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Summary

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We compare the effect of trade block formation on innovation outcomes. Integration leads to aggregate increase in both product and process innovation, resulting in aggregate welfare gains. These are concentrated in North: the research sectors of East and South collapse. Our findings explain data from eastern European countries, as well as current R&D policies in China that are designed to avoid downstream lock-in.

Keywords: Product innovation, process innovation, integration

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WINNERS AND LOSERS FROM TRADE?
– PRODUCT AND PROCESS INNOVATION IN A 3×3 MODEL

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Abstract. We develop a multi-region, multi-sector Romer-type dynamic partial equilibrium model of endogenous growth. We calibrate on equally sized regions North, East, and South, based on data from Germany, Poland, and China.

We compare the effect of trade block formation on innovation outcomes. Integration leads to aggregate increase in both product and process innovation, resulting in aggregate welfare gains. These are concentrated in North: the research sectors of East and South collapse. Our findings explain data from eastern European countries, as well as current R&D policies in China that are designed to avoid downstream lock-in.

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Section 1. Introduction

The increasing specialisation of countries into business functions rather than industries (e.g. De Backer and Miroudot 2013; Timmer, Miroudot, and de Vries 2019; Grieveson et al. 2021; Coveri and Zanfei 2023) makes the distinction between product and process innovations more important. With increasing global participation in value chains and with the fragmentation of production processes across countries also these two types of innovation become spatially separated.

Tinnefeld (2023) combined world input-output data with patent data to show that, while most patenting occurs upstream, the share of process patents is higher in the downstream stages of production. Explicitly, process shares are higher in East European countries compared to West European countries, as the former generally have low levels of patenting and take more downstream positions within the GVC. This also holds for some Asian countries such as Indonesia. Western economies take a medium position both in terms of upstreamness and in terms of process shares. Mexico and Brazil are located mainly between East European and Western countries on both dimensions. Past models have shown that under integration through intermediate trade, which makes up most trade today (e.g. Johnson 2014), advanced countries specialise in upstream research producing product innovation, less advanced in downstream manufacturing (e.g. Devereux and Lapham 1994; Walz 1998), supporting the empirical evidence of Tinnefeld (2023). Existing models however pay less attention to the distinction between product and process innovation and regional differentiation.

The present article incorporates the distinction between product and process innovation in endogenous growth theory to obtain a better understanding how differences in the process share of patents across economies may develop. We ask how innovation patterns are affected and shaped by specialisation into business functions that result from the increased participation in global trade. Explicitly, we aim to understand how innovation incentives change when trade blocs are formed between economies with different endowments, productivities, and level of economic development. We then study the outcomes of integration by looking at a welfare measure and link our findings to those on innovation outcomes.

We focus on the beginning of the 21st century: in this period trade relationships deepened strongly, both within Europe and between Europe and many Asian countries, especially China, after China's accession to the WTO. We examine the effect of regional integration not only from the perspective of a technological leader, as is the case in many studies, but also investigate whether there are differentiated implications for technological laggards. Explicitly, we study the formation of trade blocs among three different regions, where a Western economy (North) integrates with an economy from

Eastern Europe (East) and/or with an economy from Asia (South)[1]. We abstract from size effects by assuming all trade blocks to have the same population size.

We find that integration has positive effects both on upstream and downstream innovation, where the former impact on product innovation is stronger at the aggregate. Integration produces heterogeneous effects for East and South. Both regions specialise in downstream manufacturing when forming a trade bloc with the North. This shifts innovation efforts towards downstream processes and away from upstream research. But the East, relatively stronger in the upstream research compared to the South, experiences welfare losses from integration, while the South obtains net gains. This is because the South experiences smaller losses from collapse of upstream research that can be compensated by downstream welfare gains. The North, on the other hand, specialises in upstream research and intermediate goods production when forming a trade bloc with a technological laggard region. We also find that North has a clear preference for integration with East rather than South: this is driven by the larger market size per capita, resulting in higher demand in the upstream sector. Our results therefore show that, without additional policies, integration can lead to a deepening of market concentration among technological leaders and laggards when they form a trade bloc.

Understanding the impact trade liberalisation has on countries' incentives to invest in product versus process innovations is not a new concern. Existing empirical studies (Bertschek 1995; Becker and Egger 2013) mainly analyse the effect of import competition on product versus process innovation, focussing on advanced economies such as the United States and Germany. Theoretical models (e.g. series of models following Rivera-Batiz and Romer 1991b) look at trade liberalisation and its effect on upstream versus downstream human capital, but the focus is on the long-term effects on growth. In contrast, our model sheds light on the innovation outcomes of integration in the short to medium term, explicitly the 10 year time span of the great wave of integration starting in 2000.

Our model is a dynamic multiregional and multisectoral partial equilibrium model, based on the endogenous growth model of Romer (1990). There are three industrial sectors: the upstream research sector produces blueprints of product innovations; these are inputs to intermediate good firms that produce capital goods; the downstream final good sector combines the intermediate capital goods and labour to produce consumption goods. We diverge from the standard Romer model in that investment into process innovation is possible, increasing the productivity of final good production.

The model also features multiple regions, each hosting each type of industrial sector. This allows for trade among regions by making intermediate goods available to final

1. Western economies in our model are represented by the region termed "North". We decided to remain with the original terminology of North-South models and introduce an "intermediate" region — East.

good sectors of regions that are part of the same trade bloc. The Romer model structure allows to see sectors as different business functions along value chains, in which countries can specialise, rather than different industries.

We calibrate the model for three regions, representing the global North, South and East, using patent and world input-output data for Germany, China and Poland, respectively, for the years 2000–2010. We concentrate on this constellation of countries, because although Poland and China are very different economies, they have played for Germany in the past comparable roles. For instance, in 2024 Germany exported more goods value to Poland than to China (Wagner and Martinez 2024) for the first time since 2009, the year in which China overtook Poland as a sales market for German goods (Observatory of Economic Complexity 2025). This is despite the enormous population difference of around 1.38 billion, placing Poland now as Germany's fourth-largest export market, while China is the fifth-largest.

As mentioned, we adjust the model parameters such that all regions are of the same population size, which makes their comparison easier. Our calibration allows us to analyse whether and in what ways trade liberalisation affects East and South differently in terms of upstream vs. downstream innovation, employment of human capital, output levels and welfare. It also allows us to investigate integration of the North with the Eastern versus the Southern trade block, and to pinpoint winners and losers of different integrations, not only on the regional but also on the sectoral level. This gives hints on interregional effects on inequalities.

The theoretical trade literature has investigated several factors influencing offshoring: comparative advantages in the availability of labour and capital (Sposi, Yi, and Zhang 2021) and skills (Goto, Ma, and Takeuchi 2025), cost differences, contractual frictions and technology adoption (Antràs and Helpman 2004; Antràs 2005; Acemoglu, Antràs, and Helpman 2007; Antràs and Helpman 2008). There is a separate literature on human capital and trade (Grossman 2004; Bougheas and Riezman 2007; Ohnsorge and Trefler 2007). Grossman and Rossi-Hansberg (2008, 2012) focus on trade in tasks, which are performed by heterogeneously skilled workers (e.g. workers vs managers). In their model production requires different tasks. Differences in factor endowments and prices then create incentives for offshoring of certain tasks. Most of the above models are static and none make explicit distinction between product and process innovations.

The theoretical R&D literature that analyses knowledge development and product and process innovations makes typically use of a multi-sectoral setting but does not allow for multiple regions (e.g. Boone (2000) and Dawid, Pellegrino, and Vivarelli (2021)). Similarly, empirical evidence on the relationship between product and process innovation in a trade context comes mainly from country-level studies in developed countries and remains quiet on the effects in countries that are offshoring targets (Bertschek 1995; Becker and Egger 2013; Branstetter et al. 2021; Bena and Simintzi 2022).

Romer (1990) models endogenous technological growth in a three sector economy. Early integrated versions of Romer models are discussed by Walz (1997a) who highlights the roles of reallocation (e.g. Rivera-Batiz and Romer 1991b; Rivera-Batiz and Xie 1993; Devereux and Lapham 1994), redundancy (e.g. Rivera-Batiz and Romer 1991b), and scale effects (e.g. Rivera-Batiz and Romer 1991a). These models focus on various forms of integration among two regions. Other modifications to the Romer model include, for example, the addition of more regions (Walz 1997b, 1998; Diao, Roe, and Yeldan 1999), and modifications to the upstream innovation process (e.g. Arnold and Kornprobst 2008). However, to the best of our knowledge, there is no model that incorporates product and process innovations explicitly taking part in different parts of the value chain in a multi-region set-up.

Similarly to Walz (1998), we integrate regions that have heterogeneous levels of productivity. Our aim is to compare integration of technological leaders with different types of technological laggard regions in the medium run: as in Devereux and Lapham (1994) regions start out with different knowledge stocks. We refrain from introducing knowledge spillovers explicitly, as Jaffe, Trajtenberg, and Henderson (1993) has shown that — especially in the short term — knowledge spillovers are highly localised.

Finally, we contribute to the strand of literature that brings the Romer model to data (e.g. Diao, Roe, and Yeldan 1999; Dinopoulos and Thompson 2000; Gong, Greiner, and Semmler 2004). Gong, Greiner, and Semmler (2004) criticise empirical studies that test the Romer model using cross-sectional data, that lump together countries with different development status and assume, for instance, technology parameters to be static and equal across space. Motivated by our interest in the medium term, we employ a mixed strategy in our calibration: technology parameters differ across countries but factor shares are equal.

Section 2. Model

There are n regions whose industries are described by the same production functions. They differ in initial conditions and productivity parameters. There are three sectors, producing respectively blueprints, intermediate goods, and final goods, using labour and capital as inputs.

Labour is differentiated in production workers, upstream human capital, and downstream human capital.

The sole input of the research sector is upstream human capital. Using technology, whose level is described by an upstream knowledge stock, human capital produces product innovations, in the form of blueprints, which are sold to intermediate goods producers.

Each active firm in the intermediate goods sector buys a single upstream blueprint. It then rents a capital stock to manufacture monopolistically a unique producer durable. Blueprints can only be bought from a research sector in the trade block the intermediate goods firm belongs to. The producer durables are sold to final good sectors under monopolistic competition, which allows the intermediate goods firms to accumulate profits. The producer durables can be sold only to final goods firms in the same trade bloc.

The inputs of the final good sector are production workers and producer durables x_j. Production uses a technology whose level is represented by a downstream knowledge stock to produce consumption goods. These are sold domestically to consumers. It also employs downstream human capital to develop process innovations that increase the downstream knowledge stock and consequently productivity.

In our model, upstream and downstream knowledge are region-specific: there are no knowledge spillovers across regions in the knowledge production. We base this assumption on literature showing that knowledge spillovers are localised. For example, Jaffe, Trajtenberg, and Henderson (1993) find that knowledge spillovers are limited, especially in the short run. Bottazzi and Peri (2003) use patent data on European regions to show that small spillovers exist across regions, but that these are limited to 300km from the region producing the knowledge. We however note that membership of a trade block makes non-regional knowledge accessible, as intermediate goods firms can purchase non-domestic blueprints, and final goods firms can buy non-domestic producer durables. In the following, we first describe the equations of our different sectors and then show how the model works by coupling the sectors.

Subsection 2.1. **Regions and trade blocks.** Regions are indexed by $i \in R = \{1, \dots, n\}$. The set of all regions R is partitioned in trade blocks $G_1, \dots, G_M$, that is, all trade blocks are non-empty and each region is member of exactly one trade block. In the analysis below we consider $n = 3$ regions and four trade block configurations. Autarky: $G_1 = \{1\}$, $G_2 = \{2\}$ and $G_3 = \{3\}$; full integration: $G_1 = \{1, 2, 3\}$; offshoring: $G_1 = \{1, 2\}$ and $G_3 = \{3\}$; and reshoring: $G_1 = \{1, 3\}$ and $G_2 = \{2\}$. The last two configurations are different as our regions are not interchangeable.

Subsection 2.2. **Research sector (RS).** The research sector of region i in trade block G_m consists of a myopic profit-maximising monopolist that chooses the amount of upstream human capital to employ depending on the willingness of the intermediate good sector firms to pay for the right to produce the underlying technologies of the blueprints. This means that the research sector is not a standard price-setting monopolist.

As Romer (1990) highlights, knowledge has both a public good as well as a private good component. The public component is modelled as a knowledge stock that is used as a non-rival and non-excludable input for the production of blueprints. Blueprints, or patents, produced by the research sector represent the private good component, as they are excludable. In the model they are sold to the intermediate good sector as ownership rights of the underlying technology. The strict division between research sector and intermediate goods sector emphasises the two components of knowledge — in practice, knowledge production and knowledge utilisation are often done by the same firm. In the model, this is expressed by the assumption that even if regions are integrated, intermediate good firms are associated to the regions from which they purchase their blueprints.

Production of upstream blueprints $B_{u,i}$ depends on the region-specific upstream research productivity $b_{u,i}$, upstream human capital $H_{u,i}$, and the upstream knowledge stock $S_{u,i}$ as

$$B_{u,i} = b_{u,i} H_{u,i}^{\alpha_u} S_{u,i}^{\beta_u} \, ; \tag{1}$$

the parameters $0 < \alpha_u < 1$ and $0 < \beta_u < 1$ are the output elasticities with respect to upstream human capital and upstream knowledge, respectively.

