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Global Value Chain and Business Cycle Comovement: Does Distance Matter?

Daoju Peng, Kang Shi and Juanyi Xu

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Keywords: Global Value Chain, Distance, Business Cycle Comovement
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1 Introduction

A salient feature of global production is the emergence of global production networks, with each country specializing in particular stages of goods production sequence, a phenomenon which Hummels, et. al (2001) refer to as vertical specialization. Meanwhile, the international business cycle synchronization has increased markedly all over the world over the last 20 years, especially after large events like the global financial crisis. For example, during 2007-2008, global output correlation has increased dramatically. The ongoing coronavirus pandemic has also caused a large output drop in the first and second quarters for almost all major economies. Greater comovements of business cycle among countries signal higher interdependence and call for greater coordination of public policies. Have changes in trade patterns, in particular, greater trade integration through global value chain, lead economies to comove more? Understanding the linkage between international production and trade network and business cycle comovement will have important implications for macroeconomic policies and international policy coordination.

A growing literature has studied the relationship between greater engagement in global production networks and business cycle synchronization. For example, Ng (2010) finds that production fragmentation has a strong positive effect on output correlation. Duval et al. (2016) identify a positive role of bilateral value-added trade on business cycle synchronization. Burstein et al. (2008) find that production sharing between U.S. and Mexico increases their output correlation. However, these studies are silent on one important feature of global production: countries or sectors are usually specialized in different positions in global value chain. As a result, even they have the same bilateral trade relationship captured by either value added trade intensity or gross trade intensity, their different positions could also matter for business cycle comovements given the fact that the effects of shocks are usually different for countries specialized in different positions. With the rapid development of global production, it is important to investigate the role of the distance of their positions along the global value chain in affecting their output comovement.

In this paper, we investigate this issue both theoretically and empirically. We first define a measure of distance based on an assumed influence matrix which determines the impact of country-specific idiosyncratic shocks on GDP of each country. Specifically, a certain country's GDP could be written as the inner product of country-specific shocks and the influence vector. The distance measure characterizes the heterogeneity across two countries in terms of the response of their GDP to idiosyncratic productivity shocks. If two countries differ significantly in their response to shocks originated from the same country(including themselves and other countries), the distance is longer. Given this definition, it is very intuitive that there exists a negative relationship between the output correlation and the distance measure.

Our definition of distance measure depends on influence matrix, which in turn depends on the underlying economic structure as well as the global production network. To understand the intuition behind distance measure, we set up a multi-country, multi-factor model of production and trade following Duval et.al (2016) and production network literatures such as Acemoglu et.al (2012). Using this model, we can show analytically that when the economy is only disturbed by country-specific productivity shock, influence matrix can be entirely captured by global input-output linkage; it is in fact the economy's Leontief inverse matrix. More importantly, since productivity shocks will only be transmitted downstream, distance derived using influence matrix in the model is actually the distance of two countries along the global value chain, measured using downstreamness position measure developed by Fally (2012) and Antràs et.al (2012).

Therefore, we proved theoretically that there exists a negative relationship between distance *along the global value chain* and the business cycle comovement across two countries, when only country-specific productivity shocks are considered. Intuitively, distance along the global value chain captures the heterogeneous response to country-specific shock embedded in the global input-output linkage. A closer distance, therefore, will imply higher business cycle comovement. We then show analytically that the channel through which distance affects output correlation is different from other existing determinants of international comovement, such as bilateral trade intensity and production or trade structure similarity. Compared to these measures, distance can capture correlations of output fluctuation from indirect trade (no direct trade of two economies but share same suppliers), as well as impacts through second or higher-order input-output linkage.

We then test the relationship between our distance measure and the output correlation using data on the world input-output table. We first use the WIOD input-output data to obtain the distance based on the downstreamness measure following Fally (2012) and Antràs et.al(2012). There exists a significant variation in the distance across country pairs. Specifically, the average distance ranges from 0 to 1.24 between different country pairs. The tests show that after controlling for various types of fixed effects and other competing mechanisms such as bilateral trade intensity and production structure similarity, distance still significantly and negatively correlated with business cycle comovement. Shorter distance increases output correlation. Our estimate is also economically significant. In the baseline regression, our estimated coefficient implies that if we increase the distance from its 10th percentile to 90th percentile, holding all other variables at their means, output correlation decreases by 0.47.

Our benchmark estimation results are based on the downstreamness position measure developed by Fally (2012) and Antràs et.al(2012), since it is clearly defined as the heterogeneity of response to supply shocks theoretically, consistent with our model. To verify the robustness of the distance-comovment relationship, we consider other measures of countries' position in the production network based on global input-output linkage in the extension. These measures help us to understand the effect of supply shocks prorogated along the production network through other channels, such as value added trade, on output comovement. The negative relationship between distance along the global value chain and business cycle comovement still holds for alternative distance measures, indicating the importance of distance measured from multiple dimensionscin in explaining comovements. In robustness checks, we also consider alternative measures of correlation and aggregation methods for the calculation of distance, the main result still holds. Finally, we find that the effect of distance on comovement is weaker during financial crisis period. This finding, to some extent, is consistent with Wang et al. (2017)'s finding that activities along global value chain decrease during financial crisis times.

This paper is related to several strands of literature. The first strand of literature focuses on economic distance and similarity (e.g. Conley and Dupor, 2002; Imbs, 2004). Conley and Dupor(2002) define an economic distance between sectors in a closed economy by the degree to which different sectors have a common input-output structure. Our measure is conceptually similar to them, but we focus on a global production chain framework.[1] Imbs (2004) defines a measure capturing the heterogeneity of domestic production structure between countries. Our distance measure is conceptually different:

[1]Also, since our distance measure is constructed based on an influence matrix, which enables us to examine the heterogeneous effect of shocks due to differences in underlying economic structure, including input-output linkage.

countries with different domestic production structures can have similar distance along the global value chain. Moreover, compared to distance measure, production similarity measures fails to consider the higher-order effect of supply shocks through indirect input-output linkage on output correlation.

