Quantifying the Economic Effects of the Belt and Road Initiative: A Global Value Chain Approach

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Quantifying the Economic Effects of the Belt and Road Initiative: A Global Value Chain Approach

Siyi Peng¹, Daocheng Zhong²

Abstract
Limited literature studies the economic effects of the Belt and Road Initiative considering the rising trend of fragmented production. By distinguishing between intermediates and final goods in a general equilibrium model and estimating asymmetric trade costs, we quantify the economic impacts of the initiative. We find that the Belt and Road Initiative has welfare gains worldwide especially for Malaysia and Vietnam. China, the initiative's proponent, has moderate welfare gains. Some non-members experience slight welfare loss, such as 0.008% for Germany. The initiative's trade effects are more pronounced in final goods than intermediates. To figure out the direction of value-added, we distinguish the perspective of forward- (as a supply-side for sales) and backward-linkages (as a demand-side for use). Furthermore, members of the initiative participate more in GVCs at both forward- and backward-linkage. The change in the GVC position index reveals that the initiative reshapes members’ positions in production chains. Both forward- and backward-linkage production lengths within members become longer, implying more complex chains and tighter linkages between members. Counterfactuals show that if Germany were to join the initiative, it would yield improved economic effects for itself and its members. Additionally, we employ more counterfactuals to demonstrate the role of asymmetric trade costs, input-output linkages, and industry heterogeneity. Through quantification of the initiative, we aim to provide insights for policymakers from the perspective of global value chains.

Keywords The Belt and Road initiative; Welfare; Global value chains; Quantitative trade models

JEL Classification: D5, F10, F11, F13, F14, F17

1 Introduction
The rising fragmentation of production processes worldwide has highlighted the role of intermediates and input-output linkages. The Belt and Road Initiative (referred to as BRI), a pivotal Chinese strategy in recent years, has had a profound impact on the countries along its routes. However, quantification of its economic effects from the perspective of input-output linkages and trade in intermediates is relatively limited. This study aims to address the following three key questions: What are the economic effects of BRI among members and non-members in a general equilibrium framework? What would be the impacts if Germany had joined the Belt and Road

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Initiative? What roles do asymmetric trade costs, input-output linkages, and industry heterogeneity play in this context? We utilize a general equilibrium model that distinguishes trade shares in intermediates and final goods.

In October 2013, Chinese President Xi officially introduced the Belt and Road Initiative to promote closer bilateral trade and address China's surplus production capacity. On October 24 in 2014, China, India, Singapore, and 21 other countries formally signed the "Memorandum of Understanding on Establishing the Asian Infrastructure Investment Bank (AIIB)" in Beijing. As of 2023, more than 152 countries and 32 international organizations have signed over 200 cooperative agreements related to the BRI. While this initiative does not involve direct tariff reductions, it effectively reduces bilateral trade barriers by signing memoranda. For example, the China-Pakistan Economic Corridor leverages Pakistan's labor to attract labor-intensive industries from China. China-Europe Railway Express reduces transit times for the transportation of goods between European countries and China.

This paper primarily extends existing research on the BRI from two perspectives. For the model, we extend traditional general equilibrium models with the features of intermediates, iceberg costs, and roundabout production, building upon Caliendo and Parro (2015) and Antrás and Chor (2018). Specifically, we differentiate trade shares, expenditures, and equilibrium conditions for intermediates and final goods, respectively. This extension incorporates input-output linkages into the general equilibrium model and develops cost functions for intermediates and final goods, respectively. Furthermore, we align the model with decomposition framework of global value chains, as proposed by Wang et al. (2022). This linkage is impossible without input-output linkages and the distinction between trade shares in intermediates and final goods.

For the measurements, we use GVC participation and production length metrics to evaluate the economic impacts of BRI. From a producer's perspective (forward-linkages) or a user's perspective (backward-linkages), we further decompose production activities in GVCs into more detailed categories.

Specifically, for the GVC participation index, Forward-Linkage GVC Participation Index (abbreviated as PTF) describes the domestic value added generated from a country-industry's GVC activities through downstream firms as a share of that country-industry's total value added. Backward-linkage GVC Participation index (PTB) measures the percentage of a country-industry's total production of final goods that represent the value added in GVC activities through upstream firms. For the GVC production lengths, Forward-Linkage GVC Production Length (PLF_GVC) is the average production length of domestic value-added embodied in intermediates from its first use as a primary input until its final absorption in final goods. Backward-Linkage GVC Production Length (PLB_GVC) is the average production length of foreign value-added embodied in intermediate imports from their first use as primary inputs until their final absorption into a country's production of final products. These two metrics provide a comprehensive picture of a country-sector's production lengths in GVCs, with their relative values describing a country-sector's relative position within the global production network, which is GVC position index (Wang et al., 2022).

We apply the model to data and examine the trade, welfare, and global value chain effects of trade cost reduction among BRI members. Based on the Asian Development Bank's multi-regional...
input-output tables, we measure the modified Head-Ries index to derive asymmetric trade costs (Head and Ries, 2001). Then, we quantify the economic effects for members within a general equilibrium framework. Specifically, we conduct counterfactuals by only reducing the trade costs among the BRI countries and assuming that trade costs in the rest of the world remain unchanged. Our base year is 2009, five years before the initiative was proposed. We utilize 2019 as the counterfactual period, five years after the policy came into force.

Several interesting facts stand out. Firstly, BRI countries have welfare gains of 4.398%. Non-BRI countries experience welfare gains of 0.019% on average (weighted by outputs). Notably, Southeast Asian countries such as Malaysia, Vietnam, and Thailand have significant welfare gains of 51.406%, 43.374%, and 25.405%, respectively. Larger economies like China and India, which have lower trade dependencies with moderate welfare gains. China's welfare gains are 1.148%. Some non-BRI countries suffer from slight welfare loss, such as 0.008% for Germany.

Secondly, the trade creation effects in BRI are more significant in final goods, with exports in final goods (32.480%) surpassing intermediates (29.466%). Furthermore, imports in final goods (34.699%) exceed intermediates (32.547%). Countries like Indonesia, Thailand, and Vietnam experience substantial trade creation effects, with Indonesia's exports in final goods and intermediates, growing by 233% and 148%, respectively.

Thirdly, concerning GVC participation, on average, BRI countries increase PTF by 4.4%, while non-BRI countries increase it by 0.2%. For the BRI countries, the decomposition, according to the sources, reveals that the increase in PTF originates from BRI countries at 5.5%, with a decrease from non-BRI countries of -1.1%. Interestingly, PTF for non-BRI countries also improved. Specifically, they rely more on BRI countries (0.3%) and less on non-BRI countries (-0.1%). Moreover, Indonesia witnesses a substantial increase of 11.0%. In contrast, Italy, China, and India had modest increases of 1.9%, 2.6%, and 2.6%, respectively.

For PTB, the increase for BRI countries is 6.1%, while non-BRI countries decline by 0.2% on average. The results show that the liberalization boosts trade in intermediate inputs imported from BRI members while the intermediate inputs from non-BRI countries decline. Notably, Vietnam, Malaysia, and Thailand have witnessed substantial growth of 17.5%, 13.7%, and 13.5%, respectively. In contrast, Italy, India, and China have slight growth of 1.5%, 1.8%, and 2.4%, respectively. These findings highlight the significant distributional impacts of the BRI on members.

Fourth, for production lengths and position in GVCs. The results for GVC position index demonstrate that South Korea increases its position index at 0.101, followed by India, Thailand, and Italy, which have moved to more upstream positions at 0.097, 0.096, and 0.046, respectively. These countries engage in more upstream activities along the GVCs. In contrast, countries like Indonesia and Malaysia witness declines of 0.023 and 0.089. As specialization deepens, they leverage their comparative advantages to complement other countries in BRI and thus participate more in downstream activities. We further show that members have a growth in both forward- and backward-linkage GVC production lengths, signaling a more intricate production division.

We conduct additional counterfactuals to quantify the impact of the BRI on its members. Specifically, we examine the economic effects if Germany, a significant economic power in Europe, had signed a memorandum for BRI. Our quantitative results indicate that Germany's welfare, GVC

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4 We selected 2019 as the year for the counterfactual period because of the outbreak of the COVID-19 pandemic in 2020 and the formal signing of the Regional Comprehensive Economic Partnership (2019). These events are likely to influence the estimates of trade costs since such quantification are based on historical trade flows.
participation, and GVC position all improved, and most members also benefited from this.

Furthermore, we explored the setting of model specifications. Firstly, we study the role of input-output linkages and find that the welfare gains would be significantly underestimated if we neglect the IO linkages. Secondly, we replace asymmetric trade costs in the baseline scenarios with symmetric ones. The results indicate that symmetric trade costs can bias the effects. As emphasized by Waugh (2010), poorer countries usually have higher trade costs than richer countries, and there is large heterogeneity among different countries. Thirdly, we considered the role of multiple industries. As pointed out by Giri (2021), distinction between different industries matters in computing the gains from trade. We assume a uniform 10% reduction for industries and compare the counterfactuals with the baseline scenario. Without distinguishing industry heterogeneity, the effects also would be distorted.

Our paper is closely related to trade effects in the context of the Belt and Road Initiative, which can be divided into two aspects. Firstly, they employ a reduced-form approach to investigate the economic effects on the countries along the BRI. Ramasamy and Yeung (2019) compared the role of marginal management and tangible infrastructure within the BRI and found that the former had a more pronounced promotional effect on trade. Sun (2021) studied the BRI's impact on upgrading the quality of Chinese export products. Foo et al. (2020) examined the effects of the BRI on trade within Asian members. Herrero and Xu (2017) studied China's BRI on trade effects in European countries. Mau and Seuren (2023) studied the impacts of transport infrastructure within the BRI on the countries along its route and found that Central Europe, Eastern Europe, and Southern Europe are more likely to benefit from it. Yang (2020) evaluated infrastructure investments under the BRI. Additionally, some studies examine the initiative’s influence on the GVCs of members (Ge et al., 2020; Ali and Wang, 2023). Other studies used complex network analysis to investigate the role of regional value chains on the BRI (Pu et al., 2023).

Secondly, some literature uses quantitative structural models to quantify the trade and welfare effects of the BRI. De Soyres et al. (2019) evaluated how the BRI would reduce trade costs. Then, De Soyres et al. (2020) further integrated the BRI into trade models to quantify the welfare impacts of transport infrastructure. Gao et al. (2023) calculated the reduction in trade costs with a synthetic control method and adopted the methodology of Anderson and Wincoop (2003) to evaluate the welfare effects of the BRI.

