

Fischer-Thöne, Christian; Egger, Hartmut

Conference Paper

Institutional Reform and Global Value Chains

Beiträge zur Jahrestagung des Vereins für Socialpolitik 2021: Climate Economics

Provided in Cooperation with:

Verein für Socialpolitik / German Economic Association

Suggested Citation: Fischer-Thöne, Christian; Egger, Hartmut (2021) : Institutional Reform and Global Value Chains, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2021: Climate Economics, ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg

This Version is available at:

<https://hdl.handle.net/10419/242442>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Institutional Reform and Global Value Chains

Hartmut Egger[§]

*University of Bayreuth
CESifo, GEP, and IfW*

Christian Fischer-Thöne

University of Bayreuth

March 1, 2021

Abstract

This paper sets up a model of trade, in which two countries with differing levels of technology specialize on the production of subsets of the global value chain. In the open economy equilibrium, the technologically backward country exports intermediates in exchange for imports of a homogeneous consumption good from the technologically advanced country. This vertical specialization pattern gives the two countries access to different instruments for appropriating rents in the open economy. The technologically advanced country can impose an import tariff on intermediates to lower foreign wages and increase national welfare. An import tariff is ineffective for the technologically backward economy, which can instead lower institutional quality and allow its workers to partially expropriate firms and directly consume intermediate goods at a utility discount. In a non-cooperative policy equilibrium, welfare levels of the two countries will fall to their autarky levels. This gives scope for a trade agreement that conditions tariff reductions on institutional quality improvements and is beneficial for both countries. A beneficial trade agreement may not exist if the import tariff has an upper bound.

Keywords: Global value chains, trade policy, institutional quality, tariffs

JEL Classification: F12, F13, F68

[§]Corresponding author: University of Bayreuth, Department of Economics, Universitätsstr. 30, 95447 Bayreuth, Germany; hartmut.egger@uni-bayreuth.de.

1 Introduction

Global value chains have become increasingly important over the last decades and are now a predominant factor of international trade (see Johnson and Noguera, 2017; Johnson, 2018).¹ Their wide dissemination has brought global value chains to the attention of academic research which has tried to decipher them, using advanced theoretical models (see Antràs and Chor, 2013; Costinot, Vogel, and Wang, 2013; Antràs and De Gortari, 2020). Leading to vertical patterns of trade with intermediate goods exchanged for final goods, global value chains also challenge our knowledge about the impact of trade policies, inducing Blanchard (2017) to conclude that we have to rewrite the book on how to think about these policies. Whereas such a strong conclusion may be too bold, it is a widespread concern that value chains may be more vulnerable to policy interventions, as nicely illustrated by the frantic appeal of UK car makers to their component suppliers that they should relocate their production from continental Europe to Britain to avoid increasing import tariffs after the Brexit (see Financial Times, 2017). Despite such concerns, theoretical work on trade policy in the context of value chains is scarce. It is the purpose of this paper to fill this gap.

We conduct our analysis in a prototype model of the global value chain put forward by Costinot et al. (2013). In this model, the production of a single consumption good requires the execution of a continuum of tasks in consecutive order. This production process captures the vertical structure of value chains in a simple way. We embed this theoretical account of the value chain into a trade model, in which two countries specialize on subsets of the necessary production stages in the open economy. The pattern of vertical specialization in our model is thereby the result of exogenous differences of the two countries in their production technologies. Following Costinot et al. (2013), we assume production at each stage to combine output of the previous stage with labor input to process the intermediate good. However, production at each stage is prone to mistakes, which destroy production and thus the output used from all previous stages. Countries differ in the rate at which these mistakes occur, and the country with the higher rate of mistake operates the inferior technology and ends up executing the earlier stages of the global value chain. This outcome is intuitive, because a mistake is less costly if it materializes at earlier stages for the simple reason of a lower loss of valuable labor input.

After characterizing the open economy equilibrium and showing comparative static effects of technology change, we then introduce instruments of trade policy. Thereby, our model points to an important asymmetry of the sets of policy measures available to the two economies. Whereas the technologically advanced economy – executing the later stages of the global value chain and producing the consumption good – can use an import tariff to appropriate rents from workers in the technologically backward economy, this tariff instrument is ineffective (and thus unavailable) for the technologically backward economy, provided that the consumption good is produced under perfect competition at all stages of the global value chain. This asymmetry of import tariffs in the case of vertical specialization is crucial for our analysis,

¹Putting numbers to the increasing importance of global value chains, Hummels, Ishii, and Yi (2001) report that exports due to vertical specialization along the value chain accounts for almost one third of the growth of worldwide exports between 1970 and 1990.

because it deprives the exporter of the intermediate good of an instrument commonly used for appropriating rents in the open economy. In our model, the loss of one instrument is compensated by access to another one, namely the institutional quality to protect the property rights of firms against expropriation by workers. Thereby, we associate lower institutional quality with a lower fraction of the intermediate good to be exported for further processing abroad and assume the residual to be consumed by domestic workers at a utility discount. Lowering institutional quality is only available for the technologically backward economy in our model.

Analyzing how the two policy instruments affect the open economy equilibrium, we highlight an important difference between them. Since the production structure in the open economy is pinned down by a full employment condition, imposing an import tariff on intermediates, while redistributing rents from the technologically backward to the technologically advanced country, does not change the organization of the global value chain. Therefore, increasing an import tariff leaves global welfare unaffected, but changes the distribution of this welfare between the two economies. Things are different in the case of institutional quality. Lowering institutional quality redistributes welfare to the technologically backward economy. However, it also reduces the fraction of intermediate goods exported for further processing in the technologically advanced economy, leading to a restructuring of the global value chain with less stages produced by the technologically backward economy. This restructuring process captures an efficiency loss from lowering institutional quality, which reduces global welfare.

In a non-cooperative policy game, the two countries will end up imposing a prohibitive tariff in the technologically advanced economy and a minimum institutional quality in the technologically backward economy. This leads to an open economy equilibrium with welfare levels of the two economies equaling those under autarky. In this case, a trade agreement that conditions tariff reductions on improvements of institutional quality in the backward economy can be welfare-improving. This provides a possible explanation for the increasing importance of arbitration clauses in recent negotiations on preferential trade agreements (see OECD, 2012, and the controversial debate regarding the Transatlantic Trade and Investment Partnership). However, if the tariff policy of the technologically advanced economy is constrained by an upper bound – imposed, for instance, by WTO rules – the technologically backward country may impose the best institutional quality even without cooperation, leaving no scope for an agreement on further tariff reductions that would be beneficial for both countries. This highlights the important role of conditioning tariff reductions on improvements of institutional quality for the successful implementation of trade agreements in a North-South context.

Our analysis is related to several important strands of the trade literature. For instance, we contribute to recent research on vertical specialization and global value chains. Prominent examples to this literature include Yi (2003); Kohler (2004); Grossman and Rossi-Hansberg (2008), and more recently Costinot et al. (2013); Antràs and Chor (2013); Antràs and De Gortari (2020). Particularly important for us is Alfaro, Antràs, Chor, and Conconi (2019), who develop a property-rights model of vertical production and its organization along the value chain. While their analysis is focused on the decision to integrate suppliers or not, thereby shifting firm boundaries, we analyze how changes in institutional quality directly affect the global value chain. Whereas in the interest of analytical tractability, we consider a simple one-directional

value chain, Harms, Lorz, and Urban (2012) and Baldwin and Venables (2013) analyze more complex patterns.

Emphasizing the role of global value chains for trade policy, we contribute to a sizable literature on non-cooperative and cooperative tariff regimes. Prominent examples to this literature include Johnson (1953); Dixit (1987); Bagwell and Staiger (1997, 1999), and in models of the new trade theory Ossa (2011); Campolmo, Fadinger, and Forlatti (2014); Costinot, Rodríguez-Clare, and Werning (2020). More closely related to our analysis, Blanchard, Bown, and Johnson (2017) consider the effect of supply chain linkages on trade policy and find that governments set lower tariffs when interdependencies of countries along the global value chains are stronger. Related to this argument, Blanchard (2010) shows that foreign ownership has a direct impact on countries' optimal tariff policies. Ornelas and Turner (2012) investigate in a property rights model the effects of tariffs on the organizational structure of firms along the value chain. They show that the existence of tariffs can make organizational choices inefficient. We complement this literature by emphasizing an important asymmetry in the access to trade policy instruments of countries that are specialized in the execution of different stages of the global value chain.

Finally, there exists a comparably small literature studying the effects institutional quality and the protection of property rights on international trade. A seminal contribution in this respect is Levchenko (2007), who shows that introducing incomplete contracts into an international trade model generates a distinct source of comparative advantage between countries with differing institutional settings.² In Levchenko (2013) institutional quality results endogenously from a policy game. In this paper, countries are incentivized under free trade to improve their institutional quality if the production technologies of the trading partners are sufficiently homogeneous. In a related study, Stefanadis (2010) shows that the direction of the institutional effect depends on the quality level of institutions prior to the opening up for trade. We address the role of institutional quality in the context of global value chains and therefore add a new facet to this literature.

The remainder of the paper is organized as follows. In Sections 2 and 3, we outline the basic model structure and study the open economy equilibrium without policy distortions. In Section 4, we extend the analysis of the open economy and allow for arbitrary levels of import tariffs in the technologically advanced economy and arbitrary levels of institutional quality in the technologically backward economy. There, we also study comparative-static effects of changing the two policy instruments. In Section 5, we then analyze a non-cooperative policy game between the two countries and investigate the scope for trade agreements that are beneficial for both economies. Section 6 concludes with a summary of the most important results.

2 Basic model structure

We conduct our formal analysis in a production model along the lines of Costinot et al. (2013), in which a continuum of stages must be executed to produce a single consumption good. Assuming that the produc-

²Nunn (2007) test for the relevance of institutional comparative advantage and find support for it in the data.

tion stages must be executed consecutively in a predetermined order, the model describes a value chain, which we assume to have unit length. In the subsequent analysis, we capture each production stage by an index s from the unit interval. We embed this production model into a world composed of two countries, $c = 1, 2$, which are endowed with an equal mass of labor L but differ in their production technologies. Labor is immobile between countries and technology determines the Poisson rate, $\lambda_c \in (0, 1)$, at which mistakes materialize at each production stage. Whenever a mistake occurs the processed intermediate is destroyed, making labor input in all previous stages a wasteful loss. We assume that mistakes occur at a higher rate in country 1 than in country 2, i.e. $\lambda_1 > \lambda_2$. This makes country 1 the technologically backward economy (the “South”) and country 2 the technologically advanced economy (the “North”).