The knowledge stock $S_{u,i}$ is the measure of the set of up-to-date blueprints. Producing new blueprints pushes the technological frontier by adding to the knowledge stock $S_{u,i}$; existing blueprints become obsolete at a rate δ_u. This results in the upstream knowledge dynamics

$$\dot{S}_{u,i} = B_{u,i} - \delta_u S_{u,i}, \qquad S_{u,i}(0) = S_{u,i,0} \, .$$

Profits are revenues from the sale of blueprints at a price $p_{B,m}$, which is the same for all regions in the trade block, net of upstream human capital wages $s_{u,i}$, which are specific to the region i, resulting in

$$\pi_{RS,i} = p_{B,m} B_{u,i} - s_{u,i} H_{u,i} = p_{B,m} b_{u,i} H_{u,i}^{\alpha_u} S_{u,i}^{\beta_u} - s_{u,i} H_{u,i} \, .$$

If profit is maximised, then

$$0 = \frac{\partial \pi_{RS,i}}{\partial H_{u,i}} = \frac{\alpha_u b_{u,i} p_{B,m} S_{u,i}^{\beta_u}}{H_{u,i}^{1-\alpha_u}} - s_{u,i} \, ,$$

which results in

$$H_{u,i} = \left(\frac{\alpha_u b_{u,i} p_{B,m} S_{u,i}^{\beta_u}}{s_{u,i}} \right)^{\frac{1}{1-\alpha_u}} \, . \tag{2}$$

We remark that in the model, the knowledge stock evolution is not actively managed. Its dynamics

$$\dot{S}_{u,i} = b_{u,i}\left(\frac{\alpha_u b_{u,i} p_{B,m}}{s_{u,i}}\right)^{\frac{\alpha_u}{1-\alpha_u}} S_{u,i}^{\frac{\beta_u}{1-\alpha_u}} - \delta_u S_{u,i}\,.$$

depend on the current level of the knowledge stock and the price at which blueprints are sold.

Subsection 2.3. **Intermediate good sector (IM).** A firm in the intermediate good sector of trade block G_m buys one blueprint from the research sector and rents capital, at a fixed rate[2], to produce intermediate goods based on the blueprint, e.g. machinery. Let

$$S_{u,G} = \sum_{i \in G} S_{u,i}$$

denote the total amount of available upstream knowledge within trade block G. As blueprints are interchangeable, we can index currently producing firms in trade block G_m by a real variable j with $0 \leq j \leq S_{u,G_m}$.

One unit of the intermediate good is produced using one unit of capital. Therefore the amount of the intermediate good $x_{i,j}$ produced by firm j and sold to a region i in the same trade block G_m as the firm is

$$x_{i,j} = k_{i,j}.$$

The intermediate goods firms engage in monopolistic competition with each other. Let $p_{i,j} = p_{i,j}(x_{i,j})$ denote the inverse demand for intermediate goods of the final good sector. Then the profits of firm j in trade block G_m are

$$\pi_{IM,m,j} = \sum_{i \in G_m} (p_{i,j}(x_{i,j})x_{i,j} - rk_{i,j}) = \sum_{i \in G_m} (p_{i,j}(x_{i,j}) - r)x_{i,j}.$$

The intermediate good becomes obsolete when the knowledge on which the blueprint is based becomes obsolete, which occurs at the obsolescence rate δ_u. We make the behavioural assumption that the intermediate goods firm expects the future profit stream to be equal to today's. We make the symmetry assumption that all firms make the same profits, so that $\pi_{IM,m,j} = \pi_{IM,m}$ does not depend on j. The firm expects to make a lifetime profit $\pi_{IM,m}/(r + \delta_u)$, and bids this quantity to buy a blueprint, which is therefore priced at

$$p_{B,m} = \frac{\pi_{IM,m}}{r + \delta_u}. \tag{3}$$

When trade blocks form such that intermediate goods can be bought from other regions, all blueprints are sold for the same price, as intermediate good firms are symmetric and do not rely on domestic inputs into production that have region-specific prices. After

2. We assume that financial capital is mobile across regions and hence use a single international common interest rate (see also e.g. Rivera-Batiz and Xie 1993; Walz 1998).

integration, we cannot distinguish between the intermediate goods sectors of regions in the same trade block.

Subsection 2.4. **Final good sector (FG).** Following Romer (1990), final goods are produced using labour, intermediate goods, and human capital. Assuming free entry, the production function has constant returns to scale, meaning that profit maximisation determines the price of the final goods but not the magnitude of the output. In order to fix the size of the latter, we introduce for each region a demand function for final goods.

The level of technology used in downstream production is described by a downstream knowledge stock $S_{d,i}$, which is the measure of the set of up-to-date process innovations. The rate of new innovations

$$B_{d,i} = b_{d,i} H_{d,i}^{\alpha_d} S_{d,i}^{\beta_d}$$

depends on the region-specific downstream research productivity $b_{d,i}$, downstream human capital $H_{d,i}$, and the downstream knowledge stock $S_{d,i}$; $0 < \alpha_d < 1$ and $0 < \beta_d < 1$ are the output elasticities of, respectively, downstream human capital and the downstream knowledge stock. Our calibration, detailed in the Appendix, obtains parameter values that satisfy $\alpha_d < \alpha_u$ — process innovations compared to product innovations are less driven by human capital, which is in line with empirical evidence (Rammer 2016) — and $\beta_d > \beta_u$ — upstream knowledge is more difficult to develop and depends less on previously accumulated knowledge than downstream process innovations, which are more incremental.

Downstream knowledge is created through learning-by-doing, in which better solutions and new innovations are not explicitly searched for, like in the formal upstream R&D sector, but rather come about as a by-product of working with technology. This motivates our human capital entering the production function of final output as well as the production function of downstream knowledge. Also downstream process innovation does not take place in a separate R&D sector but rather is a by-product of production. Process innovations become obsolete at a rate δ_d. The knowledge dynamics are therefore

$$\dot{S}_{d,i} = B_{d,i} - \delta_d S_{d,i}, \qquad S_{d,i}(0) = S_{d,i,0}.$$

The final good sector makes use of the full set intermediate inputs available in its trade block. The measure of different types of inputs available to the final good sector in region i in trade block G_m is S_{u,G_m}. Total output of the final good in region $i \in G_m$ is therefore

$$Y_{FG,i} = b_d H_{d,i}^{\alpha_d} S_{d,i}^{\beta_d} L_i^{\alpha} \int_0^{S_{u,G_m}} x_{i,j}^{1-\alpha-\alpha_d} \,\mathrm{d}j\,. \tag{4}$$

Profit of the final good firms is

$$\pi_{FG,i} = p_{FG,i}Y_{FG,i} - s_{d,i}H_{d,i} - w_i L_i - \int_0^{S_{u,G_m}} p_{i,j}x_{i,j}\,\mathrm{d}j\,.$$

Maximising profits with respect to the inputs production workers L_i, downstream human capital $H_{d,i}$ and each variety of intermediates $x_{i,j}$ gives

$$\begin{aligned}
L_i &= \frac{\alpha}{w_i} p_{FG,i}Y_{FG,i},\\
H_{d,i} &= \frac{\alpha_d}{s_{d,i}} p_{FG,i}Y_{FG,i},\\
x_{i,j} &= \frac{(1-\alpha-\alpha_d)}{p_{i,j}} p_{FG,i}Y_{FG,i}\frac{x_{i,j}^{1-\alpha-\alpha_d}}{\int_0^{S_{u,G_m}} x_{i,j}^{1-\alpha-\alpha_d}\,\mathrm{d}j}\,.
\end{aligned}$$

Maximised profits are zero.

Using the symmetry across intermediate good firms we have $x_{i,j} = x_i$ and $p_{i,j} = p_i$ for each intermediate good firm j. The demand for intermediate goods simplifies to

$$x_i = (1-\alpha-\alpha_d)\frac{p_{FG,i}}{p_i S_{u,G_m}} Y_{FG,i}$$

and output from Equation (4) reads as

$$Y_{FG,i} = b_{d,i}S_{d,i}^{\beta_d} L_i^{\alpha} H_{d,i}^{\alpha_d} S_{u,G_m} x_i^{1-\alpha-\alpha_d}\,.$$

Substituting in the latter the demands for labour, downstream human capital, and intermediate goods yields

$$Y_{FG,i} = b_{d,i}S_{d,i}^{\beta_d} S_{u,G_m}\left(\frac{\alpha}{w_i}\right)^{\alpha}\left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d}\left(\frac{(1-\alpha-\alpha_d)}{S_{u,G_m}p_i}\right)^{1-\alpha-\alpha_d} p_{FG,i}Y_{FG,i}\,,$$

which results in the final good prices

$$p_{FG,i} = \frac{1}{b_{d,i}S_{d,i}^{\beta_d}S_{u,G_m}^{\alpha+\alpha_d}}\left(\frac{w_i}{\alpha}\right)^{\alpha}\left(\frac{s_{d,i}}{\alpha_d}\right)^{\alpha_d}\left(\frac{p_i}{1-\alpha-\alpha_d}\right)^{1-\alpha-\alpha_d}\,. \tag{5}$$

The final good price increases with the costs of production inputs (w_i, $s_{d,i}$, and p_i); it decreases in downstream knowledge stocks and research productivity, as both contribute to cost reductions. It also decreases if the trade blocks upstream knowledge stock increases, as this allows for a larger input variety of producer durables.

We assume that demand in region i is of the form

$$D_i(p_{FG,i}) = \frac{A_i}{p_{FG,i}^{\xi}}\,, \tag{6}$$

where $A_i > 0$ is the market size of final goods and $\xi > 0$ the absolute price elasticity of final good demand.

Market clearing $D_i(p_{FG,i}) = Y_{FG,i}$ determines the output at

$$Y_{FG,i} = A_i b_{d,i}^{\xi} S_{d,i}^{\beta_d \xi} S_{u,G_m}^{(\alpha+\alpha_d)\xi} \left(\frac{\alpha}{w_i}\right)^{\alpha\xi} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d \xi} \left(\frac{1-\alpha-\alpha_d}{p_i}\right)^{(1-\alpha-\alpha_d)\xi} .$$

From this, we obtain labour, downstream human capital, and intermediate capital goods

$$\begin{aligned}
L_i &= A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} S_{u,G_m}^{(\alpha+\alpha_d)(\xi-1)} \\
&\quad \left(\frac{\alpha}{w_i}\right)^{\alpha(\xi-1)+1} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d(\xi-1)} \left(\frac{1-\alpha-\alpha_d}{p_i}\right)^{(1-\alpha-\alpha_d)(\xi-1)} , \\
H_{d,i} &= A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} S_{u,G_m}^{(\alpha+\alpha_d)(\xi-1)} \\
&\quad \left(\frac{\alpha}{w_i}\right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d(\xi-1)+1} \left(\frac{1-\alpha-\alpha_d}{p_i}\right)^{(1-\alpha-\alpha_d)(\xi-1)} , \\
x_{i,j} &= A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} S_{u,G_m}^{(\alpha+\alpha_d)(\xi-1)-1} \\
&\quad \left(\frac{\alpha}{w_i}\right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d(\xi-1)} \left(\frac{1-\alpha-\alpha_d}{p_i}\right)^{(1-\alpha-\alpha_d)(\xi-1)+1} .
\end{aligned}$$

As $\xi > 0$ it follows that the three exponents $\alpha(\xi-1)+1$, $\alpha_d(\xi-1)+1$ and $(1-\alpha-\alpha_d)(\xi-1)+1$ are positive, resulting in the standard inverse relationship between production inputs L_i, $H_{d,i}$ and $x_{i,j}$ and their prices w_i, $s_{d,i}$ and $p_{i,j}$, respectively. The relation between the production inputs and upstream and downstream knowledge stocks is however ambiguous and depends on the value of the price elasticity $\xi > 0$ of final good demand.

If $\xi > 1$, demand is elastic and larger downstream knowledge stocks and research productivity result in greater demand for production inputs[3], while higher costs for other production inputs result in lower demand. For inelastic demand, where $\xi < 1$, the reverse is true. With elastic demand, a decrease in final output price results in a high relative demand increase, which necessitates additional employment of production inputs; the reverse holds in the inelastic situation.

We introduce the exponent $\eta = (1-\alpha-\alpha_d)(\xi-1)+1 > 0$ and note that $\eta > 1$ if and only if $\xi > 1$. Solving for inverse demand of intermediate goods yields

$$p_i = \frac{1-\alpha-\alpha_d}{S_{u,G_m}} \left(A_i^{\frac{1}{\xi-1}} b_{d,i} S_{d,i}^{\beta_d} S_{u,G_m} \left(\frac{\alpha}{w_i}\right)^{\alpha} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d} \right)^{\frac{\xi-1}{\eta}} x_{i,j}^{-\frac{1}{\eta}} . \tag{7}$$

This shows that $-\eta$ is the output elasticity of the price of intermediate goods.

3. An exception here is the upstream knowledge stock in demand for intermediate goods, where instead a higher elasticity of $\xi > 1 + 1/(\alpha+\alpha_d)$ is required for increases in the upstream knowledge stock of the trade block to positively influence intermediate good demand. In our calibration, we do not find that this is satisfied, and that upstream knowledge of the trade block decreases demand for each individual variety of an intermediate good. This can be thought of as intermediate goods being partial substitutes.

Subsection 2.5. Coupling the sectors.

