_i} w_i^{1-\sigma_i}\right]^{-\frac{1}{1-\sigma_i}}. \tag{7}$$

C.2 Final good production

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

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

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

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

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

$$\frac{L^a_{igf}}{M_{igf}} \;=\; \frac{1-\beta_g}{\beta_g} \, \frac{P^m_i}{w_i}. \tag{C4}$$

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 with perfect competition is also the final good price:

$$P_{ig} \;=\; C_{ig}(w_i, P^m_i) \;=\; \frac{1}{z_g} \left(\frac{w_i}{1-\beta_g} \right)^{1-\beta_g} \left(\frac{P^m_i}{\beta_g} \right)^{\beta_g}, \quad \forall g \in \{1,2\}. \tag{8}$$

By replacing the price of the routine intermediate in (8) by its function of primitive factor prices (7), we can express the price of each final good in terms of the primitive factor prices, the wage and rental rate of capital:

$$P_{ig} \;=\; \frac{1}{z_g \, Z^{\beta_g}} \left[\frac{w_i}{1-\beta_g} \right]^{1-\beta_g} \left[\frac{\left(\alpha^{\sigma_i} r^{1-\sigma_i} + (1-\alpha)^{\sigma_i} w_i^{1-\sigma_i}\right)^{\frac{1}{1-\sigma_i}}}{\beta_g} \right]^{\beta_g} \tag{C5}$$

C.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 (C3), as

$$K_{if} \;=\; \frac{M_{if}}{Z}\left[1+\frac{w_i}{r_i}\left(\frac{w_i/(1-\alpha)}{r_i/\alpha}\right)^{-\sigma_i}\right]^{-\frac{\sigma_i}{\sigma_i-1}}.$$

From this we find the optimal quantity of the routine intermediate 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

$$\sum_f M_{if} \;=\; M_i \;=\; Z\,\bar{K}\,\alpha^{\frac{\sigma_i}{\sigma_i-1}}\left[1+\frac{w_i}{r_i}\left(\frac{w_i/(1-\alpha)}{r_i/\alpha}\right)^{-\sigma_i}\right]^{\frac{\sigma_i}{\sigma_i-1}}.$$

Labor market clearing then gives the total quantity of abstract labor that can be used in the final good sectors 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 necessary expression for L_{if}^m is given directly by the ratio of first order conditions in routine production (C1).

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:

$$\frac{L_i^a}{M_i} \;=\; \frac{\bar{L}-L_i^m}{M_i} \;=\; \frac{\bar{L}-\left[\frac{w_i/(1-\alpha)}{r_i/\alpha}\right]^{-\sigma_i}\bar{K}}{Z\bar{K}\alpha^{\frac{\sigma_i}{\sigma_i-1}}\left\{1+\frac{w_i}{r_i}\left[\frac{w_i/(1-\alpha)}{r_i/\alpha}\right]^{-\sigma_i}\right\}^{\frac{\sigma_i}{\sigma_i-1}}}. \tag{9}$$

Equivalently, we can use (7) to write the relative factor supply as a function of the wage and of the price of the routine input:

$$\frac{L_i^a}{M_i} \;=\; \frac{\bar{L}-\left[\frac{\alpha}{1-\alpha}\right]^{\frac{\sigma_i}{\sigma_i-1}}\left[\left(\frac{P_i^m}{w_i}\right)^{1-\sigma_i}(1-\alpha)^{-\sigma_i}Z^{1-\sigma_i}-1\right]^{-\frac{\sigma_i}{\sigma_i-1}}\bar{K}}{Z\bar{K}\alpha^{\frac{\sigma_i}{\sigma_i-1}}\left[1-\left(\frac{P_i^m}{w_i}\right)^{-(1-\sigma_i)}(1-\alpha)^{\sigma_i}Z^{-(1-\sigma_i)}\right]^{-\frac{\sigma_i}{\sigma_i-1}}}. \tag{C6}$$

C.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 a representative 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:

$$P_{i2}Q_{i2} = \frac{\theta_2}{\theta_1} P_{i1}Q_{i1}. \tag{C7}$$

By substitution in the final good prices (8), we can re-write this expression as a function of the wage rate and the price of the routine input:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{\theta_1 z_1 \beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}}{\theta_2 z_2 \beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}} \left(\frac{w_i}{P_i^m}\right)^{\beta_1-\beta_2}. \tag{10}$$