Considering a Leontief technology that combines $q(s)$ units of the intermediate produced at stage s with $q(s)ds$ units of labor to produce $q(s + ds)$ units of the consecutive stage $s + ds$, we can express the technology of producing $q(s + ds)$ as $q(s + ds) = (1 - \lambda_c ds)q(s)$. For infinitesimal ds , the production function of country c at stage s can then be written in the form of a differential equation as follows

$$q'(s) = -\lambda_c q(s). \quad (1)$$

Markets at all stages are perfectly competitive. The world price of intermediate good s is given by $p(s)$. The initial input at stage $s = 0$ is available in perfectly elastic supply at a price $p(0) = 0$. The consumer good at stage $s = 1$ is chosen as our numéraire and its price is therefore normalized to one.³

Making use of our technology assumption, we can write the costs of country c to produce output $q(s + ds)$ as $p(s)q(s) + w_c q(s)ds$. Substituting $q(s + ds) = (1 - \lambda_c ds)q(s)$ gives the unit cost function $c(s + ds) = [p(s) + w_c ds]/(1 - \lambda_c ds)$. Under perfect competition, profit-maximization then establishes

$$\begin{aligned} p(s + ds) &\leq \frac{p(s) + w_c ds}{1 - \lambda_c ds}, \\ p(s + ds) &= \frac{p(s) + w_c ds}{1 - \lambda_c ds} \text{ if } Q_c(s') > 0 \text{ for all } s' \in (s, s + ds], \end{aligned} \quad (2)$$

where $Q_c(s)$ is economy-wide output of stage s in country c . Labor market clearing establishes for each country c that

$$\int_0^1 Q_c(s) ds = L, \quad (3)$$

with L denoting the symmetric labor endowment of both countries. This completes the description of the model structure.

³To apply the solution concept of Costinot et al. (2013), we impose the additional formal condition that each firm produces a measure $\Delta > 0$ of consecutive stages. To be more specific, we assume that if a firm produces stage $s' = s + ds$, then it produces all stages $s' \in (s, s + \Delta]$. This implies that each unit of the consumer good is produced by a finite number of firms.

3 The open economy without policy distortions

In this section, we investigate a baseline version of our model in the absence of policy. In this case, our setting reduces to a two-country variant of the model proposed by Costinot et al. (2013). For this case, the open economy equilibrium is characterized by the following lemma.

Lemma 1 *In the open economy equilibrium, there exists a unique partitioning of the unit interval of production stages into two subintervals of length S_1 and $1 - S_1$, respectively, such that $Q_1(s) > 0$ if and only if $s \in (0, S_1]$ and $Q_2(s) > 0$ if and only if $s \in (S_1, 1]$. We thereby have*

$$S_1 = -\frac{1}{\lambda_1} \ln \left(1 - \frac{\lambda_1 L}{Q_0} \right), \quad 1 = S_1 - \frac{1}{\lambda_2} \ln \left(1 - \frac{\lambda_2 L}{Q_1} \right), \quad (4)$$

and output levels

$$Q_1 = Q_0 - \lambda_1 L, \quad Q_2 = Q_1 - \lambda_2 L. \quad (5)$$

Proof The first part of the lemma on the vertical structure of the global value chain directly follows from the proof of Proposition 1 in Costinot et al. (2013). To derive Eqs. (4) and (5), we solve the differential equation (1) at the country level and compute the general solutions $Q_1(s) = \exp[-\lambda_1 s]Q_0$ and $Q_2(s) = \exp[-\lambda_2(s - S_1)]Q_1$, where $Q_1(0) \equiv Q_0$ and $Q_2(S_1) = Q_1(S_1) \equiv Q_1$ have been used. Substituting these two solutions into the labor market clearing conditions of countries 1 and 2 establishes Eq. (4). Eq. (5) then follows from substituting Eq. (4) into $Q_1 = \exp[-\lambda_1 S_1]Q_0$ and $Q_2 = \exp[-\lambda_2(1 - S_1)]Q_1$.

Figure 1 gives a graphical account of the global value chain in our model. The important finding of Lemma 1 that the South executes the early stages of the global value chain, whereas the North executes later ones is a direct consequence of our assumption that country 1 is the technologically backward economy. This is intuitive, because – as outlined above – a mistake at stage $s > 0$ destroys the production from all previously executed stages. Hence, the loss from mistakes and thus the (expected) costs of production are minimized by the vertical production structure captured by Figure 1.

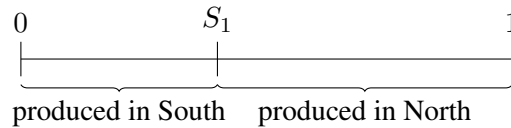


Figure 1: *The distribution of production stages across countries.*

The two equations in (4) can be combined to the global labor market clearing condition

$$1 = -\frac{1}{\lambda_1} \ln \left(1 - \frac{\lambda_1 L}{Q_0} \right) - \frac{1}{\lambda_2} \ln \left(1 - \frac{\lambda_2 L}{Q_0 - \lambda_1 L} \right) \equiv F(Q_0), \quad (6)$$

where $Q_1 = Q_0 - \lambda_1 L$ has been substituted from Eq. (5). Eq. (6) implicitly determines Q_0 in the open economy equilibrium. Noting that $\lim_{Q_0 \rightarrow (\lambda_1 + \lambda_2)L} F(Q_0) = \infty$, $\lim_{Q_0 \rightarrow \infty} F(Q_0) = 0$, and $F'(Q_0) < 0$, it follows that the equilibrium level of Q_0 , denoted by \hat{Q}_0 , is unique and satisfies $\hat{Q}_0 > (\lambda_1 + \lambda_2)L$.

The following proposition summarizes comparative static effects of changes in λ_c on the open economy equilibrium characterized in Lemma 1.

Proposition 1 *Technological progress in either country, captured by a decline in the mistake rate λ_c , decreases the quantity of the initial input \hat{Q}_0 and increases the length of the Southern value chain S_1 .*

Proof See the Appendix.

Proposition 1 gives important insights on the mechanics of our model by showing how technology interacts with the labor market clearing conditions of the two countries in determining the open economy equilibrium. If technology improves, more intermediates can be handed over to the next production stage, ceteris paribus. This increases labor demand and requires \hat{Q}_0 to fall in order to restore the global labor market clearing condition in Eq. (6). However, since workers are immobile between countries global labor market clearing is not sufficient for an open economy equilibrium. Instead, the labor market must clear for each country individually. Therefore, if technological progress occurs in the North, due to a fall in λ_2 , S_1 needs to increase for labor market clearing to be achieved in the South. If in contrast technological progress occurs in the South, due to a fall in λ_1 , the effect on S_1 is not immediately clear. However, we show in the Appendix that, in the case of a constant loss rate, S_1 needs to increase in order to restore labor market clearing in the North.

With the important insight from Proposition 1 that technological progress in the South increases S_1 , it follows that the length of the Southern value chains reaches a maximum in the limiting case of $\lambda_1 = \lambda_2 \equiv \lambda$. In this case, we compute

$$\lim_{\lambda_1 \rightarrow \lambda_2^+} \hat{Q}_0 = 2\lambda L \frac{\exp[\lambda]}{\exp[\lambda] - 1}, \quad \lim_{\lambda_1 \rightarrow \lambda_2^+} S_1 = -\frac{1}{\lambda} \ln \left[\frac{1 + \exp[-\lambda]}{2} \right]$$

and thus $\lim_{\lambda_1 \rightarrow \lambda_2^+} S_1 < 1/2$.⁴ This is a notable result, which points to an inherent asymmetry of countries along the value chain. Since the South operates earlier production stages, it has to handle a larger volume of intermediates per stage, which increases labor demand ceteris paribus. For a given position in the value chain, the South therefore executes fewer stages than the North with the same level of labor input L .

With the characterization of the open economy equilibrium and our findings regarding the comparative-static effects of technological change at hand, we now continue our analysis with determining welfare of North and South in the open economy. Since all workers in country $c = 1, 2$ receive the same wage w_c and since profits are zero and consumers only purchase a single consumption good, we use the total real wage income – and thus GDP – as a welfare criterion. Noting that consumption good Q_2 serves as

⁴Note that if $\lambda_1 = \lambda_2 = \lambda$, $\lim_{\lambda_1 \rightarrow \lambda_2^+} S_1 < 1/2$ is equivalent to $2 < \exp[\lambda/2]\{1 + \exp[-\lambda]\} \equiv f_0(\lambda)$. Acknowledging $f'_0(\lambda > 0)$ and $f_0(0) = 2$ establishes the result.

our numéraire, welfare can then be expressed (in indirect form) as $V_c = w_c L$. This implies that in the baseline model welfare changes are fully determined by changes in the country-specific wage rates, w_c . To characterize welfare in the open economy equilibrium, we therefore compute the equilibrium levels of w_1 , w_2 , and $p_1 \equiv p(S_1)$, which are jointly determined by the three-equation system:

$$\begin{aligned} p_1 &= \{\exp[\lambda_1 S_1] - 1\} \frac{w_1}{\lambda_1}, \\ 1 &= \exp[\lambda_2(1 - S_1)] p_1 + \{\exp[\lambda_2(1 - S_1)] - 1\} \frac{w_2}{\lambda_2}, \\ w_2 &= w_1 + p_1(\lambda_1 - \lambda_2). \end{aligned} \tag{7}$$

Whereas the derivation of (7) is tedious and thus deferred to the Appendix, the three equations have a straightforward economic interpretation. Making use of Lemma 1, we find that the first line corresponds to the binding budget constraint of country 1, while the second line corresponds to the binding budget constraint of country 2. The third line captures a no arbitrage condition under the profit-maximizing choice of executing stages $s \in (0, S_1]$ in country 1 and executing stages $s \in (S_1, 1]$ in country 2. Equation system (7) can be solved for

$$w_1 = \frac{(\hat{Q}_0 - \lambda_1 L)(\hat{Q}_0 - (\lambda_1 + \lambda_2)L)}{L(2\hat{Q}_0 - (\lambda_1 + \lambda_2)L)}, \quad w_2 = \frac{(\hat{Q}_0 - \lambda_2 L)(\hat{Q}_0 - (\lambda_1 + \lambda_2)L)}{L(2\hat{Q}_0 - (\lambda_1 + \lambda_2)L)}, \tag{8}$$

and

$$p_1 = \frac{\hat{Q}_0 - (\lambda_1 + \lambda_2)L}{2\hat{Q}_0 - (\lambda_1 + \lambda_2)L}. \tag{9}$$

It is easily confirmed from Eq. (8) that $w_1 = w_2$ if $\lambda_1 = \lambda_2$, whereas $w_1 < w_2$ whenever $\lambda_1 > \lambda_2$. This gives the intuitive result that the technologically advanced North pays higher wages than the technologically backward South. The following proposition summarizes how changes in λ_c affect welfare in the two economies.