2.5.1. *Coupling the final goods sector to the intermediate goods sector.* The inverse demand of region i for intermediate goods from firm j, following Equation (7), has the general shape

$$p_i(x_{i,j}) = C_i x_{i,j}^{-\frac{1}{\eta}}.$$

The profits of the intermediate goods firm j in trade block G_m are

$$\pi_{IM,m,j} = \sum_{i \in G_m} p_i(x_{i,j}) x_{i,j} - r x_{i,j} = \sum_{i \in G_m} C_i x_{i,j}^{1-\frac{1}{\eta}} - r x_{i,j}.$$

Profit maximisation yields outputs

$$x_{i,j} = \left(\frac{1-\frac{1}{\eta}}{r} \right)^{\eta} C_i^{\eta}.$$

Prices are consequently

$$p_i(x_{i,j}) = \frac{r}{1-\frac{1}{\eta}},$$

such that we eventually obtain

$$x_{i,j} = A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} S_{u,G_m}^{(\xi-1)-\eta} \left(\frac{\alpha}{w_i} \right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}} \right)^{\alpha_d(\xi-1)} \phi^{\eta}, \tag{8}$$
$$\text{where} \quad \phi = \frac{(1-\frac{1}{\eta})(1-\alpha-\alpha_d)}{r}.$$

Intermediate good firms' profits evaluate to

$$\begin{aligned}
\pi_{IM,j} &= \frac{r}{\eta-1} \sum_{i \in G_m} x_{i,j} \\
&= \frac{r\phi^{\eta}}{\eta-1} S_{u,G_m}^{(\xi-1)-\eta} \sum_{i \in G_m} A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} \left(\frac{\alpha}{w_i} \right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}} \right)^{\alpha_d(\xi-1)}.
\end{aligned}$$

Employment in the final good sector is

$$L_i = A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} S_{u,G_m}^{(\alpha+\alpha_d)(\xi-1)} \left(\frac{\alpha}{w_i} \right)^{\alpha(\xi-1)+1} \left(\frac{\alpha_d}{s_{d,i}} \right)^{\alpha_d(\xi-1)} \phi^{(1-\alpha-\alpha_d)(\xi-1)}, \tag{9}$$

$$H_{d,i} = A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} S_{u,G_m}^{(\alpha+\alpha_d)(\xi-1)} \left(\frac{\alpha}{w_i} \right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}} \right)^{\alpha_d(\xi-1)+1} \phi^{(1-\alpha-\alpha_d)(\xi-1)}. \tag{10}$$

The rate of process innovations evaluates to

$$\begin{aligned}
B_{d,i} = &\left(A_i S_{u,G_m}^{(\alpha+\alpha_d)(\xi-1)} \left(\frac{\alpha}{w_i} \right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}} \right)^{\alpha_d(\xi-1)+1} \right)^{\alpha_d} \\
&\left(b_{d,i} S_{d,i}^{\beta_d} \right)^{1+(\xi-1)\alpha_d} \phi^{(1-\alpha-\alpha_d)(\xi-1)\alpha_d}.
\end{aligned}$$

We obtain for output of the final good sector

$$Y_{FG,i} = A_i b_{d,i}^{\xi} S_{d,i}^{\beta_d \xi} S_{u,G_m}^{(\alpha+\alpha_d)\xi} \left(\frac{\alpha}{w_i}\right)^{\alpha\xi} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d \xi} \phi^{(1-\alpha-\alpha_d)\xi},$$

which is sold at the region specific price

$$p_{FG,i} = \frac{1}{b_{d,i} S_{d,i}^{\beta_d} S_{u,G_m}^{\alpha+\alpha_d}} \left(\frac{w_i}{\alpha}\right)^{\alpha} \left(\frac{s_{d,i}}{\alpha_d}\right)^{\alpha_d} \left(\frac{1}{\phi}\right)^{1-\alpha-\alpha_d}. \tag{11}$$

The price behaviour is as expected: it decreases in both the domestic downstream knowledge stock and the total upstream knowledge stock, but increase in the wage rates for production workers and human capital, as well as in the cost of capital.

2.5.2. *Coupling the intermediate goods sector to the R&D sector.* The price $p_{B,m}$ for blueprints in trade block G_m equals the total expected lifetime profit of the intermediate good firms winning the bidding. Using (3), we obtain

$$p_{B,i} = \frac{r\phi^{\eta}}{(r+\delta)(\eta-1)} S_{u,G_m}^{(\xi-1)-\eta} \sum_{i\in G_m} A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} \left(\frac{\alpha}{w_i}\right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d(\xi-1)}. \tag{12}$$

The research sectors take prices $p_{B,i}$ of the blueprints as given and employ the amount of upstream human capital that maximises their profits, which is

$$H_{u,i} = \left(\frac{r\phi^{\eta}}{(\eta-1)(r+\delta)}\right)^{\frac{1}{1-\alpha_u}} \left(\frac{\alpha_u b_{u,i} S_{u,i}^{\beta_u}}{s_i} S_{u,G_m}^{(\xi-1)-\eta}\right)^{\frac{1}{1-\alpha_u}}$$
$$\left(\sum_{i\in G_m} A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} \left(\frac{\alpha}{w_i}\right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d(\xi-1)}\right)^{\frac{1}{1-\alpha_u}}.$$

Upstream human capital $H_{u,i}$ is increasing in its domestic upstream knowledge stock, if the trade blocks knowledge stock is held constant, but decreasing in total upstream knowledge available within the trade block, if the domestic knowledge stock is held constant, unless ξ is large (see footnote 3). It is increasing in the market size of all trading partners. If demand is elastic, that is $\xi > 1$, upstream human capital increases in all downstream knowledge stocks and downstream productivities of the integrated regions and decreases in all wages within the trade block. For inelastic demands, these opposites are true.

The number of new blueprints created by the research sector in region i becomes

$$B_{u,i} = \left(\frac{r\phi^\eta}{(\eta-1)(r+\delta)}\right)^{\frac{\alpha_u}{1-\alpha_u}} \left(b_{u,i} S_{u,i}^{\beta_u}\right)^{\frac{1}{1-\alpha_u}} \left(\frac{\alpha_u}{s_i} S_{u,G_m}^{(\xi-1)-\eta}\right)^{\frac{\alpha_u}{1-\alpha_u}} \left(\sum_{i\in G_m} A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} \left(\frac{\alpha}{w_i}\right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d(\xi-1)}\right)^{\frac{\alpha_u}{1-\alpha_u}},$$

and similar relations hold as for upstream human capital.

Subsection 2.6. **Dynamics.** The above relations allow us to express all quantities of the model in terms of the upstream and downstream knowledge stocks. Their evolution is described by a system of $2n$ coupled differential equations: for $i = 1, \ldots, n$

$$\dot{S}_{d,i} = \phi^{(1-\alpha-\alpha_d)(\xi-1)\alpha_d} \left(b_{d,i} S_{d,i}^{\beta_d}\right)^{(\xi-1)\alpha_d+1} \left(A_i S_{u,G_m}^{\xi-\eta} \left(\frac{\alpha}{w_i}\right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d(\xi-1)+1}\right)^{\alpha_d} - \delta_d S_{d,i}, \tag{13}$$

and

$$\dot{S}_{u,i} = \left(b_{u,i} S_{u,i}^{\beta_u}\right)^{\frac{1}{1-\alpha_u}} \left(\frac{r\phi^\eta}{(\eta-1)(r+\delta)} \frac{\alpha_u}{s_{u,i}} S_{u,G_m}^{(\xi-1)-\eta}\right)^{\frac{\alpha_u}{1-\alpha_u}} \left(\sum_{i\in G_m} A_i b_{d,i}^{\xi-1} S_{d,i}^{\beta_d(\xi-1)} \left(\frac{\alpha}{w_i}\right)^{\alpha(\xi-1)} \left(\frac{\alpha_d}{s_{d,i}}\right)^{\alpha_d(\xi-1)}\right)^{\frac{\alpha_u}{1-\alpha_u}} - \delta_u S_{u,i}\,. \tag{14}$$

The evolution of downstream knowledge stocks depends only on domestic parameters, the downstream knowledge stock itself, and the trade blocks total upstream knowledge S_{u,G_m}. Increasing the latter allows a larger variety of intermediates to be sourced, which helps in the production of final goods and results in a positive effect on the downstream knowledge stock. For all regions, other things being equal, integration has a positive effect on downstream knowledge production. On the other hand, the evolution of the upstream knowledge stocks depends on downstream parameter values of all regions within the trade block, wages, downstream productivities, and market size, as well as on all knowledge stocks, downstream and upstream.

When a trade block is formed, we see two counteracting effects at play in the dynamics of the upstream knowledge stock. In the most interesting situation $(\xi-1)-\eta < 0$, see footnote 3, the increase of the total upstream knowledge stock S_{u,G_m} of the trade block has a negative effect on the future growth of the domestic upstream knowledge stock: as the supply of blueprints expands, there is less demand for each individual variety. In some cases, this effect can be offset by the increase in downstream demand as more markets are accessible to the intermediate goods. Which factor prevails depends on the relative sizes of upstream knowledge stocks versus size of downstream final good sector of a domestic region's trading partners. For instance, our simulations suggest that upstream knowledge stock growth rates for North are higher under integration, but for East and South they are higher under autarky.

Table 1. General parameters
Parameters calibrated using patent or input-output data, unless indicated otherwise

Name	Description	Value
r	return on capital (Jagannathan et al. 2016)	0.08
δ_u, δ_s	annual knowledge stock depreciations (Griliches 1990)	0.1
α	labour share in Y_{FG}	0.19
α_u	upstream human capital share in B_u	0.11
α_d	downstream human capital share in B_d	0.03
β_u	upstream knowledge share in B_u	0.87
β_d	downstream knowledge share in B_d	0.95
ξ	absolute value PED for final goods	1.1459

Subsection 2.7. **Parameters.** The model is used for a medium-term analysis, which in our case is over a period of ten years. For calibration, we have used patent data as well as input-output data (World Input–Output Database 2016) and macroeconomic data of the manufacturing sector; some parameters are taken from the literature. For example, for the return on capital, we chose a value (8%) that is close to the lower bound of the discount rates used by firms in manufacturing (Jagannathan et al. 2016), which itself is close to the 6.9% used by Diao, Roe, and Yeldan (1999).

We have calibrated the model with data from three countries: Germany, Poland, and China, which respectively are taken to represent the regions North, East, and South. All parameter and initialisation values are scaled to a population that works a total of 1 million hours per year.

Table 1 gives a summary of the parameters that are the same across regions; Table 2 gives parameters and initial values that are region-specific. Appendix A.1 describes the calibration in full. For instance, the market sizes given in Table 2 highlight that in our model the regions are at different stages of their economic development: South's market size, per million of hours worked, is much smaller than East's.

Section 3. Results

Subsection 3.1. **Baseline results: autarkies.** In our baseline scenario, we do not allow for trade between regions: intermediate goods are only supplied to the domestic final goods sector such that for each region i its set of integrated regions is $G_i = \{i\}$.

We have calibrated the model for three regions ($n = 3$) and set the parameters and initial values according to Tables 1 and 2. Figure 1 shows the resulting time-series for sectoral output and employment. All sectors of all three regions expand over time. Due to its

Table 2. Region-specific parameters
Parameters and initial values per 1 million hours worked, calibrated using patent or input-output data

Name	Description	North ($i = 1$)	East ($i = 2$)	South ($i = 3$)	Unit
$s_{u,i}$, $s_{d,i}$	human capital wages	35.17	10.86	0.95	USD/hrs
w_i	labour wages	20.34	5.36	0.61	USD/hrs
$b_{u,i}$	upstream research prod.	0.0683	0.0679	0.0521	patents$^{1-\beta_u}$/hrs$^{\alpha_u}$
$b_{d,i}$	downstream research prod.	0.3573	0.1985	0.3953	patents$^{1-\beta_d}$/hrs$^{\alpha_d}$
$S_{u,i}(0)$	init. upstream knowledge	12.226	0.078	0.020	patents
$S_{d,i}(0)$	init. downstream knowledge	3.230	0.065	0.007	patents
A_i	market size (in millions)	92.85	58.95	8.62	patents*hrs*USD

productivity advantage in knowledge production upstream and downstream, North has by far the largest output in all sectors, followed by East. South has the lowest output levels, which is a consequence of its low initial knowledge stocks and upstream research productivity. But over time, South catches up with East in downstream output: this is driven by its higher downstream research productivity.

Figure 1 shows that employment shares among labour types remain fairly stable over time, especially for North and East. This is in line with Bontadini et al. (2024), who found for different EU regions that the shares of managers and manual workers during 2000-2014 have been stable.

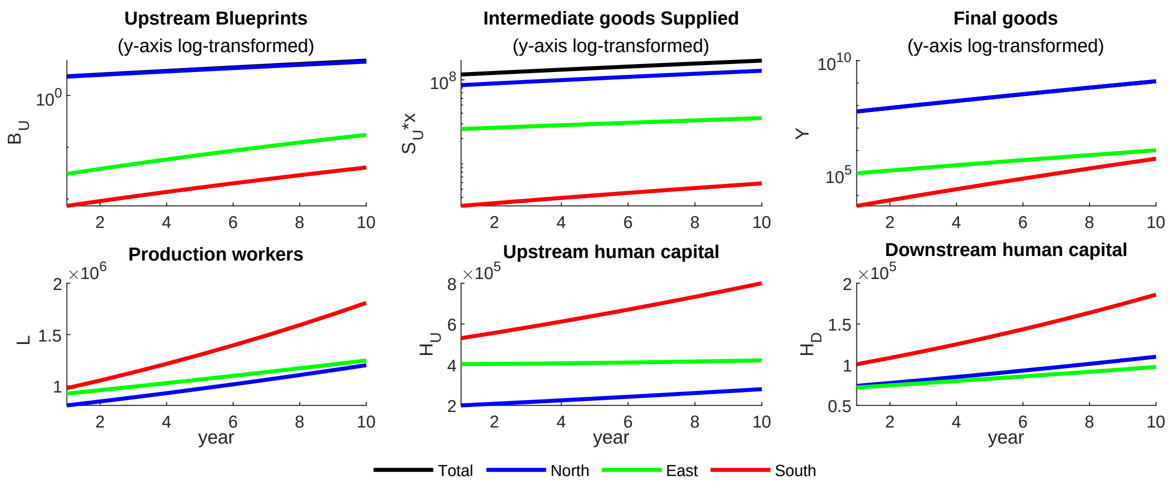

Figure 1. Baseline case: Sectoral outputs and employment (time series 10-year horizon). Aggregate (black; sum of all regions), North (blue), East (green) and South (red); *Row 1:* total and regional output for research sector, intermediate good sector and final good sector (from left to right, y-axis are log-transformed); *Row 2:* employment in production workers, upstream human capital and downstream human capital (from left to right).

We find that low wages and productivities in the South create higher employment across all worker types. This matches the data for China, where we find higher employment growth of both low skilled and high skilled workers (see upper panels of Figure F1 in the Appendix).