The second strand of literature examines the effect of trade integration on business cycle comovement.[2] Theoretically, Burstein et al.(2008) analyzes business cycle comovement in a model of cross-border production sharing. Johnson (2014) models how intermediate goods trade enhances business cycle synchronization. Empirically, most studies find that business cycle is more comoved if trade is more integrated between two countries (Frankel and Rose, 1998; Imbs, 2004; Baxter and Kouparitsas, 2005; Caldern et al., 2007; Ng,2010; Liao and Santacreu, 2015; Duval et al. 2016). Among them, Caldern et al. (2007) and Duval et al. (2016) are the closest to our paper. Caldern et al. (2007) find that the impact of trade integration on cycle synchronization is high among country pairs with more symmetric economic structure and a higher degree of intra-industry trade. Duval et al. (2016) emphasize the importance of bilateral value-added trade intensity on business cycle synchronization.

Compared with these papers, our paper identifies both empirically and theoretically a new channel through which trade linkage affect business cycle comovement - distance. By separating distance from input intensity in a vertically integrated production network, we emphasize the role of distance as an alternative mechanism in explaining business cycle correlation. For two countries or sectors, even they have the same bilateral trade relationship captured by either value added or gross trade intensity, it is also possible they have different positions in production network and different distances as a result. Distance, as an independent explaining factor, could matter significantly for business cycle comovement. Moreover, compared to trade intensity or similar measures, our measure of distance in global value chain can capture not only the intermediate goods trade effect, but also correlations of output fluctuation from indirect trade (no direct trade of two economies but share the same suppliers), as well as impacts through second or higher-order input-output linkage. Therefore, our findings offer a more complete evaluation of the implication of global value chain for business

[2] There is also a growing literature that investigates the role of global value chain in explaining other macroeconomic activities. For example, Auer et al. (2017a, 2017b) study how the international input-output linkage and global value chain affect the international inflation spill-over and the globalization of inflation.

cycle comovements.

This paper is also related to an active recent literature that emphasizes the extent of heterogeneity in input-output structure in the propagation of idiosyncratic shock to the aggregate economy(Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi 2012, Acemoglu, Ozdaglar and Tahbaz-Salehi 2017, Carvalho and Tahbaz-Salehi,2019). Our study complements their study by extending domestic production network to an international setting. Our results show in a global context more symmetric input-output linkages (shorter distance) of two countries lead to more symmetric response to underlying shocks, and in turn higher output correlation. This result resembles the argument made by Carvalho and Tahbaz-Salehi (2019) in a closed-economy model where they show the economy with more symmetric sectoral input-output linkage has higher average pairwise sectoral output correlation.

The paper proceeds as follows. Section 2 first proposes the distance measure and illustrates the negative relationship between distance and output correlation. Then a model is developed to derive the influence matrix and show the consistency between distance measure and the distance along the global value chain. Section 3 describes the data and measures distance and correlation empirically. Section 4 presents the empirical results. Robustness check is given in Section 5 and Section 6 concludes.

2 A theoretical model of distance and output correlation

In an interconnected world, international business cycle comovment between two countries will be affected by their distance in the production network since country-specific shocks will be prorogated along the global value chain. In this section, using a simple theoretical framework we illustrate theoretically how business cycle comovements are influenced by the country's relative position in the global production network. We will proceed with two steps. First, we drive a measure of distance based on an assumed influence matrix, which determines the impact of country-specific idiosyncratic shocks on each country, and shows there exists a negative relationship between the output correlation and the distance measure. Then we develop a more complete model to derive the influence matrix and thus the distance measure. We show that this distance measure is in fact consistent with the distance along the global value chain based on the measure of backward position in the literature, such as Fally (2012) and Antràs et.al(2012). Finally, we discuss the difference between the channel that affects output correlation through distance and other channels emphasized in the literature.

2.1 Measure of distance

We start with considering a perfectly competitive global economy with N countries indexed by $c = 1, 2, ..., N$. Each country produces one good which can be used as both intermediate goods or final goods. It will also trade with other countries.

Country c is subject to an independently distributed idiosyncratic shock ϵ_{ct} that follows normal distribution with mean zero and standard error of one. Output in country c is denoted by Y_{ct}. The effect of shocks on a specific country c is governed by influence vector $\nu_c = (\nu_{1c}, \nu_{2c}, ..., \nu_{Nc})$ with ν_{dc} capturing the response of country c's output to idiosyncratic shocks originating from country d ($d = 1, 2, 3, \cdots N$). Influence vector is determined by the linkage between country c and the rest of world through production network. To compute business cycle comovement, taking all countries into consideration, we can write the following equation:

$$\hat{Y}_t = \nu \epsilon_t \tag{2.1}$$

where $\hat{Y}_t = (\hat{Y}_{1t}, ..., \hat{Y}_{Nt})'$ is a vector denoting output's deviation from its steady state for countries $c = 1, 2, 3, \cdots N$. $\nu = (\nu_1, ..., \nu_N)'$ and $\epsilon_t = (\epsilon_{1t}, ..., \epsilon_{Nt})'$ are the N×N influence matrix governing the response of each country's output to idiosyncratic shocks and N×1 vector of underlying country-level idiosyncratic productivity shocks, respectively.

Obviously, from Equation (2.1) we can see that international business cycle comovements are determined by the structure of the influence matrix. More specifically, the output comovement between country c and country d is given by [3]

$$\rho_{cd} = \frac{cov(\nu_c \epsilon_t, \nu_d \epsilon_t)}{\sigma(\nu_c \epsilon_t) \cdot \sigma(\nu_d \epsilon_t)} = \frac{< \nu_c, \nu_d >}{\|\nu_c\| \cdot \|\nu_d\|} \tag{2.2}$$

where $< \nu_c, \nu_d >= \sum_{k=1}^{N} \nu_{kc} \nu_{kd}$ is the inner product of two N-vectors ν_c and ν_d.

[3] Equation (2.2) holds because we assume that independent shocks to each country are of the same size.

$\|\nu_c\| = \sqrt{\sum_{k=1}^{N}\nu_{kc}^2}$ is the Euclidean norm of vector ν_c. It can be verified that correlation is determined by the asymmetry in influence vector between two countries. When two countries have exactly the same influence vectors, they will be perfectly correlated. More formally, we can define the asymmetry of influence vectors as a measure of "distance" as follows:

Definition 1. *Distance is defined as* $d_{cd} = |\sum_{k=1}^{N}(\nu_{kc} - \nu_{kd})|$

This definition states that the distance measure characterizes the heterogeneity across two countries in terms of their response to idiosyncratic productivity shocks. If two countries differ significantly in their response to shocks originated from the same country (including themselves and other countries), the distance is longer. On the other hand, if they respond similarly to shocks from the same origin, i.e., $\nu_{kc} = \nu_{kd}$, $\forall k = 1, 2, 3, \cdots N$. the distance would be zero, and their GDP fluctuations will be perfectly correlated.