Proposition 2 *Technological progress in the South, captured by a decrease in λ_1 , increases Southern welfare and decreases Northern welfare. Technological progress in the North, captured by a decrease in λ_2 , increases welfare in both countries.*

Proof See the Appendix.

As pointed out above, technological progress in the South increases labor demand in country 1, *ceteris paribus*. This increases Southern wages and thus Southern welfare. There are two effects on labor demand in the North, due to an induced increase in the length of the Southern value chain S_1 and an induced reduction in the quantity of initial input \hat{Q}_0 . Since both effects go into the same direction, labor demand in the North unambiguously falls along with wages and welfare, so that Northern workers lose in relative and absolute terms. Things are different if the technological progress occurs in the North. In this

case, Northern labor demand increases along with wages and welfare. In the South, there are now two counteracting effects on labor demand. Whereas the induced reduction in the quantity of initial input \hat{Q}_0 lowers Southern labor demand, the induced increase in the length of the Southern value chain increases Southern labor demand, with the overall effect being positive. This implies that the South benefits from technological progress in the North. We can describe the welfare effects in alternative terms when noting that price p_1 increases with technological progress in either economy. This implies that the terms of trade always improve for the South, the exporter of intermediates, which is sufficient for positive welfare effects there. In contrast, with both forms of technological progress the terms of trade deteriorate for the North, the exporter of the consumption good. Only if there is technological progress in the North, the negative welfare effects from the terms-of-trade deterioration are counteracted and dominated by an increase in labor productivity.

4 The open economy with policy distortions

We now consider an open economy equilibrium with policy distortions. We distinguish two policy instruments, namely an import tariff and institutional quality to prohibit expropriation of producers by workers. Due to the vertical production structure and the order of countries along the global value chain, the import tariff is only a meaningful instrument for country 2, but not for country 1.⁵ We denote the (ad-valorem) import tariff of country 2 by $\tau \geq 1$. Whereas lacking access to a tariff instrument, the South can engage in rent appropriation by allowing for institutional deficiencies. We assume that this instrument is unavailable for the North (where institutional quality is usually considered to be high). We capture the institutional instrument by a parameter $\delta \in [0, 1]$, which measures the fraction of production output Q_1 that is actually shipped to the North for further processing. The residual fraction $1 - \delta$ of this output is consumed by Southern workers at a utility discount of $\rho(S_1) < 1$. In this section, we take the two policy instruments as given and characterize the open economy equilibrium for the more general case of $\tau \geq 1$ and $\delta \leq 1$. We postpone a discussion of non-cooperative policy setting by the South and the North to Section 5.

Following the analysis from Section 3, we compute

$$S_1 = 0 - \frac{1}{\lambda_1} \ln \left(1 - \frac{\lambda_1 L}{Q_0} \right), \quad 1 = S_1 - \frac{1}{\lambda_2} \ln \left(1 - \frac{\lambda_2 L}{\delta Q_1} \right), \quad (4')$$

and

$$1 = -\frac{1}{\lambda_1} \ln \left(1 - \frac{\lambda_1 L}{Q_0} \right) - \frac{1}{\lambda_2} \ln \left(1 - \frac{\lambda_2 L}{\delta(Q_0 - \lambda_1 L)} \right) \equiv \tilde{F}(Q_0, \delta). \quad (6')$$

instead of Eqs. (4) and (6), respectively. Eq. (6') has a unique solution in Q_0 , which we denote by \tilde{Q}_0 .

⁵An import tariff of country 1 would increase the costs of the consumer good but at the same time provide the consumers with the additional means necessary to bear the higher consumption expenditures when redistributing tariff revenues in a lump-sum fashion.

Proposition 3 summarizes the influence of policy parameters on the equilibrium production structure.

Proposition 3 *An increase in the Northern import tariff τ does not change the production structure in the open economy equilibrium. An improvement of institutional quality in the South, i.e. an increase in δ , lowers the initial input \tilde{Q}_0 and increases the length of the Southern value chain S_1 . For the case of minimum institutional quality, we compute $\lim_{\delta \rightarrow 0} \tilde{Q}_0 = \infty$ and $\lim_{\delta \rightarrow 0} S_1 = 0$. In the polar case of $\delta = 1$, the production structure in the open economy is given by Lemma 1.*

Proof From Eqs. (4') and (6'), we directly observe that $d\tilde{Q}_0/d\tau = dS_1/d\tau = 0$. Moreover, we compute $d\tilde{Q}_0/d\delta < 0$, which, in view of $dS_1/dQ_0 < 0$, establishes $dS_1/d\delta > 0$. Moreover, for $\lim_{\delta \rightarrow 0} \tilde{F}(\tilde{Q}_0, \delta)$ to have a finite value equal to one $\lim_{\delta \rightarrow 0} \tilde{Q}_0 = \infty$ and thus $\lim_{\delta \rightarrow 0} S_1 = 0$ must hold. Finally, the equivalence of Eqs. (4') and (6') with Eqs. (4) and (6) in the case of $\delta = 1$ is immediate. This completes the proof.

It is an important insight from Proposition 3 and obvious from an inspection of Eqs. (4') and (6') that higher import tariffs of the North do not influence the production structure in the open economy equilibrium. This is, because the production structure in our model is pinned down by the labor market clearing conditions of the two countries. Hence, there is no scope of trade policy in the North to influence the labor allocation in the open economy. Things are different for the institutional quality in the South. A lower level of δ reduces the fraction of Southern production output shipped to the North and thus, all other things equal, labor demand in the North. Restoring labor market clearing therefore requires a higher initial input \tilde{Q}_0 , which in turn is only consistent with labor market clearing in the South if S_1 declines.

To determine the welfare effects of changes in our two policy variables, we first derive an equation system similar to (7). As formally shown in the Appendix, for arbitrary levels of δ and τ this system changes to

$$\begin{aligned} \delta \tilde{p}_1 &= \{\exp[\lambda_1 S_1] - 1\} \frac{w_1}{\lambda_1} \\ 1 &= \exp[\lambda_2(1 - S_1)] \tau \tilde{p}_1 + \{\exp[\lambda_2(1 - S_1)] - 1\} \frac{w_2}{\lambda_2} \\ \delta w_2 &= \tau w_1 + \tau \delta \tilde{p}_1 (\lambda_1 - \lambda_2) \end{aligned} \tag{7'}$$

where \tilde{p}_1 is the free-on-board price per unit of output *shipped* in country 1. Since only a fraction δ of country 1's output is exported the price per unit of output produced is equal to $p_1(S_1) = \delta \tilde{p}_1$. Moreover, the tariff-inclusive price of the imports from country 1 for a firm producing in country 2 equals $p_2(S_1) = \tau \tilde{p}_1$. These changes imposed by our policy variables aside, the economic interpretations of the three equations in (7') remain unchanged. The first two lines capture the balanced budget constraints of the two economies, whereas the third line refers to a no arbitrage condition that must hold under a profit-maximizing production structure.

Equation system (7') can then be solved for the open economy equilibrium wages and prices. This

gives

$$\begin{aligned} w_1 &= \frac{1}{\tau} \frac{\delta(\tilde{Q}_0 - \lambda_1 L)}{L} \frac{\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L}{\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} \equiv \tilde{w}_1(\tau, \delta), \\ w_2 &= \frac{\tilde{Q}_0 - \lambda_2 L}{L} \frac{\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L}{\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} \equiv \tilde{w}_2(\delta), \end{aligned} \quad (8')$$

and

$$\tilde{p}_1 = \frac{1}{\tau} \frac{\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L}{\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} \equiv \tilde{p}_1(\tau, \delta), \quad (9')$$

respectively. The following lemma summarizes how changes in the two policy variables τ and δ affect wages and prices in the open economy equilibrium.

Lemma 2 *An increase in the Northern import tariff lowers South's wage rate w_1 and export price \tilde{p}_1 , while it leaves North's wage rate w_2 and import price $\tau\tilde{p}_1$ unaffected. A decline in Southern institutional quality decreases both wage rates as well as the import and the export price of the intermediate good shipped from the South to the North.*

Proof See the Appendix.

Lemma 2 highlights the differential impact of the two policy instruments. Whereas an increase in the Northern import tariff redistributes rents from the South to the North it leaves the market outcome and thus wages and import prices of the North unaffected. Things are different for changes in the institutional quality of the South. A decrease of δ redistributes rents from the North to the South, while it also lowers market efficiency. It is this negative efficiency effect that leads to a reduction of both wage rates and to a simultaneous decline in the export and import price of the intermediate good shipped to the North.

Of course, the wage and price effects in Lemma 2 give an incomplete picture of the total welfare effects of changes in the two policy instruments. To conduct the welfare analysis, we can first note that similar to the baseline model in Section 3, consumers spend their entire income on the single consumption good. However, if $\delta < 1$ inhabitants of country 1 gain additional welfare from consuming a fraction $(1 - \delta)$ of the intermediate good Q_1 . Assuming that consumption of unfinished goods gives a utility discount of $\rho(S_1) < 1$, we can write Southern welfare as $V_1 = w_1 L_1 + (1 - \delta)\rho(S_1)Q_1$. Considering the specific functional form of $\rho(S_1) \equiv \{\exp[\lambda_1 S_1] - 1\} / \{\exp[\lambda_1] - 1\}$ gives a particularly tractable welfare function for the South:

$$V_1 = \frac{1}{\tau} \frac{\delta(\tilde{Q}_0 - \lambda_1 L)[\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L]}{\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} + \frac{(1 - \delta)\lambda_1 L}{\exp[\lambda_1] - 1} \equiv \tilde{V}_1(\tau, \delta). \quad (10)$$

Northern welfare is increased if $\tau > 1$, because, when lump-sum redistributed, the tariff revenues are

spent as well for the consumption level of good Q_2 . We get $V_2 = w_2L + (\tau - 1)\tilde{p}_1\delta Q_1$, or

$$V_2 = \frac{(\tilde{Q}_0 - \lambda_2 L)[\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L]}{\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} + \frac{\tau - 1}{\tau} \frac{\delta(\tilde{Q}_0 - \lambda_1 L)[\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L]}{\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} \equiv \tilde{V}_2(\tau, \delta). \quad (11)$$

The following proposition summarizes how changes in the two policy variables affect welfare in the open economy.

Proposition 4 *An increase in the Northern import tariff increases welfare in the North and reduces welfare in the South. A decline in Southern institutional quality lowers welfare in the North, whereas the welfare effects in the South depend on the Northern import tariff and are not a priori clear. There exists a critical $\bar{\tau} \equiv \frac{\exp[\lambda_1] - 1}{\exp[\lambda_2] - 1} \frac{\lambda_2}{\lambda_1} > 1$, such that Southern welfare decreases monotonically in institutional quality δ if $\tau \geq \bar{\tau}$. There exists a second critical $\underline{\tau} \in \{\tau \geq 1 : \partial \tilde{V}_1(\tau, 1)/\partial \delta < 0\}$ lower than $\bar{\tau}$, such that Southern welfare has a unique interior maximum at some $\delta \in (0, 1)$ if $\tau \in (\underline{\tau}, \bar{\tau})$.*

Proof See the Appendix.