Instead, our paper incorporates a general equilibrium model that distinguishes trade shares in intermediates and final goods into the research on BRI. Specifically, we use the modified Head-Ries index to estimate changes in asymmetric trade costs and quantify the economic impacts among members. Moreover, our paper extends to GVC-related indicators such as forward- and backward-linkage GVC participation and production lengths in addition to the welfare and trade effects mentioned earlier.

Our paper is closely aligned with methods on the estimation of trade costs. There are primarily two approaches. One approach is OLS regression using bilateral data and fixed effects (Eaton and Kortum, 2002; Guillermo, 2012). However, this approach focuses on the trade costs between countries and fails to capture industry heterogeneity. Another approach is the Head-Ries index (Head and Ries, 2001). The advantage of this method lies in its applicability without assuming the economy is in equilibrium. Nevertheless, the limitation is that the assumption of symmetric trade costs for any two countries. In reality, due to inconsistent bilateral trade policies between two countries, trade costs vary depending on the direction of trade flows (Waugh, 2010). To address this
issue, Tombe (2015) proposed the assumption that asymmetric trade costs are characterized as exporter-specific fixed effects. Based on Tombe (2015), we measure the asymmetric trade costs at the country-sector level and compare them with the symmetric one.

This paper is closely related to recent advancements in quantitative trade models. We build upon previous work by distinguishing trade shares between intermediates and final goods (Caliendo and Parro, 2015; Antràs and Chor, 2018; Caliendo and Parro, 2022). This enables us to measure the indicators of GVCs. Following Wang et al. (2022), we examine GVC participation and production lengths considering the perspectives of forward- and backward- linkages. In fact, trade in intermediates accounts for over two-thirds of total production (Johnson and Noguera, 2012). It is crucial to investigate the effects of a policy with trade in intermediates and input-output linkages.

The paper is organized as follows. In section 2, we provide the theoretical model and the mechanism for trade costs in intermediates and final goods; In section 3, we provide the estimation for trade costs and the trade costs between BRI and non-BRI countries; Section 4 presents stylized facts for measure of GVCs at baseline and data sources; Section 5 shows the economic effects of BRI; Section 6 provides further analysis for the BRI and model specification. Section 7 concludes.

2. Theoretical Model and measures

Based on Caliendo and Parro (2015) and Antràs and Chor (2018), which incorporates a multi-country, multi-sector economy, our model deviates from the settings and distinguishes the roles and functions of intermediates and final goods. First, we set roundabout production, which indicates that intermediates are used as inputs to reproduce intermediates or final goods, while final goods are then used for final consumption or materials for intermediates. Second, households and firms purchase final goods and intermediates from the lowest-priced producers, respectively. Thirdly, the costs, prices, and trade shares for intermediates and final goods are heterogeneous.

The market is perfect competitive and labor is mobile across sectors but immobile across countries. There are \( N \) regions (denoted by \( i, j \), where \( N = 63 \), which corresponds to 62 countries in ADB-MRIO and one Rest of the world, or ROW), and \( R \) sectors (denoted by \( s, r \), where \( R = 35 \)). The matrix \( Z \) denotes intermediates and \( F \) denotes final goods, such as \( Z_{ij}^{rs} \) denotes the flow of intermediates produced in sector \( r \) in region \( r \) to sector \( s \) in region \( j \).

2.1 Theoretical Model that distinguished intermediates and final goods

A representative household consumes a range of final goods and aims to maximize utility:

\[
U(C) = \prod_{s=1}^{R} C_j^{\alpha_j} \tag{1}
\]

Where \( C_j^{s} \) denotes the consumption of final goods in sector \( s \) by representative households in region \( j \). The parameter \( \alpha_j^{s} \) denotes the share of final consumption in region \( j \) on sector \( s \) and \( \sum_{s=1}^{R} \alpha_j^{s} = 1 \).

Each sector \( s \) produces a bundle of \( \omega^s \in [0,1] \). The production function follows the structure of Cobb-Douglas functions consisting of composites and labor inputs. The production function of the product \( \omega^s \) in sector \( s \) of country \( j \) is,

\[
q_j^s(\omega^s) = z_j^s(\omega^s)[l_j^s(\omega^s)]^{\gamma_j^s}\prod_{r=1}^{R} [M_{jr}^{rs}(\omega^s)]^{\gamma_{jr}^s}, \tag{2}
\]

where \( q_j^s(\omega^s) \) denotes the production of \( \omega^s \) in sector \( s \) and region \( j \). \( z_j^s(\omega^s) \) denotes the productivity of sector \( s \) in region \( j \) and follows the Frechèt distribution (type-II extreme distribution). \( l_j^s(\omega^s) \) denotes the amounts of labor inputs for the production of \( \omega^s \) in sector \( s \) and region \( j \). The parameter \( \gamma_j^s \) denotes the share of labor inputs in total inputs. \( M_{jr}^{rs}(\omega^s) \) denotes the amount of
intermediate inputs from sector \( r \) required for the production in sector \( s \) and region \( j \), and the parameter \( y_j^r \) denotes the share of intermediate inputs originating from sector \( r \) in total inputs, and \( y_j^r = 1 - \sum_{s=1}^{S} y_j^r \).

With constant returns to scale and perfect competition, firms set prices based on the unit cost of production \( c_j^s / z_j^s(\omega^s) \) where \( c_j^s \) is a function of a bundle of inputs.

\[
c_j^s = Y_j^s w_j Y_j^s \prod_{r=1}^{R} P_j^{rs} y_j^r
\]

(3)

Where \( Y_j^s \) is a constant, \( w_j \) denotes the wage in region \( j \) and \( P_j^{rs} \) denotes the price of intermediate inputs originating in sector \( r \) that are used for production in sector \( s \) of region \( j \).

The composites in sector \( j \) and region \( s \) consist of two parts, final goods \( (C_j^r) \) and intermediate input \( (M_j^r) \). Final goods are consumed by households and the intermediate inputs are used for materials. The production function for composites is a CES function

\[
Q_j^s = \left[ \int q_j^r(\omega^s)^{\frac{1}{\sigma}} d\omega^s \right]^{(\sigma - 1)}
\]

(4)

\( Q_j^s \) denotes the production of composites in region \( j \) and sector \( s \). \( q_j^r(\omega^s) \) denotes the quantity of \( \omega^s \) used to produce composites in sector \( s \) of region \( j \). The parameter \( \sigma \) denotes the substitution elasticity of intermediate inputs.

We denote \( \kappa_j^{r,s} \) as the trade cost of importing intermediates from sector \( r \) in region \( i \) to sector \( s \) in region \( j \). Furthermore, \( \kappa_j^{r} \) denote the trade cost of importing final goods to households in region \( j \) from sector \( r \) in region \( i \). It satisfies the no arbitrage assumption \( \kappa_{in}^{r,s} \kappa_{nj}^{r} > \kappa_j^{r,s} \).

Producer searches for the lowest-price providers. Prices of intermediates can be obtained as follows

\[
P_j^{rs} = A^r \left[ \sum_{i=1}^{N} T_i^r \left( c_i^{r} \kappa_i^{r,s} \right)^{-\theta r} \right]^{-\frac{1}{\theta r}}
\]

(5)

Where \( A^r \) is a constant. The parameter \( T_i^r \) governs the location of the distribution of sector \( r \) in region \( i \). A larger \( T_i^r \) implies a larger probability for higher productivity of products and denotes the absolute advantage. The parameter \( \theta r \) denotes variation within the distribution. A larger \( \theta r \) implies less variability.

Similarly, consumers of region \( j \) consume the lowest prices of final goods,

\[
P_j^{rF} = A^r \left[ \sum_{i=1}^{N} T_i^r \left( c_i^{r} \kappa_i^{r} \right)^{-\theta r} \right]^{-\frac{1}{\theta r}}
\]

(6)

The expenditures \( X_j^r \) of region \( j \) on sector \( r \) is divided into two parts, one for expenditures on intermediates and the other for expenditures on final goods. The share of region \( j \)'s intermediates' expenditures on sector \( r \) and region \( i \) is the probability that sector \( r \) in region \( i \) supplies the good at the lowest price, which can be expressed as \( \pi_j^{rs} = Pr \left[ p_j^{rs}(\omega^s) \leq \min_n p_{n}^{rs}(\omega^r) : n \neq i \right] \).

Following the property of Frechèt distribution, we follow that

\[
\pi_j^{rs} = \frac{T_j^r (c_j^{r} \kappa_j^{r,s})^{-\theta r}}{\Sigma_{i=1}^{N} T_i^r (c_i^{r} \kappa_i^{r,s})^{-\theta r}}
\]

(7)

Similarly, the share of consumer consumption on final goods \( \pi_j^{rF} \) in region \( j \) on sector \( r \) of region \( i \) is

\footnote{The iceberg cost means transporting 1 unit of product from sector \( r \) in region \( i \) to sector \( s \) in region \( j \) leaves only \( 1/\kappa_j^{r,s} \) units.}
\[
\pi_{ij}^{IF} = \frac{\tau_{ij}(c_i^F c_j^F)^{-\sigma}}{\sum_{i=1}^{N} \tau_{ij}^F (c_i^F c_j^F)^{-\sigma}}
\]

The higher the production efficiency and lower the production and trade costs in the source sector, the more competitive it is in the international market and the larger its import share of the destination. Based on Antràs and Chor (2018), we further distinguish the trade shares between intermediates and final goods to identify the impacts of GVCs.

The total output of sector \( s \) in region \( j \) is the sum of sales in intermediates and final goods.

\[
Y_j^s = \sum_{i=1}^{N} \sum_{r=1}^{R} \pi_{ij}^{sr} Y_i^s + \sum_{i=1}^{N} \pi_{ij}^{sf} \alpha_i^s I_i
\]

Where \( I_i \) is the income of region \( i \) consisting of wage payments \( w_i L_i \) and trade balance \( D_i \), which can be expressed as

\[
I_i = w_i L_i + D_i
\]

Imports include imports of intermediates \( M_{ij}^{rs} \) and final goods \( M_{ij}^{sf} \). Similarly, exports include exports of intermediates \( E_{ij}^{sr} \) and final goods \( E_{ij}^{sf} \). The equilibrium for the trade balance can be expressed as,

\[
\sum_{i=1}^{N} \sum_{r=1}^{R} \pi_{ij}^{sr} Y_j^s + I_j = \sum_{i=1}^{N} \sum_{r=1}^{R} \pi_{ij}^{sr} Y_i^s + \sum_{i=1}^{N} \pi_{ij}^{sf} \alpha_i^s I_i
\]

where \( M_{ij}^{rs} = \pi_{ij}^{sr} \gamma_j^r Y_j^r \), denotes the imports of intermediates by region \( j \) and sector \( r \) from region \( i \) and sector \( s \). \( M_{ij}^{sf} = \pi_{ij}^{sf} \alpha_i^s I_i \) denotes region \( j \)'s imports of final goods from sector \( s \) in region \( i \).