Alternatively, we can also write this expression as a function of the primitive factor prices by using equation (C5) instead to eliminate the final good prices:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{\theta_1 z_1 \beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}}{\theta_2 z_2 \beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}} \left(Zw_i\right)^{\beta_1-\beta_2} \left[\alpha^{\sigma_i} r^{1-\sigma_i} + (1-\alpha)^{\sigma_i} w_i^{1-\sigma_i}\right]^{\frac{\beta_2-\beta_1}{1-\sigma_i}}. \tag{C8}$$

C.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:

$$\frac{Q_{i1}}{Q_{i2}} = \frac{Y_{i1}}{Y_{i2}} = \frac{z_1 {L_{i1}^a}^{1-\beta_1} {M_{i1}}^{\beta_1}}{z_2 {L_{i2}^a}^{1-\beta_2} {M_{i2}}^{\beta_2}}. \tag{11}$$

Using the first order conditions in final goods production (C4), 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 ratio. We do this twice, first for the routine intermediates M_{i1} and M_{i2} and then for both abstract labor inputs:

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

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

We then equate both of these expressions to (10), 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:

$$\frac{L_{i1}^a}{L_{i2}^a} = \frac{\theta_1(1-\beta_1)}{\theta_2(1-\beta_2)} \qquad ; \qquad \frac{M_{i1}}{M_{i2}} = \frac{\theta_1\beta_1}{\theta_2\beta_2}. \tag{C9}$$

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 (C9) and rearranging, we find

$$L_{i1}^a = \frac{\theta_1(1-\beta_1)}{\sum_g \theta_g(1-\beta_g)} L_i^a \qquad ; \qquad M_{i1} = \frac{\theta_1\beta_1}{\sum_g \theta_g\beta_g} M_i. \tag{C10}$$

Next, we take the ratio of the two factor demands (C10) for sector 1 and equate it to the first order condition ratio (C4). 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:

$$\frac{L_i^a}{M_i} = \frac{\sum_g \theta_g(1-\beta_g)}{\sum_g \theta_g\beta_g} \frac{P_i^m}{w_i} \tag{12}$$

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 (7) to find the relative factor demand in terms of the primitive factor prices

$$\frac{L_i^a}{M_i} = c\left[\frac{w_i}{r_i} Z\alpha^{\frac{\sigma_i}{\sigma_i-1}}\right]^{-1} \left[1 + \left(\frac{w_i}{r_i}\right)\left(\frac{w_i/(1-\alpha)}{r_i/\alpha}\right)^{-\sigma_i}\right]^{\frac{1}{1-\sigma_i}}. \tag{C11}$$

C.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—(9) and (C11)—and in terms of the produced factor prices—(C6) and (12). We equate the first two equations and find

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

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

$$\omega_i^* \quad = \quad c\left[\frac{\bar{L}}{\bar{K}} - (1+c)\left(\frac{1-\alpha}{\alpha}\right)^{\sigma_i}(\omega_i^*)^{-\sigma_i}\right]^{-1}. \tag{C12}$$

Appendix D Comparative statics results

Given that the effective relative cost of labor is given by $[w_i/(1-\alpha_i)]\,/\,[r_i/\alpha_i]$, we can establish that, without normalization,

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

When labor is scarce and the equilibrium wage exceeds $(1-\alpha_i)/\alpha_i$, labor will be relatively cheap in the high-σ country. Note this refers to a ratio-of-ratios: the *relative* real wage is lower in the high-σ country. Conversely, when labor is abundant and cheap, it will be relatively expensive in the high-σ country.

A complication with these comparative statics results is that they hinge on the effective cost of labor and α_i is itself a function of σ_i. To break this circularity and pin down the effect of σ on the equilibrium factor price ratio as a function of only endowments and parameters, it is necessary to normalize the CES function.