Our definition of distance measure is in the same spirit of economic distance defined by Conley and Dupor(2003). In their paper they assume covariance of two random variables (e.g sectoral output fluctuation) is a smooth function of their economic distance $\|s_{it} - s_{jt}\|$, where s_{it} (s_{jt}) is the location of sector $i(j)$ in domestic input-output structure. We also define distance as economic distance, but our definition is based on the influence matrix, which is endogenous to theoretical models. It enables us to get a clear understanding of distance and how it affects shock transmissions in an open economy. Our measure of distance is therefore more endogenous to the model setting and nature of shocks.

Given the definition of distance, we can now show the relationship between the distance and the correlation as follows:

$$\rho_{cd} = -\frac{1}{2}\left(\frac{d_{cd}^2}{\|\nu_c\| \cdot \|\nu_d\|} - \sqrt{\frac{\sigma^2(\nu_c\epsilon_t)}{\sigma^2(\nu_d\epsilon_t)}} - \sqrt{\frac{\sigma^2(\nu_d\epsilon_t)}{\sigma^2(\nu_c\epsilon_t)}} - \frac{2\sum_{k,m,k\neq m}(\nu_{kc} - \nu_{kd})(\nu_{mc} - \nu_{md})}{\|\nu_c\| \cdot \|\nu_d\|}\right) \quad (2.3)$$

where correlation between output fluctuation of country c and country d, ρ_{cd} can be decomposed into three components: distance effect (first term), volatility effect (second and third terms) and correlation due to countries responses to shocks from different countries (last term). The negative relationship between ρ_{cd} and distance is obvious from Equation (2.3). But how to understand the relationship between distance measure and global value chain? Since the influence matrix depends on the model setting, in the following subsection we will explore how to derive the influence matrix and distance in an illustrative multicountry trade model with global value chain.

2.2 Determination of influence matrix

Following Duval et.al (2016) and production network literatures (see among others, Acemoglu et al 2012; Baqaee, 2018; Baqaee and Farhi,2019), we assume the goods can be produced by the following Cobb-Douglas production function in each country i

$$Q_{ct} = Z_{ct} L_{ct}^{\alpha_c} (\prod_{d=1}^{N} X_{dc,t}^{\omega_{dc}}) \tag{2.4}$$

where $X_{dc,t}$ is the quantity of goods produced by country d used as input in the production of country c goods at time t. $Q_{c,t}$ is gross output of country c goods. Z_{ct} represents the idiosyncratic productivity in country c. L_{ct} is labor supply. ω_{dc} denotes the share of intermediate goods d in the production of goods c. The production is assumed to be constant return to scale, so $\alpha_c + \sum\limits_{d=1}^{N} \omega_{dc} = 1$.

Each country c is also populated by a representative household endowed with one unit of labor. He/she derives utility from consumption of N types of goods and leisure;

$$U_{ct} = \prod_{d=1}^{N} C_{dc,t}^{\beta_{dc}} (1 - L_{ct})^{\lambda} \tag{2.5}$$

where β_{dc} denotes taste of household in country c over goods produced by country d. It is also the expenditure share of goods d in country c's household total consumption, normalized such that $\sum_{d=1}^{N} \beta_{dc} = 1$. $C_{dc,t}$ is the consumption of good d in country c. λ is Frisch elasticity of labor supply. This utility function follows Acemoglu et.al (2017).

We further assume the international financial market is in autarky, and thus trade is balanced in each period. Trade cost is assumed to be zero, so goods prices are the same in the source country and the destination country. The household uses its labor income to finance its consumption. So for each country c, we have $W_{ct} L_{ct} = \sum_{j=1}^{N} P_{dt} C_{dc,t}$.

Since goods c can be used either as intermediate input for production or final consumption goods, the goods market clearing condition for country c is given by

$$Q_{ct} = \sum_{d=1}^{N} C_{cd,t} + \sum_{d=1}^{N} X_{cd,t} \tag{2.6}$$

Since every country is subject to an idiosyncratic country-level productivity shock, we can log-linearize the production function around steady-state to get:

$$\hat{Q}_{ct} = \hat{Z}_{ct} + \sum_{d=1}^{N} \omega_{dc}\hat{X}_{dc,t} + \alpha_c \hat{L}_{ct} \tag{2.7}$$

where variables with hat denote deviation from steady state $\hat{X} = log(X) - log(\bar{X})$. FOCs from the household problem imply that $\frac{1-L_{ct}\beta_{dc}}{L_{ct}\lambda} = \frac{P_{dt}C_{dct}}{W_{ct}L_{ct}}$. Summing up over d, and use the household's budget constraint, we can easily show that labor supply is constant and equal $L_{ct} = \frac{1}{1+\lambda}$. From the Cobb-Douglas production function we can have $P_{dt}X_{dc,t} = \omega_{dc}P_{ct}Q_{ct}$ and $W_{ct}L_{ct} = \alpha_c P_{ct}Q_{ct}$, respectively. Log-linearizing these two equations and substituting them back to Equation (2.2), we can obtain an equation similar to Duval et.al(2016), [4]

$$\hat{Q}_t = (I - \Omega')^{-1}\hat{Z}_t \tag{2.8}$$

where Ω is the input-output matrix and is given by

$$\begin{bmatrix} \omega_{11} & \omega_{12} & \dots & \omega_{1N} \\ \omega_{21} & \omega_{22} & \dots & \omega_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_{N1} & \omega_{N2} & \dots & \omega_{NN} \end{bmatrix}$$

with each entry ω_{dc} is the share of intermediate goods d in the production of goods c, as defined earlier.