Total spending on final goods in region \( j \) is equal to the sum of imports on final goods. Furthermore, \( E_{ij}^{sr} = \pi_{ij}^{sr} \gamma_i^r Y_i^r \) denotes exports of intermediates from region \( j \) and sector \( s \) to region \( i \) and sector \( r \). \( E_{ij}^{sf} = \pi_{ij}^{sf} \alpha_i^s I_i \) denotes exports of final goods from sector \( s \) in region \( j \) to region \( i \).

We use the exact hat algebra method proposed by Dekle et al. (2008) to solve for the relative change of equilibrium. We define any variable change as \( \hat{x} \), where \( \hat{x} = x' / x \). \( x' \) denotes any variable in the counterfactual, and \( x \) denotes the variable at baseline scenario. Then, we change trade costs in intermediates \( \kappa_{ij}^{rs} \) and final goods \( \kappa_{ij}^{sf} \) respectively and then derive the equilibrium of wages and prices that satisfy the following equations.

\[
\hat{c}_{ij}^s = \hat{w}_j \prod_{p=1}^{R} \hat{p}_{ij}^{rs} \hat{Y}_j^s
\]

\[
\hat{p}_{ij}^{rs} = \left[ \frac{\sum_{i=1}^{N} \pi_{ij}^{rs} (c_i^r c_j^r)^{-\sigma}}{\sum_{i=1}^{N} \pi_{ij}^{rs} (c_i^r c_j^r)^{-\sigma}} \right]^{-\frac{1}{\sigma}}
\]

\[
\hat{p}_{ij}^{sf} = \left[ \frac{\sum_{i=1}^{N} \pi_{ij}^{sf} (c_i^F c_j^F)^{-\sigma}}{\sum_{i=1}^{N} \pi_{ij}^{sf} (c_i^F c_j^F)^{-\sigma}} \right]^{-\frac{1}{\sigma}}
\]

\[
\hat{\gamma}_j^s = \frac{c_i^r c_j^r \pi_{ij}^{rs} \gamma_j^r}{\hat{p}_{ij}^{rs}}
\]

\[
\hat{\gamma}_j^s = \frac{c_i^F c_j^F \pi_{ij}^{sf} \gamma_j^r}{\hat{p}_{ij}^{sf}}
\]

\[
Y_j' = \sum_{i=1}^{R} \sum_{r=1}^{R} \pi_{ij}^{rs} Y_j^s Y_i^r + \sum_{i=1}^{N} \pi_{ij}^{sf} \alpha_i^s I_i
\]

\[
\sum_{i=1}^{N} \sum_{r=1}^{R} \pi_{ij}^{rs} Y_j^s Y_i^r + \hat{w}_j w_i L_i = \sum_{i=1}^{N} \sum_{r=1}^{R} \pi_{ij}^{rs} Y_i^r Y_j^s + \sum_{i=1}^{N} \sum_{r=1}^{R} \pi_{ij}^{sf} \alpha_i^s I_i
\]

### 2.2 The measure for the welfare effects

We use real wages to measure welfare effects (Arkolakis et al., 2012). Real wages can be expressed as \( w_j / P_j \), where \( w_j \) denotes the nominal wage and \( P_j \) denotes the consumer price index.
We decompose the relative change in real wages \( \frac{\hat{w}_j}{\hat{P}_j} \) to obtain

\[
\ln \left( \frac{\hat{w}_j}{\hat{P}_j} \right) = -\sum_{s=1}^{S} \frac{\alpha_j^s}{\theta_j^s} \ln \hat{\pi}_{jj}^{sf} - \sum_{s=1}^{S} \frac{\alpha_j^s}{\theta_j^s} \frac{1 - \gamma_j^s}{\gamma_j^s} \ln \hat{\pi}_{jj}^{sf} - \sum_{s=1}^{S} \frac{\alpha_j^s}{\theta_j^s} \frac{\gamma_j^s}{\gamma_j^s} \ln \sum_{r=1}^{R} \hat{P}_{rr}^{ts} \hat{P}_{rr}^{sf} \]  

(19)

The change in real wages can be decomposed into the change in the domestic share of final goods and the change in the price of intermediates relative to that of final goods. From the first term and the second term of equation (19), the change in real wages is only related to the share of trade in final goods produced domestically, and this finding is one of the crucial differences between our model and Caliendo and Parro (2015).

We consider trade cost reduction in final goods. According to the last term of equation (19), the price of final goods in country \( j \)'s sector \( s \) \( \hat{P}_{jj}^{sf} \) decreases directly, ceteris paribus, increasing real wages. But at the same time, a fall in \( \hat{P}_{jj}^{sf} \) also indirectly decreases domestic share of final goods \( \hat{\pi}_{jj}^{sf} \), thereby raising the real wage. The implications for reduction of intermediates are more complicated. On the one hand, the price of imported intermediate goods \( \hat{P}_{jr}^{rs} \) declines, which raises real wages. One the other hand, a decline in \( \hat{P}_{jr}^{rs} \) also reduces production costs \( \hat{c}_j^s \), which in turn the share of domestic final goods expenditures \( \hat{\pi}_{jj}^{sf} \) in equation (16) increases. Thus, the effect of a decline in tariffs on imported intermediate goods on real wages depends on the outcome of the interaction of these two forces.

### 2.3 The measure for global value chain effects

Next, we construct a new input-output system. There are two key elements. \( Z_{ij}^{rs'} \) denotes the counterfactual flows in intermediates from sector \( r \) in region \( i \) used for production to sector \( s \) in region \( j \), and \( Y_{ij}^{f'} \) denotes the counterfactual flows of final goods from sector \( r \) in region \( i \) consumed in region \( j \). This is also one of the extensions of our paper's model compared to Caliendo and Parro (2015).\(^7\)

According to Eq. (18), it can be obtained,

\[
Z_{ij}^{rs'} = \pi_{ij}^{rs'} y_j^{rs'} x_j^{st} 
\]  

(20)

\[
Y_{ij}^{f'} = \pi_{ij}^{f'} a_j^r [\sum_{r=1}^{R} (X_j^{r'} - \sum_{i=1}^{N} \sum_{r=1}^{R} Z_{ij}^{rs'}) + D_j'] 
\]  

(21)

The elements of value added \( V A_{ij}^{r'} \) are,

\[
V A_{ij}^{f'} = (X_j^{r'} - \sum_{i=1}^{N} \sum_{r=1}^{R} Z_{ij}^{rs'}) 
\]  

(22)

We measure the GVC effects of the BRI from two aspects: GVC participation and GVC production length. The GVC participation index indicates the degree of participation of a country, industry, or enterprise in the global value chains. The deeper the participation index, the more production links it undertakes. GVC production length indicates the average distance (number of stages) in the GVCs of the products produced by a country, industry, or enterprise to their final consumption. According to the Smile Curve, a higher production length in GVCs implies higher value added and greater dominance in chains (Meng et al., 2020). For each measure, we further distinguish the direction of trade in GVCs. Fig. 1 illustrate the distinction of the forward- and backward-linkage. Take water conservancy construction as an example, industries at forward-linkage refers to the sectors that are the destination of products in the water conservancy construction industry exported to, such as industrial and residential use, irrigation, hydropower, inland water transportation, freshwater aquaculture and among others. And industries at backward-
linkages represent the intermediate inputs of the water conservancy construction, such as steel, cement, electricity, labor and residence.

![Diagram](image)

**Fig. 1** Distinction between forward- and backward-linkages

Firstly, for the GVC participation index. Following Wang et al. (2022), GVC participation index is categorized into Forward-Linkage GVC Participation and Backward-Linkage GVC Participation. Forward-Linkage GVC Participation (PTF) describes the domestic value added generated from a country-industry’s GVC activities through downstream firms as a share of that country-industry’s total value added. If the share is larger, it implies a deeper forward participation in GVCs. PTF takes values between 0 and 1. Backward-Linkage GVC Participation (PTB) measures the percentage of a country-industry’s total production of final goods and services that represent the value added that is involved in GVC activities through upstream firms. We use PTF to denote the Forward-Linkage GVC Participation of a country-industry and PTB to denote the Backward-Linkage GVC Participation of a country-industry. Take the counterfactual values of GVC participation in country $i$ and industry $s'$ as an example, we derive,

$$PTB_{i}^{s'} = \left( \sum_{j}^{\ell} \sum_{r'}^{l} v_{j}^{s'} r_{i}^{s'} \sum_{k}^{J} \sum_{j}^{S} a_{i k}^{s'} b_{i j}^{s'} F_{i}^{s'} \right) / \left( \sum_{j}^{\ell} \sum_{r'}^{l} b_{i j}^{s'} F_{i}^{s'} \right)$$  \hspace{1cm} (23)

$$PTF_{i}^{s'} = \left( v_{i}^{s'} l_{i i}^{s'} \sum_{k}^{J} \sum_{j}^{S} a_{i k}^{s'} \sum_{j}^{S} b_{i j}^{s'} F_{i}^{s'} \right) / \left( v_{i}^{s'} \sum_{j}^{S} b_{i j}^{s'} F_{i}^{s'} \right)$$  \hspace{1cm} (24)

Where $v_{i}^{s'}$ is the value-added coefficient for industry $s$ in country $i$ and calculates as $VA_{i}^{s'}/X_{i}^{s'}$. $F_{i}^{s'}$ is the final consumption of industry $s'$ in country $i$. The element $a_{i k}^{s'}$ is the inputs of industry $i$ in country $k$ from imported intermediates in industry $s$ of country $i$ and is calculated as $Z_{i k}^{s'}/X_{k}^{s'}$. The element $b_{i j}^{s'}$ represents the production that industry $r$ in country $j$ directly and indirectly requires from industry $t$ in country $k$ to produce one unit of final consumption and is obtained by Leontief inverse matrix $B' = (1 - A')^{-1}$. $l_{i i}^{s'}$ is the element in the local Leontief inverse matrix, and the matrix $L'$ can be calculated as $L' = (1 - A_{i i}')^{-1}$.