The welfare effects in Proposition 4 provide useful insights for studying non-cooperative policy setting in the next section.

5 Non-cooperative trade and institutional policies

Having characterized the impact of Northern import tariffs and Southern institutional quality on the model's open economy equilibrium, we now analyze the policy choices of the governments in South and North that maximize their respective economy-wide welfare levels in Eqs. (10) and (11). The following proposition summarizes the non-cooperative equilibrium if the two governments are unconstrained in setting their policy instruments.

Proposition 5 *It is a dominant strategy of the North to set the maximum possible tariff rate. If the government is unconstrained, this establishes $\tau = \infty$. The optimal response of the South to $\tau = \infty$ is setting $\delta = 0$. Hence, the non-cooperative policy equilibrium of unconstrained governments is given by $\delta = 0$ and $\tau = \infty$, establishing*

$$\lim_{\tau \rightarrow \infty} V_1(\tau, 0) = \frac{\lambda_1 L}{\exp[\lambda_1] - 1} \equiv V_1^{nc}, \quad \lim_{\tau \rightarrow \infty} V_2(\tau, 0) = \frac{\lambda_2 L}{\exp[\lambda_2] - 1} \equiv V_2^{nc} \quad (12)$$

Proof The proposition follows from Proposition 4 and Eqs. (10), (11).

Non-cooperative policies of unconstrained governments establish an outcome with $\lim_{\delta \rightarrow 0} S_1 = 0$, implying that country 2 hosts the entire global value chain. As a consequence, the non-cooperative policies in Proposition 5 put the North into an autarky equilibrium. This is intuitive, because the North sets a

prohibitive import tariff, and it implies that $V_2^{nc} = V_2^a$, with superscript a referring to autarky. With its wages going to zero, the South cannot afford the final output produced by the North and is compelled to consume the initial input \tilde{Q}_0 , which gives a maximum utility discount but is in unlimited availability at a price of zero. Due to the chosen functional form of the discount factor $\rho(S_1)$, our model has the nice property that welfare in the South also converges to the autarky level if δ goes to zero, establishing $V_1^{nc} = V_1^a$.

An immediate question regarding the non-cooperative policy outcome is whether cooperation gains can be achieved simultaneously for both countries. To tackle this question, we contrast the non-cooperative welfare levels in Proposition 5 with the welfare levels that could be achieved if the two countries coordinate on free trade with perfect institutional quality, $\delta = \tau = 1$. The results from this comparison are summarized in Proposition 6.

Proposition 6 *Policy coordination on $\tau = \delta = 1$ increases welfare in both countries relative to the non-cooperative case in Proposition 5.*

Proof We first note that setting $\lambda_1 = \lambda_2 \equiv \lambda$, we compute $\hat{Q}_0 = 2\lambda L \exp[\lambda] / \{\exp[\lambda] - 1\}$. In this case, we have $\tilde{V}_1(1, 1) = \tilde{w}_1(1, 1) = \lambda L / \{\exp[\lambda] - 1\}$ and thus $\tilde{V}_1(1, 1) = V_1^{nc}$. Noting $dw_1/d\lambda_2 < 0$ from Proposition 2 then establishes $V_1(1, 1) > V_1^{nc}$ for all $\lambda_2 < \lambda_1$. In a similar vein, we can note that setting $\lambda_1 = \lambda_2 \equiv \lambda$ gives $\tilde{V}_2(1, 1) = \tilde{w}_2(1, 1) = \lambda L / \{\exp[\lambda] - 1\}$ and thus $\tilde{V}_2(1, 1) = V_2^{nc}$. Then, noting from Proposition 2 that $dw_2/d\lambda_1 > 0$, it follows that $V_2(1, 1) > V_2^{nc}$ holds for all $\lambda_1 < \lambda_2$. This completes the proof.

Propositions 5 and 6 provide an important insight. In a trade model featuring vertical specialization of two countries along the global value chain, with intermediate goods produced in the South exchanged against the consumption good produced in the North, a trade agreement can be beneficial for both countries only if it conditions the tariff reduction of the North on improvements of institutional quality in the South. The expansion of offshoring and intermediate goods imports from the South may therefore provide an explanation for the increasing importance of arbitration clauses in recent trade investment agreements as an attempt to enforce better institutional quality in countries executing comparably early changes of the value chain.⁶

Of course, the results from Propositions 5 and 6 should not be seen as an argument that conditioning tariff reductions on improvements of institutional quality in the South can always secure the implementation of a mutually beneficial trade agreement. Whereas the analysis above considers the case of unconstrained governments, the possibility of countries to impose high tariffs is strongly constrained by WTO rules, rendering an import tariff of $\tau = \infty$ an unrealistic outcome. We therefore ask in a final step, how the analysis from above has to be adjusted if we consider a tariff policy of the North that is constrained by $\tau \leq \tau_{max}$. The following proposition summarizes our results.

⁶As pointed out by Kohler and Stähler (2019), agreements on investor-state dispute settlement mechanisms are common practice in international investment agreements (see OECD, 2012). In recent years, arbitration clauses have become strongly disputed in the negotiation of new preferential trade agreements, with the Transatlantic Trade and Investment Partnership being a prominent example for this.

Proposition 7 *In the non-cooperative case, the North sets $\tau = \tau_{max}$, whereas the optimal response of the South to this tariff depends on the level of τ_{max} . If $\tau_{max} \geq \bar{\tau}$, the South sets $\delta = 0$ and the results from Propositions 5 and 6 therefore carry over to the case of a high upper tariff bound. In contrast, if $\tau_{max} < \bar{\tau}$ the South chooses $\delta > 0$ in a non-cooperative environment and in this case cooperation needs not be beneficial for both countries.*

Proof See the Appendix.

According to Proposition 7, an initially low tariff τ_{max} makes coordination on $\tau = \delta = 1$ less likely to be beneficial for both countries. To be more specific, we show in the Appendix that if the technology advantage of the North is small, the South maximizes its welfare by unilaterally setting $\delta = 1$ and thereby implementing the highest possible institutional quality if τ_{max} is close to one. In this case, the North has no incentive to agree on tariff reductions, as this would mean to forgo the associated tariff revenues. Since the production structure is efficient if $\delta = 1$ there is also no scope to simultaneously increase welfare in both countries by complementing further tariff reductions with side-payments of the South. In this case, trade agreements cannot be expected to be implemented by the two economies.

6 Conclusions

This paper sets up a trade model with vertical specialization of two countries along the global value chain. We show that in the open economy equilibrium, the global value chain is partitioned into two subintervals, with a technologically backward South specializing on early production stages and a technologically advanced North executing the later ones. As a consequence of the vertical specialization of countries, the South exports intermediates in exchange for the import of a homogeneous consumption good from the North. In the open economy, the Northern country can use an import tariff to appropriate rents from the South. The import tariff lowers the wage received by Southern workers, but it does not change the equilibrium production structure and leaves the partitioning of the global value chain between the two trading partners unchanged. As a consequence, Northern welfare increases and Southern welfare decreases with a higher import tariff.

Due to the vertical structure of trade in our model, the South cannot appropriate rents from the North by imposing an import tariff itself. However, it can lower the institutional quality and allow for partial expropriation of firms by domestic workers. The expropriation is modeled as an upfront consumption of intermediates at a utility discount. A lower institutional quality lowers welfare of the North and it may increase or decrease welfare in the South. Both countries lose if the efficiency loss from expropriation is sufficiently high. The efficiency loss from lower institutional quality in the South is reflected in our model by a shortening of the Southern and an expansion of the Northern value chain. In a non-cooperative policy game, the North will choose a prohibitive tariff and the South will choose the minimum institutional quality if government policy is unconstrained. This reduces welfare of both countries to their respective autarky levels. In this case, an agreement of the two countries that implements free trade and high

institutional quality in the South is beneficial for both economies. If the maximum tariff of the North is constrained by an upper bound, a trade agreement may not be successfully implemented. In particular, if the upper bound for the tariff is low, it may be in the self-interest of the South to choose the maximum possible level of institutional quality without cooperation. In this case, the South has nothing to offer to make further tariff reductions attractive for the North.

References

- ALFARO, L., P. ANTRÀS, D. CHOR, AND P. CONCONI (2019): “Internalizing Global Value Chains: A Firm-Level Analysis,” *Journal of Political Economy*, 127, 508–559.
- ANTRÀS, P. AND D. CHOR (2013): “Organizing the Global Value Chain,” *Econometrica*, 81, 2127–2204.
- ANTRÀS, P. AND A. DE GORTARI (2020): “On the Geography of Global Value Chains,” *Econometrica*, 88, 1553–1598.
- BAGWELL, K. AND R. W. STAIGER (1997): “Multilateral Tariff Cooperation during the Formation of Customs Unions,” *Journal of International Economics*, 42, 91–123.
- (1999): “An Economic Theory of GATT,” *American Economic Review*, 89, 215–248.
- BALDWIN, R. AND A. J. VENABLES (2013): “Spiders and Snakes: Offshoring and Agglomeration in the Global Economy,” *Journal of International Economics*, 90, 245–254.
- BLANCHARD, E. J. (2010): “Reevaluating the Role of Trade Agreements: Does Investment Globalization Make the WTO Obsolete?” *Journal of International Economics*, 82, 63–72.
- (2017): “Renegotiating NAFTA: The Role of Global Supply Chains,” in *Economics and Policy in the Age of Trump*, CEPR Press, 175–183.
- BLANCHARD, E. J., C. P. BOWN, AND R. C. JOHNSON (2017): “Global Value Chains and Trade Policy,” *Working Paper*.
- CAMPOLMO, A., H. FADINGER, AND C. FORLATTI (2014): “Trade Policy: Home Market Effect versus Terms-of-Trade Externality,” *Journal of International Economics*, 93, 92–107.
- COSTINOT, A., A. RODRÍGUEZ-CLARE, AND I. WERNING (2020): “Micro to Macro: Optimal Trade Policy with Firm Heterogeneity,” *Econometrica*, forthcoming.
- COSTINOT, A., J. VOGEL, AND S. WANG (2013): “An Elementary Theory of Global Supply Chains,” *Review of Economic Studies*, 80, 109–144.
- DIXIT, A. (1987): “Strategic Aspects of Trade Policy,” in *Advances in Economic Theory: Fifth World Congress*, ed. by T. F. Bewley, Cambridge: Cambridge University Press, 329–362.
- GROSSMAN, G. M. AND E. ROSSI-HANSBERG (2008): “Trading Tasks: A Simple Theory of Offshoring,” *American Economic Review*, 98, 1978–1997.
- HARMS, P., O. LORZ, AND D. URBAN (2012): “Offshoring along the Production Chain,” *Canadian Journal of Economics*, 45, 93–106.