In this simple economy, since there is no investment or government expenditure and trade is balanced, real GDP equals real consumption. Meanwhile, from the household's budget constraint and the expenditure on labor, we can see that the real GDP is a

[4]Please see the Technical Appendix A for details of the derivation of Equation (2.8).

constant share of real gross output. As a result, fluctuation in real GDP equals that of the real gross output. Thus we have

$$\hat{Y}_t = (I - \Omega')^{-1} \hat{Z}_t = \nu \hat{Z}_t \tag{2.9}$$

Therefore, in this simple model with supply shocks only, the influence matrix ν is in fact the economy's Leontief inverse matrix. According to the definition of distance measure in Section 2.1, we have

$$d_{cd} = |\sum_{k=1}^{N} (\nu_{kc} - \nu_{kd})| \tag{2.10}$$

where influence vector ν is from Leontief inverse matrix.

2.3 Discussion on the distance measure

Although we have shown in Equation (2.3) that the correlation between output fluctuation is a function of the distance, it is still unclear how this distance measure implied by our simple model is related to the position of countries along the global value chain. To answer that question, we begin by specifying the direction of the propagation of productivity shocks.

In our simple model, same as results shown in the production network literature(among others, see Acemoglu et. al 2012, Acemoglu, et al. 2015, and Carvalho and Tahbaz-Salehi 2019), idiosyncratic productivity shock will propagate downstream from one country to its consumer, its consumer's consumers and so on[5]. It is because the Cobb-Douglas production function implies that a productivity shock to a specific intermediate good can only have impact on the its price. The expenditure share spent on this good is unchanged, which implies productivity shocks will be only propagated downstream but not upstream.. Given this, we can use the downstreamness measure developed by Fally (2012) and Antràs et.al(2012) to construct the position of two coun-

[5]However, this property relies heavily on frictionless trade. In a more realistic economy where trade cost drives different prices in the source country and destination country, real GDP fluctuations will not necessarily equal those of real gross output. A recent study by Tintelnot et al. (2018) quantifies the effect of change in trade cost on price in a global economy with both domestic and international production networks.

tries in the global value chain.

The downstreamness measure in the literature is usually at country-sector level (section i in country c). To be consistent with our simple model, we will follow the spirit of Fally (2012) and Antràs et.al (2012) to define the position of countries along the global value chain. In our empirical analysis, we will use the country-sectoral level position to construct the distance measure.

Following Fally (2012) and Antràs and Chor (2012), measure of downstreamness of a given country, or the backward-looking position, can be defined by the following recursive definition:

$$POS_t^{c,b} = 1 + \sum_{j=1}^{N} \omega_{dc} POS_t^{d,b} \tag{2.11}$$

in which b stands for *backward*, ω_{dc} is the dollar amount of country d's output used to produce one dollar worth of country c's, or the share of intermediate goods d in the production of goods c, as defined in Equation (2.4). $POS_t^{c,b}$ and $POS_t^{d,b}$ are the backward-looking position, or the downstreamness of country c and country d at time t respectively.

This "downstreamness" index developed by Fally (2012) and Antràs, et.al (2012) is based on the notion that countries purchasing a disproportionate share of intermediate goods from downstream countries should be relatively downstream themselves. Therefore, country cs backward position $POS_t^{c,b}$ equals to the sum of downstreamness (or distance to its suppliers) of its suppliers, weighted by its expenditure share spent on each intermediated good supplied by all other countries in the production. It is clear that a larger value of $POS_t^{c,b}$ corresponds to a higher level of downstreamness of country c, or a longer distance to its suppliers.

Given Equation (2.11), the backward distance between countries c and d along the global value chain can be defined as follows.

$$DIS_t^{cd,b} = |POS_t^{c,b} - POS_t^{d,b}| \tag{2.12}$$

where $DIS_t^{cd,b}$ represents backward-looking distance.

Now we can show that the distance measure we proposed earlier is exactly $DIS_t^{cd,b}$. Rearrange the Equation (2.11) in matrix notation, we can get

$$\boldsymbol{POS} = (\boldsymbol{I} - \boldsymbol{\Omega}')^{-1}\mathbf{1} \quad (2.13)$$
$$= \nu\mathbf{1} \quad (2.14)$$

in which the row d and column c of matrix Ω collects ω_{dc} and denotes country-level Leontif inverse matrix. $\mathbf{1}$ is N×1 vector of 1. We can then show that the absolute difference of the downsteamness along the global value chain, $DIS_t^{cd,b}$, is exactly the distance defined in Equation (2.10)[6].

$$DIS_t^{cd,b} = |POS_t^{c,b} - POS_t^{d,b}| = |\nu_c\mathbf{1} - \nu_d\mathbf{1}| \quad (2.15)$$
$$= |\sum_{k=1}^{N}\nu_{kc} - \sum_{k=1}^{N}\nu_{kd}| \quad (2.16)$$
$$= d_{cd} \quad (2.17)$$

2.4 Comparison of distance measure and other measure

To understand how distance affects output correlation, it is helpful to compare it with other determinants of international comovement. As discussed in the literature, international business cycle comovment is significantly correlated with two types of variables: bilateral trade intensity and production or trade structure's similarity. To understand how distance measure differs with them, we first express the influence matrix as the infinite sum of the powers of input-output matrix Ω', that is

$$\nu = (I - \Omega')^{-1} = I + \Omega' + \Omega'^2 + ... + \Omega'^N + ... \quad (2.18)$$

For comparison convenience, we focus on covariance between country c and d and the square of the distance $d_{cd}^2 = |\sum_{k=1}^{N}(\nu_{kc} - \nu_{kd})|^2$. To see the relationship between business cycle correlation, distance, and gross trade intensity more clearly, we first consider the first-order terms of influence matrix only. That is, $\nu = I + \Omega'$. Given this simplification, covariance of GDP fluctuation between country c and d, $cov_{cd,t} =$

[6]Distance measure defined in our model is the absolute value of the sum of the difference between two countries' responses to the productivity shock from the same country ($|\sum_{k=1}^{N}(\nu_{kc}-\nu_{kd})|$), which is exactly the absolute value of the difference between two countries' responses to all productivity shocks as derived from downstramness measure ($|\sum_{k=1}^{N}\nu_{kc} - \sum_{k=1}^{N}\nu_{kd}|$) since ν_{kd} or ν_{kc} is scalor.