Despite increased employment in manufacturing, the actual share of production workers in value added of the manufacturing sector is declining. Figure 2 compares the evolution of labour shares of production workers in our model with data for Germany, Poland and China. We find that the model reproduces the decline in labour shares of production workers, as well as the ordering of the shares across the three regions. These labour shares are high for South, while Eastern and especially Northern levels are low.

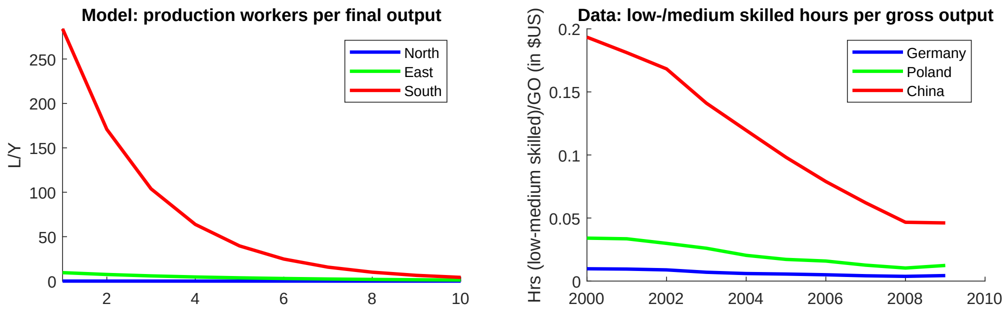

Figure 2. Evolution of labour shares for production workers model vs data. *Left panel:* Model evolution of number of hours worked by production workers (L) per unit of final output (Y) under autarky; *Right panel:* Actual evolution of low- and medium-skilled hours worked per \$US of gross output during 2000-2009 (averages across manufacturing industries using data from the SEA 2013 version)

Figure 3 shows the evolution of the knowledge stocks on a logarithmic scale. Although upstream human capital is only slightly increasing over time in East and South, the knowledge increase derived from new blueprints more than offsets knowledge depreciation, so that upstream knowledge stocks grow for all regions.

However, the discrepancy between the upstream and downstream research productivities (i.e., between b_u and b_d in Table 2) is much larger for East than for North or South. Combined with the relatively low downstream productivity, the share of knowledge stock upstream increases over time in the East under autarky to around 60% in 2009. North and South on the other hand, have with respect to the East higher downstream research productivities and gain relatively more downstream knowledge over time. This causes the share of knowledge stock upstream in autarky to fall over time to 35% and 25%, respectively, for North and South. This is because the differences in research productivities b_u and b_d are not sufficient to offset the fact that the returns of upstream knowledge are lower than the returns of downstream knowledge ($\beta_u < \beta_d$).

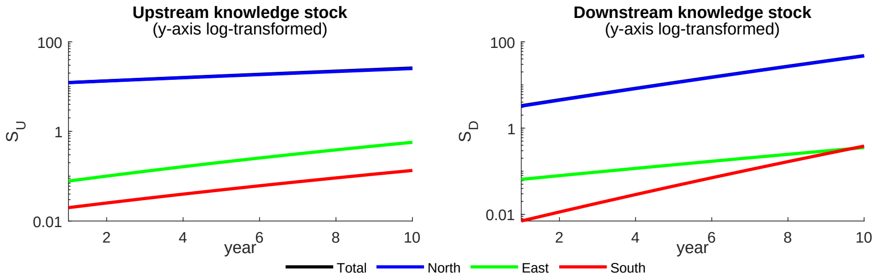

Figure 3. Baseline case: Knowledge stocks (time series 10-year horizon). Aggregate (black; sum of all regions), North (blue), East (green) and South (red); *Left*: upstream knowledge stock; *Right*: downstream knowledge stock.

This results in South catching up with East in terms of downstream knowledge (Figure 3, right panel), and explains the convergence in final output in Figure 1. This convergence is also found in the data: although not as pronounced as in our model, Figure F2 in the appendix shows a faster growth rate in downstream patents per year for China than for Poland, resulting in faster growth of downstream knowledge stocks and catching up with Poland (Figure F3). Besides this our model also mimics the clear technological divide of East and South relative to North, both in upstream and downstream knowledge production, supporting our calibration.

Subsection 3.2. **Allowing for trade: global integration and formation of trade blocks.** As a next step, we study different forms of integration. First we consider *full integration*. A single trade block is formed, which includes all regions, that is $G_1 = G = \{N, S, E\}$ for all i. Each region can sell its intermediate goods domestically and to any other region. Hence each final good sector makes use of all intermediate goods globally available, such that the total upstream knowledge stock available to i is $S_{u,G} = \sum_{i=1}^{n} S_{u,i}$. We think of full integration as replicating the first wave of outsourcing production to Asia at the beginning of the 21st century, which utilised the large and cheap pool of production workers in China after its WTO accession, and the simultaneously occurring Eastern EU enlargements following the collapse of the Soviet Union.

Offshoring is the second situation to be considered, which models outsourcing to Asia without trade liberalisation of eastern Europe. In this situation North and South integrate while East remains in autarky. The trade blocks are $G_1 = \{N, S\}$ and $G_2 = \{E\}$, and the upstream knowledge available to countries in the trade blocks are $S_{u,G_1} = S_{u,N} + S_{u,S}$ and $S_{u,G_2} = S_{u,E}$.

Lastly we consider *reshoring*. To contribute to the ongoing debate on global supply chain volatility, the political shift toward strengthening domestic markets, and decreasing dependence on foreign markets, we model a case representing near- or friend-shoring of production. Here the trade block forms between North and East, that is $G_1 = \{N, E\}$), while the South remains in autarky, $G_2 = \{S\}$, such that $S_{u,G_1} = S_{u,N} + S_{u,E}$ and $S_{u,G_2} = S_{u,S}$.

Figure 4 presents sectoral outputs for all forms of integration as relative changes from the baseline autarky case. First, we find the expected result that any form of integra-

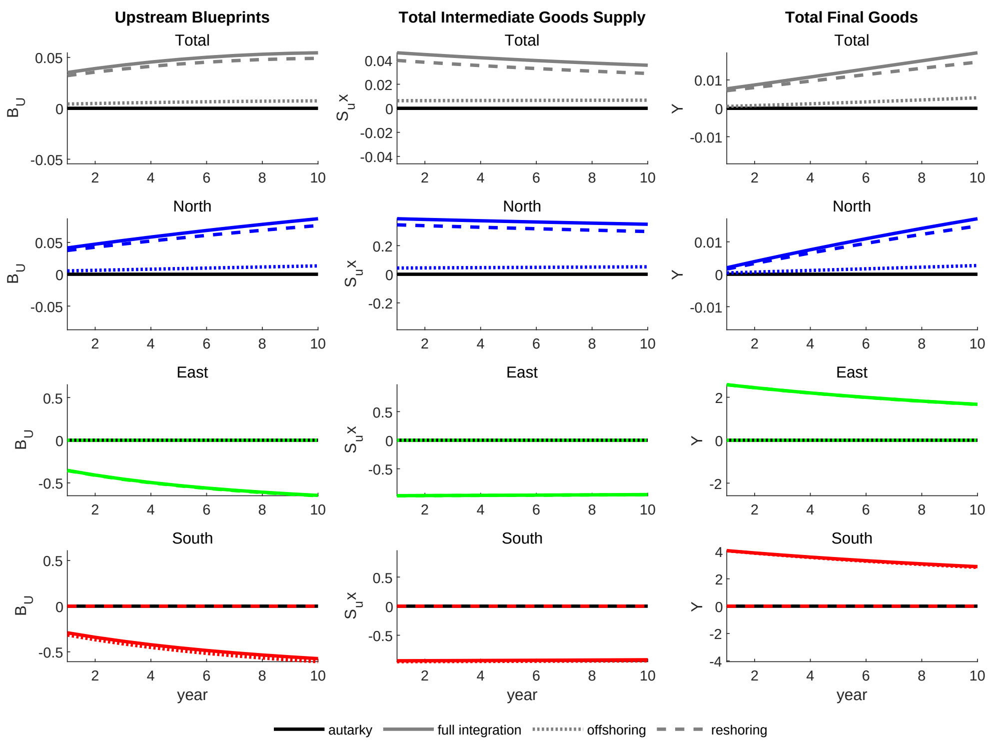

Figure 4. Relative sectoral outputs under types of integration with respect to autarky (time series 10-year horizon; Relative change with respect to baseline). Aggregate (black, sum of all regions), North (blue), East (green) and South (red). *Rows 1-4:* total output for research sector, intermediate good sector and final good sector (from left to right)

tion results in aggregate higher output for all three sectors during the 10-year period. Moreover, there is a consistent ordering: full integration yields the largest aggregate increase in all outputs, followed by reshoring and then offshoring, which all improve on autarky. Second, we find that there are clear advantages for North to integrate with East rather than South. This is driven by the larger market size per capita for final goods in East, $A_E > A_S$, creating more demand for intermediate goods, higher profits in that sector, and eventually a 5% increase in blueprint production. North's downstream manufacturing is however largely unaffected, expanding around 1%.

We recall at this point that in the model, regions are of the same size, and market size is not driven by population size. This explains why in our model offshoring is underperforming with respect to reshoring. The initial wave of offshoring at the beginning

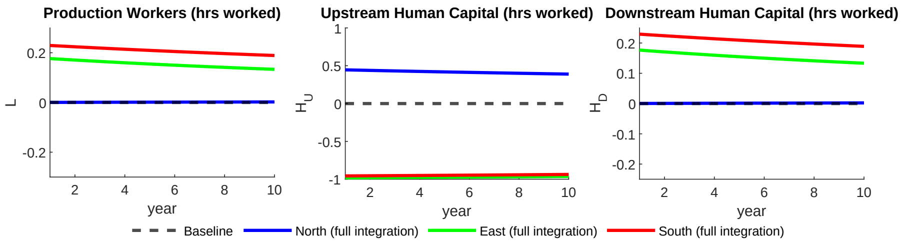

Figure 5. Change in employment under full integration with respect to the baseline autarky case. *From left to right:* production workers, upstream human capital, and downstream human capital

of the 21st century of production to, mainly, China was motivated by gaining access to an economy with a large population and a large pool of low-wage labour. But the per capita manufacturing in Poland has been much larger than in China.

Under integration, our model shows clear patterns of specialisation, which are common in endogenous growth models with intermediate good trade but without knowledge spillovers. In contrast to the large upstream expansion in North, integration causes in East and South a collapse of intermediate input production, and the development of new product innovations drops to 50%-60% of autarky level. Although the aggregate increase in final good production can be attributed to all three regions, compared to the 1% expansion in the North, East and South experience increases between 200% and 400%, respectively.

Specialisation is driven by the employment choices of regions. Figure 5 summarises the differences in employment under full integration relative to the baseline autarky case. Downstream expansion of the final good sector in the East and South under integration is driven by an increase in production workers and downstream human capital. Employment for both type of workers is around 15-25% higher compared to autarky, and this difference remains stable over time, indicating the level effect integration has on relative employment. In the North employment also rises, but the increase is not even close to 1%.

While under autarky in the North division of human capital between downstream and upstream is fairly balanced, East and South invest the majority of human capital into upstream research as blueprint prices and upstream profits are high. Introducing trade changes this drastically. Figure 6 shows that integration radically changes the ratio between downstream and upstream human capital for East and South. South's downstream human capital increases more than 5 times under full integration, and more than 6 times under offshoring. This is mirrored by East, which experiences an initially more than 10-fold increase under both full integration and reshoring. North also moves towards relatively greater downstream employment, but the increase of the ratio between downstream and upstream human capital is, only 25% under full integration, 35% under offshoring and 28% higher under reshoring, compared to autarky. Downstream human capital plays however, only a minor role in the production of process innovations, as the returns to downstream human capital are $\alpha_d = 0.03$. We therefore need to look at the actual development of downstream innovation and knowledge stocks to get a complete picture on the innovation side.

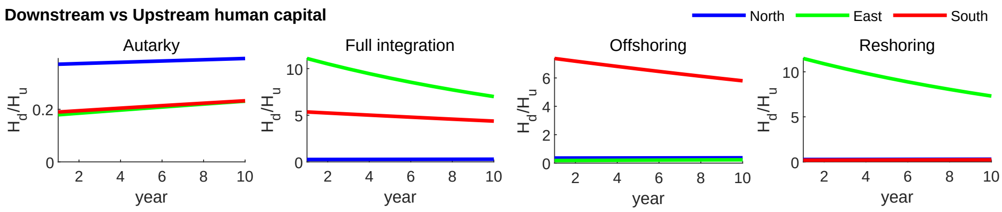

Figure 6. Division of human capital employment downstream versus upstream. *From left to right:* autarky, full integration, offshoring, reshoring

Under full integration, North specialises in research as its upstream human capital increases around 40% with respect to autarky, which is mirrored by extreme decreases for East and South (Figure 5, middle panel). These decreases are not offset by North's increase, as we find that aggregate upstream human capital decreases under integration. However, as North's research productivity is high, aggregate blueprint production and the aggregate upstream knowledge stock expand with respect to autarky (see the top left panel of both Figures 4 and 8).

In downstream manufacturing, on the other hand, integration results in productivity gains in final good production. Two effects cause these gains: access to a larger variety of intermediate goods in all regions, and greater investment into process innovation through rising downstream human capital in East and South. This results in lower shares of production workers per unit of final output, Figure 7. Downstream manufacturing productivity gains in the North are only minor as the increase in access to intermediate inputs is insignificant for this region.