Then we define GVC Position Index (Ps_GVC), which is the ratio of the average distance from a country or industry's output to final demand, to the average distance from their output to the primary inputs in the GVCs. This GVC Position Index serves as a linear measure to determine where a country or industry stands along the linear sequence of GVCs. A higher value indicates a position in the relative upstream segment of GVCs, while a lower value signifies a more downstream position.

$$Ps_{GVC}^{s'} = PLF_{GVC}^{s'}/PLB_{GVC}^{s'}$$  \hspace{1cm} (25)
Among these, Forward-Linkage GVC Production Length (PLF_GVC) measures the average production length of domestic value-added embodied in intermediate products from its first use as a primary input until its final absorption in final goods and services. Take PLF_GVC of country $i$ and industry $s$ as an example, we derive

$$PLF_{GVC}^{i} = \left[ v_{i}^{'j} \left( \sum_{k}^{k} \sum_{s}^{s} b_{ik}^{s} r_{i}^{s} - \sum_{k}^{k} \sum_{s}^{s} v_{k}^{s} r_{i}^{s} F_{j}^{r} \right) \right] \sum_{k}^{k} \sum_{s}^{s} b_{ik}^{s} r_{i}^{s} F_{j}^{r} / \left[ \sum_{k}^{k} \sum_{s}^{s} b_{ik}^{s} r_{i}^{s} F_{j}^{r} \right]$$

(26)

Backward-Linkage GVC Production Length (PLB_GVC) measures the average production length of foreign value-added embodied in intermediate imports from their first use as primary inputs until their final absorption into a country-industry’s production of final products. Take PLB_GVC of country $i$ and industry $s$ as an example, we derive

$$PLB_{GVC}^{i} = \left[ v_{i}^{'j} \left( \sum_{k}^{k} \sum_{s}^{s} b_{ik}^{s} r_{i}^{s} - \sum_{k}^{k} \sum_{s}^{s} v_{k}^{s} r_{i}^{s} F_{j}^{r} \right) \right] \sum_{k}^{k} \sum_{s}^{s} b_{ik}^{s} r_{i}^{s} F_{j}^{r} / \left[ \sum_{k}^{k} \sum_{s}^{s} b_{ik}^{s} r_{i}^{s} F_{j}^{r} \right]$$

(27)

For PTF, according to equation (12), a reduction in intermediate trade costs $\hat{\tau}_{ij}^{rs}$ decreases the prices of intermediates $\hat{P}_{ij}^{rs}$ sourced from industry $r$. With wage held constant, this reduction lowers the costs, $\hat{c}_{j}^{s}$, for industry $s$ in country $j$. In equation (15), a decrease in $\hat{c}_{j}^{s}$ encourages more exports in intermediates, thus increasing its involvement from downstream and raising its PTF.

For PTB, as indicated by equations (13) and (15), the reduction in intermediate trade costs $\hat{\tau}_{ij}^{rs}$ increases intermediates by country $j$’s industry $s$ from country $i$’s industry $r$. This implies that country $j$’s industry $s$ incorporates more foreign value-added stages in its exported products, thereby enhancing its PTB.

Concerning $PLF_{GVC}^{i}$, the mechanism is more complex. On the one hand, as per equation (12), the reduction in intermediate trade costs $\hat{\tau}_{ij}^{rs}$ decreases in the prices of intermediates, $\hat{P}_{ij}^{rs}$. With constant wages, the reduction lowers $\hat{c}_{j}^{s}$. According to equations (15) and (16), it prompts the industry to export more intermediates. This, in turn, increases the average distance from the industry's output to final demand, resulting in higher $PLF_{GVC}^{i}$. On the other hand, reduction in $\hat{\tau}_{ij}^{rs}$ decreases $\hat{c}_{j}^{s}$, thereby lowering prices of final goods $\hat{P}_{ij}^{rs}$ and stimulating the industry to export more final goods. This reduces the average distance from the industry’s output to final consumption, then $PLF_{GVC}^{i}$ decreases. Therefore, a decrease in intermediate trade costs $\hat{\tau}_{ij}^{rs}$ on $PLF_{GVC}^{i}$ depends on the net effect of these two opposing forces. Regarding $PLB_{GVC}^{i}$, based on equations (13) and (15), the reduction in intermediate trade costs $\hat{\tau}_{ij}^{rs}$ increases imports in intermediates by country $j$’s industry $s$ from country $i$’s industry $r$. This implies that industry $s$ in country $j$ incorporates more foreign production stages in its exported products, thus increasing average distance from the primary factors to the outputs, thus raising $PLB_{GVC}^{i}$.

In contrast to changes in intermediate trade cost for imports, the mechanism by which changes in the importing trade cost of final goods affect GVCs measures is relatively straightforward. As per equations (14) and (16), the reduction in the importing cost of final goods, $\hat{\tau}_{ij}^{rf}$, increases in the share of final goods imports from country $i$ and industry $r$. However, it simultaneously inhibits the import of intermediates by country $j$ from country $i$’s industry $r$, subsequently leading to a reduction in the import of intermediates by industries in country $j$. Thus, this generates opposing effects of reduction in intermediate trade cost.

The mechanism presented here illustrates the first-moment effect of trade liberalization. Within a general equilibrium framework, the reduction in trade costs among Belt and Road Initiative members reflects interaction and complex effects of trade liberalization originating from...
other countries and their trade liberalization to other countries, along with the unchanged trade costs with non-members. Changes in GVCs metrics between countries depend on the general equilibrium outcomes of market clearing.

3. Trade cost estimates and characterization facts

3.1 Estimation of trade costs

Head and Ries (2001) proposed the H-R index to estimate trade costs based on historic bilateral trade flows between countries. Albrecht and Tombe (2016) argue that the inter-country trade share of each region contains information about the country’s trade costs. Specifically, if there are no trade costs between countries, the share of trade between countries and other countries would be equal to the domestic trade share. The H-R index is calculated as follows.

\[ \bar{\tau}_{ij}^r = \sqrt{\frac{\tau_{ij}^r \tau_{ji}^r \pi_{ij}^r \pi_{ji}^r}{\pi_{ij}^r \pi_{ji}^r}}^{1/2} \theta^r \]  

(28)

Where \( \bar{\tau}_{ij}^r \) denotes symmetric component, \( \tau_{ij}^r \) is the bilateral trade costs faced by country \( i \) in industry \( r \) from country \( j \) and \( \tau_{ji}^r \) is the intra-regional trade cost for country \( i \) on industry \( r \). \( \pi_{ij}^r \) represents the share of country \( j \)'s imports from country \( i \) on industry \( r \). \( \pi_{ji}^r \) represents the domestic share of country \( i \) on industry \( r \). The parameter \( \theta^r \) denotes trade elasticity of the industry \( r \).

Further, we estimate asymmetric trade costs. Asymmetries in trade costs are due to additional export costs. Poorer countries usually have higher export trade costs than richer countries. There is large heterogeneity for different countries. To measure exporter-specific costs, we follow Waugh (2010) and assume \( \ln \left( \frac{\pi_{ij}^r}{\pi_{jj}^r} \right) = S^r_i - S^r_j - \theta \ln (\tau_{ij}^r) \). \( S \) terms capture region-specific factors such as productivity and factor prices. If \( \tau_{ij}^r = D_{ij}^x \tau_i^r \) then

\[ \ln \left( \frac{\pi_{ij}^r}{\pi_{jj}^r} \right) = \delta^r \ln (D_{ij}) + \eta^r_j + \epsilon_{ij}. \]  

(29)

Where \( \eta_i = S^r_i - \theta \ln (\tau_i^r) \) and \( \eta_j = -S^r_j \). \( D_{ij} \) denotes the geography distances between country \( i \) and country \( j \). We infer the exporter-specific trade costs from fixed-effect estimates \( \hat{\tau}_i = e^{-\eta_i + \eta_j} \) and adjust the Head-Rice index \( \hat{\tau}_{ij} \) with \( \tau_{ij} = \tau_{ij} \sqrt{\hat{\tau}_{ij}/\hat{\tau}_j} \).

3.2 Analysis of Trade Cost Changes between BRI and Non-BRI Countries

To analyze the differential characteristics of trade cost changes between the BRI and non-BRI countries, we estimate the importing trade costs for intermediates and final goods from 2009 to 2019. The results are presented in Fig. 2, where Panel A denotes trade costs in intermediates and Panel B denotes trade costs in final goods. Figure 2 presents the results for non-BRI's importing trade costs from non-BRI countries and BRI countries, respectively and BRI's importing trade costs from non-BRI countries and BRI countries, respectively.

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8 We assume that trade costs for domestic is 1 and \( \tau_i^r = 1 \). Therefore \( \tau_{ij}^r \) is the relative trade costs, and if \( \tau_{ij}^r = 1.5 \), then the bilateral trade costs faced by country \( j \) in importing sector \( r \) products from country \( i \) is 1.5 times the costs of domestic trade.

9 Caliendo and Parro (2015) estimated the trade elasticity of disaggregated manufacturing industries, including the 16 manufacturing industries in the ADB MRIO data and in the range of [1.82,16.52]. The specific industry elasticities are presented in Appendix B of Table B.2.
As shown in Fig. 2, several notable features emerge: firstly, for intermediates in Panel A, countries importing from the BRI face relatively higher trade costs than those importing from non-BRI. Specifically, trade costs in intermediates for the BRI countries importing from other BRI countries decreased from 18.2 in 2009 to 12.5 in 2019, with a substantial drop of 5.7. Meanwhile, trade costs in intermediates for the BRI countries importing from non-BRI countries decrease from 11.0 in 2009 to 7.9 in 2019, with a moderate decrease of 3.1. Notably, the former experienced a more significant decline than the latter. Also, non-BRI countries importing intermediates from the BRI countries witnessed a moderate reduction of 3.8. Meanwhile, trade costs for non-BRI imports from the non-BRI region change smoothly, with a drop of 1.3.

Secondly, compared with Panel A, trade costs in final goods are generally larger than in intermediates as shown in Panel B of Fig. 2. Moreover, the reductions for final goods are also generally larger. The trade costs for BRI countries importing final goods from other BRI countries decrease significantly from 19.5 in 2009 to 11.3 in 2019. Meanwhile, BRI countries’ imports from non-BRI countries decrease from 13.3 in 2009 to 8.9 in 2019. Once again, the former experienced a more significant decline.

In summary, BRI contributes to substantial reductions in importing trade costs for other BRI countries. In contrast, the reductions in trade costs for non-BRI countries remain moderate, showing great asymmetric patterns. These observations are closely related to the quantitative results presented later.