$cov(\nu_d\epsilon_t, \nu_d\epsilon_t) = \sum_{k=1}^{N} \nu_{kc}\nu_{kd}$ is given by

$$cov_{cd,t} = \underbrace{\sum_{k=1}^{N} \omega_{kc}\omega_{kd}}_{\text{same-supplier covariance}} + \underbrace{\omega_{cd} + \omega_{dc}}_{\text{direct intermedaite trade intensity}} \tag{2.19}$$

in which $\sum_{k=1}^{N} \omega_{kc}\omega_{kd}$ captures the covariance of output between country c and d since they share the same supplier k. ω_{cd} and ω_{dc} captures the direct bilateral trade relationship through intermediate goods.

On the other hand, square of distance d_{cd}^2 can be expressed as

$$\begin{aligned} d_{cd}^2 &= \underbrace{\sum_{k=1,\neq c}^{N} \omega_{kc}^2 + \sum_{k=1,\neq d}^{N} \omega_{kd}^2 + (1+\omega_{cc})^2 + (1+\omega_{dd})^2}_{\text{Volatility effect}} - \underbrace{2(\sum_{k=1}^{N} \omega_{kc}\omega_{kd} + \omega_{cd} + \omega_{dc})}_{\text{Covariance}} \\ &+ 2 \sum_{k,m=1,k\neq m,k,m\neq c,d}^{N} (\omega_{kc} - \omega_{kd})(\omega_{mc} - \omega_{md}) + 2\sum_{k,k\neq c,d}^{N} (1+\omega_{cc} - \omega_{cd})(\omega_{kc} - \omega_{kd}) \\ &+ \underbrace{2\sum_{k,k\neq c,d}^{N} (\omega_{dc} - 1 - \omega_{dd})(\omega_{kc} - \omega_{kd}) + 2(1+\omega_{cc} - \omega_{cd})(\omega_{dc} - 1 - \omega_{dd})}_{\text{Different-supplier covariance effect}} \end{aligned} \tag{2.20}$$

in which volatility effect captures the volatility in country c and d ($\sum_{k=1}^{N} \omega_{kc}^2$ and $\sum_{k=1}^{N} \omega_{kd}^2$) and domestic trade intensity($\omega_{cc} + \omega_{dd}$). Covariance effect is exactly the measured covariance of GDP fluctuation between country c and d as shown in Equation (2.19), which is obviously negatively correlated with distance. The rest of right-hand side of Equation (2.20) captures the effect of shocks originated from different countries.[7] Although here we only focus on first order terms of influence matrix, the economic intuition of these terms will be similar once second and higher order terms of ν are considered.

The bilateral trade intensity, can be measured either in gross terms or in value added

[7] In our current simple model it is assumed that shocks are independent across countries, so the effects of correlation of shocks on output covariance will not accounted in the measured GDP correlation in our model. Nevertheless, these effect will be a build-in component of distance. So in a more realistic world, distance can help to capture the GDP correlation due to these effects.

terms and we will first look at the bilateral trade intensity between countries c and d in gross terms. Following Frankel and Rose(1998), it is defined as $T_{cd,t} = \frac{E_{cd,t}+E_{dc,t}}{GDP_{ct}+GDP_{dt}}$ where $E_{cd,t}$ is value of country c's gross export to country d. In our model, it is given by

$$
\begin{aligned}
T_{cd,t} &= \frac{P_{ct}X_{cd,t} + P_{dt}X_{dc,t} + P_{ct}C_{cd,t} + P_{dt}C_{dc,t}}{\alpha_c P_{ct}Q_{ct} + \alpha_d P_{dt}Q_{dt}} &\quad (2.21)\\
&= \frac{\omega_{cd} + \omega_{dc}\frac{\alpha_d}{\alpha_c}\frac{GDPct}{GDP_{dt}} + \beta_{cd}\alpha_d + \beta_{dc}\alpha_d\frac{GDPct}{GDP_{dt}}}{\alpha_d + \alpha_d\frac{GDPct}{GDP_{dt}}} &\quad (2.22)
\end{aligned}
$$

where $X_{cd,t}$ is the country c goods used as intermediate goods in the production of country d goods, while $C_{cd,t}$ is the country c goods used to produce final consumption of country d. So the numerator is the total gross export between country c and d and the denominator is the sum of GDP of country c and d. If we only focus on the bilateral trade intensity on intermediate goods trade like in Duval et al (2016), it can be seen clearly from Equation (2.22) that it is closely related to $\omega_{cd} + \omega_{dc}$.

Now we can summarize some differences between bilateral trade intensity (intermediate goods trade) and distance. First, as shown in Equation (2.19), direct bilateral intermediate goods trade is positively correlated with covariance, while Equation (2.20) implies that squared distance is negatively correlated with covariance. Second, from Equation (2.19), bilateral trade intensity only capture a portion of covariance resulting from direct trade linkage and is silent on the correlation of output fluctuations resulting from sharing the same supplier k, i.e., $\sum_{k=1}^{N}\omega_{kc}\omega_{kd}$. Distance measure, however, can capture covariance from this channel. Finally, it is obvious that gross bilateral trade intensity matters for covariance if we only consider first-order terms of ν. Nevertheless, if second or higher-order input-output linkage, such as Ω'^2 or Ω'^3 in ν, dominates the influence matrix, the importance of bilateral trade intensity may decrease. Distance measure, however, by construction can capture these higher-order effects.

Bilateral value added trade intensity is similar to bilateral gross trade intensity except that it takes the indirect trade linkage through other countries and the higher-order input-output linkage on output correlation into consideration. But similar to gross intensity, it ignores the component $\sum_{k=1}^{N}\omega_{kc}\omega_{kd}$, the correlation of output fluctuations when both countries d and c do not trade directly or indirectly with each other but share the same supplier k in the global production network. Distance, however, can capture the covariance due to this channel.[8]

We can also compare our distance measure with production structure similarity. In Imbs(2004), it is defined as $SIS_{cdt} = \sum_{k=1}^{N} |s_{ck,t} - s_{dk,t}|$ and $s_{ck,t}$ is the share of industry k in the GDP of country c. Conceptually, both distance measure and similarity measure capture the heterogeneity between these two countries, but they measure different aspects of heterogeneity. Countries with different domestic production structures can have similar distances with other countries along the global value chain. For instance, consider two countries, one specializes in capital intensive goods and the other on labor-intensive goods. They can, however, import intermediate goods from the same sources. Shocks to supplier countries could lead to their business cycle synchronization, regardless of their different specialization pattern. Moreover, production similarity measures fail to consider the higher-order effect of supply shocks through indirect input-output linkage on output correlation. Hence, the distance measure is also different from the production structure similarity measure.