- HUMMELS, D., J. ISHII, AND K.-M. YI (2001): “The Nature and Growth of Vertical Specialization in World Trade,” *Journal of International Economics*, 54, 75–96.
- JOHNSON, H. G. (1953): “Optimum Tariffs and Retaliation,” *Review of Economic Studies*, 21, 142–153.
- JOHNSON, R. C. (2018): “Measuring Global Value Chains,” *Annual Review of Economics*, 10.
- JOHNSON, R. C. AND G. NOGUERA (2017): “A Portrait of Trade in Value-Added over Four Decades,” *Review of Economics and Statistics*, 99, 896–911.
- KOHLER, W. (2004): “International Outsourcing and Factor Prices with Multistage Production,” *The Economic Journal*, 114, 166–185.
- KOHLER, W. AND F. STÄHLER (2019): “The Economics of Investor Protection: ISDS versus National Treatment,” *Journal of International Economics*, 121, 103254.
- LEVCHENKO, A. A. (2007): “Institutional Quality and International Trade,” *Review of Economic Studies*, 74, 791–819.
- (2013): “International Trade and Institutional Change,” *The Journal of Law, Economics, & Organization*, 29, 1145–1181.
- NUNN, N. (2007): “Relationship-Specificity, Incomplete Contracts, and the Pattern of Trade,” *The Quarterly Journal of Economics*, 122, 569–600.
- OECD (2012): “Investor-State Dispute Settlement,” *Public Consultation: 16 May - 9 July 2012, Paris*.
- ORNELAS, E. AND J. L. TURNER (2012): “Protection and International Sourcing,” *The Economic Journal*, 122, 26–63.
- OSSA, R. (2011): “A New Trade Theory of GATT/WTO Negotiations,” *Journal of Political Economy*, 119, 122–152.
- STEFANADIS, C. (2010): “Appropriation, Property Rights Institutions, and International Trade,” *American Economic Journal: Economic Policy*, 2, 148–72.
- YI, K.-M. (2003): “Can Vertical Specialization Explain the Growth of World Trade?” *Journal of Political Economy*, 111, 52–102.

A Appendix

A.1 Proof of Proposition 1

We first show that $d\hat{Q}_0/d\lambda_c > 0$. Applying the implicit function theorem to Eq. (6) we compute

$$dF(\cdot) = \frac{\partial F(\cdot)}{\partial \hat{Q}_0} d\hat{Q}_0 + \frac{\partial F(\cdot)}{\partial \lambda_c} d\lambda_c = 0 \quad (\text{A.1})$$

Moreover, we compute $\partial F(\hat{Q}_0)/\partial \lambda_1 = \lambda_1^{-2} f(\lambda_1)$, with

$$f(\lambda_1) \equiv \frac{\lambda_1 L (\hat{Q}_0 - \lambda_2 L)}{(\hat{Q}_0 - \lambda_1 L)(\hat{Q}_0 - \lambda_1 L - \lambda_2 L)} + \ln \left(\frac{\hat{Q}_0 - \lambda_1 L}{\hat{Q}_0} \right),$$

$$f'(\lambda_1) = \frac{\lambda_1 L^2}{(\hat{Q}_0 - \lambda_1 L)(\hat{Q}_0 - \lambda_1 L - \lambda_2 L)} + \frac{L(\hat{Q}_0 - \lambda_2 L)[2(\hat{Q}_0 - \lambda_1 L) - \lambda_2 L]}{(\hat{Q}_0 - \lambda_1 L)^2(\hat{Q}_0 - \lambda_1 L - \lambda_2 L)^2} > 0.$$

Then, noting $f(0) = 0$, it follows that $f(\lambda_1) > 0$ and thus $\partial F(\hat{Q}_0)/\partial \lambda_1 > 0$ holds for all $\lambda_1 > \lambda_2$. Substitution into Eq. (A.1) then establishes $d\hat{Q}_0/\lambda_1 > 0$. In a similar way, we compute $\partial F(\hat{Q}_0)/\partial \lambda_2 = \lambda_2^{-2} \tilde{f}(\lambda_2)$, with

$$\tilde{f}(\lambda_2) = \frac{\lambda_2 L}{\hat{Q}_0 - \lambda_1 L - \lambda_2 L} + \ln \left(1 - \frac{\lambda_2 L}{\hat{Q}_0 - \lambda_1 L} \right), \quad \tilde{f}'(\lambda_2) = \frac{L^2}{(\hat{Q}_0 - \lambda_1 L - \lambda_2 L)^2} > 0.$$

From $\tilde{f}(0) = 0$, it follows that $\tilde{f}(\lambda_2) > 0$ and thus $\partial F(\hat{Q}_0)/\partial \lambda_2 > 0$ holds for all $\lambda_2 \in (0, \lambda_1)$. Substitution into Eq. (A.1) then establishes $d\hat{Q}_0/\lambda_1 > 0$.

We next show $dS_1/d\lambda_c < 0$. Differentiating $S_1 = -\frac{1}{\lambda_1} \ln \left(1 - \frac{\lambda_1 L}{\hat{Q}_0} \right)$ with respect to λ_2 gives

$$\frac{dS_1}{d\lambda_2} = -\frac{L}{\hat{Q}_0} \frac{1}{\hat{Q}_0 - \lambda_1 L} \frac{d\hat{Q}_0}{d\lambda_2} < 0.$$

Furthermore, differentiating S_1 with respect to λ_1 establishes

$$\frac{dS_1}{d\lambda_1} = \frac{1}{\lambda_1^2} \left[\frac{\lambda_1 L}{\hat{Q}_0 - \lambda_1 L} + \ln \left(\frac{\hat{Q}_0 - \lambda_1 L}{\hat{Q}_0} \right) \right] - \frac{L}{\hat{Q}_0} \frac{1}{\hat{Q}_0 - \lambda_1 L} \frac{d\hat{Q}_0}{d\lambda_1}.$$

Substituting

$$\frac{d\hat{Q}_0}{d\lambda_1} = -\frac{\partial F/\partial \lambda_1}{\partial F/\partial \hat{Q}_0} = \frac{f(\lambda_1)}{\lambda_1^2} \frac{\hat{Q}_0(\hat{Q}_0 - \lambda_1 L)}{L} \frac{\hat{Q}_0 - \lambda_1 L - \lambda_2 L}{2\hat{Q}_0 - \lambda_1 L - \lambda_2 L},$$

we obtain

$$\frac{dS_1}{d\lambda_1} = \frac{1}{\lambda_1^2} \left[\frac{\lambda_1 L}{2\hat{Q}_0 - \lambda_1 L - \lambda_2 L} + \frac{\hat{Q}_0}{2\hat{Q}_0 - \lambda_1 L - \lambda_2 L} \ln \left(\frac{\hat{Q}_0 - \lambda_1 L}{\hat{Q}_0} \right) \right].$$

Rearranging terms, we finally arrive at

$$\frac{dS_1}{d\lambda_1} = \frac{1}{\lambda_1^2} \frac{\lambda_1 L}{2\hat{Q}_0 - \lambda_1 L - \lambda L_2} \left(1 - \frac{\hat{Q}_0}{L} S_1 \right).$$

Partially differentiating S_1 for λ_1 , holding \hat{Q}_0 constant, we compute

$$\frac{\partial S_1}{\partial \lambda_1} = \frac{1}{\lambda_1^2} \left[\frac{\lambda_1 L}{\hat{Q}_0 - \lambda_1 L} + \ln \left(1 - \frac{\lambda_1 L}{\hat{Q}_0} \right) \right] > 0$$

From $\lim_{\lambda_1 \rightarrow 0} S(\lambda_1, \hat{Q}_0) = L(\hat{Q}_0 - \lambda_1 L)^{-1}$, we can therefore conclude that $\hat{Q}_0 S_1 / L > 1$ holds for all $\lambda_1 > 0$, implying that $dS_1/d\lambda_1 < 0$. This completes the proof.

A.2 Derivation of equation system (7)

From Eq. (2), we know that $[p(s+ds) - p(s)]/ds = [p(s)\lambda_c + w_c]/(1 - \lambda_c ds)$ holds whenever $Q_c(s') > 0$ for all $s' \in (s, s+ds]$. Taking the limit of $ds \rightarrow 0$ gives the differential equation $p'(s) = p(s)\lambda_c + w_c$. We can now solve this differential equation for the general solution $p(s) = -w_c/\lambda_c + B_c \exp[\lambda_c s]$. Making use of the equilibrium production structure from Lemma 1, we compute $p(0) = -w_1/\lambda_1 + B_1 = 0$ and thus $B_1 = w_1/\lambda_1$. This establishes $p(s) = \{\exp[\lambda_1 s] - 1\}w_1/\lambda_1$ for all $s \in (0, S_1]$ and thus the first line in system (7) when setting $s = S_1$ and $p(S_1) = p_1$. Moreover, evaluating $p(s) = -w_2/\lambda_2 + B_2 \exp[\lambda_2 s]$ at $s = S_1$, we compute $B_2 = [p_1 + w_2/\lambda_2] \exp[-\lambda_2 S_1]$, which establishes $p(s) = p_1 \exp[\lambda_2(s - S_1)] + (w_2/\lambda_2)\{\exp[\lambda_2(s - S_1)] - 1\}$, which evaluated at $s = 1$ and setting $p(1) = 1$ gives the second line of equation system (7).

In a final step, we acknowledge that a profit-maximizing choice of executing stages $s > S_1$ in country 2 and executing stages $s < S_1$ in country 1 requires

$$\begin{aligned} p(S_1 + ds) - \frac{p(S_1) + w_2 ds}{1 - \lambda_2 ds} &\geq p(S_1 + ds) - \frac{p(S_1) + w_1 ds}{1 - \lambda_1 ds}, \\ p(S_1) - \frac{p(S_1 - ds) + w_1 ds}{1 - \lambda_1 ds} &\geq p(S_1) - \frac{p(S_1 - ds) + w_2 ds}{1 - \lambda_2 ds} \end{aligned}$$

to simultaneously hold according to Eq. (2). Making use of standard mathematical manipulation and setting $p(S_1) = p_1$, we can reformulate the two conditions for the limiting case of $ds \rightarrow 0$

$$p_1(\lambda_1 - \lambda_2) \geq w_2 - w_1, \quad w_2 - w_1 \geq p_1(\lambda_1 - \lambda_2),$$

which jointly establish the third line of equation system (7). This completes the proof.