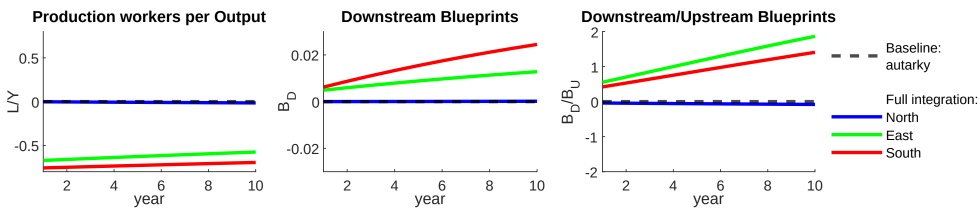

Figure 7. Relative change of measures under full integration with respect to baseline autarky case (time series 10-year horizon). *Left:* share of production workers per unit of final good output; *Middle:* downstream blueprints; *Right*: downstream blueprints versus upstream blueprints

Integration causes global levels of both upstream and downstream knowledge to rise (Figure 8, top left and top middle panel), with upstream knowledge increasing faster (Figure 8, top right panel). This is mainly driven by the growth of North's, already large, upstream knowledge stock.[4]

Full integration causing their research sectors to collapse, for South and East downstream knowledge becomes the dominant type, as illustrated by Figure 8, bottom row. This reflects evidence from Tinnefeld (2023), who found that specialisation of an upstream country-industry pair is slightly negatively associated with the process-share of patents (i.e., reflects a move towards product innovation), while downstream country-industry pairs, when becoming specialised, are associated with higher process shares of patents. In the model this is most prominent for South, where during our 10-year period the share of downstream knowledge increases from 30% to 85% (a final 10% more than under autarky).

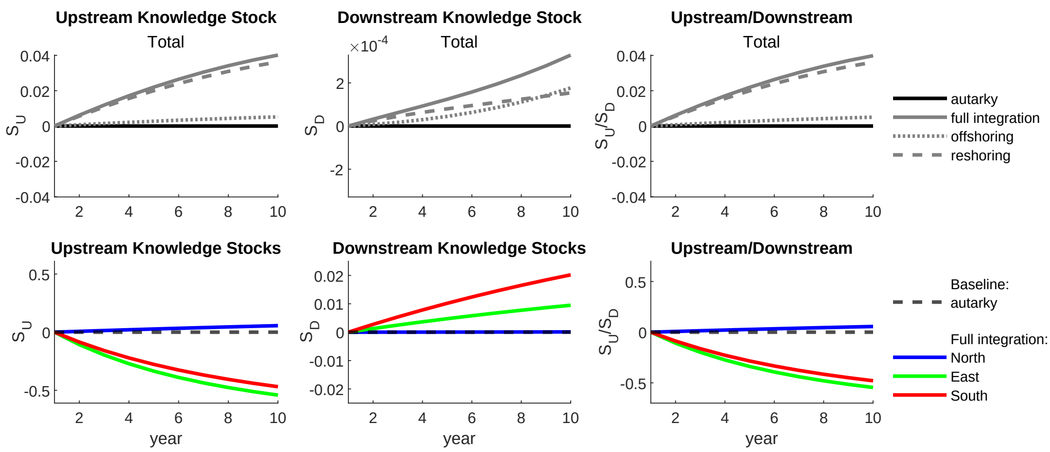

Figure 8. Relative change in knowledge stocks under full integration with respect to the baseline autarky case. *Rows 1:* Aggregate (sum of all regions) knowledge stocks upstream and downstream, and their ratio (upstream/downstream) (from left to right) comparing all forms of integration to autarky; *Row 2:* Regional knowledge stocks and their ratio for North (blue), East (green) and South (red) comparing full integration to autarky.

We point out a marked difference between offshoring and reshoring: relative to autarky, the increase in upstream knowledge is large for reshoring and small for offshoring (Figure 8, top left panel); but this is not the case for downstream knowledge, where the increases are roughly of the same size (Figure 8, top middle panel). We have discussed the upstream outcome above.

4. This fits the empirical findings on product versus process innovation in Germany concerning its relationships with import competition/inward FDI (Bertschek 1995) and concerning its relationship with the likelihood to export (Becker and Egger 2013).

The downstream result is caused by the higher downstream productivity of knowledge production of South relative to East, which allows South to produce more downstream blueprints after year six (see Appendix Figure F5). This holds despite the fact that East's ratio of downstream versus upstream human capital is higher than South's, Figure 6. Although time-series data does not show that China had already overtaken Poland in the hours-adjusted production of downstream patents by 2009, we find a lower growth rate of downstream patents for Poland than with respect to China (see bottom left and bottom centre panel of Appendix Figure F2) and hence a convergence of Chinese levels towards Polish levels for the number of process patents per 1 million hours worked.

We summarise the results of this section as follows: integration causes global expansion of output in all sectors, specialisation of the technological leader in research and specialisation of technological laggards in downstream manufacturing. These results are common for this type of models. Moreover reshoring, when compared to offshoring, results in larger sectoral outputs and more upstream knowledge within the trade bloc, but not in larger long term downstream knowledge production.

Any form of regional integration shifts the global level of knowledge towards product innovation, an effect completely driven by the technological leader. On the regional level the effects are differentiated. While both product and process knowledge expand for the leader, the former effect dominates. For the laggards upstream research collapses, and downstream knowledge becomes the dominant type.

Gains from trade are not equal across regions. North achieves large gains, especially in the upstream sector. When entering a trade block, South's downstream specialisation leads it to form large downstream knowledge stocks. East, despite stronger initial endowments compared to South, is caught in a crossfire: specialising after trade integration, it achieves lower productivity gains downstream than South, while it loses out on upstream innovations to North.

Subsection 3.3. **Welfare analysis.** The previous section has shown that integration causes regions to specialise in either upstream or downstream production. This section investigates whether and for which regions this specialisation is also welfare-enhancing.

3.3.1. *Welfare: Output per sector.* That any form of integration is beneficial for North, which specialises upstream, is clear: in all scenarios North's output is higher than in autarky. For South and East upstream output in research as well as intermediate good production is largest in autarky and lowest when fully integrated; on the other hand, their final goods output is higher when integrated.

Figure 9 compares the value of the output of all sectors and all regions: as prices are affected by integration, total output values of each region across all sectors are shown.

For East autarky and offshoring are indistinguishable scenarios, as are autarky and reshoring for South. Therefore the corresponding lines overlap. Also full integration and reshoring are nearly indistinguishable for East, as are full integration and offshoring for South, resulting in a second pair of nearly overlapping lines.

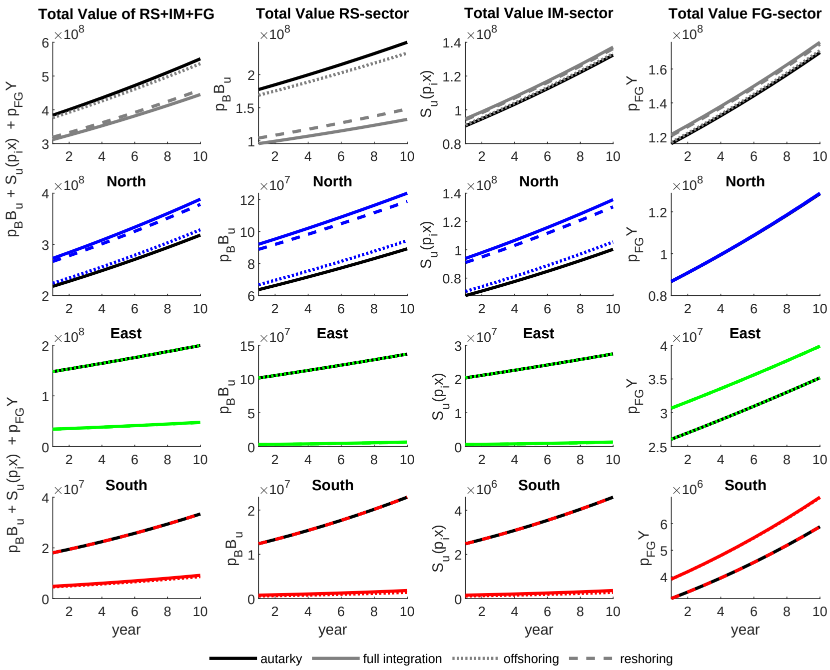

Figure 9. Evolution of the total value of sectors for different forms of integration.
From left to right: sum of all sectors, research sector, intermediate good sector, and final good sector. *Row 1*: aggregate for each sector; *Row 2-4*: each sector per region for North, East and South respectively

The figure confirms North gaining from integration across all sectors, as well as East and South losing upstream and gaining downstream. However, using total value as a welfare measure yields misleading conclusions. For instance, Figure 9, upper left panel, shows that the total value across all sectors at the aggregate is lowest under integration and highest in autarky. This result is driven by the decrease of aggregate total value experienced by East and South. In fact, offshoring for South and reshoring for East produce even slightly lower total values than full integration[5].

3.3.2. *Welfare: Consumer and Producer surplus.* Taking consumer surplus as a measure of welfare instead, we reach a different conclusion. Integration results in lower prices and larger variety: both effects are beneficial for consumers. Indeed, final good prices drop precipitously in East and South when these regions are integrated with North: see Table 3. This is caused by the increase of the total available upstream knowledge stock $S_{u,G}$ when the trade block is enlarged, see Equation (11).

5. The differences are too small to be visible in Figure 9.

Table 3. Final good prices for all regions and all integration types
Colour scale: high values in red and low values in blue

Year	North				East				South			
	Aut.	Integ.	Offs.	Res.	Aut.	Integ.	Offs.	Res.	Aut.	Integ.	Offs.	Res.
1	1.596	1.593	1.595	1.594	268	87.94	268	87.97	924.3	224.6	224.9	924.3
2	1.16	1.156	1.159	1.157	210	71.34	210	71.38	556	139.2	139.6	556
3	0.847	0.843	0.847	0.844	165.3	58.03	165.3	58.07	338.1	87.06	87.43	338.1
4	0.622	0.618	0.621	0.619	130.6	47.32	130.6	47.36	207.7	54.97	55.27	207.7
5	0.459	0.455	0.458	0.456	103.7	38.68	103.7	38.72	128.9	35.02	35.26	128.9
6	0.34	0.337	0.339	0.337	82.57	31.69	82.57	31.73	80.77	22.5	22.68	80.77
7	0.253	0.25	0.253	0.251	66.02	26.03	66.02	26.07	51.09	14.58	14.72	51.09
8	0.189	0.187	0.189	0.187	52.98	21.43	52.98	21.46	32.6	9.527	9.626	32.6
9	0.142	0.14	0.142	0.14	42.66	17.68	42.66	17.71	20.99	6.274	6.346	20.99
10	0.107	0.105	0.107	0.106	34.47	14.62	34.47	14.65	13.63	4.164	4.216	13.63

In the model, the final good sector makes zero profits, while the intermediate good sector bids its expected value of lifetime profits at market entry to buy a blueprint from the research sector. Hence upstream research is the only source of profit accumulation that can give rise to market power. We have seen in Section 3.1 that even in autarky, most of the new upstream blueprints are developed in the North, creating research sector profits that are twice as large as the profits in East and more than twenty times larger than those in South. This concentration is amplified by any form of integration, as this causes research sector profits in North to rise and those in East and South to fall. Table 4 shows that this profit decrease is driven by huge price drops of blueprints[6] in East and South under integration. Lower profits attracts less upstream human capital, so that total profits in the research sector shrink due to lower output as well as lower prices.

Table 4. Blueprint prices in millions for all regions and all integration types
Colour scale: high values in red and low values in blue

Year	North				East				South			
	Aut.	Integ.	Offs.	Res.	Aut.	Integ.	Offs.	Res.	Aut.	Integ.	Offs.	Res.
1	27.6	38.3	28.8	37.1	1303	38.3	1303	37.1	623	38.3	28.8	623
2	26.6	36.5	27.7	35.3	1046	36.5	1046	35.3	528.4	36.5	27.7	528.4
3	25.6	34.8	26.7	33.7	846.9	34.8	846.9	33.7	450.9	34.8	26.7	450.9
4	24.6	33.1	25.7	32.1	691.8	33.1	691.8	32.1	386.9	33.1	25.7	386.9
5	23.7	31.6	24.8	30.6	569.7	31.6	569.7	30.6	333.7	31.6	24.8	333.7
6	22.9	30.2	23.9	29.3	472.7	30.2	472.7	29.3	289.2	30.2	23.9	289.2
7	22.1	28.9	23	28	395	28.9	395	28	251.8	28.9	23	251.8
8	21.3	27.6	22.2	26.8	332.4	27.6	332.4	26.8	220.3	27.6	22.2	220.3
9	20.5	26.4	21.4	25.6	281.4	26.4	281.4	25.6	193.5	26.4	21.4	193.5
10	19.8	25.3	20.7	24.5	239.7	25.3	239.7	24.5	170.6	25.3	20.7	170.6

6. It is common for this type of model that post integration prices of blueprints lie between pre-integration levels of the two regions. This is also the case here: upstream blueprint prices for North increase and those for East and South decrease under integration.

Equation (12) shows that access to foreign intermediate goods $S_{u,G}$ decreases demand for each variety of domestic intermediates. Hence intermediate good firms have lower lifetime profits available to acquire blueprints. For the North, integration yields higher blueprint prices, as the drop in the price of blueprints due to increased competition in the intermediate goods market is compensated by reaching a larger market thanks to the formation of the trade bloc. For East and South the gains from integration are concentrated on the consumer side in the downstream sector, while for North, they stem from the upstream research sector. To understand whether the positive consumer effects outweigh the negative producer effects, we compute consumer and producer surpluses.