Appendix E Free trade equilibrium

E.1 Factor price equalization for produced factors

We focus on the case where both countries $i = \{A, B\}$ produce both final goods $g = \{1, 2\}$. As in the canonical HO model, trade then leads to the equalization of the relative factor prices for the 'produced' factors that are the inputs for the two final goods. To see this, we start from the fact that the ratios of both final goods' prices equalize in the two countries, i.e.,

$$\frac{P_{A1}}{P_{A2}} = \frac{P_{B1}}{P_{B2}}.$$

Given perfect competition in the final goods sectors, we already established that prices equal production costs, i.e. that

$$P_{ig} = \frac{1}{z_g \beta_g^{\beta_g} (1-\beta_g)^{1-\beta_g}} (P_i^m)^{\beta_g} (w_i)^{1-\beta_g}. \tag{8}$$

Substituting these expressions for the final good prices in the above ratios yields

$$\left(\frac{P_A^m}{w_A}\right)^{\beta_1-\beta_2} = \left(\frac{P_B^m}{w_B}\right)^{\beta_1-\beta_2}, \tag{E1}$$

and we see that the produced factor price ratios equalize in the two countries.

E.2 No factor price equalization for primitive factors

Importantly, however, opening up to trade does not lead to equalization of the factor price ratios for the 'primitive' factors, capital and labor, that countries are endowed with. This can be seen directly from equation (7) which reflects that price equals marginal costs in the perfectly competitive routine sector, i.e.,

$$P_i^m = \frac{1}{Z} \left[\alpha^{\sigma_i} r_i^{1-\sigma_i} + (1-\alpha)^{\sigma_i} w_i^{1-\sigma_i}\right]^{-\frac{1}{1-\sigma_i}}. \tag{7}$$

By factoring out $w_i^{1-\sigma_i}$ from both terms, we can rewrite the expression as

$$\frac{P_i^m}{w_i} = \frac{1}{Z} \left[\alpha^{\sigma_i} \left(\frac{r_i}{w_i}\right)^{1-\sigma_i} + (1-\alpha)^{\sigma_i}\right]^{-\frac{1}{1-\sigma_i}}. \tag{E2}$$

Equalization of the produced factor price ratio in (E1), makes it impossible for the primitive factor price ratio on the right-hand side of equation (E2) to be the same for two countries that differ in σ_i.

E.3 Trade reduces the wedge in the primitive factor price ratio

We established that the relative price of the primitive factors is not equalized in the free trade equilibrium. Now we show that the wedge becomes smaller under free trade than in autarky.

We first express the relative price of the two final goods as a function of the ratio of the two real wages $\nu = \omega_B/\omega_A$. We start by substituting the price of the routine intermediate (7) into the expression for the price of the final good (8) and take the ratio of the two final good prices:

$$\frac{P_{i1}}{P_{i2}} = \frac{z_2\beta_2^{\beta_2}(1-\beta_2)^{1-\beta_2}Z^{\beta_2}}{z_1\beta_1^{\beta_1}(1-\beta_1)^{1-\beta_1}Z^{\beta_1}}\left(\alpha^{\frac{\sigma_i}{\sigma_i-1}}\frac{w_i}{r_i}\right)^{\beta_2-\beta_1}\left[1+\left(\frac{w_i}{r_i}\right)^{1-\sigma_i}\left(\frac{1-\alpha}{\alpha}\right)^{\sigma_i}\right]^{\frac{\beta_2-\beta_1}{\sigma_i}}.$$

We simplify the expression by grouping all country-invariant terms under a constant B, replacing $\omega_i = w_i/r_i$, imposing the normalization $\alpha = 1/(1+\omega_0)$, and bringing the first ω_i term into the square brackets:

$$\frac{P_{i1}}{P_{i2}} = B(1+\omega_0)^{\frac{\sigma_i}{\sigma_i-1}(\beta_1-\beta_2)}\left[\omega_i^{\sigma_i-1}+\omega_0^{\sigma_i}\right]^{\frac{\beta_2-\beta_1}{\sigma_i}}.$$

Note that the derivative of this relative price ratio with respect to the relative wage ω_i is positive if good 1 is non-routine abundant ($\beta_1 < \beta_2$).