4. Stylized facts and Data sources
4.1 Stylized facts regarding the global value chains measures
In order to analyze the typical characteristics of forward- and backward-linkage GVC participation of BRI countries in the base year, we utilized ADB multi-regional input-output data at baseline to compute the participation for 13 representative countries. These 13 countries include China, Indonesia, India, Italy, South Korea, Malaysia, Thailand, Vietnam, the United States, Japan,
Germany, France, and the United Kingdom. The first eight countries are BRI members, while the latter five are non-BRI countries.

Fig. 3 displays the Forward-Linkage GVC Participation (PTF) for these countries. We further divide the index into the share of value added generated through GVC production activities by BRI countries and non-BRI countries' downstream enterprises, respectively, termed PTF from BRI and PTF from non-BRI.

The key observations include, firstly, there are varying PTF among countries with notable heterogeneity. BRI countries, such as Malaysia, Thailand, and Vietnam, demonstrate significantly higher PTF, suggesting a high reliance on foreign countries for production and sales. Secondly, we divide PTF according to the sources of value-added. PTF to non-BRI countries is generally higher for most countries when compared to their PTF from BRI countries. The market share for non-BRI countries is larger. For instance, in Malaysia, PTF from non-BRI constitutes 72.7% (0.24/0.33) of its change, whereas PTF from BRI countries accounts for only 27.3%.

The characteristics of PTB across countries are similar to PTF. Fig. 4 illustrates the PTB for each country at baseline. Notably, larger economies like China, the United States, and Japan exhibit relatively lower levels of PTB due to their large domestic markets. In contrast, many BRI countries with smaller sizes, such as Malaysia, Thailand, and Vietnam, rely more on foreign intermediate inputs in their production processes with relatively higher levels of PTB. Additionally, for most countries, PTB exposed to non-BRI countries is significantly higher compared to those exposed to BRI.

Fig. 3 The Forward-Linkage GVC participation in the baseline scenario

Fig. 4 The Backward-Linkage GVC participation in the baseline scenario
Table 1 presents the GVC participation of different categories and its decompositions (which are weighted by the outputs). We highlight several interesting facts. First, on average, both forward- and backward-linkage GVC participation in the BRI countries exceed those in non-BRI countries. It indicates that BRI countries highly rely on GVCs trade in the process of production. Second, BRI countries exhibit higher PTB compared to its PTF, while non-BRI countries show the opposite pattern—higher PTF compared to its PTB. It implies that BRI countries mainly participate in the lower-end segments of the GVCs. In contrast, non-BRI countries, such as the United States and European countries, tend to be positioned more upstream in the GVCs, with their products relying more on foreign markets for product sales. According to the "Smile Curve" theory, countries positioned further upstream in the GVCs reap greater benefits. Lastly, European countries that have joined the Belt and Road Initiative have similar exposure to BRI regions compared to EU member states that have not joined at baseline.

**Table 1 Forward- and Backward- linkage GVC Participation by Categories**

<table>
<thead>
<tr>
<th>Region</th>
<th>PTF at baseline</th>
<th>PTF from BRI</th>
<th>PTB at baseline</th>
<th>PTB from BRI</th>
<th>PTB from Non-BRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRI</td>
<td>0.169</td>
<td>0.055</td>
<td>0.114</td>
<td>0.174</td>
<td>0.055</td>
</tr>
<tr>
<td>Non-BRI</td>
<td>0.165</td>
<td>0.051</td>
<td>0.114</td>
<td>0.156</td>
<td>0.046</td>
</tr>
<tr>
<td>ASEAN</td>
<td>0.289</td>
<td>0.088</td>
<td>0.201</td>
<td>0.276</td>
<td>0.097</td>
</tr>
<tr>
<td>Eur BRI</td>
<td>0.176</td>
<td>0.055</td>
<td>0.121</td>
<td>0.164</td>
<td>0.055</td>
</tr>
<tr>
<td>Eur Non-BRI</td>
<td>0.174</td>
<td>0.043</td>
<td>0.130</td>
<td>0.157</td>
<td>0.040</td>
</tr>
</tbody>
</table>

Notes: BRI refers to the Belt and Road initiative countries. Non-BRI refers to the countries that didn’t joined the Belt and Road initiative. ASEAN refers to the Association of Southeast Asian Nations; Eur BRI refers to the European countries that joined the initiative. Eur Non-BRI refers to the European countries that didn’t joined the initiative.

We present the results for GVC production lengths at baseline in Fig. 5. Firstly, the GVC production lengths of countries exhibit significant heterogeneity. Non-BRI countries like the United States and Japan tend to have shorter GVC production lengths. In contrast, BRI countries like Malaysia and South Korea exhibit longer GVC production lengths. Secondly, countries’ production lengths from non-BRI generally are longer, indicating a higher reliance on foreign markets. Thirdly, countries are also heterogeneous in forward- and backward-linkage GVC production lengths. For countries like France, the United Kingdom, Germany, and the United States, their Forward- and Backward-linkage GVC Production Lengths are quite similar. However, in the case of countries such as China, South Korea, Thailand, and Vietnam, the Backward-Linkage GVC Production Length is significantly longer than the Forward-Linkage GVC Production Length. These countries locate more downstream, with the output being further from the primary factors and align with their great involvements in downstream activities within GVCs.
4.2 Data sources

Our data sources are from the Asian Development Bank Multi-Regional Input-Output Database (ADB-MRIO) from 2009 to 2019. The ADB-MRIO includes 63 countries (62 and 1 RoW) and 35 sectors. These countries include not only developed countries such as the United States, Japan, and EU but also developing countries like Vietnam and Kazakhstan. It thus provides comprehensive requirements for estimating trade costs and conducting quantitative analysis for BRI. Additionally, the specific signing time for countries' memoranda is provided by the Belt and Road Initiative portal website. The variables used in estimation of trade cost are from CEPII, such as dummy for common languages, geographic distances, and dummy for adjacency.

4.3 Calibration

The trade elasticities are obtained from Caliendo and Parro (2015). We also derive information on the share of final consumption ($\alpha^{f}_j$), trade share of intermediates ($\pi^{rs}_{ij}$) and trade share of final goods ($\pi^{f}_{ij}$), the share of value-added ($\gamma^{v}_j$), the share of intermediate inputs ($\gamma^{rs}_{j}$) ($\gamma^{rs}_{j}$). These parameters can be obtained from the ADB-MRIO.

5. Quantifying the economic effects of the Belt and Road Initiative

We select the base year as 2009 and the counterfactual year as 2019. We evaluate the welfare, trade, and global value chain effects among BRI members. Specifically, we keep the trade costs between BRI countries and non-BRI countries constant while only changing the trade costs between BRI countries. In the counterfactuals, we focus more on the impacts of changes in trade costs without specifying their precise sources, which may result from factors such as road infrastructure and institutional barriers.

We present the results in two aspects. Firstly, we aggregate five categories: the BRI countries, non-BRI countries, ASEAN countries (Maritime Silk Road), European countries within BRI (Land-based Silk Road)\(^\text{11}\), and European countries outside BRI. Secondly, we quantify the economic effects.
impacts of BRI on 13 representative countries. These countries include China, Indonesia, India, Italy, South Korea, Malaysia, Thailand, Vietnam, the United States, Japan, Germany, France, and the United Kingdom. The first eight countries are BRI members, while the latter five are non-BRI countries.

5.1 Trade and welfare effects

Table 2 presents the changes in welfare effects of BRI in 2019 compared to 2009. Firstly, the welfare effects for BRI countries (4.398%) are more significant than for non-BRI countries (0.019%). The whole world benefits from the initiative at 1.011%. Secondly, there are substantial trade creation effects within BRI countries, with exports of 39.137% and imports of 32.448%. Notably, for imports, the trade creation effects of final goods surpass those of intermediates. For exports, the growth in the exports of final goods (32.480%) significantly exceeds that of intermediates (29.466%).

Thirdly, after joining the BRI, ASEAN members witnessed substantial growth in welfare (16.325%) and trade volume, with total exports and imports increasing by 73.891% and 82.875%, respectively. Moreover, the growth in the trade of intermediates outpaces that of final goods.

Fourthly, European countries that have joined the BRI experience significant gains in welfare (4.166%) and trade volume, with total exports and imports by 36.519% and 24.201%, respectively. In contrast, EU countries that have not joined the BRI observe a slight decline in welfare and trade.

Fig. 6 illustrates welfare effects for 13 representative countries. Malaysia, Vietnam, and Thailand experience significant welfare gains, with 43.5%, 35.7%, and 13.3%, respectively. In contrast, larger economies with lower external trade dependencies, such as China, experience moderate changes in welfare. For example, China's welfare gains are 1.148%. All BRI countries benefit from trade liberalization. Conversely, non-BRI countries like the United States, Japan, and Germany experience slight welfare loss, with 0.007%, 0.073%, and 0.008%, respectively. Their welfare losses are minor compared to the welfare gains in BRI countries. Overall, the BRI narrows the gap between BRI and non-BRI countries.
Fig. 6 The welfare effects in representative countries

Fig. 7 illustrates the effects on total exports, exports in intermediates, and exports in final goods for representative countries. This reveals significant heterogeneity in trade effects across countries. Notably, countries such as Thailand and Vietnam experience the most significant trade effects. Vietnam, in particular, has witnessed a substantial increase in both exports of final goods (376.3%) and intermediates (140.0%). In these countries, exports in final goods surpass exports in intermediates. China is an outlier and its export growth in intermediates (36.4%) outpaces that of final goods (7.1%). Conversely, for non-BRI countries such as the United States, Japan, Germany, France, and the United Kingdom, trade effects exhibit minimal changes or even negative trends.

Fig. 7 The trade effects on exports in representative countries

Fig. 8 presents the changes in total imports, imports in intermediates, and imports in final goods for representative countries. Firstly, trade effects exhibit considerable variations among different countries. Countries such as Vietnam, Malaysia, and Thailand continue to experience substantial growth in trade effects. Secondly, the trade effects on imports for non-BRI countries show similar effects on exports.
5.2 Distinguishing Forward and Backward Global Value Chain Effects

Table 3 presents the impact of BRI on GVC participation for different categories. Column (1)-(3) presents the change in PTF, the change in PTF from BRI, and the change in PTF from non-BRI. Column (4)-(6) presents the change in PTB, the change in PTB from BRI, and the change in PTB from non-BRI. Several interesting findings emerge:

Firstly, overall, the change in PTF for BRI countries is more substantial than for non-BRI countries (4.4% vs 0.2%). This indicates that the BRI initiative not only generates trade creation effects within the region but also exerts a positive spillover on countries outside the BRI. Decomposing the change in participation reveals that almost all PTF changes are attributed to a surge in exposure to the BRI, while exposure to non-BRI yields negligible changes, even turning negative. For instance, for non-BRI countries, exposure to the BRI increases PTF by 0.3%, while exposure to non-BRI decreases it by 0.1%.