A.3 Proof of Proposition 2

We start by showing that an increase in λ_1 decreases w_1 and increases w_2 . Let us rewrite Eq. (6) as an implicit function of the form

$$\hat{F}(x, \Lambda) \equiv -\Lambda \ln \left(\frac{x-1}{x} \right) - \ln \left(\frac{x-1-\Lambda}{x-1} \right) - \lambda_2 = 0, \quad (\text{A.2})$$

with $\Lambda \equiv \lambda_2/\lambda_1 \in (0, 1)$ and $x \equiv \hat{Q}_0/(\lambda_1 L) > 1 + \Lambda$. Partial differentiation w.r.t. x and λ_1 yields

$$\frac{\partial \hat{F}}{\partial x} = -\frac{\Lambda}{x} \frac{2x - 1 - \Lambda}{(x - 1)(x - 1 - \Lambda)}, \quad \frac{\partial \hat{F}}{\partial \Lambda} \frac{d\Lambda}{d\lambda_1} = \left[\ln \left(\frac{x - 1}{x} \right) - \frac{1}{x - 1 - \Lambda} \right] \frac{\Lambda}{\lambda_1}$$

Applying the implicit function theorem to $\hat{F}(x, \Lambda) = 0$ then gives

$$\frac{dx}{d\lambda_1} = -\frac{x}{\lambda_1} \frac{(x - 1) \{1 - (x - 1 - \Lambda) \ln[(x - 1)/x]\}}{2x - 1 - \Lambda} < 0 \quad (\text{A.3})$$

We can also employ variables x and Λ to write wages w_1 and w_2 as follows

$$w_1 = \lambda_1 \frac{(x - 1)(x - 1 - \Lambda)}{2x - 1 - \Lambda}, \quad \text{and} \quad w_2 = \lambda_1 \frac{(x - \Lambda)(x - 1 - \Lambda)}{2x - 1 - \Lambda}. \quad (\text{A.4})$$

Before turning to formal derivation details, we document two auxiliary results that are used later on.

A1. The Mercator series establishes for all $-1 < y \leq 1$: $\ln(1 + y) = y - \frac{y^2}{2} + \frac{y^3}{3} - \frac{y^4}{4} \dots$ or, equivalently,

$$\ln(1 + y) = \sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{n} y^n. \quad \text{Setting } y = -1/x \text{ (and acknowledging } x > 1 + \Lambda), \text{ this implies}$$

$$-\ln \left(\frac{x - 1}{x} \right) > \frac{1}{x}, \quad \implies \quad 1 + x \ln \left(\frac{x - 1}{x} \right) < 0.$$

A2. Using the solution for w_1 in $dx/d\lambda_1$, we get

$$\frac{dx}{d\lambda_1} = -\frac{x}{\lambda_1} \frac{w_1}{\lambda_1} \frac{1 - (x - 1 - \Lambda) \ln[(x - 1)/x]}{x - 1 - \Lambda}$$

With the insights at hand, we can now continue with determining the effect of an increase in λ_1 on w_1 . Totally differentiating w_1 yields

$$\frac{dw_1}{d\lambda_1} = \frac{\partial w_1}{\partial x} \frac{dx}{d\lambda_1} + \frac{\partial w_1}{\partial \Lambda} \frac{d\Lambda}{d\lambda_1} + \frac{\partial w_1}{\partial \lambda_1}. \quad (\text{A.5})$$

We further compute

$$\frac{\partial w_1}{\partial \Lambda} = -\frac{w_1}{\Lambda} \frac{x\Lambda}{(2x - 1 - \Lambda)(x - 1 - \Lambda)}$$

and thus

$$\frac{\partial w_1}{\partial \Lambda} \frac{d\Lambda}{d\lambda_1} + \frac{\partial w_1}{\partial \lambda_1} = \frac{w_1}{\lambda_1} \frac{(2x - 1)(x - 1 - \Lambda) + \Lambda(1 + \Lambda)}{(2x - 1 - \Lambda)(x - 1 - \Lambda)}.$$

Moreover, we compute

$$\frac{\partial w_1}{\partial x} = \lambda_1 \frac{2x(x - \Lambda - 1) + \Lambda(1 + \Lambda)}{(2x - 1 - \Lambda)^2}$$

and thus

$$\frac{\partial w_1}{\partial x} \frac{dx}{d\lambda_1} = -\frac{w_1}{\lambda_1} \frac{2x^2(x-1-\Lambda) + x\Lambda(1+\Lambda)}{(2x-1-\Lambda)^2(x-1-\Lambda)} \left[1 - (x-1-\Lambda) \ln \left(\frac{x-1}{x} \right) \right].$$

Substituting into $dw_1/d\lambda_1$, we obtain

$$\frac{dw_1}{d\lambda_1} = -\frac{w_1}{\lambda_1} \frac{F_1(\Lambda)}{(2x-1-\Lambda)^2},$$

with

$$F_1(\Lambda) \equiv (2x-1-\Lambda) - [2x(x-1-\Lambda) + \Lambda(1+\Lambda)] \left[1 + x \ln \left(\frac{x-1}{x} \right) \right].$$

From A1, we know that $1 + x \ln[(x-1)/x] < 0$, implying that $F_1(\Lambda) > 0$ and $dw_1/d\lambda_1 < 0$.

We next determine the impact of an increase in λ_1 on w_2 . For this purpose, we write $w_2 = w_1[(x-\Lambda)/(x-1)]$ and compute

$$\begin{aligned} \frac{dw_2}{d\lambda_1} &= \frac{x-\Lambda}{x-1} \frac{dw_1}{d\lambda_1} - \frac{(1-\Lambda)w_1}{(x-1)^2} \frac{dx}{d\lambda_1} + \frac{w_1}{x-1} \frac{\Lambda}{\lambda_1} \\ &= -\frac{w_1}{\lambda_1(x-1)} \left\{ \frac{(x-\Lambda)F_1(\Lambda)}{(2x-1-\Lambda)^2} - \frac{(1-\Lambda)x}{2x-1-\Lambda} \left[1 - (x-1-\Lambda) \ln \left(\frac{x-1}{x} \right) \right] - \Lambda \right\} \quad (\text{A.6}) \end{aligned}$$

and thus

$$\frac{dw_2}{d\lambda_1} = -\frac{w_1}{\lambda_1(x-1)} \frac{F_2(\Lambda)}{(2x-1-\Lambda)^2},$$

with

$$F_2(\Lambda) = -(x-1)x \left\{ 2(x-\Lambda) + [2x(x-1-\Lambda) + 1+\Lambda] \ln \left(\frac{x-1}{x} \right) \right\}$$

To make progress with the sign of $F_2(\Lambda)$, we look at the properties of

$$\bar{F}_2(x; \Lambda) \equiv 2(x-\Lambda) + [2x(x-1-\Lambda) + 1+\Lambda] \ln \left(\frac{x-1}{x} \right).$$

Partially differentiating \bar{F}_2 w.r.t. Λ , we compute $\partial \bar{F}_2 / \partial \Lambda = -(2x-1)\bar{f}_2(x)$, with

$$\bar{f}_2(x) \equiv \frac{2}{2x-1} + \ln \left(\frac{x-1}{x} \right).$$

From $\bar{f}_2^l(x) = \{x(x-1)(2x-1)^2\}^{-1} > 0$ and $\lim_{x \rightarrow \infty} \bar{f}_2(x) = 0$, we conclude that $\bar{f}_2(x) < 0$ and in extension $\partial \bar{F}_2 / \partial \Lambda > 0$. This establishes $\bar{F}_2(x, \Lambda) > \bar{F}_2(x, 0)$ for all $\Lambda > 0$. We can write $\bar{F}_2(x, 0) = 2x\bar{f}(x)$, with

$$\bar{f}(x) \equiv 1 + \left[(x-1) + \frac{1}{2x} \right] \ln \left(\frac{x-1}{x} \right)$$

and compute $\lim_{x \rightarrow 1} \bar{f}(x) = -\infty$, $\lim_{x \rightarrow \infty} \bar{f}(x) = 0$, and

$$\bar{f}'(x) = \frac{2x^2 - 1}{2x^2} \left[\ln \left(\frac{x-1}{x} \right) + \frac{2x^2 - 2x + 1}{(x-1)(2x^2 - 1)} \right].$$

We observe that if $\bar{f}(x)$ has an interior extremum, it is reached at $\ln \left(\frac{x-1}{x} \right) = -\frac{2x^2 - 2x + 1}{(x-1)(2x^2 - 1)}$ and denoted \underline{x} . We compute

$$\bar{f}(\underline{x}) = \frac{4\underline{x}^3 - 10\underline{x}^2 + 6\underline{x} - 1}{2\underline{x}(\underline{x} - 1)(2\underline{x}^2 - 1)} = \frac{2\underline{x}(\underline{x} - 1)(2\underline{x} - 3) - 1}{2\underline{x}(\underline{x} - 1)(2\underline{x}^2 - 1)}.$$

Using the Mercator series in the definition of $\hat{F}(x, \Lambda)$ and accounting for $\Lambda > \lambda_2$, we can write

$$\hat{F}(x, \Lambda) > \frac{\Lambda}{x} + \frac{\Lambda}{x-1} - \Lambda = -\frac{\Lambda}{x(x-1)} [(x-1)^2 - x].$$

Noting that $(x-1)^2 - x > 0$ requires $x > (3 + \sqrt{5})/2 > 2$ (or $x < 3 - \sqrt{5} < 1$, which is excluded by condition $x > 1 + \Lambda$), we can safely conclude that $\hat{F}(x, \Lambda) = 0$ establishes $x > 2$. Acknowledging that $\bar{f}(\underline{x}) > 0$ if $\underline{x} > 2$ and that $\lim_{x \rightarrow \infty} \bar{f}(x) = 0$, it follows from $\bar{f}(2) > 0$, that $\bar{f}(x) > 0$ and in extension $\bar{F}_2(x, \Lambda) > 0$, $F_2(\Lambda) < 0$ hold over the relevant parameter range. This implies that $\hat{F}(x, \Lambda) = 0$ establishes $dw_2/d\lambda_1 > 0$ and completes the proof regarding the impact of an increase in λ_1 on w_1, w_2 .