The relative final goods' price ratio in the two countries is then

$$\frac{P_{A1}/P_{A2}}{P_{B1}/P_{B2}} = (1+\omega_0)^{\frac{\sigma_A(1-\sigma_B)}{\sigma_B(1-\sigma_A)}(\beta_2-\beta_1)}\left[\omega_A^{\sigma_A-1}+\omega_0^{\sigma_A}\right]^{\frac{\beta_2-\beta_1}{\sigma_A}}\left[\omega_B^{\sigma_B-1}+\omega_0^{\sigma_B}\right]^{\frac{\beta_1-\beta_2}{\sigma_B}}.$$

Using $\omega_B/\omega_A = \nu$, we can write it as

$$\frac{P_{A1}/P_{A2}}{P_{B1}/P_{B2}} = \left\{(1+\omega_0)^{\frac{\sigma_A(1-\sigma_B)}{\sigma_B(1-\sigma_A)}}\frac{\left[(\omega_B/\nu)^{\sigma_A-1}+\omega_0^{\sigma_A}\right]^{\frac{1}{\sigma_A}}}{\left[\omega_B^{\sigma_B-1}+\omega_0^{\sigma_B}\right]^{\frac{1}{\sigma_B}}}\right\}^{\beta_2-\beta_1}. \tag{E3}$$

This equation reflects how a difference in the relative prices for final goods between the two countries is reflected in a wedge between their real wages. Given that the exponent on $1/\nu$ is positive—because $\sigma_i > 1$ and $\beta_2 > \beta_1$—it implies that the derivative of the RHS of expression (E3) is negative. This means that the relative price of the non-routine-intensive good in the high-σ country A is decreasing in ν.

In the case of capital deepening in autarky, we have established that both countries will reach a new equilibrium with $\nu > 1$. To equate the relative final good price ratio in both countries once they open up to trade, the price of the non-routine good needs to rise relatively in the high-σ country A. To increase the relative price ratio and equation (E3) still holding, ν must be reduced such that country A's relative real wage rises. We have already shown, however, that primitive factor prices do not equalize entirely and $\nu > 1$ remains true in the free trade equilibrium.

Appendix F Additional empirical results

F.1 Step 1 point estimates for EU countries

Table F.1: (Non-)Routine export specialization coefficients estimated using gross exports

	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	(.016)	-0.104	(.015)	-0.079	(.013)
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	-	-0.028	-	-0.018	-
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	(.016)	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)	0.042	(.015)	0.058	(.013)
HRV	0.021	(.018)	0.039	(.015)	0.063	(.014)
EST	0.080	(.018)	0.051	(.015)	0.020	(.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	(.013)
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 (AUT 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 three years.

Table F.2: (Non-)Routine export specialization coefficients estimated using value-added trade

	2000		2007		2014	
	Coef.	**St.Dev.**	**Coef.**	**St.Dev.**	**Coef.**	**St.Dev.**
FIN	-0.185	(.022)	-0.194	(.022)	-0.163	(.022)
IRL	-0.132	(.022)	-0.125	(.022)	-0.192	(.022)
SWE	-0.141	(.022)	-0.135	(.022)	-0.132	(.022)
SVN	-0.068	(.022)	-0.060	(.022)	-0.060	(.022)
CYP	-0.056	(.023)	-0.051	(.022)	-0.076	(.022)
DNK	-0.026	(.022)	-0.066	(.022)	-0.089	(.022)
GRC	-0.014	(.022)	-0.067	(.022)	-0.092	(.022)
NLD	-0.033	(.022)	-0.062	(.022)	-0.031	(.022)
HUN	-0.012	(.022)	-0.052	(.022)	-0.040	(.022)
BEL	-0.018	(.022)	-0.043	(.022)	-0.009	(.022)
MLT	-0.032	(.022)	-0.018	(.022)	-0.016	(.022)
FRA	-0.016	(.022)	-0.031	(.022)	-0.011	(.022)
GBR	-0.004	(.022)	-0.029	(.022)	-0.016	(.022)
DEU	0.007	(.022)	-0.039	(.022)	-0.015	(.022)
AUT	-0.016	-	-0.017	-	0.017	-
HRV	-0.075	(.022)	0.017	(.022)	0.051	(.022)
SVK	0.008	(.022)	0.043	(.022)	0.080	(.022)
ESP	0.040	(.022)	0.041	(.022)	0.081	(.022)
LTU	0.074	(.022)	0.090	(.022)	0.004	(.022)
POL	0.089	(.022)	0.075	(.022)	0.040	(.022)
ITA	0.067	(.022)	0.066	(.022)	0.083	(.022)
CZE	0.091	(.022)	0.058	(.022)	0.079	(.022)
PRT	0.061	(.023)	0.072	(.023)	0.101	(.023)
EST	0.096	(.022)	0.096	(.022)	0.067	(.022)
BGR	0.062	(.022)	0.095	(.022)	0.104	(.022)
LVA	0.124	(.022)	0.158	(.022)	0.073	(.022)
ROM	0.110	(.022)	0.175	(.022)	0.163	(.022)
No. of obs.	12,347		12,360		12,374	