Secondly, the change in PTB for BRI countries increases, with a magnitude of 5.9%, while non-BRI countries exhibit minimal changes. Exposure to the BRI increases backward-linkage GVC participation by 6.1%, while exposure to non-BRI decreases by 0.2%. This indicates that the initiative among BRI countries promotes the imports of intermediate inputs from members but reduces sources from non-members.

Thirdly, ASEAN countries experience a growth in both PTF and PTB. Specifically, PTF for ASEAN countries increased by 3.7%. Through decomposition, exposure to the BRI increases by 9.2%, while exposure to non-BRI decreases by 5.5%. This underscores that for ASEAN countries, participation in the BRI initiative promotes trade in intermediate from BRI countries, demonstrating the trade creation effects. However, the BRI have trade diversion effects between ASEAN countries and non-BRI countries.

Fourthly, compared to non-BRI countries in Europe, European countries that have joined the BRI initiative witness a noticeable growth in both PTF and PTB. For instance, The PTF in European countries that join the initiative is 2.8%, with exposure to the BRI contributing a rise of 4.1%, while exposure to non-BRI has declined by 1.4%.
Table 3 Changes in GVC participation in Different Categories and Their Decomposition (%)

<table>
<thead>
<tr>
<th>Category</th>
<th>Change in PTF</th>
<th>Change in PTF from BRI</th>
<th>Change in PTF from Non-BRI</th>
<th>Change in PTB</th>
<th>Change in PTB from BRI</th>
<th>Change in PTB from Non-BRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRI</td>
<td>4.40</td>
<td>5.50</td>
<td>-1.10</td>
<td>5.90</td>
<td>6.10</td>
<td>-0.20</td>
</tr>
<tr>
<td>Non-BRI</td>
<td>0.20</td>
<td>0.30</td>
<td>-0.10</td>
<td>-0.10</td>
<td>-0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>ASEAN</td>
<td>3.70</td>
<td>9.20</td>
<td>-5.50</td>
<td>9.90</td>
<td>12.70</td>
<td>-2.80</td>
</tr>
<tr>
<td>Eur BRI</td>
<td>2.80</td>
<td>4.10</td>
<td>-1.40</td>
<td>4.30</td>
<td>4.30</td>
<td>0.10</td>
</tr>
<tr>
<td>Eur Non-BRI</td>
<td>0.10</td>
<td>0.10</td>
<td>0.00</td>
<td>-0.20</td>
<td>-0.10</td>
<td>-0.10</td>
</tr>
</tbody>
</table>

For representative countries, the changes in Forward-Linkage GVC Participation exhibit heterogeneity, as shown in Fig. 9. Within BRI, countries show heterogenous effects in PTF, primarily driven by exposure to participation from within the BRI. Notably, Indonesia and Thailand experienced significant growth of 11.0% and 8.0%, respectively. In contrast, Italy, China, and India exhibit relatively minor gains of 1.9%, 2.6%, and 2.6%, respectively. Meanwhile, non-BRI countries show minimal changes in PTF; for instance, Germany and the United Kingdom exhibit changes of only 0.2%. This underscores that the BRI initiative has positive impacts on PTF within BRI. At the same time, its influence on non-BRI, while existent, is comparatively minor.

Similarly, the changes in Backward-Linkage GVC participation (PTB) display heterogeneity across countries, as depicted in Fig. 10. Within the BRI, countries experience heterogeneous growth in PTB, primarily driven by increased exposure to participation from other countries within the BRI. Notably, Vietnam, Malaysia, and Thailand exhibit significant growth of 17.5%, 13.7%, and 13.5%, respectively. Conversely, Italy, India, and China show smaller changes of 1.5%, 1.8%, and 2.4%, respectively.

Meanwhile, non-BRI countries exhibit negligible changes in PTB. This indicates its influence on PTB of non-BRI is minimal. Additionally, decomposition of PTB changes for countries within the BRI reveals that the dominant driver of increased participation is from the exposure to PTB from other countries within the BRI, emphasizing that the reduction in trade costs fosters imports of inputs among countries. Countries within the BRI increasingly incorporate intermediate inputs from...
other BRI countries into their production processes, further strengthening production linkages.

**Fig. 10** the changes and decomposition of PTB in the typical countries

Next, we focus on the results for GVC position and production length. Fig. 11 illustrates the impact of BRI on the GVC position (Ps_GVC) for representative countries, encompassing both the overall effect and its decomposition. Overall, there is a noticeable restructuring in countries' positions from BRI.

Firstly, South Korea, India, and Thailand exhibit substantial changes in their GVC position index, which increase 0.101, 0.097, and 0.091, respectively. China and Italy follow closely with 0.045 and 0.046. A decomposition based on the source of these changes reveals that countries like China, India, and Thailand primarily benefit from improvements in other BRI countries. For instance, China's GVC position index from the BRI increases by 0.103. At the same time, its positioning from non-BRI experiences a minor decline of 0.007, indicating a closer trade relationship with BRI. In contrast, countries like Italy exhibit more significant improvements in Ps_GVC from their non-BRI, with Italy's position from non-BRI increasing by 0.097.

Secondly, a decline in GVC position within the BRI is primarily observed in countries such as Indonesia and Malaysia, with decreases of 0.023 and 0.089, respectively. Due to the deepening of specialization and complementary utilization of labor resources, these countries increasingly participate in backward production activities in order to cooperate the other BRI countries.

**Fig. 11** The changes in the GVC position and its decomposition
Furthermore, we dig into Forward- and Backward-linkage GVC production lengths. The results are presented in Table 4. Column (1)-(3) presents change in PLF_GVC and its compositions. Column (4)-(6) shows change in PLB_GVC and its compositions. For Forward-Linkage GVC production length (GVC_PLF), the overall change in GVC_PLF within BRI surpasses that of non-BRI countries. These changes primarily emanate from other BRI countries within the region. For instance, Thailand’s GVC_PLF increases by 0.096, with contributions of 0.097 from within. For Backward-Linkage GVC production length (GVC_PLB), countries within the BRI region experience a notable increase in their GVCs, primarily due to extension in production lengths stemming from other countries within BRI as well. Notably, Vietnam, Thailand, and Indonesia exhibit substantial increases of 0.096, 0.087, and 0.082, respectively, with more pronounced increases in GVC_PLB. It indicates a trend towards downstream production. Conversely, Italy, China, and India display minor increases of 0.027, 0.027, and 0.018, respectively. Meanwhile, non-BRI countries also witnessed slight improvements in backward-linkage GVC production length, albeit minimal, such as the 0.001 increase in the United Kingdom.

<table>
<thead>
<tr>
<th>Country</th>
<th>Change in PLF_GVC</th>
<th>Change in PLF_GVC from BRI</th>
<th>Change in PLF_GVC from Non-BRI</th>
<th>Change in PLB_GVC</th>
<th>Change in PLB_GVC from BRI</th>
<th>Change in PLB_GVC from Non-BRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>0.022</td>
<td>0.021</td>
<td>0.001</td>
<td>0.027</td>
<td>0.023</td>
<td>0.004</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0.109</td>
<td>0.097</td>
<td>0.011</td>
<td>0.082</td>
<td>0.061</td>
<td>0.021</td>
</tr>
<tr>
<td>India</td>
<td>0.031</td>
<td>0.032</td>
<td>-0.001</td>
<td>0.020</td>
<td>0.018</td>
<td>0.002</td>
</tr>
<tr>
<td>Italy</td>
<td>0.021</td>
<td>0.015</td>
<td>0.006</td>
<td>0.017</td>
<td>0.021</td>
<td>-0.004</td>
</tr>
<tr>
<td>South Korea</td>
<td>0.051</td>
<td>0.056</td>
<td>-0.005</td>
<td>0.031</td>
<td>0.035</td>
<td>-0.005</td>
</tr>
<tr>
<td>Malaysia</td>
<td>0.054</td>
<td>0.095</td>
<td>-0.041</td>
<td>0.075</td>
<td>0.120</td>
<td>-0.045</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.096</td>
<td>0.097</td>
<td>-0.001</td>
<td>0.087</td>
<td>0.105</td>
<td>-0.018</td>
</tr>
<tr>
<td>Vietnam</td>
<td>0.059</td>
<td>0.092</td>
<td>-0.033</td>
<td>0.096</td>
<td>0.105</td>
<td>-0.009</td>
</tr>
<tr>
<td>United States</td>
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<td>0.001</td>
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<td>0.000</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>Japan</td>
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<td>0.000</td>
<td>0.000</td>
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</tr>
<tr>
<td>Germany</td>
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<td>-0.003</td>
</tr>
<tr>
<td>France</td>
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<td>-0.002</td>
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<tr>
<td>United Kingdom</td>
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<td>-0.003</td>
<td>0.001</td>
<td>0.002</td>
<td>-0.001</td>
</tr>
</tbody>
</table>

6. Further Analysis
6.1 The economic effects if Germany had joined the Belt and Road Initiative
Germany, as a major manufacturing hub in Europe, is also one of the most important countries along the BRI route. Germany may consider joining the BRI initiative in the future. Being an economically advanced country situated at the upstream of the production chain, Germany complements the production structures of many BRI countries. Then, it can fully leverage the comparative advantages and contribute to welfare gains. In the baseline scenario, Germany is not considered part of the BRI. However, in this section, we assume there are changes in trade costs between Germany and BRI countries and investigate the economic effects of Germany had joined the BRI initiative.

Table 5 presents the welfare and global value chain effects of the counterfactual scenario.
Column (1) shows the welfare effects; Column (2)-(3) presents the measures for PTB and PTF; Column (4)-(5) shows the results for PLF_GVC and PLB_GVC, respectively; Column (6) presents the results for GVC position index.

Firstly, when compared to the baseline scenario, joining the initiative not only has welfare gains for Germany but also boosts the welfare of other BRI members, such as China (1.317% vs 1.148%) and India (1.612% vs 1.369%). Germany's welfare increases from -0.073% to 4.149%. Secondly, if Germany were to join the BRI, its PTF would increase by 2.638%, and its PTB would improve by 2.451%. Additionally, its GVC_PLF and GVC_PLB would increase by 0.029 and 0.028, respectively. In the baseline scenario where Germany does not join, the changes are relatively small or even negligible. From an economic perspective, the BRI would help Germany fully leverage its advantages and participate more actively in the production of GVCs and division of labor.