3 Data and measurements

3.1 Measure of distance

We first show how to measure the distance empirically following the definition in Equations (2.10) and (2.12). As mentioned earlier, the downstreamness measure in the literature is usually at country-sector level. So in the empirical analysis, we will follow the method discussed in Fally (2012) and Antràs and Chor (2012) and focus on one industry's downstreamness in production. As in Fally (2012), downstreamness measure of sector $i, \in 1, 2, ..., N$ in country $c \in 1, 2, ..., M$ from primary factors of production, or the backward position on the global production chain, is defined implicitly by the following linear system of equations.

$$POS_{i,t}^{c,b} = 1 + \sum_{j=1}^{N} \sum_{d=1}^{M} \omega_{ji,t}^{dc} POS_{j,t}^{d,b} \tag{3.23}$$

[8]We give an example to illustrate this point more clearly. Please see Technical Appendix B for details.

in which b stands for *backward*, $\omega^{dc}_{ji,t}$ is defined as the dollar amount of sector j's output in country d needed to produce one dollar worth of sector i's output in country c. $POS^{c,b}_{i,t}$ and $POS^{d,b}_{j,t}$ are the backward-looking position, or the downstreamness measure[9] in the global value chain for sector i in country c and sector j in country d at time t, respectively.

Based on Equation (3.23) and similar with Antràs et.al (2018), we can construct the country-level measure of backward-looking position by weighting sector-level position index in each country with the share of the sector's gross output.

$$POS^{c,b}_{t} = \sum_{i=1}^{N} POS^{c,b}_{i,t} \frac{Q^{c}_{it}}{Q^{c}_{t}} \tag{3.24}$$

Given Equation (3.24), based on the distance definition in Equation (2.10), distance can be defined as follows;

$$DIS^{cd,b}_{t} = |POS^{c,b}_{t} - POS^{d,b}_{t}| \tag{3.25}$$

3.2 Measure of correlation

Traditionally, empirical literature uses the pair-wise correlation of real output growth as the dependent variable. However, as pointed out recently by Duval et al.(2016), business cycle correlation lies between -1 and 1, and therefore the error term is less likely to be normally distributed. So in our empirical exercise, we use the time-varying quasi-correlation of output growth between two countries to measure the output correlation. Another advantage of using quasi-correlation is that its time-series structure allows us to exploit the dynamics of comovement and control for fixed effect, which is unvaried across time in a panel framework. Specifically, we calculate quasi-correlation of output growth of country c and d as

$$\rho^{cd}_{t} = \frac{(g_{ct} - g^{*}_{c})(g_{dt} - g^{*}_{d})}{\sigma^{g}_{c}\sigma^{g}_{d}} \tag{3.26}$$

[9]Similar to the "downstreamness" index for country in 2.12, "downstreamness" of a sector is based on the notion that industries using a disproportionate share of intermediate goods from relatively downstream industries should be relatively downstream themselves. $POS^{c,bo}_{it}$ is the sum of downstreamness (or distance to its supplier) of country c sector i's downstream industries, weighted by share of these industries' goods used as intermediate goods in the production of country c sector i's gross output.

where ρ_t^{cd} is the quasi-correlation of output growth of country c and d at time t. g_{ct} and g_{dt} are annual output growth rate of country c and country d, respectively, taken from Penn World Table 8.0 (ticker "rgdpe"). To be consistent with data used to calculate distance, our sample for correlation covers the period from 1995-2011.[10] g_c^* and σ_c^g denote mean and standard deviation of output growth rate over sample period, respectively.

3.3 Data and distance pattern

Following Equation (3.25), we construct the distance measure using world input-output table from WIOD database. The database covers input-output table for 40 countries over the period 1995-2011[11]. The countries include all 27 countries of the European Union (as of January 1, 2007) and 13 other major economies: Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Russia, South Korea, Taiwan, Turkey, and United States. For each country, it covers 35 industries, including 14 manufacturing sectors, 17 services sectors, agriculture, mining, construction, and utility sectors. Table C1 and C2 in appendix report the list of countries and industries. [12]

We first construct the country-sector position based on Equation (3.23) using data from 35 industries and 17 countries. Figure 1 shows each country's average position across time as measured in Equation (3.24). Resource-rich small open economies, such as Mexico, Brazil or Canada are usually positioned in a more upstream position, while some Asian countries, such as China and Korea, are more downstream, reflecting their role as world factories and greater involvement in global production chains. Based on the position of a particular country in global value chain, we construct the distance between two countries following Equation (3.25). Figure 2 gives the histogram of the

[10] Output growth data is annual. The reason we use annual data in our baseline estimation is because we try to eliminate measurement error of output correlation. Measurement error issue for annual data is less severe than that for quarterly data. In the robustness check, we also use the quarterly output growth data.

[11] It reports recent input-output information to 2014. But the industry classification changes and we can not rely on the latest data to construct long time series.

[12] One potential problem with World input-output table is that the sample is significantly biased towards European countries. Several important Asian countries, such as Thailand and Philippine, are only included in ROW group (Rest of World). Although the total ROW output only accounts for 15 percent of world GDP, it does raise the question of whether the pattern changes when these Asian countries are taken out of the ROW group. Baldwin and Lopez-Gonzalez(2014) use 2000 JETRO Asian IO table and suggests that the lack of WIOD input-output table for these countries is probably not a major issue in terms of interpreting the pattern of supply-chain trade among large countries covered in the WIOD sample.

distance across country pairs. As shown in this figure, there exists a significant variation in the distance across country pairs. Specifically, the average distance ranges from 0 to 1.24 between different country pairs. When looking at subsamples, the average distance is lowest (0.11) in North-North subsample and highest in North-South subsample(0.20).

We also calculate the quasi-correlation of country pairs following Equation (3.26) and then take the average to obtain normal correlation. The mean of the output correlation across country-pairs is around 0.304. A parallel comparison using the same subsamples indicates that output correlation in North-North countries is also the highest (with an average bilateral output correlation of 0.49), while the South-South and South-North subsamples have similar output correlation (average correlation is 0.22).