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 (AUT 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 three years.

F.2 Results on sample of 50 largest global exporters

Data

As a robustness check for the results on intra-EU trade, we replicate all results in the paper for a second sample. In this case, 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.

When using value-added trade flows, we again rely on the WIOD, which contains information for 43 countries and a 'Rest of the World' aggregate. Of the 50 largest exporters, 36 countries appear in the WIOD and that is the sample we use for the results using value-added trade. On the import side, we combine the imports of the 7 small EU countries into a single destination.

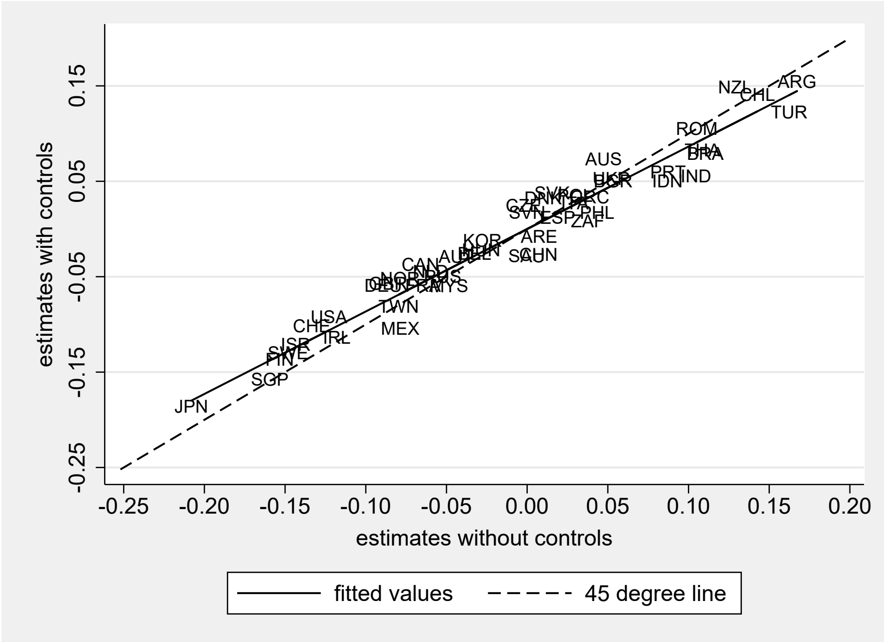
Step 1

Figure F.1 replicates Figure 1 for the sample of large exporters. It is intuitive that the estimates with controls on the vertical axis are slightly lower in absolute value than those without controls. Estimates on the left tend to lie above the 45-degree line and on the right below the dashed line. The solid, fitted line confirms that the results change towards zero if controls are included.

The average change is minor, but more noticeable than in the sample of EU countries that are more similar in terms of other endowments. The adjustment is most notable for 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 export specialization.

Finland, Sweden, and Ireland again show a pronounced specialization away from routine-intensive industries. Japan and Singapore show an even more extreme in specialization in the same direction. The next cluster of countries is also intuitive, including Israel, Switzerland, and the United States.