### Table 5 The economic effects if Germany had joined the Belt and Road Initiative

<table>
<thead>
<tr>
<th>Country</th>
<th>Welfare</th>
<th>Change in PTF</th>
<th>Change in PTB</th>
<th>Change in PLF_GVC</th>
<th>Change in PLB_GVC</th>
<th>Change in Ps_GVC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>China</td>
<td>1.317</td>
<td>2.807</td>
<td>2.664</td>
<td>0.024</td>
<td>0.030</td>
<td>0.046</td>
</tr>
<tr>
<td>Indonesia</td>
<td>11.562</td>
<td>12.258</td>
<td>10.932</td>
<td>0.120</td>
<td>0.091</td>
<td>-0.028</td>
</tr>
<tr>
<td>India</td>
<td>1.612</td>
<td>2.681</td>
<td>2.202</td>
<td>0.032</td>
<td>0.024</td>
<td>0.084</td>
</tr>
<tr>
<td>Italy</td>
<td>2.352</td>
<td>2.044</td>
<td>1.716</td>
<td>0.022</td>
<td>0.019</td>
<td>0.047</td>
</tr>
<tr>
<td>South Korea</td>
<td>3.353</td>
<td>4.744</td>
<td>3.223</td>
<td>0.053</td>
<td>0.030</td>
<td>0.109</td>
</tr>
<tr>
<td>Malaysia</td>
<td>44.783</td>
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<td>13.772</td>
<td>0.051</td>
<td>0.077</td>
<td>-0.103</td>
</tr>
<tr>
<td>Thailand</td>
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<td>8.695</td>
<td>14.122</td>
<td>0.101</td>
<td>0.091</td>
<td>0.097</td>
</tr>
<tr>
<td>Vietnam</td>
<td>37.124</td>
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<td>18.180</td>
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<td>-0.016</td>
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<tr>
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<td>-0.039</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.001</td>
</tr>
<tr>
<td>Japan</td>
<td>-0.059</td>
<td>-0.043</td>
<td>-0.127</td>
<td>-0.001</td>
<td>0.000</td>
<td>-0.009</td>
</tr>
<tr>
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<td>4.149</td>
<td>2.638</td>
<td>2.451</td>
<td>0.029</td>
<td>0.028</td>
<td>-0.033</td>
</tr>
<tr>
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</tr>
<tr>
<td>United Kingdom</td>
<td>0.069</td>
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<td>0.007</td>
</tr>
<tr>
<td>BRI</td>
<td>5.030</td>
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<td>5.956</td>
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<td>0.047</td>
<td>-0.020</td>
</tr>
<tr>
<td>Non-BRI</td>
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<td>0.235</td>
<td>-0.223</td>
<td>0.002</td>
<td>0.001</td>
<td>0.005</td>
</tr>
<tr>
<td>ASEAN</td>
<td>17.896</td>
<td>3.870</td>
<td>10.294</td>
<td>0.053</td>
<td>0.068</td>
<td>-0.056</td>
</tr>
<tr>
<td>Eur BRI</td>
<td>5.109</td>
<td>3.176</td>
<td>4.723</td>
<td>0.037</td>
<td>0.040</td>
<td>-0.097</td>
</tr>
<tr>
<td>Eur Non-BRI</td>
<td>-0.023</td>
<td>0.266</td>
<td>-0.399</td>
<td>0.002</td>
<td>-0.001</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Note: for the column (1)-(3), the unit is percentage point (%).

### 6.2 The Role of Input-Output linkages

In Figure 12, the gray bars represent the welfare effects with input-output linkage, while the black bars indicate the scenario without input-output linkages\(^{12}\). It is evident that the welfare effects generated by input-output linkages are significantly greater than those without it. For example, taking Malaysia as an example, its welfare in the baseline scenario is 43.5%, but in the scenario without input-output analysis, the welfare is only 26.3%. The underestimation amounts to 17.2%.

\(^{12}\) We distinguish the differences between scenarios with and without input-output analysis by setting \(\gamma_j^{sr} = 0\) (the share of intermediate inputs) and \(\gamma_j^v = 1\) (the share of value added) for all sectors in the counterfactuals.
As emphasized by Waugh (2010), poorer countries usually have higher trade costs than richer countries. Since most BRI members are developing countries, symmetric trade costs would bias the results. To examine the impacts of distinguishing between asymmetric and symmetric importing trade costs, we also conduct counterfactuals with symmetric trade costs and present the results in Table 6. Column (1) shows the welfare effects; Column (2)-(3) presents the measures for PTB and PTF; Column (4)-(5) shows the results for PLF\_GVC and PLB\_GVC, respectively; Column (6) presents the results for GVC position index.

By comparing the results of symmetric trade costs with those of asymmetric trade costs, the impact of symmetric trade costs is slightly higher than that of asymmetric trade costs. This is primarily because the reduction in symmetric trade costs is more significant than asymmetric trade costs. For instance, taking China's trade cost in intermediates change as an example, from 2009 to 2019, China's asymmetric importing trade costs decreased by 9.51%, while symmetric import trade costs decreased by 10.77%. This demonstrates that symmetric trade costs would bias the effects.

### Table 6 Economic effects with Symmetric Trade Costs

<table>
<thead>
<tr>
<th>Country</th>
<th>Welfare (1)</th>
<th>Change in PTF (2)</th>
<th>Change in PTB (3)</th>
<th>Change in PLF_GVC (4)</th>
<th>Change in PLB_GVC (5)</th>
<th>Change in Ps_GVC (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>1.470</td>
<td>2.294</td>
<td>2.898</td>
<td>0.019</td>
<td>0.031</td>
<td>0.019</td>
</tr>
<tr>
<td>Indonesia</td>
<td>25.405</td>
<td>10.680</td>
<td>14.285</td>
<td>0.097</td>
<td>0.114</td>
<td>-0.239</td>
</tr>
<tr>
<td>India</td>
<td>1.749</td>
<td>3.843</td>
<td>3.162</td>
<td>0.044</td>
<td>0.031</td>
<td>0.121</td>
</tr>
<tr>
<td>Italy</td>
<td>1.569</td>
<td>1.733</td>
<td>1.599</td>
<td>0.020</td>
<td>0.018</td>
<td>0.039</td>
</tr>
<tr>
<td>South Korea</td>
<td>5.490</td>
<td>6.450</td>
<td>4.962</td>
<td>0.082</td>
<td>0.043</td>
<td>0.172</td>
</tr>
<tr>
<td>Malaysia</td>
<td>51.406</td>
<td>6.602</td>
<td>15.360</td>
<td>0.078</td>
<td>0.077</td>
<td>-0.028</td>
</tr>
<tr>
<td>Thailand</td>
<td>13.022</td>
<td>6.502</td>
<td>9.117</td>
<td>0.075</td>
<td>0.065</td>
<td>0.083</td>
</tr>
<tr>
<td>Vietnam</td>
<td>43.374</td>
<td>9.024</td>
<td>13.907</td>
<td>0.106</td>
<td>0.081</td>
<td>0.148</td>
</tr>
<tr>
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<td>0.000</td>
<td>0.001</td>
<td>-0.007</td>
</tr>
<tr>
<td>Japan</td>
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<td>-0.025</td>
<td>-0.079</td>
<td>-0.001</td>
<td>0.001</td>
<td>-0.017</td>
</tr>
<tr>
<td>Germany</td>
<td>-0.086</td>
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<td>-0.360</td>
<td>0.000</td>
<td>-0.001</td>
<td>0.009</td>
</tr>
<tr>
<td>France</td>
<td>-0.023</td>
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<td>0.000</td>
</tr>
<tr>
<td>United Kingdom</td>
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<td>0.071</td>
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<td>0.000</td>
<td>0.001</td>
<td>-0.002</td>
</tr>
</tbody>
</table>

Note: for the column (1)-(3), the unit is percentage points (%).
6.4 Heterogeneity in Trade Cost Changes by Industry

In this section, we compare the quantification results with and without industrial heterogeneity in trade cost changes. Specifically, we conduct a counterfactual where the uniform reduction of trade costs for all industries along is 10%. The counterfactuals are presented in Table 7. Column (1) shows the welfare effects; Column (2)-(3) presents the measures for PTB and PTF; Column (4)-(5) shows the results for PLF_GVC and PLB_GVC, respectively; Column (6) presents the results for GVC position index.

By comparing the results with and without heterogeneity in trade cost changes, we find that without industry-specific heterogeneity in trade cost does not affect the direction of the baseline scenario but bias the results. For example, in China, in the baseline scenario, China's welfare gain is 1.148%, PTF changes by 2.616%, and PTB changes by 2.417%. However, if we do not consider industry heterogeneity for trade costs, the welfare gains are only 0.633%, PTF changes by 1.757%, and PTB changes by 2.371%. Therefore, not accounting for industry-specific heterogeneity in trade cost changes slightly underestimates the welfare and global value chain effects for China, but it does not alter the direction of the effects. This also provides evidence for the robustness of the conclusions in our paper.

<table>
<thead>
<tr>
<th>Country</th>
<th>Welfare (1)</th>
<th>Change in PTF (2)</th>
<th>Change in PTB (3)</th>
<th>Change in PLF_GVC (4)</th>
<th>Change in PLB_GVC (5)</th>
<th>Change in Ps_GVC (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>0.633</td>
<td>1.757</td>
<td>2.371</td>
<td>0.017</td>
<td>0.026</td>
<td>0.018</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1.385</td>
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<td>0.030</td>
<td>0.044</td>
</tr>
<tr>
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<td>1.270</td>
<td>0.033</td>
<td>0.013</td>
<td>0.135</td>
</tr>
<tr>
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<td>1.305</td>
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<td>0.015</td>
<td>0.027</td>
</tr>
<tr>
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<td>3.960</td>
<td>0.042</td>
<td>0.031</td>
<td>0.065</td>
</tr>
<tr>
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<td>0.029</td>
<td>0.009</td>
</tr>
<tr>
<td>Thailand</td>
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<td>3.486</td>
<td>3.281</td>
<td>0.038</td>
<td>0.026</td>
<td>0.065</td>
</tr>
<tr>
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<td>5.729</td>
<td>4.534</td>
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<td>0.159</td>
</tr>
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<td>-0.019</td>
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<td>0.000</td>
<td>-0.004</td>
</tr>
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<td>-0.001</td>
<td>0.000</td>
<td>-0.006</td>
</tr>
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<td>-0.003</td>
</tr>
<tr>
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<td>-0.098</td>
<td>-0.001</td>
<td>0.000</td>
<td>-0.006</td>
</tr>
<tr>
<td>United Kingdom</td>
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<td>0.015</td>
<td>-0.054</td>
<td>0.000</td>
<td>0.001</td>
<td>-0.002</td>
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</table>

Note: for the column (1)-(3), the unit is percentage point (%).