From Equation (6) we obtain the inverse demand of the final good

$$P_{FG,i}(Y_i) = \left(\frac{A_i}{Y_i}\right)^{\frac{1}{\xi}},$$

and consequently — stars indicating market equilibrium quantities — the consumer surplus

$$CS_{FG,i} = \int_0^{Y_i^*} P_{FG,i}(Y_i)dY_i - P_{FG,i}(Y_i^*)Y_i^* = \frac{1}{\xi - 1} A_i^{1/\xi} {Y_i^*}^{\frac{\xi-1}{\xi}}.$$

To obtain the producer surplus in the research sector, we first combine Equations (1) and (2) to obtain the inverse supply of blueprints

$$P_{B,i}(B_{u,i}) = \left(\frac{B_{u,i}^{1-\alpha_u}}{b_{u,i} S_{u,i}^{\beta_u}}\right)^{\frac{1}{\alpha_u}} \frac{s_i}{\alpha_u}.$$

Using Equation (3) for the equilibrium market price of blueprints, producer surplus reads as

$$\begin{aligned} PS_{RS,i} &= P_{B,i}(B_{u,i}^*)B_{u,i}^* - \int_0^{B_{u,i}^*} P_{B,i}(B_{u,i})dB_{u,i} \\ &= \frac{\pi_{IM,j}}{r+\delta} B_{u,i}^* - \left(\frac{B_{u,i}^*}{b_{u,i} S_{u,i}^{\beta_u}}\right)^{\frac{1}{\alpha_u}} s_i . \end{aligned}$$

Figure 10 shows total, consumer, and producer surplus. Relative to autarky total surplus increases around 2.4% under full integration, around 2% under reshoring and around 0.4% under offshoring. These increases are fully driven by increases in consumer surplus, as aggregate producer surplus falls around 10% under full integration and reshoring, and around 1% under offshoring.

The disaggregated numbers show that North unambiguously benefits from any form of integration, but mainly in terms of higher producer surplus: full integration yields a 45% increase of producer surplus, whereas consumer surplus increases less than 1%. The numbers for reshoring are similar; offshoring brings much more modest increases. In terms of total surplus, full integration nets North a 4% increase in initial years. East

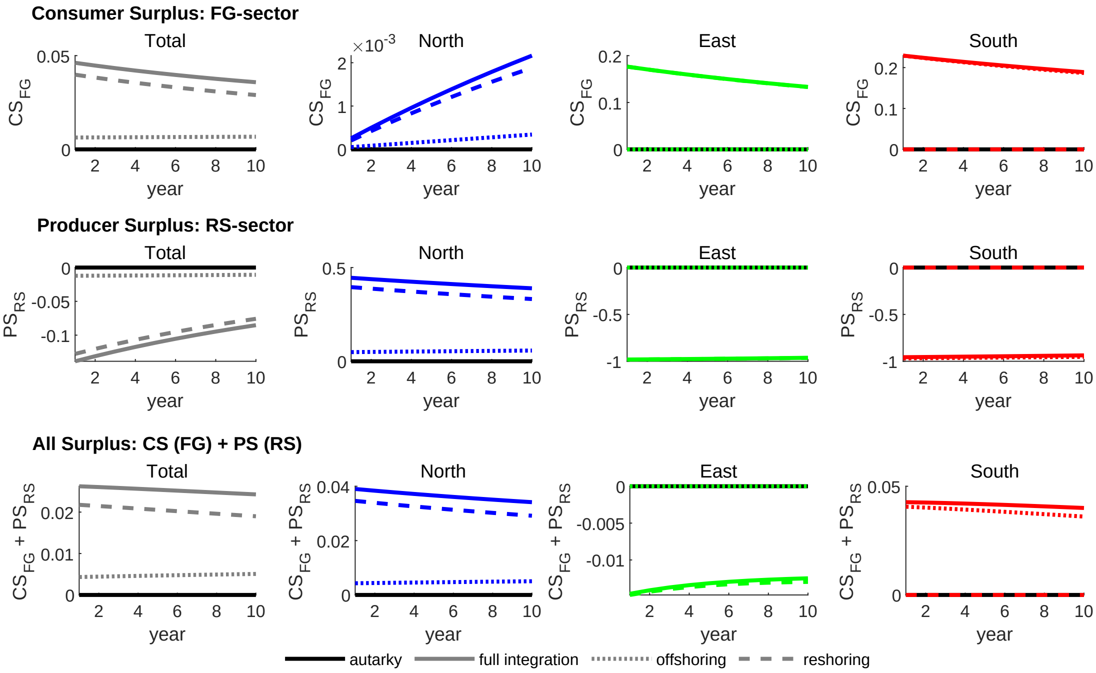

Figure 10. Evolution of surplus for different forms of integration
Relative sectoral change respect to baseline autarky case. *From top to bottom*: consumer surplus, producer surplus, total surplus. *Column 1*: aggregate for all regions; *Columns 2–4*: surpluses for North, East, and South respectively.

and South experience a large increase in consumer surplus from regional integration, around 18% and 23%, irrespective of whether the integration is full or only with North. This has to be offset against reductions in the producer surplus close to 100%. The net effect on total surplus is positive for South, whose total surplus is around 4.2% higher than under autarky; it is negative for East, where total surplus is 1.5% lower compared to remaining in autarky.

Compare these findings to Goto, Ma, and Takeuchi (2025), who show that offshoring increases entrepreneurial income but lowers wages for routine task workers in the skill-abundant country, and has the opposite effect in the less skill-abundant country.

Summing up, we find that integration with North results in large setbacks in a regions research sector and leads to lock-in in downstream activities, irrespective of whether the effect on total surplus is positive or negative. In the model East is better off by remaining under autarky, building first a strong R&D base and capacity that is competitive with future integration partners, and only then opening up for integration, to be able to compete not only downstream with low wages but also remain competitive upstream in the research sector. In fact, this is a strategy that has worked well, for example, for South Korea (Dayton 2020).

Subsection 3.4. **Process innovation vs integration — Are they substitutes?** In this last exercise, we ask what consequences North faces if offshoring to low-wage countries is substituted by additional process innovation. Offshoring of downstream manufacturing processes is often presented as a means for firms to reduce costs of production, and for the consumers in the offshoring country to achieve higher consumer surplus. Our results suggest that precisely the opposite happens.

We compare model outcomes in North for two different scenarios. The first is the full integration case with parameters and initial values set according to Table 2. In the second scenario, North remains in autarky, but starts with a higher downstream knowledge stock, which lowers final good production costs through productivity gains in manufacturing, see Atkinson (2020). The initial stock is chosen such that North's total surplus is the same for both scenarios at the end of the 10 year simulation period. To achieve this, the initial downstream knowledge stock is increased by 2.69%.

Figure 11 shows the main results. Under autarky total surplus starts at a lower level, compared to the integrated scenario, but grows faster. But it is not producer surplus but rather consumer surplus that causes autarky total surplus to outpace integration total surplus. Although it is not readily visible in the figure, producer surplus grows at a slightly faster rate under integration.

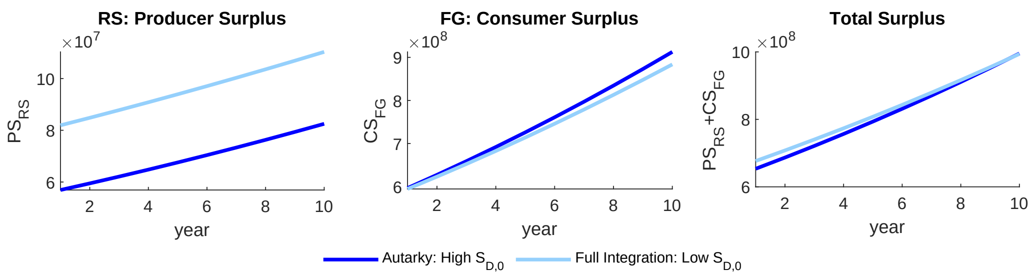

Figure 11. Producer and Consumer Surplus for the North under two scenarios
From left to right: Producer surplus, consumer surplus, and total surplus. *Light blue line:* full integration with standard values. *Dark blue line:* surplus under autarky with higher initial downstream knowledge stock

As the dynamics of downstream knowledge are exponential in the stock of downstream knowledge, see Equation (13), the small initial increase of 2.69% creates large gains later on, both in downstream knowledge and in final goods output: Figure 12, upper left and right panels. These effects outpace the loss that the final good sector experiences due to the forgone foreign access to intermediate inputs, Equation (4).

Producer surplus, on the other hand, remains significantly larger under integration by the gain of foreign downstream market demand, which is more significant than the domestic downstream expansion under autarky. Integration results in higher upstream

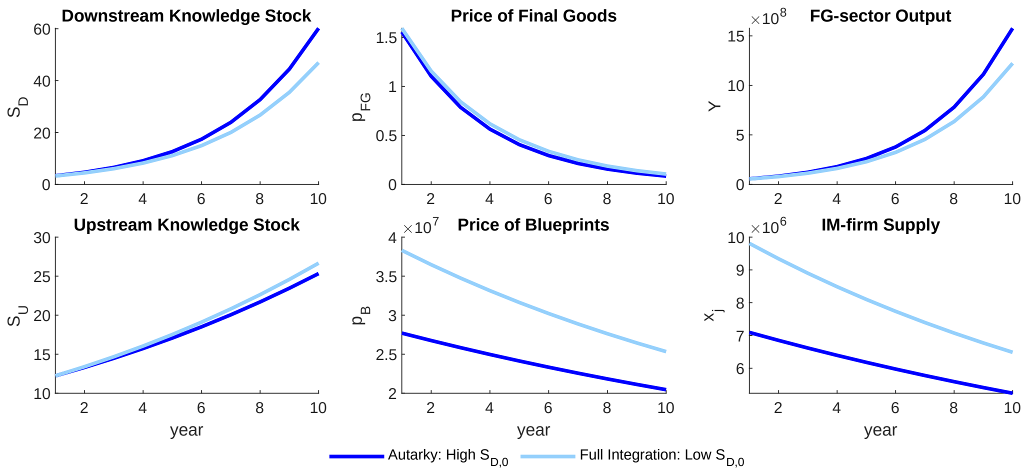

Figure 12. Knowledge Stocks, prices and output for the North under two scenarios
From top left to bottom right: Downstream knowledge stock, final good price, output of final good sector, upstream knowledge stock, price for upstream blueprints, output of an intermediate good firm; *Light blue line:* values under full integration with standard downstream knowledge stock $S_{d,0,North}$ as set in Table 2; *Dark blue line:* values under autarky with higher initial downstream knowledge stock ($1.0269 \times S_{d,0,North}$)

profits as more inputs are demanded and higher monopoly prices can be charged for upstream blueprints, see the lower panels of Figure 12.

To summarise the above, if a decision needs to be made between facilitating integration or investing in downstream manufacturing knowledge locally, the interests of consumers and firms do not align. From the perspective of a profit-driven firm, integration remains the preferred option, as it allows for larger profits due to additional downstream market demand. To make producer surplus equal in year 10, between the two scenarios, would require a much larger initial increase in downstream knowledge stock, of around 25.5%[7].

We conclude that for technological leaders, offshoring is mainly in the interest of knowledge producing firms, as it allows them access to larger markets. Hence, even in the absence of wage increases in South and East due to specialisation in downstream activities, which our model excludes, increasing downstream knowledge in North can make offshoring to low-wage countries unattractive. At the same time, the larger domestic knowledge stock has an opposite effects on foreign regions, which now have a greater incentive to integrate with the North to also benefit from additional downstream demand for their own intermediates produced upstream.

Section 4. Conclusion

We proposed a Romer-type dynamic, multi-region partial equilibrium model of trade and endogenous growth, in which we allow for trade of intermediate goods, but not for

7. See Appendix Figure F6, which compares autarky with a 25.5% higher downstream knowledge stock to the standard full integration scenario.

knowledge spillovers. By introducing a downstream knowledge stock, we added incentives to invest in downstream process innovations. This allows us to compare upstream and downstream investments and the relative evolution of the two knowledge stocks across different types of integration. We calibrated this model using cross-sectional patent and input-output data Germany, Poland, and China, which represent the three regions North, South and East. We could reproduce the decreasing labour shares across countries and the ordering of upstream and downstream knowledge stocks across regions, as well as the evolution of upstream and downstream patents during 2000-2010.

If trade blocs form, our model finds an aggregate global shift towards product innovation, resulting from a higher relative incentive for product innovation in the North, as well as higher knowledge production. The reverse is true for East and South, who focus on process innovation when integrated, creating a possible lock-in into downstream activity. The shift of the latter two regions towards process innovation is, however, more than counterbalanced by the shift of the North towards product innovation. At the aggregate, both upstream and downstream knowledge is higher under integration. Even in the North process innovation is increased when integrated, but much less than product innovation.

The East is caught in a trap: it has a productivity advantage over the South in upstream blueprint creation, but it is less apt at downstream innovation. When integration forces the East into downstream specialisation, it loses a large potential surplus from foregone upstream research while being outcompeted by the South on downstream knowledge. As a consequence, total welfare under integration is lower for the East than before entering a trade bloc. Integration causes welfare gains for the South: there are large gains in consumer surplus, which offset the losses in producer surplus as the research sector collapses. The North experiences large gains, especially in the upstream sector, due to increasing demand for intermediate inputs and the possibility of extracting economic rents in its research activities. Moreover, the gains in consumer surplus due to lower prices and larger variety are positive, if much less significant.

Regional integration therefore benefits already highly innovative regions most. Without explicit R&D or trade policies that promote and actively invest in the development of product innovations and the diffusion of knowledge, countries that are less knowledge intensive compared to their trading partners will have small chances of upgrading. This may explain why in reality China has adopted intense and aggressive R&D policies — by many perceived as unfair — to escape this trap.

Our model is prone to overstate the negative effects of regional integration as we neglect potential knowledge spillovers, which should result in positive effects for technological laggard regions in terms of growth and welfare. At the same time, our research calls for policies that recognise the importance of exactly these spillovers to avoid potential negative consequences of global integration.

Finally, in a counterfactual analysis, we investigate whether for the North investment into process innovation can be seen as a substitute to integration with low wage production partners. We therefore computed the necessary increase of the initial downstream knowledge for North to be, at the end of 10 years, indifferent between integration and remaining in autarky. Surprisingly, we find that this requires only a small increase of the initial downstream knowledge stock. However, indifference is achieved solely due to the increase in consumer surplus. Producer surplus remains higher under integration unless the initial downstream knowledge stock is raised by a much larger amount, indicating that for upstream actors integration is more strongly preferred than what the social optimum might indicate.