Figure F.1: (Non-)Routine export specialization among 50 largest global exporters



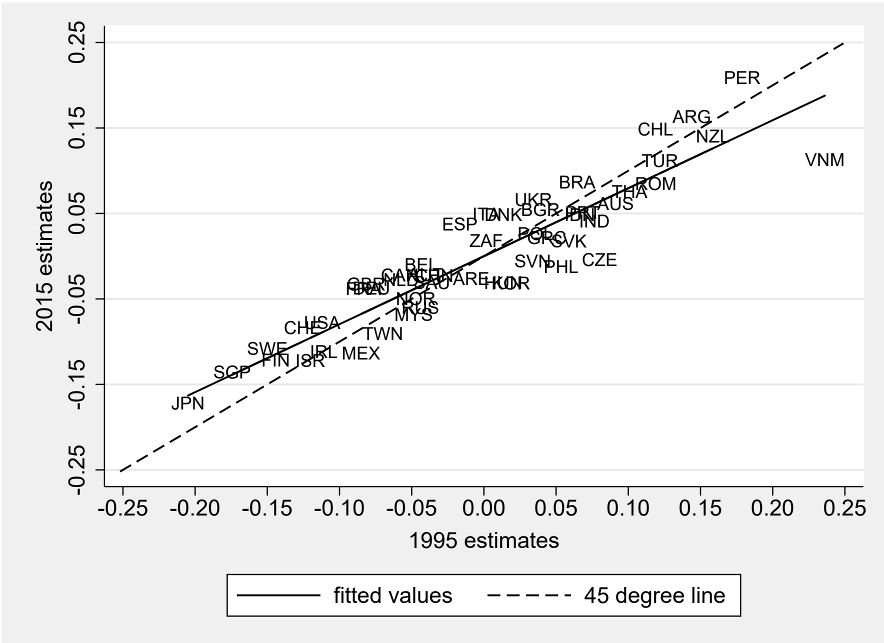
At the other end of the spectrum (on the right) are countries with a revealed comparative advantage in routine-intensive industries. Here we find more developing or emerging economies, first Peru and Vietnam, followed by Argentina and Chile. Exports of New Zealand, which is well-known to specialize in primary products, and Turkey, which is an assembly hub for EU-bound exports, are also highly routine intensive. The EU countries with the strongest specialization in routine-intensive industries are Romania and Portugal, similarly as for intra-EU trade.

The results again reveal some relatively large differences in specialization between countries that share similar levels of development. Finland and Sweden have much lower (more negative) point estimates than Norway or Denmark. The contrast between France and Italy or between Spain and Portugal is also quite large. The same holds on 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.

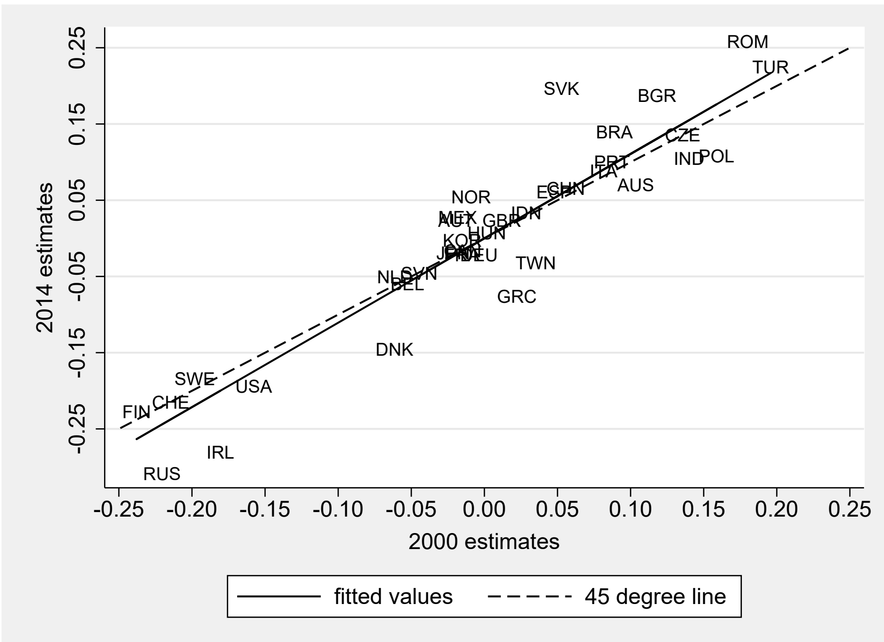
The relative ranking of countries is broadly consistent with Figure 1, suggesting that the overall and intra-EU export bundles of most countries are highly correlated. This is not surprising as the intra-EU share of exports is very high for most member states. Among the countries that appear in both samples, only the United Kingdom and Slovakia show a noticeably lower specialization towards routine-intensive sectors on the intra-EU sample. The difference is especially large for Slovakia, indicating that its intra-EU exports are systematically different from its extra-EU exports. The emergence of a large Slovak automotive industry notably shifted (only) its intra-EU specialization towards non-routine industries.