Figures 4-7 display the relationship between output correlation and distance. From Figure 4 we can see that there exists a negative relationship between distance and output correlations. The negative relationship between distance and output correlation is more pronounced for developed countries (Figure 5) or between developed and developing countries (Figure 6) and less so for developing countries(Figure 7). To formally identify the effect of distance we rely on the following empirical examination.

4 Empirical specification and results

4.1 Empirical specification

We use the following panel regression framework to explore the effect of distance along production network on their output growth quasi-correlation

$$\rho_t^{cd} = \alpha + \beta_1 d_t^{cd} + \beta_x F_t^{cd} + \psi_{cd} + \eta_t + \epsilon_t^{cd} \tag{4.27}$$

where d_t^{cd} denotes the distance between country c and d at time t constructed based on Equation (3.25), consistent with the theoretical measure of distance in the model. F_t^{cd} is other competing hypothesis for business cycle comovement, which will be discussed in detail shortly. ψ_{cd} is country-pair fixed effect. η_t is time fixed effects. ϵ_t^{cd} is the error term. β_1 is the coefficient of interest which captures the marginal effect of distance on business cycle correlation. If longer distance, that is, higher degree of heterogeneity in influence matrix, leads to lower business cycle comovement, we should expect β_1 to be negative and significant. Standard errors are clustered at country-pair level, to allow for autocorrelation and heteroscedasticity for each country pair. Output growth correlation is a generated regressor and not observable. Therefore it is possible that the standard error is not normally distributed. In all estimation specifications, standard error is generated by bootstrapping method with replication 1000 times to alleviate this concern.

4.2 Important control variables

In this section, we first discuss the important control variables. There is an large literature studying channels through which bilateral trade may affect business cycle correlation (Franke and Rose, 1998, Clark and Van Wincoop, 2001, Baxter and Kouparitsas, 2005; Kose and Yi, 2006, Giovanni and Levchenko, 2010, Liao and Santacreu, 2015, among others). To explore if the new channel we emphasize in this paper, distance along the global value chain, is important for understanding how trade linkage affects business cycle comovement, we need to control for those channels discussed in the literature.

Several variables, such as the bilateral trade intensity emphasized by Duval et al. (2016) and production or trade similarity structure discussed by Imbs (2004), are considered to be significantly correlated with the international business cycle comovement, as discussed in Section 2.4. Also, financial market integration, as argued by Imbs (2004) and Kalemli-Ozcan (2010), negatively affect global business cycle correlation. Finally, specialization in the production network is increasingly determined by countries' skill endowment (Antràs et.al 2006, among others), which implies skill intensity could be another important driver for international business cycle comovement. We control all these competing mechanisms in our specifications.

4.2.1 Bilateral trade intensity: gross export based and value-added based

Following Frankel and Rose (1998), we measured bilateral trade intensity in the following way

$$Trade_t^{cd} = \frac{x_t^{cd} + m_t^{dc}}{Y_t^c + Y_t^d} \tag{4.28}$$

where x_t^{cd} is export from country c to country d and m_t^{dc} is import of country c from country d at time t. Y_t^c is GDP of country c at time t.

Duval et. al(2016) argue that it is bilateral value-added trade intensity that matters for international business cycle comovement. we also consider this channel and measure bilateral value added trade intensity as

$$VAtrade_t^{cd} = \frac{VA_t^{cd} + VA_t^{dc}}{Y_t^c + Y_t^d} \tag{4.29}$$

where VA_t^{cd} is value added export from country c to d at time t. Following Johnson and Noguera (2012) and Koopman et al. (2014), VA_t^{cd} is calculated as

$$VA_t^{cd} = \sum_{g=1}^{N} V_t^c B_t^{cg} Y_t^{gd} \tag{4.30}$$

where N denotes the total number of countries, V_t^c is a matrix with its diagonal being value-added coefficients in country c, B_t^{cg} is Leontief inverse matrix that contains the total requirement coefficients of country c driven by per unit final demand in country g, and Y_t^{gd} is a vector representing country d's consumption of final goods produced by country g.

4.2.2 Similarity of production structure

As discussed above, production similarity and distance are connected but also differ conceptually. To separate them, we control for different measures of similarity using rich sector-level information embodied in world input-output table: similarity of bilateral trade structure and overall production structure.

More specifically, following Imbs(2004), we measure the similarity of export structure at bilateral level for a given country pair as follows:

$$tsa3_t^{cd} = 1 - \sum_i |\frac{m_{it}^{cd}}{m_t^{cd}} - \frac{m_{it}^{dc}}{m_t^{dc}}| \tag{4.31}$$

where m_t^{cd} and m_{it}^{cd} represent total imports in country c from country d and imports of industry i goods in country c from country d, respectively. m_t^{dc} and m_{it}^{dc} are defined analogously. $tsa3_t^{cd}$ measures bilateral trade industry structure.

Similarity of overall production structure is defined as

$$isa_t^{cd} = 1 - \sum_i |\frac{y_{it}^c}{y_t^c} - \frac{y_{it}^d}{y_t^d}| \tag{4.32}$$

where y_{it}^c and y_{it}^d are the output of industry i in country c and d, respectively.

4.2.3 Capital market integration

According to the empirical literature (Imbs, 2004, Kalemli-Ozcan, 2013 among others), financial market integration between two countries is also regarded as an important factor that affects business cycle comovement. In this study, we use the measure developed by Chinn and Ito (2006) (series ticker: KAOPEN) to proxy capital market integration. It measures the degree of capital account openness in 182 countries based on binary dummy variables that codify the tabulations of restrictions on cross border financial transactions reported in the IMF's Annual Report on Exchange Arrangements and Exchange Restriction (AREAER). It takes higher values when one country is more open to cross-border capital transactions. We exploit this data set and define the bilateral financial integration index between country c and country d as

$$kaopent^{cd} = |kaopen_t^c + kaopen_t^d| \tag{4.33}$$

4.2.4 Difference in skill intensity

Countries specialize in different production stage due to the endownment of different human capital(Among others, Antràs, Garicano and Rossi-Hansberg, 2006; Autor, et.al, 2013). Therefore skill intensity could be another potential driver for business cycle comovement. To capture skill intensity distance, we follow the construction of similarity in production structure and compute skill distance as

$$skill_{it}^{cd} = \sum_i |\frac{L_{it}^c}{L_t^c} - \frac{L_{it}^d}{L_t^d}| \tag{4.34}$$

where i represents the types of labor: high-skilled labor, medium skill labor and low-skilled labor. L denotes employment. Data is taken from WIOD Socio Economic Accounts database.