7. Conclusions

We quantify the economic effects of trade cost reduction among members of the Belt and Road Initiative by incorporating input-output structures and distinguishing trade shares of intermediates and final goods into a general equilibrium model. The initiative boosts a surge in trade for BRI countries on average, with exports in final goods (32.480%) exceeding exports in intermediates (29.466%) and imports in final goods (34.699%) surpassing imports in intermediates (32.547%). The Belt and Road Initiative generate distributional welfare effects. Smaller economies experience more significant welfare gains. For example, the real wage in Malaysia grows by 51.406%, while China, Belt and Road Initiative's proponent, experiences moderate growth of 1.148%. By
employing metrics that differentiate between Forward- and Backward-Linkage GVC participation and production lengths, we find that, on average, the Belt and Road Initiative has greater changes in Backward-Linkage GVC participation than in Forward-Linkage GVC participation, indicating more specialized production. As the members generally participate more in Backward-Linkage at the baseline scenario. Furthermore, the change in the GVC position index suggests that the initiative reshapes the position of members in the production chain. Countries such as China, India, Italy, and South Korea move more upstream, while Indonesia and Malaysia shift downstream. Furthermore, the growth in both Forward- and Backward-Linkage GVC production lengths indicate a more complex production chains among countries with tighter production linkages.

The Belt and Road Initiative differs from traditional preferential trade agreements as it does not involve direct tariff reductions. Instead, it significantly lowers trade costs through infrastructure construction and institutional barriers such as political ties. Our paper utilizes the modified Head-Rice index to estimate the changes in trade costs after the BRI and quantify the economic effects for members. This quantitative approach also applies to other policies involving changes in trade costs and the evaluation of economic effects, such as welfare, trade and global value chains.
References


Appendix A Derivation of real wage

From equation (10), we have

\[ \hat{P}_j = \prod_{s=1}^{S} (\hat{P}_{js}^{SF})^{\alpha_j^s} \]  

(A1)

We take the logarithm of the real wage

\[ \ln \frac{\hat{w}_j}{\hat{P}_j} = \ln \hat{w}_j - \ln \hat{P}_j \]  

(A2)

Due to the free movement of domestic labor, \( \hat{w}_j = \hat{w}_j^s \) and \( \hat{P}_j = \prod_{s=1}^{S} (\hat{P}_{js}^{SF})^{\alpha_j^s} \)

\[ \ln \frac{\hat{w}_j}{\hat{P}_j} = \ln \hat{w}_j - \ln \prod_{s=1}^{S} (\hat{P}_{js}^{SF})^{\alpha_j^s} = \ln \hat{w}_j - \sum_{s=1}^{S} \alpha_j^s \hat{P}_{js}^{SF} = \sum_{s=1}^{S} \alpha_j^s \ln \hat{w}_j - \sum_{s=1}^{S} \alpha_j^s \ln \hat{P}_{js}^{SF} = \sum_{s=1}^{S} \alpha_j^s (\ln \hat{w}_j - \ln \hat{P}_{js}^{SF}) \]  

(A3)

we converse the equation (B3) to yields,

\[ \ln \hat{w}_j = \frac{1}{\gamma_j^s} \ln \hat{c}_j^s - \gamma_j^s / \gamma_j^s \sum_{r=1}^{S} \ln \hat{P}_{jr}^{sf} \]  

(A4)

The real wage change in industry \( s \) in country \( j \) is first obtained as \( \hat{w}_j^s / \hat{P}_{js}^{SF} \), which is linearized. According to equation (12), we first obtain \( \hat{w}_j^s \)

\[ \ln \hat{c}_j^s = \ln \left( \hat{w}_j^s \prod_{r=1}^{S} (\hat{P}_{jr}^{SF}) \right) = \gamma_j^s \ln \hat{w}_j + \gamma_j^s \sum_{r=1}^{S} \ln \hat{P}_{jr}^{sf} \]  

(A5)

Then, we get

\[ \ln \hat{w}_j = \frac{1}{\gamma_j^s} \ln \hat{c}_j^s - \gamma_j^s / \gamma_j^s \sum_{r=1}^{S} \ln \hat{P}_{jr}^{sf} \]  

(A6)

We obtain the expression for \( \ln \hat{c}_j^s \) from equation (32)

\[ \hat{r}_{ij}^{SF} = \left[ \frac{S_{ij}^{SF}}{S_{ij}} \right]^{\theta_j^s} \]  

(A7)

We take the logarithm of the trade share

\[ \ln \hat{r}_{ij}^{SF} = \ln \left[ \frac{S_{ij}^{SF}}{S_{ij}} \right]^{\theta_j^s} = -\theta_j^s \ln \hat{c}_j^s - \theta_j^s \ln \hat{w}_j^{SF} + \theta_j^s \hat{P}_{ij}^{SF} \]  

(A8)

Then we get

\[ \ln \hat{c}_j^s = -\frac{1}{\theta_j^s} \ln \hat{r}_{ij}^{SF} - \ln \hat{w}_j^{SF} + \ln \hat{P}_{ij}^{SF} \]  

(A9)

Substituting (A7) into (A4), we get

\[ \ln \hat{w}_j = \frac{1}{\gamma_j^s} \left( -\frac{1}{\theta_j^s} \ln \hat{r}_{ij}^{SF} - \ln \hat{w}_j^{SF} + \ln \hat{P}_{ij}^{SF} \right) - \gamma_j^s / \gamma_j^s \sum_{r=1}^{S} \ln \hat{P}_{jr}^{sf} \]  

(A10)

We now derive the change of real wage of equation (A3) with equation (A8)

\[ \ln \frac{\hat{w}_j}{\hat{P}_j} = \sum_{s=1}^{S} \alpha_j^s \left( \frac{1}{\gamma_j^s} \left( -\frac{1}{\theta_j^s} \ln \hat{r}_{ij}^{SF} - \ln \hat{w}_j^{SF} + \ln \hat{P}_{ij}^{SF} \right) - \gamma_j^s / \gamma_j^s \sum_{r=1}^{S} \ln \hat{P}_{jr}^{sf} \right) \]  

We assume intra-country trade cost \( \hat{k}_{ij}^{SF} \) is 1 and remains constant.

\[ \ln \frac{\hat{w}_j}{\hat{P}_j} = -\sum_{s=1}^{S} \alpha_j^s \left( -\frac{1}{\theta_j^s} \ln \hat{r}_{ij}^{SF} - \sum_{s=1}^{S} \alpha_j^s \frac{\gamma_j^s}{\gamma_j^s} \ln \sum_{r=1}^{S} \frac{\theta_{jr}^{SF}}{\theta_j^s} + -\sum_{s=1}^{S} \frac{\alpha_j^s}{\theta_j^s} \ln \hat{w}_j^{SF} - \sum_{s=1}^{S} \alpha_j^s \frac{\gamma_j^s}{\gamma_j^s} \ln \sum_{r=1}^{S} \frac{\theta_{jr}^{SF}}{\theta_j^s} \right) \]  

\[ \sum_{s=1}^{S} \frac{\alpha_j^s}{\theta_j^s} \ln \hat{w}_j^{SF} - \sum_{s=1}^{S} \alpha_j^s \frac{\gamma_j^s}{\gamma_j^s} \ln \sum_{r=1}^{S} \frac{\theta_{jr}^{SF}}{\theta_j^s} \]  

(A11)
## Appendix B

Table B.1 World input-output table

<table>
<thead>
<tr>
<th>Int</th>
<th>Country 1</th>
<th>...</th>
<th>Country J</th>
<th>Final goods</th>
<th>Total outputs</th>
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<tbody>
<tr>
<td></td>
<td>sector1</td>
<td>...</td>
<td>sectorS</td>
<td>...</td>
<td>sector1</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>Sector 1</td>
<td>...</td>
<td>Sector J</td>
<td>...</td>
<td>Sector S</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Table B.2 Trade elasticity for each industry

<table>
<thead>
<tr>
<th>Industry</th>
<th>θ</th>
<th>Industry</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>9.11</td>
<td>Retail sale of fuel</td>
<td>7.6</td>
</tr>
<tr>
<td>Mining</td>
<td>13.53</td>
<td>Wholesale trade</td>
<td>7.6</td>
</tr>
<tr>
<td>Food</td>
<td>2.62</td>
<td>Retail trade</td>
<td>7.6</td>
</tr>
<tr>
<td>Textiles</td>
<td>8.1</td>
<td>Hotels and restaurants</td>
<td>7.6</td>
</tr>
<tr>
<td>Leather</td>
<td>8.1</td>
<td>Inland transport</td>
<td>7.6</td>
</tr>
<tr>
<td>Wood</td>
<td>11.5</td>
<td>Water transport</td>
<td>7.6</td>
</tr>
<tr>
<td>Paper</td>
<td>16.52</td>
<td>Air transport</td>
<td>7.6</td>
</tr>
<tr>
<td>Coke</td>
<td>8.2</td>
<td>Other supporting transport activities</td>
<td>7.6</td>
</tr>
<tr>
<td>Chemicals</td>
<td>3.13</td>
<td>Telecommunications</td>
<td>7.6</td>
</tr>
<tr>
<td>Rubber and Plastics</td>
<td>1.67</td>
<td>Financial intermediation</td>
<td>7.6</td>
</tr>
<tr>
<td>Other Non-Metallic Mineral</td>
<td>2.41</td>
<td>Real estate activities</td>
<td>7.6</td>
</tr>
<tr>
<td>Basic Metals</td>
<td>3.28</td>
<td>Renting of M&amp;E</td>
<td>7.6</td>
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<td>Machinery</td>
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<td>Public administration</td>
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<tr>
<td>Electrical and Optical Equipment</td>
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<td>Education</td>
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<tr>
<td>Transport Equipment</td>
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<td>Health and social work</td>
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<td>Recycling</td>
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<td>Other community services</td>
<td>7.6</td>
</tr>
<tr>
<td>Electricity supply</td>
<td>7.6</td>
<td>Private households</td>
<td>7.6</td>
</tr>
<tr>
<td>Construction</td>
<td>7.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Data sources from Caliendo and Parro (2015) and the trade elasticity for services industry is set at 7.6.