The two panels in Figure F.2 show the changes in point estimates over time for both type of trade flows. The fitted (solid) line is flatter than the 45-degree dashed line for the estimates using gross exports (in the top panel). It indicates a diminished specialization in terms of routine intensity over time. However, the change is less pronounced than it was in the EU sample. The fitted line is steeper than the 45-degree line for the estimates using value-added trade (in the bottom panel), indicating an enhanced specialization.

Figure F.2: Change in (non-)routine export specialization over time



(a) Estimates using gross exports



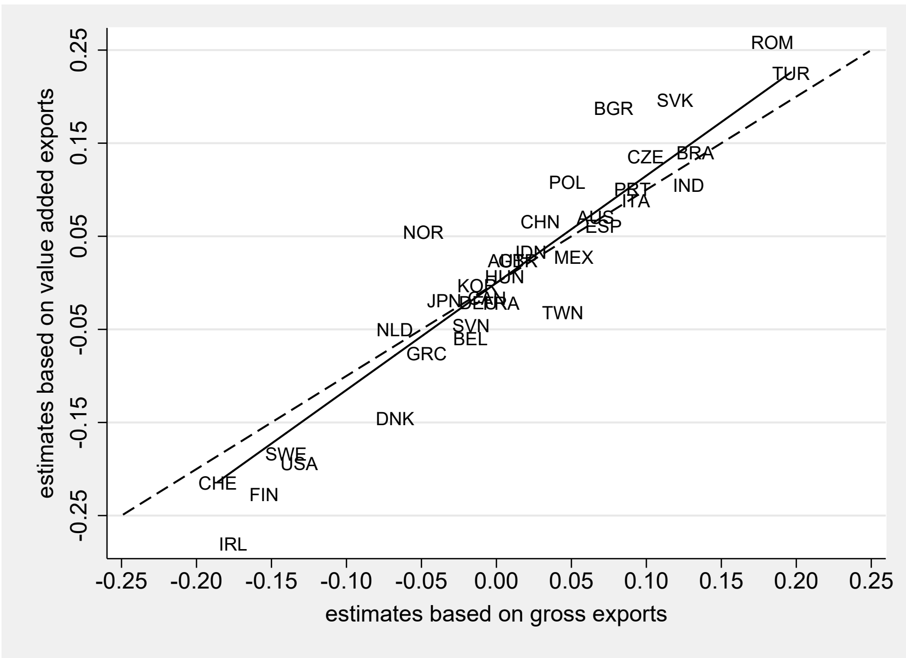
(b) Estimates using value-added trade

Over the twenty year period from 1995 to 2015, countries' relative specialization by routine-intensity is rather stable. Large deviations from the 45-degree line are rare. The two largest changes are for Vietnam and the Czech Republic which both specialize 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.

In Figure F.3 we show the two sets of estimates, for gross exports and value-added trade, for 2014 both estimated on the sample of 36 large exports in the WIOD and the reduced sectoral detail. The steep fitted (solid) line indicates that routine specialization is more pronounced using the value-added trade measure. However, most countries are fairly close to the 45-degree line and the overall ranking is maintained. The partial correlation of the two sets of estimates is above 0.8.

A few countries, in particular Denmark, the United States, and Taiwan, are found to specialize more in non-routine industries based on the value-added trade measure. In the case of Denmark, it moves the country closer to the position of the other Scandinavian countries and also the other two changes are plausible. We find the reverse pattern for Slovakia which is found to specialize more in routine industries for value-added trade than for gross exports. This difference is caused by the lower weight on its automotive sector, as gross exports are much higher than value-added trade for this highly non-routine product. This industry also explains Slovakia's greater specialization in non-routine products for within-EU than for global trade that we mentioned before.