We continue by showing that an increase in λ_2 decreases w_1 and w_2 . For this purpose, we consider the alternative implicit function

$$\tilde{G}(x, \Lambda) \equiv -\ln \left(\frac{x-1}{x} \right) - \frac{1}{\Lambda} \ln \left(\frac{x-1-\Lambda}{x-1} \right) - \lambda_1 = 0, \quad (\text{A.7})$$

with $\Lambda \tilde{G}(x, \Lambda) = \hat{F}(x, \lambda)$. Partial differentiation w.r.t. x and Λ yields

$$\frac{\partial \tilde{G}}{\partial x} = -\frac{1}{x} \frac{2x-1-\Lambda}{(x-1)(x-1-\Lambda)}, \quad \frac{\partial \tilde{G}}{\partial \Lambda} \frac{d\Lambda}{d\lambda_2} = \left[\frac{1}{\Lambda} \ln \left(\frac{x-1-\Lambda}{x-1} \right) + \frac{1}{x-1-\Lambda} \right] \frac{1}{\lambda_2}$$

Applying the implicit function theorem to $\tilde{G}(x, \Lambda) = 0$ then gives

$$\frac{dx}{d\lambda_2} = \frac{x}{\lambda_2} \frac{x-1}{2x-1-\Lambda} \left[1 + \frac{x-1-\Lambda}{\Lambda} \ln \left(\frac{x-1-\Lambda}{x-1} \right) \right]. \quad (\text{A.8})$$

To determine the sign of $dx/d\lambda_2$ it is worth looking at the properties of $f(y) = 1 + [(1-y)/y] \ln(1-y)$, which corresponds to the bracket expression in Eq. (A.8), when setting $y \equiv \Lambda/(x-1) < 1$. Differentiating $f(y)$ gives

$$f'(y) = -\frac{1}{y^2} [\ln(1-y) + y] > 0.$$

From $\lim_{y \rightarrow 0} f(y) = 0$, we therefore conclude that $dx/d\lambda_2 > 0$ if $\Lambda > 0$ (reaching a maximum at $y = 1$, with $f(1) = 1$). From the definition of w_1 , we moreover obtain

$$\frac{dx}{d\lambda_2} = \frac{w_1}{\lambda_1} \frac{x}{\lambda_2} \frac{1}{x-1-\Lambda} \left[1 + \frac{x-1-\Lambda}{\Lambda} \ln \left(\frac{x-1-\Lambda}{x-1} \right) \right]. \quad (\text{A.9})$$

Totally differentiating w_1 yields

$$\frac{dw_1}{d\lambda_2} = \frac{\partial w_1}{\partial x} \frac{dx}{d\lambda_2} + \frac{\partial w_1}{\partial \Lambda} \frac{d\Lambda}{d\lambda_2}. \quad (\text{A.10})$$

We further compute

$$\frac{\partial w_1}{\partial \Lambda} \frac{d\Lambda}{d\lambda_2} = -\frac{w_1}{\lambda_1} \frac{x}{(2x-1-\Lambda)(x-1-\Lambda)}$$

and

$$\frac{\partial w_1}{\partial x} \frac{dx}{d\lambda_2} = \frac{w_1}{\lambda_2} \frac{2x^2(x-1-\Lambda) + x\Lambda(1+\Lambda)}{(2x-1-\Lambda)^2(x-1-\Lambda)} \left[1 + \frac{x-1-\Lambda}{\Lambda} \ln \left(\frac{x-1-\Lambda}{x-1} \right) \right].$$

Substituting into $dw_1/d\lambda_2$, we then obtain

$$\frac{dw_1}{d\lambda_2} = \frac{w_1}{\lambda_2} \frac{xG_1(\Lambda)}{(2x-1-\Lambda)^2},$$

with

$$G_1(\Lambda) \equiv 2(x-\Lambda) + [2x(x-1-\Lambda) + \Lambda(1+\Lambda)] \frac{1}{\Lambda} \ln \left(\frac{x-1-\Lambda}{x-1} \right).$$

Recollecting from the Mercator series that $\ln(1+y) < y - y^2/2$ if $y \in (-1, 0)$ and setting $y = -\Lambda/(x-1)$, we compute

$$\ln \left(\frac{x-1-\Lambda}{x-1} \right) < -\frac{\Lambda}{2(x-1)^2} [2(x-1) + \Lambda],$$

and thus

$$\begin{aligned} 2(x-1)^2 G_1(\Lambda) &< 4(x-1)^2(x-\Lambda) - [2x(x-1-\Lambda) + \Lambda(1+\Lambda)] [2(x-1) + \Lambda] \\ &= 2(x-1) [2(x-1)(x-\Lambda) - 2x(x-1-\Lambda) - \Lambda(1+\Lambda)] - \Lambda [2x(x-1-\Lambda) + \Lambda(1+\Lambda)] \\ &= \Lambda [2(x-1)(1-\Lambda) - 2x(x-1-\Lambda) - \Lambda(1+\Lambda)] = -\Lambda [2(x-1)^2 - \Lambda(1-\Lambda)] \end{aligned}$$

This implies that $x > 2$ is sufficient for $G_1(\Lambda) < -\Lambda [2(x-1)^2 - \Lambda(1-\Lambda)] < 0$ (see above). We can therefore safely conclude that $\hat{F}(x, \Lambda) = 0$ ensures $G_1(\Lambda) < 0$ and therefore $dw_1/d\lambda_2 < 0$.

In a next step, we can note that $w_2 = w_1(x-\Lambda)/(x-1)$ and compute

$$\frac{dw_2}{d\lambda_2} = \frac{x-\Lambda}{x-1} \frac{dw_1}{d\lambda_2} - \frac{w_1(1-\Lambda)}{(x-1)^2} \frac{dx}{d\lambda_2} - \frac{w_1}{x-1} \frac{\Lambda}{\lambda_2}, \quad (\text{A.11})$$

which in view of $dw_1/d\lambda_2 < 0$ and $dx/d\lambda_2 > 0$ is unambiguously negative. This completes the proof regarding the impact of an increase in λ_1 on w_1, w_2 .

A.4 The impact of changes in λ_c on p_1

To show that an increase in λ_1 or λ_2 decreases p_1 , we can rewrite the price at stage S_1 as follows

$$p_1 = \frac{x - 1 - \Lambda}{2x - 1 - \Lambda}, \quad (\text{A.12})$$

with $\Lambda = \lambda_2/\lambda_1 \in (0, 1)$ and $x = \hat{Q}_0/(\lambda_1 L) > 1 + \Lambda$ as defined in Appendix A.3. We then compute

$$\frac{dp_1}{d\lambda_1} = \frac{\partial p_1}{\partial x} \frac{dx}{d\lambda_1} + \frac{\partial p_1}{\partial \Lambda} \frac{d\Lambda}{d\lambda_1}, \quad (\text{A.13})$$

with

$$\frac{\partial p_1}{\partial x} = \frac{1 + \Lambda}{(2x - 1 - \Lambda)^2}, \quad \frac{\partial p_1}{\partial \Lambda} \frac{d\Lambda}{d\lambda_1} = \frac{x}{(2x - 1 - \Lambda)^2} \frac{\Lambda}{\lambda_1},$$

and $dx/d\lambda_1$ given by equation (A.3). Plugging in and rearranging terms we get

$$\frac{dp_1}{d\lambda_1} = \frac{x(x - 1 - \Lambda)}{\lambda_1(2x - 1 - \Lambda)^3} \left[-1 + \Lambda + (1 + \Lambda)(x - 1) \ln \left(\frac{x - 1}{x} \right) \right] < 0.$$

Moreover, we have

$$\frac{dp_1}{d\lambda_2} = \frac{\partial p_1}{\partial x} \frac{dx}{d\lambda_2} + \frac{\partial p_1}{\partial \Lambda} \frac{d\Lambda}{d\lambda_2}, \quad (\text{A.14})$$

with

$$\frac{\partial p_1}{\partial \Lambda} \frac{d\Lambda}{d\lambda_2} = -\frac{x}{\lambda_1(2x - 1 - \Lambda)^2},$$

and $dx/d\lambda_2$ given by equation (A.8). Plugging in, we obtain

$$\frac{dp_1}{d\lambda_2} = \frac{x(x - 1 - \Lambda)}{\lambda_2 \Lambda} \frac{H(x, \Lambda)}{(2x - 1 - \Lambda)^3},$$

where

$$H(x, \Lambda) \equiv (1 - \Lambda)\Lambda + (1 + \Lambda)(x - 1) \ln \left(\frac{x - 1 - \Lambda}{x - 1} \right).$$

Since we know from Appendix A.3 that $x > 2$ holds in the open economy equilibrium, the Mercator series establishes that

$$\ln \left(\frac{x - 1 - \Lambda}{x - 1} \right) < -\frac{\Lambda}{x - 1}$$

and hence $H < (1 - \Lambda)\Lambda - (1 + \Lambda)\Lambda = -2\Lambda^2 < 0$, implying that $dp_1/d\lambda_2 < 0$. This completes the proof.

A.5 Derivation of equation system (7')

The derivation steps have the same order as in Appendix A.2. Starting point is differential equation $p'_c(s) = p_c(s)\lambda_c + w_c$, where a country index is attached to the price, because $\delta < 1$ drives a wedge between the price per produced and the price per exported unit and because $\tau > 1$ drives a wedge between the export and the import price. The differential equation has the general solution $p_c(s) = -w_c/\lambda_c + B_c \exp[\lambda_c s]$. In view of $p_1(0) = -w_1/\lambda_1 + B_1 = 0$, we get $B_1 = w_1/\lambda_1$. This establishes $p_1(s) = \{\exp[\lambda_1 s] - 1\}w_1/\lambda_1$ for all $s \in (0, S_1]$. Acknowledging $\delta\tilde{p}_1 = p_1(S_1)$, then gives the first line in system (7') for $s = S_1$. Moreover, evaluating $p_2(s) = -w_2/\lambda_2 + B_2 \exp[\lambda_2 s]$ at $s = S_1$, we compute using $p_2(S_1) = \tau\tilde{p}_1$ $B_2 = [\tau\tilde{p}_1 + w_2/\lambda_2] \exp[-\lambda_2 S_1]$. This establishes $p_2(s) = \tau\tilde{p}_1 \exp[\lambda_2(s - S_1)] + (w_2/\lambda_2)\{\exp[\lambda_2(s - S_1)] - 1\}$, which evaluated at $s = 1$ and setting $p_2(1) = 1$ gives the second line of equation system (7).

Finally, we acknowledge that a profit-maximizing choice of executing stages $s > S_1$ in country 2 and executing stages $s < S_1$ in country 1 requires

$$\begin{aligned} p(S_1 + ds) - \frac{p(S_1) + w_2 ds}{1 - \lambda_2 ds} &\geq p(S_1 + ds) - \frac{\tau p(S_1) + w_1 ds}{\delta(1 - \lambda_1 ds)}, \\ p(S_1) - \frac{\tau p(S_1 - ds) + w_1 ds}{\delta(1 - \lambda_1 ds)} &\geq p(S_1) - \frac{p(S_1 - ds) + w_2 ds}{1 - \lambda_2 ds} \end{aligned}$$

to simultaneously hold according to Eq. (2). Making use of standard mathematical manipulation and setting $p_1(S_1) = \delta\tilde{p}_1$, $p_2(S_1) = \tau\tilde{p}_1$, we can reformulate the two conditions for the limiting case of $ds \rightarrow 0$

$$\tau\tilde{p}_1(\lambda_1 - \lambda_2) \geq w_2 - \tau\delta^{-1}w_1, \quad w_2 - \tau\delta^{-1}w_1 \geq \tau\delta p_1(\lambda_1 - \lambda_2),$$

which jointly establish the third line of equation system (7'). This completes the proof.