Extensions to the model may include transport costs, capturing institutional and geographic proximity and altering the incentives of North to integrate with either East or South; the fractional use of foreign knowledge stocks in knowledge production; and absorptive capacity into the use of foreign knowledge in domestic intermediate goods production.

In our model, we allow trade in intermediate goods, but not in final goods: each region's final goods production only satisfies domestic demand. In fact, most of the consumption of final goods is domestic and has also been domestic during 2000-2010. For example, in 2010 Germany exported 18.8% of its final goods, Poland around 16.3% and China approximately 14.7% [8]. Allowing final goods to be traded abroad is another interesting extension. It would however raise issues of substitutability and trade costs, adding to the complexity of the model.

Geopolitical and economic tensions in recent years resulted in Western economies discussing greater protectionism and self-reliance. The rest of the world, nowadays often faced with high tariffs or trade sanctions, has since been looking for new allies and partners. In future work, we propose to understand this shift better with an analysis of the last integration possibility left in our model: namely, the formation of a trade bloc between East and South, leaving the North in isolation.

8. These percentages can be seen as an upper bound as they are based on final consumption expenditure by households, non-profit organisations, governments and also include gross fixed capital formation. With respect to our model, these percentages of final goods exported are even lower considering that we focus on regions that are larger than single countries. The statistics come from our own calculations using data from WIOD Release 2016 and include all industries.

Appendix A. Supplementary Material

Subsection A.1. Calibration. The model has been calibrated on patent data, input-output data, and macroeconomic data: some parameter values have been taken from the literature. For labour shares, fraction of production workers, wages of production workers and wages of human capital workers we have used SEA Data (Socio Economic Accounts Data) that belong to the WIOD Release 2013 (World Input–Output Database 2013; Timmer et al. 2015). We did not make use of the newer 2016 release as it does not provide a disaggregation of employment by skill level. Initial values for upstream and downstream knowledge stocks have been calculated using patent data concorded with the upstream measures calculated in Chapter 1, which uses the input-output tables from WIOD Release 2016. Table 1 in the main text lists parameter values that are the same across regions; Table 2 lists region-specific parameters and initial values.

Our initial data is on industry-country level. As WIOD Release 2013 utilises Industry Classification ISIC Rev.3, while WIOD Release 2016 is build on ISIC Rev.4, we concord the two, only selecting manufacturing industries, see Table T1.

For data on production and human capital workers, WIOD Release 2013 provides a breakdown of the share of hours worked by persons engaged by three different skill levels (low-, medium- and high-skilled)[9]. In 2000, the share of hours worked by high-skilled workers in manufacturing sectors was for Germany 18.9%, Poland 7.5% and China around 2.3%. The share of hours worked by low- and medium-skilled (LM-skilled)labour in a population of 1 million hours worked is taken to represent the number of hours worked by production workers (L), and the share of hours worked by high-skilled (H-skilled) labour to represent human capital workers ($H_u + H_d$), that is

$$L = (\text{share of hrs worked by LM-skilled}) * 10^6 \,.$$

Similarly, the number of hours worked by human capital becomes

$$H = (\text{share of hrs worked by H-skilled}) * 10^6 \,.$$

Production workers wages are determined by

$$w = \frac{\text{Labour compensation for LM-skilled}}{L} \,;$$

wages for high-skilled (H-skilled) human capital workers are obtained by

$$s = \frac{\text{Labour compensation for H-skilled}}{H} \,.$$

We make use of patent data to set initial knowledge stocks $S_{u,i,0}$, $S_{d,i,0}$, research productivities $b_{u,i}$, $b_{d,i}$ and shares of knowledge production inputs in blueprint production

9. For details on how low-, medium- and high-skilled labour are defined, see Erumban et al. (2012, p.4).

Table T1. Industry codes included in the analysis and their descriptions
Manufacturing of coke and refined petroleum is excluded in our analysis

Code	**WIOD Release 2013; ISIC Rev.3**
15t16	Food, beverages and tobacco
17t18	Textiles and textile
19	Leather, leather and footwear
20	Wood and of wood and cork
21t22	Pulp, paper, printing and publishing
24	Chemicals and chemical
25	Rubber and plastics
26	Other non-metallic mineral
27t28	Basic metals and fabricated metal
29	Machinery, nec
30t33	Electrical and optical equipment
34t35	Transport equipment
36t37	Manufacturing nec; recycling
F	Construction

Code	**WIOD Release 2016; ISIC Rev.4**
C10-C12	Manufacture of food products, beverages and tobacco products
C13-C15	Manufacture of textiles, wearing apparel and leather products
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment
C31-C32	Manufacture of furniture; other manufacturing
F	Construction
J62-J63	Computer programming, consultancy and related activities; information service activities

α_u, α_d, β_u, and β_d. The patent data stems from PATSTAT edition 2020 which has been aggregated in Tinnefeld (2023) on country-industry-level using concordance between patent classification codes (CPC) and industrial classification codes (ISIC Rev.4).

Initial conditions for knowledge stocks, upstream ($S_{u,0}$) and downstream ($S_{d,0}$), are obtained from the average process share of patents in manufacturing industries, as in the lower panel of Table T1, for each country in the year 2000. We take this aggregate process share to indicate the fraction of process patents and its complement to be the fraction of product patents.

We correct for the relatively low propensity to patent process innovation compared to product innovations (e.g. Cohen, Nelson, and Walsh 2000; Banholzer et al. 2019), by adding an additional 16.5% of patents to the downstream knowledge stock, while subtracting 16.5% from the upstream knowledge stock. This percentage is obtained from Germany's average process/use share of patents across industries, which we calculated to be approximately 10.5%, contrasting it with the German innovation survey (GIS) data and the German R&D survey (GRS). In these surveys, firms report to have devoted around 27% (23% for GRS) of R&D expenditure to process innovation and around 53% (62% for GRS) to product innovation (Rammer 2016). Besides this, findings from the Community Innovation Survey 2012 (covering 31 European countries) show that 47% of enterprises that introduced new innovations reported to have introduced new process innovations (while 53% reported to have introduced a product innovation) (Rammer 2016). We therefore assume that the gap between our calculated process share and actual share of process innovations (representing, inter alia, relative low-propensity to patent process innovations), is constant across countries and is around 33% (2*16.5%).

We compute upstream knowledge stock and downstream knowledge stock for the year 2000, the initial year $t = 0$ in our calibration, as indicated in Equations (15) and (16): we take the respectively approximated amount of product and process patents in 2000 as a base amount and assume constant patent applications in the previous 20 years that add to the stocks in 2000 with knowledge depreciation of 20% annually (Griliches 1990; Zucker et al. 2007). The upstream knowledge stock for manufacturing industries i in country c in year $t = 0$ for a representative population of 10^6 hours worked:

$$\begin{aligned} S_{c,u,0} =& (1 - 0.165)\left(\frac{1 - 0.8^{20}}{1 - 0.8}\right)\left(\frac{10^6}{\text{total hrs worked}}\right) \\ & \sum_i (\text{Patents}_{i,c,t} * (1 - \text{process-share of patents}_{i,c,t})) \end{aligned} \tag{15}$$

Similarly, the downstream knowledge stock becomes:

$$\begin{aligned} S_{c,d,0} =& (1 + 0.165)\left(\frac{1 - 0.8^{20}}{1 - 0.8}\right)\left(\frac{10^6}{\text{total hrs worked}}\right) \\ & \sum_i (\text{Patents}_{i,c,t} * \text{process-share of patents}_{i,c,t}) \end{aligned} \tag{16}$$

We calculate the share of intermediates used $(1 - \alpha - \alpha_d)$ as being the value of intermediate inputs used over gross output minus capital compensation of all manufacturing industries. We subtract capital from the gross output because our function for the final output $Y_{FG,i}$ does not include capital as a factor of production.

$$1 - \alpha - \alpha_d = \frac{\text{Intermediate Inputs (II)}}{\text{Gross output (GO) - Capital compensation (K)}}.$$

This gives us an intermediate input share of around 78%. The remaining 22% we attribute to workers and distinguish between the share of production workers α and the share of downstream human capital workers α_d by disaggregating the 22% between the two types based on the share of hours workers by low- and medium-skilled (production workers) and the share of hours worked by high-skilled (downstream human capital workers). In the data the share of high-skilled hours worked is around 14%, while the share of low-and medium-skilled hours is around 86% in the year 2000 across all countries and manufacturing industries in the SEA data.

This means that attributing 14% of the 22% labour share to human capital and 86% of the 22% labour share to production workers results in $\alpha_d = 0.03$ and $\alpha = 0.19$. To get the upstream human capital share α_u and upstream and downstream knowledge shares β_u and β_d we estimate

$$\log(B_{u,c,i,t}) = \log(b_u) + \alpha_u \log(H_{u,c,i,t}) + \beta_u \log(S_{u,c,i,t}) + \varepsilon_{c,i,t}\,, \tag{17}$$

where the $\varepsilon_{c,i,t}$ are iid normal variables, using a simple OLS on the panel that combines patent data on industry level and socio-economic account data from WIOT. From this estimation, we get $\alpha_u = 0.11$, $\beta_u = 0.87$. Similarly, for the downstream sector, we estimate:

$$\log(B_{d,c,i,t}) = \log(b_d) + \alpha_d \log(H_{d,c,i,t}) + \beta_d \log(S_{d,c,i,t}) + \varepsilon_{c,i,t}, \tag{18}$$

which results in $\alpha_d = 0.08$, $\beta_d = 0.9$. As α_d in this estimation deviates from the one calculated using labour shares in final good production (0.03) by 0.05 we keep the value from the latter calibration and add the difference of 0.05 to the knowledge share, such that $\beta_d = 0.95$. Our calibration yields diminishing returns in human capital, both upstream and downstream, with $\alpha_d < \alpha_u$, reflecting that process innovations are less driven by human capital (Rammer 2016).

As $b_{u,i}$ and $b_{d,i}$ are region specific, we do not make use of the estimates from Equations (17) and (18). Instead, we choose these parameters for Germany, Poland and China by separately estimating for each country an intercept-only model making use of the rearranged estimation Equations (17) and (18) using the selected values for α_u, α_d, β_u, and β_d as well as panel data on knowledge stocks, new blueprints developed and human capital employment for the years 2000–2009. As we cannot distinguish between upstream and downstream human capital employment, we assume in these estimations that $H_u = H_d$ is equal to the total employment of high-skilled. We find $b_u < b_d$ for all three countries, reflecting that upstream knowledge is more difficult to obtain than downstream knowledge.

Equation (9) is used to calibrate the market size of regions and the price elasticity of final goods, as it sets the number of production workers. We calibrate for autarky. For each region, we use all known parameters, initial values of knowledge stocks, and research productivities; the number of production workers is taken from its observed value in 2000 for manufacturing industries. We can then solve for A_i. This gives us three equations for A_i in terms of the price elasticity ξ of the final good, which is assumed to be equal across regions.

From input-output data we obtain gross output (GO) of the manufacturing sector in relative terms. Polish gross output per capita is about a third of the value of the German gross output in manufacturing sectors. Instead, the Chinese gross output per capita is around 6% that of Germany (see Table T2). We make use of this ordering and assume that it also applies to market size. This gives us the three relationships

$$\begin{aligned} (I) \quad & A_{DE}(\xi) = A_{PL}(\xi)\frac{GO_{DE}}{GO_{PL}} \\ (II) \quad & A_{DE}(\xi) = A_{CN}(\xi)\frac{GO_{DE}}{GO_{CN}} \\ (III) \quad & A_{CN}(\xi) = A_{PL}(\xi)\frac{GO_{CN}}{GO_{PL}} \,. \end{aligned}$$

As market size A is a function of ξ the system of equations is overidentified. We therefore take the mean of the three values for ξ as the price elasticity of demand for the final good sector, which, under autarky, evaluates to $\xi = 1.1459$. For integrated economies, we would have obtained $\xi = 1.1915$.

Table T2. Comparison of gross output (GO) per capita across Germany, Poland and China

Country	**Share**
GO_{DE} p.c. / GO_{DE} p.c.	1
GO_{PL} p.c. / GO_{DE} p.c.	0.3277
GO_{CN} p.c. / GO_{DE} p.c.	0.0610

Subsection A.2. Additional Figures and Tables.