Figure F.3: (Non-)routine export specialization for two different export measures



Step 2

The results of the second step estimates in Table F.3, using the first step estimates as dependent variable, are similar as on the EU sample. We highlight a few differences.

The strictness of employment protection legislation (EPL) has the predicted positive sign using either set of estimates, but is only a significant predictor of export specialization using the estimates based on value-added trade. The alternative labor market legislation indicator from Botero et al. (2014) still leads to statistically insignificant coefficients, which now even have the opposite sign.

The 'Workforce characteristics and organization' variable again shows the predicted negative coefficients, but is now a better predictor of specialization in terms of gross exports than for value-added trade. The relatively strong correlation with GDP per capita might explain the less stable results. Finally, the internal migration again shows a robust negative effect on both sets of estimates.

The absolute magnitudes of the point estimates tend to be lower on the sample of large exporters than on the EU sample. Recall that the coefficients have the interpretation of number of standard deviation change in the dependent variable for each standard deviation change in the explanatory variable. The smaller magnitude, especially for the most robust predictors—EPL and internal migration—likely reflects that the countries in the sample of large exporters used in Table F.3 are less similar in other dimensions.

Table F.3: Country determinants for routine export specialization

	Gross exports (76 sectors)				Value added trade (17 sectors)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(GDP/capita)	-0.655***	-0.629***	-0.069	-0.663***	-0.760***	-0.574***	-0.331**	-0.568***
	(.119)	(.079)	(.136)	(.121)	(.123)	(.089)	(.157)	(.130)
Strictness of employment protection legislation	0.057				0.161*			
	(.092)				(.091)			
Labor market legislation (Botero et al., 2004)		-0.002				-0.131		
		(.069)				(.084)		
Workforce characteristics and organization			-0.544***				-0.215	
			(.120)				(.138)	
Internal migration				-0.177*				-0.175*
				(.091)				(.098)
Observations	102	144	120	90	84	108	93	84
Adjusted R2	0.249	0.295	0.339	0.267	0.366	0.353	0.312	0.312

Single step

On the sample of large exporters, human capital is the most important determinant of countries' export specialization in 2000 and remains highly predictive afterwards. Capital intensity and the ability to enforce contracts for differentiated inputs do not show the predicted positive sign in any of the three years, but change in the respective endowments does correlate positively with export growth in the affected sectors. The importance of financial development for capital dependent industries shows up consistently. The effect is small initially, grows over time, and is also apparent in the first difference results.

Most importantly, the interaction of routine task intensity and EPL has a very strong effect on export specialization. By the end of the sample period it even becomes the strongest predictor, similarly as in the EU sample. For the change in exports, the level of EPL is also the strongest predictor of the five mechanisms considered.

Results are broadly similar using gross exports as dependent variable for this sample, but in that case human capital remains the most important predictor of comparative advantage throughout the entire sample period.

Table F.4: Relative importance of different Heckscher-Ohlin mechanisms

	Value added trade (17 sectors)				
	level of exports			change in exports	
	2000	2007	2014	2000 to 2014	
	(1)	(2)	(3)	(4)	(5)
Routineness	0.236***	0.332***	0.369***	0.201***	0.224***
* EPL (level)	(.026)	(.030)	(.036)	(.042)	(.042)
Differentiated input share	0.002	-0.012	0.009	-0.146***	
* Rule of law (level)	(.012)	(.013)	(.012)	(.016)	
Differentiated input share					0.058***
* Rule of law (change)					(.013)
External capital dependency	0.007	0.038***	0.140***	0.087***	
* Financial development (level)	(.006)	(.007)	(.009)	(.010)	
External capital dependency					0.018***
* Financial development (change)					(.007)
Capital-intensity	-0.099***	-0.106***	-0.125***		
* K/L ratio (level)	(.012)	(.014)	(.014)		
Capital-intensity				0.087***	0.099***
* K/L ratio (change)				(.015)	(.015)
Human capital-intensity	0.301***	0.316***	0.313***		
* School enrollment (level)	(.027)	(.033)	(.035)		
Human capital-intensity				-0.075***	-0.050**
* School enrollment (change)				(.023)	(.023)
Observations	16,625	16,625	16,625	16,625	16,625