A.6 Proof of Lemma 2

Noting $d\tilde{Q}_0/d\tau = 0$ from Proposition 3, $dw_1/d\tau < 0$ and $dw_2/d\tau = 0$ directly follow from Eqs. (8'), while $d\tilde{p}_1/d\tau < 0$ and $d(\tau\tilde{p}_1)/d\tau = 0$ directly follow from Eq. (9'). Moreover, making use of

$$\frac{dQ_0}{d\delta} = -\frac{1}{\delta} \frac{Q_0(Q_0 - \lambda_1 L)}{\delta(Q_0, \lambda_1 L) + Q_0 - \lambda_2 L}, \quad \frac{d(Q_0 - \lambda_1 L)}{d\delta} = \frac{(Q_0 - \lambda_1 L)[\delta(Q_0 - \lambda_1 L) - \lambda_2 L]}{\delta(Q_0, \lambda_1 L) + Q_0 - \lambda_2 L} \quad (\text{A.15})$$

from Eq. (6'), we compute

$$\frac{dw_1}{d\delta} = -\frac{w_1}{\delta} \frac{\tilde{Q}_0(\lambda_1 - \lambda_2)L}{[\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L]^2} < 0, \quad \frac{dw_2}{d\delta} = \tau w_1 \frac{\tilde{Q}_0(\lambda_1 - \lambda_2)L}{[\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L]^2} > 0,$$

and

$$\frac{d\tilde{p}_1}{d\delta} = \frac{w_1}{\delta} \frac{\tilde{Q}_0 L(1 + \delta)}{[\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L]^2} > 0, \quad \frac{d(\tau\tilde{p}_1)}{d\delta} = \frac{\tau w_1}{\delta} \frac{\tilde{Q}_0 L(1 + \delta)}{[\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L]^2} > 0.$$

This completes the proof.

A.7 Proof of Proposition 4

Noting $d\tilde{Q}_0/d\tau = 0$ from Proposition 3, $dV_1/d\tau < 0$ and $dV_2/d\tau > 0$ directly follow from Eqs. (10) and (11). Moreover, making use of derivatives in (A.15), we compute for the South

$$\frac{dV_1}{d\delta} = \frac{w_1 L}{\delta} \left\{ 1 - \frac{\tilde{Q}_0(\lambda_1 - \lambda_2)L}{[\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L]^2} \right\} - \frac{\lambda_1 L}{\exp[\lambda_1] - 1} \quad (\text{A.16})$$

and

$$\begin{aligned} \frac{d^2 V_1}{d\delta^2} = & -\frac{w_1 L}{\delta} \frac{\tilde{Q}_0(\lambda_1 - \lambda_2)L}{[\delta(\tilde{Q}_0, \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L]^2} \left\{ \frac{\delta(\tilde{Q}_0 - \lambda L)}{\delta(\tilde{Q}_0, \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} \right. \\ & \left. + \frac{(\lambda_1 - \lambda_2)L[\delta(\tilde{Q}_0 - \lambda L) - \lambda_2 L]}{[\delta(\tilde{Q}_0, \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L]^2} + 2 \frac{(\tilde{Q}_0 - \lambda_1 L)[\tilde{Q}_0 + \delta\lambda_2 L - \delta^2(\tilde{Q}_0 - \lambda L)]}{[\delta(\tilde{Q}_0, \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L]^2} \right\} < 0. \end{aligned}$$

This implies that if $\tilde{V}_1(\tau, \delta)$ has an extremum in δ on the unit interval, it must be a maximum. Noting further that

$$\lim_{\delta \rightarrow 0} \frac{dV_1}{d\delta} = \frac{1}{\tau} \frac{\lambda_2 L}{\exp[\lambda_2] - 1} - \frac{\lambda_1 L}{\exp[\lambda_1] - 1},$$

we conclude that $\lim_{\delta \rightarrow 0} dV_1/d\delta < (=) 0$ if $\tau > (=)\bar{\tau}$, with $\bar{\tau}$ defined in Proposition 4. In this case, it follows from the negative sign of the second derivative that $dV_1/d\delta < 0$ holds for all $\delta > 0$. Moreover, if $\tau < \bar{\tau}$, two outcomes are possible, depending on the sign of $dV_1/d\delta$ at $\delta = 1$: If $dV_1/d\delta < 0$ holds at $\delta = 1$, then $\tilde{V}_1(\tau, \delta)$ has an interior maximum in δ at the unit interval. In contrast, if $dV_1/d\delta \geq 0$ holds at $\delta = 1$, then $dV_1/d\delta > 0$ holds for all $\delta < 1$. Noting further that $d^2 V_1/(d\delta d\tau) < 0$, it is clear that the first case in which $dV_1/d\delta < 0$ holds at $\delta = 1$ is achieved for sufficiently high levels of τ . Using the definition of $\underline{\tau}$ in Proposition 4 and noting that, by definition, $\underline{\tau} < \bar{\tau}$, it follows that Southern welfare has an interior maximum in δ on the unit interval if $\tau \in (\underline{\tau}, \bar{\tau})$.

We now turn to the impact of changes in parameter δ on welfare in the North. For this purpose, we reformulate Eq. (11) as follows

$$\begin{aligned} V_2 = & \frac{1}{\tau} \frac{(\tilde{Q}_0 - \lambda_2 L)[\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L]}{\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} + \frac{\tau - 1}{\tau} \frac{[\delta(Q_0 - \lambda_1 L) + Q_0 - \lambda_2 L][\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L]}{\delta(\tilde{Q}_0 - \lambda_1 L) + \tilde{Q}_0 - \lambda_2 L} \\ = & \frac{w_2 L}{\tau} + \frac{\tau - 1}{\tau} [\delta(\tilde{Q}_0 - \lambda_1 L) - \lambda_2 L] \end{aligned}$$

where the second equality sign follows from Eq. (8'). Then, making used of $dw_2/d\delta$ from Lemma 2 and $d[\delta(Q_0 - \lambda_1 L)]/d\delta > 0$ from (A.15), we can safely conclude that $dV_2/d\delta > 0$. This completes the proof.

A.8 Proof of Proposition 7

The extension of Propositions 5 and 5 to $\tau_{max} \geq \bar{\tau}$ is straightforward and requires no further discussion. Therefore, we focus on $\tau_{max} < \bar{\tau}$ in the rest of this proof and show that $\delta = 1$ is indeed consistent with $\tau > 1$. From Appendix A.7 we know that this requires $\underline{\tau} > 1$ or, equivalently, $\partial \tilde{V}_1(1, 1)/\partial \delta \geq 0$. For this purpose, we first note that setting $\lambda_1 = \lambda_2 \equiv \lambda$ establishes $\tilde{Q}_0 = 2\lambda L \exp[\lambda]/\{\exp[\lambda] - 1\}$, which,

substituted into Eq. (A.16), implies

$$\frac{\partial \tilde{V}_1(1, 1)}{\partial \delta} = \frac{\lambda_1 L}{\exp[\lambda_1] - 1} - \frac{\lambda_1 L}{\exp[\lambda_1] - 1} = 0. \quad (\text{A.17})$$

Moreover, making use of $x = \tilde{Q}_0/\lambda L$ and $\Lambda = \lambda_2/\lambda_1$, we can rewrite Eq. (A.16) for an outcome with $\delta = \tau = 1$ as $dV_1(1, 1)/d\delta = \lambda_1 L A(x, \Lambda)$, with

$$A(x, \Lambda) \equiv \frac{(x-1)(x-1-\Lambda)}{2x-1-\Lambda} \left[1 - \frac{x(1-\Lambda)}{(2x-1-\Lambda)^2} \right] - \frac{1}{\exp[\lambda] - 1}, \quad (\text{A.18})$$

with x implicitly defined as a function of λ_2 by Eq. (A.7).

Total differentiation of $A(\cdot)$ with respect to λ_2 gives

$$\frac{dA(\cdot)}{d\lambda_2} = \frac{\partial A}{\partial x} \frac{dx}{d\lambda_2} + \frac{\partial A}{\partial \Lambda} \frac{d\Lambda}{d\lambda_2},$$

with $dx/d\lambda_2$ given by Eq. (A.9), $d\Lambda/d\lambda_2 = 1/\lambda_1$, and

$$\begin{aligned} \frac{\partial A}{\partial x} &= \frac{2x(x-1-\Lambda) + \Lambda(1+\Lambda)}{(2x-1-\Lambda)^2} \left[1 - \frac{x(1-\Lambda)}{(2x-1-\Lambda)^2} \right] + \frac{(x-1)(x-1-\Lambda)}{x-1-\Lambda} \frac{(1-\Lambda)(2x+1+\Lambda)}{(2x-1-\Lambda)^3}, \\ \frac{\partial A}{\partial \Lambda} &= -\frac{x(x-1)}{(2x-1-\Lambda)^2} \left[1 - \frac{x(1-\Lambda)}{(2x-1-\Lambda)^2} \right] + \frac{(x-1)(x-1-\Lambda)}{x-1-\Lambda} \frac{x[2(x-1) - (1-\Lambda)]}{(2x-1-\Lambda)^3}. \end{aligned}$$

Evaluate at $\lambda_1 = \lambda_2 = \lambda$ this establishes

$$\frac{dA(x, 1)}{d\lambda_2} = \frac{1}{2\lambda} \frac{\exp[\lambda]}{(\exp[\lambda] - 1)^2} a(\lambda),$$

with

$$a(\lambda) \equiv \exp[\lambda] - 1 + 2 \ln \left(\frac{2}{\exp[\lambda] + 1} \right) - \exp[\lambda] \left(\frac{\exp[\lambda] - 1}{\exp[\lambda] + 1} \right)^2 = \frac{\exp[\lambda] - 1}{\exp[\lambda] + 1} + 2 \ln \left(\frac{2}{\exp[\lambda] + 1} \right).$$

Accounting for $a'(\lambda) = -2 \exp[\lambda] / \{\exp[\lambda] + 1\} < 0$ and $a(0) = 0$, it follows that $a(\lambda) < 0$ and thus $dA(x, 1)/d\lambda_2 < 0$ for all $\lambda > 0$. In view of our assumption that $\lambda_2 < \lambda_1$, this implies that $\tilde{V}_1(1, 1)/d\delta > 0$ must hold for small technology differences. In this case, we have $\tau > 1$ and $dV_1/d\delta > 0$ for all $\delta \leq 1$ if $\tau \in (1, \bar{\tau})$. This completes the proof.