Figure F1. Data from SEA-data showing evolution of some key variables

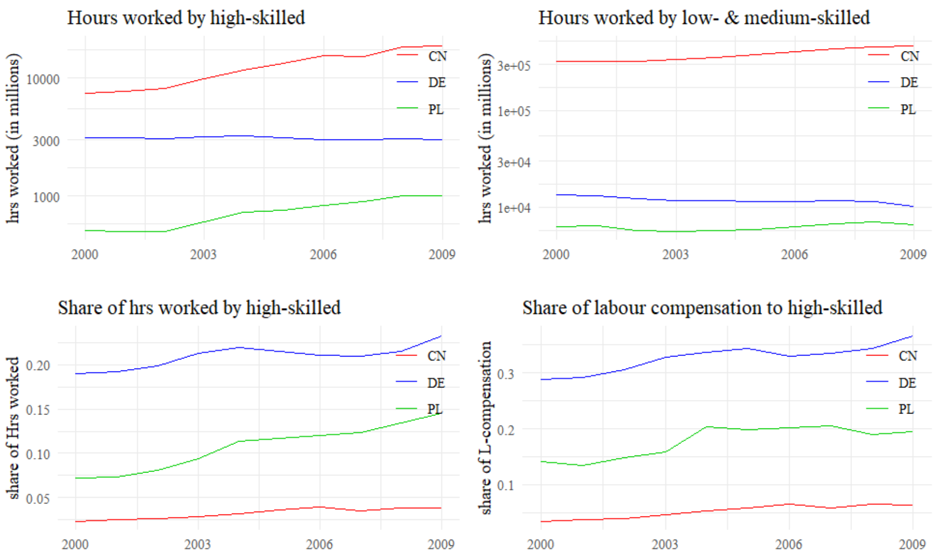

Figure F2. Evolution of patenting upstream and downstream
Patent data adjusted for low-propensity to patent process innovation (LPP) according to method outlined in the methodology; first and second columns: y-axis log-transformed; second and third columns: patent counts adjusted for population size using total number of hours worked

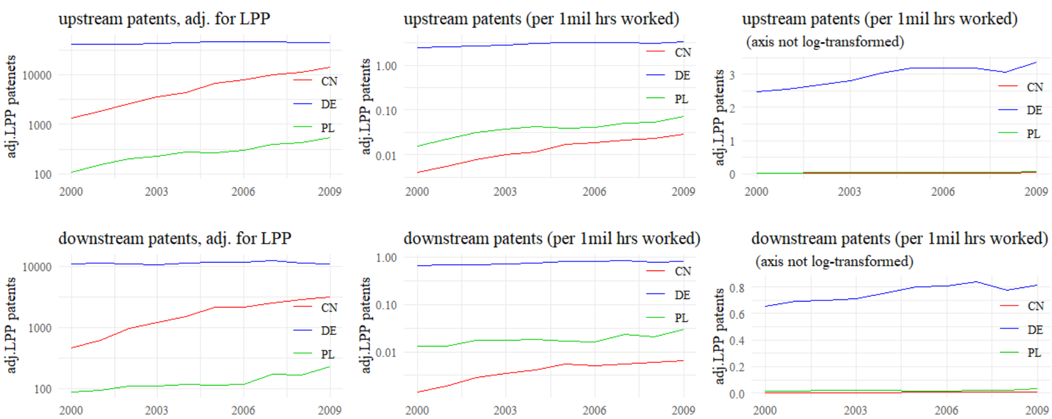

Figure F3. Evolution of upstream and downstream knowledge stocks
Patent data adjusted for low-propensity to patent process innovation (LPP); stocks build assuming constant patenting pre-2000 for 20 years and knowledge depreciation of 20%; from 2000 onwards number of upstream and downstream patents are added to the stock

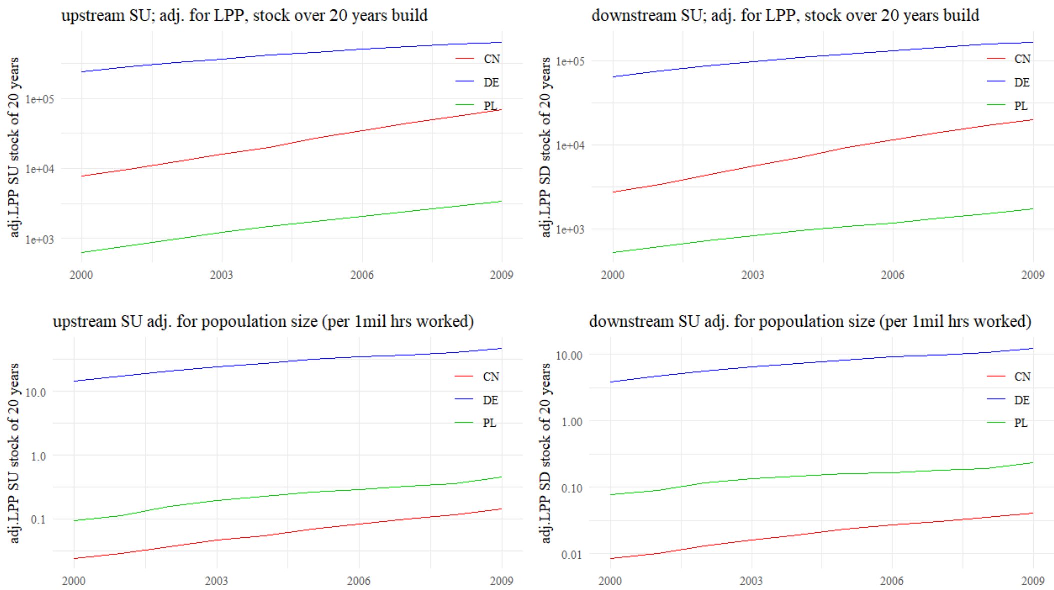

Figure F4. Integrated Cases compared to baseline case: time series 10-year horizon; Ratio with respect to baseline
North (blue), East (green) and South (red); *Rows 1-3:* employment in number of hours worked for production workers, upstream human capital and downstream human capital (from left to right)

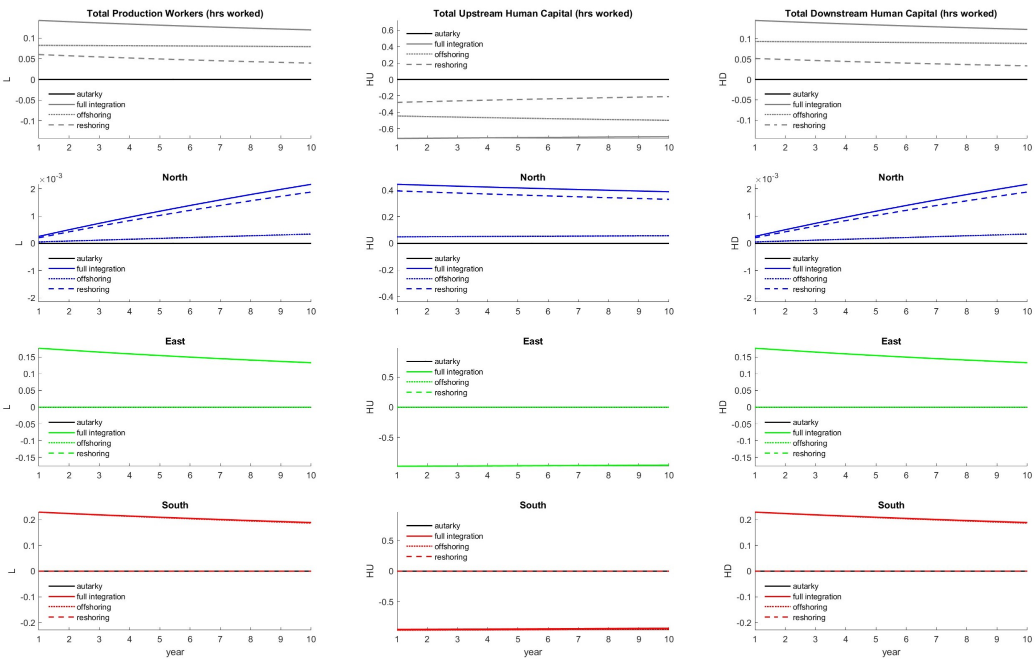

Figure F5. Evolution of the number of Blueprints for different integration types (time series 10-year horizon, vertical axes are logarithmic) *Top Row*: upstream blueprints in autarky, full integration, offshoring and reshoring case (from left to right); *Middle Row*: downstream blueprints in autarky, full integration, offshoring and reshoring case (from left to right); *Bottom Row*: downstream blueprints over upstream blueprints in autarky, full integration, offshoring and reshoring case (from left to right)

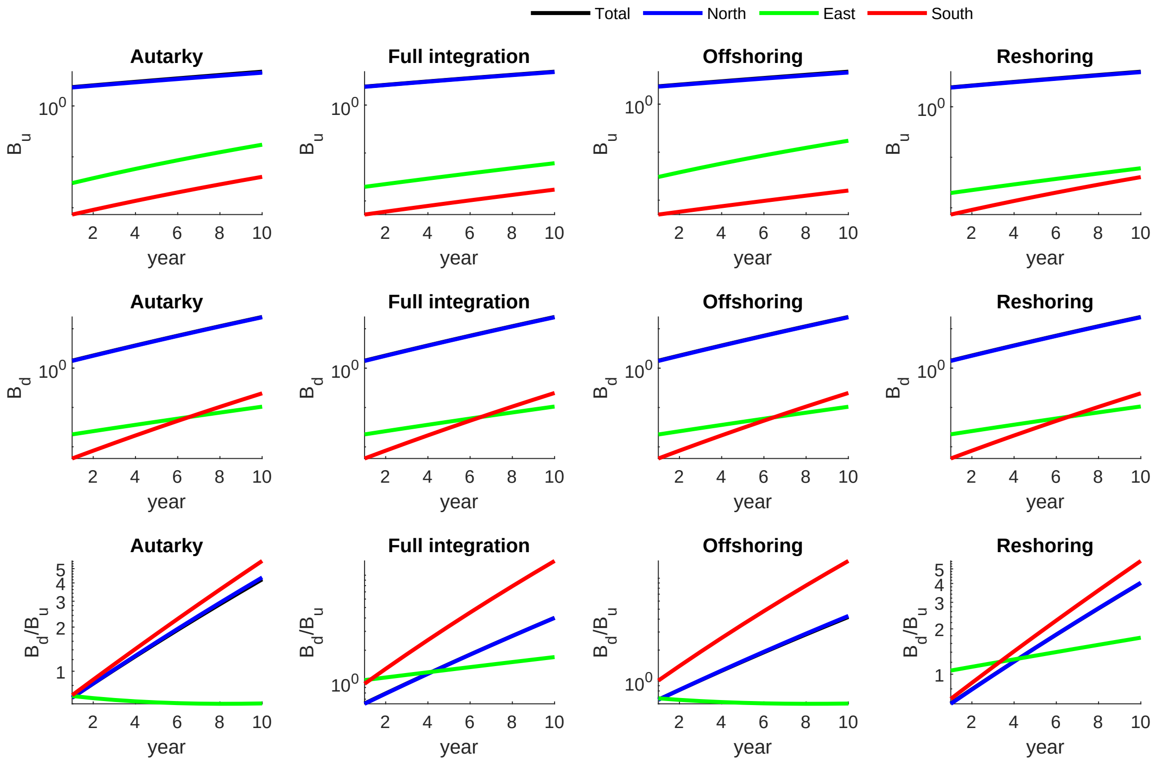

Figure F6. Surplus, Knowledge Stocks, prices and output for the North under two scenarios: (1) for autarky downstream knowledge to be 25.5% larger as standard and (2) for full integrated scenario with standard values.
From top left to bottom right: Producer surplus, Consumer surplus, Total surplus, Downstream knowledge stock, final good price, output of final good sector, upstream knowledge stock, price for upstream blueprints, output of an intermediate good firm; *Light blue line:* values under full integration with standard downstream knowledge stock $S_{d,0,North}$ as set in Table 2; *Dark blue line:* values under autarky with higher initial downstream knowledge stock $(1.255 \times S_{d,0,North})$; 25.5% larger downstream knowledge stock is chosen in the autarky case make producer surplus in year 10 equal among the two scenarios

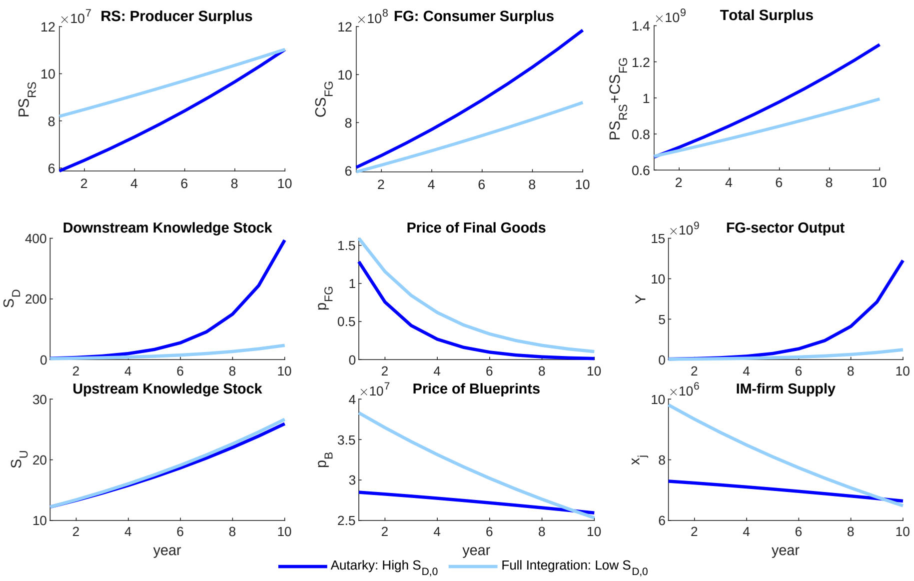

Table T3. Capital and Labour shares among manufacturing industries for all countries in the SEA data
disaggregated by low- plus medium-skilled and high-skilled workers; calculated average across industries and countries using the relationship that L-compensation + K-compensation = Value-Added

Year	**K/VA**	**L/VA**	**(LS+MS)/VA**	**HS/VA**
2000	0.390	0.610	0.500	0.110
2001	0.385	0.615	0.503	0.112
2002	0.388	0.612	0.498	0.114
2003	0.386	0.614	0.501	0.112
2004	0.392	0.608	0.484	0.124
2005	0.385	0.615	0.488	0.127
2006	0.391	0.609	0.483	0.126
2007	0.385	0.615	0.490	0.125
2008	0.360	0.641	0.509	0.132
2009	0.350	0.650	0.509	0.141

Table T4. SEA-data available data

Values	**Description**
GO	Gross output by industry at current basic prices (in millions of national currency)
II	Intermediate inputs at current purchasers' prices (in millions of national currency)
VA	Gross value added at current basic prices (in millions of national currency)
EMP	Number of persons engaged (thousands)
EMPE	Number of employees (thousands)
H_EMPE	Total hours worked by employees (millions)
COMP	Compensation of employees (in millions of national currency)
LAB	Labour compensation (in millions of national currency)
CAP	Capital compensation (in millions of national currency)
K	Nominal capital stock (in millions of national currency)
Prices	
GO_PI	Price levels gross output, 201=100
II_PI	Price levels of intermediate inputs, 201=100
VA_PI	Price levels of gross value added, 201=100
Volumes	
GO_QI	Gross output, volume indices, 201=100
II_QI	Intermediate inputs, volume indices, 201=100
VA_QI	Gross value added, volume indices, 201=100

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