Finally, we also consider other controls to measure factors such as development stage and country size, including capital/labor ratio, the absolute difference between log GDP and log GDP per capita of two countries, etc. Definitions and summary of descriptive statistics for all variables are provided in Tables 1 and 2.

4.3 Basic results

Table 3 reports the baseline results. For each specification in Table 3, we control for country-pair fixed effect and time fixed effect. Country-pair fixed effects capture the effect of macroeconomic policies, institutional differences such as labor immobility, and other differences across country pairs. Time fixed effect is meant to capture some individual year's effect on business cycle correlation, for example, the great financial crisis episode 2007-2008. The columns differ in the number of control variables that are added progressively.

In Column (1)-(2) distance measure is not included so that we can focus the role of bilateral trade intensity and similarity in explaining output correlation and compare the old estimates in the literature with the new estimation result. Each column of Columns (3)-(6) of Table 3 contains a different specification for distance-comovement relationship. In Column (3) only distance measure is considered, and in Column (4)-(6) difference in country size and income, capital intensity, bilateral trade intensity (gross and value-added), and similarity in production structure are added sequentially. In Column (6) we also consider the difference in high skill intensity and low skill intensity. The similarity of bilateral trade structure is considered in Column (7).

Column (1) shows that bilateral value added trade intensity can explain business cycle correlation, with similar size of coefficient as in Duval, et.al (2016)[13]. Column (2) shows that while bilateral value added intensity has a significant positive effect on business cycle correlation, the effect of bilateral gross trade intensity is less significant, which is also consistent with Duval et.al (2016). Meanwhile, coefficients on the two similarity measures are positively significant, as in Imbs(2001,2004).

Throughout the rest of the estimation, distance along global production chain is significantly negative at the 1% confidence level. The coefficient of distance also remains

[13]Duval et.al(2016) use extrapolated OECD-WTO TiVA database for benchmark estimation. Our input-output data is extracted directly from WIOD, so Column (1) is directly comparable with Table 5.2 in Duval, et.al(2016), where they also use WIOD data for robustness check.

stable when alternative mechanisms to explain comovement are controlled. Specifically, bilateral value-added trade intensity still has a positive effect on business cycle comovement and the size remains stable, indicating that the channel through which distance affects output correlation is different from that of bilateral value-trade intensity. So the inclusion of distance does not affect the effect of value-added trade on business cycle comovement. In Columns (4)-(7), as in Column (2), the coefficient on bilateral gross-trade trade intensity is positive but insignificant compared to bilateral value added intensity.

In addition to trade-comovement relationship, we also find bilateral financial market integration has a significant negative effect, consistent with literature about the financial-synchronization relationship (Kalemli-Ozcan et al.2013). As to industrial structure, consistent with Imbs (2001, 2004), the effect of similarity in production and bilateral trade structure on business cycle comovement are both positive, suggesting if two countries trade with each other or produce more similar goods, their business cycles are more likely to be co-moved. Country size (absolute difference between log GDP) has a significantly negative effect on comovement, consistent with Duval et al. (2016). The similarity in skill intensity, as measured by the difference in low-skilled worker and high-skilled share, also has a positive and significant effect on business cycle correlation, consistent with the prediction of production stage specialization.

In summary, after controlling for all possible mechanisms, the regression results still suggest that distance in the production network significantly affects business cycle comovement, consistent with the model's conjecture. The distance along global value chain does help to explain an important proportion of observed output correlation. The estimated effect of distance on business cycle comovement is not only statistically significant but also quantitatively important. In terms of magnitude, it is comparable to some commonly agreed factors that affect business cycle comovement, such as capital market integration and bilateral value-added trade intensity. Consider the baseline result with a full set of control variables (Table 3, Column 7), our estimated coefficient implies that if we move the distance of two countries from the 10th percentile to the 90th percentile, holding all other variables at their means, output quasi-correlation decreases by 0.47 on average. That is, for country pairs whose distance along the global production chain lies in the 10th percentile, their output quasi-correlation will be 0.47 higher than those whose distances lie in the 90th percentile. This magnitude is comparable to that of the financial integration (0.23).

4.4 Other position measures

Our benchmark result highlights the role of distance on output correlation. It should be noted that, to be consistent with the theoretical model, our distance measure explicitly captures the heterogeneity of output response to productivity shocks, which in turn depends on the global input-output structure. Nevertheless, literature on global value chain also constructs other measures of each country's position in the production network based on global input-output structure. So an interesting extension from the benchmark specification is to look at if distance based on these measures, can also explain the business cycle comovement across countries. These measures will help us to understand the effect of supply shocks propagated along the production network through other channels, such as value added trade, on output comovement and further reassure the robustness of distance-comovement relationship.

4.4.1 Value-added based distance

In the benchmark estimation, the measures for position and distance are based on gross output decomposition, including both intermediate goods and final goods production (Antràs and Chor 2013 and Fally 2012). However, recent studies on business cycle comovement, such as Johonson (2014) and Soyres (2017), suggest that trade in intermediate goods will only increase the correlation of gross output, but not the correlation of value-added output or GDP in a friction-free model. It implies the effect of intermediate good trade on output comovement could be different from that of the value-added trade. Therefore, another relevant measure would be the distance that a unit of value-added goes through before arriving at the destination country. [14] We also check if our main result about distance and comovement still holds when measures based on value-added decomposition are considered.

Backward-looking value-added based downstreamness is defined as the length that intermediate goods go through before arriving at domestic country and participating in domestic final goods production. More specifically, production length of a particular

[14] Wang et al. (2017) also argue that measures based on gross output decomposition, like the measurement proposed by Antràs and Chor (2012), generates inconsistent position measures from backward and forward-looking perspective at the global level.

sector based on backward industrial linkages measures total value-added induced by a unit of final product produced in that particular sector. Following Wang et al. (2017), we first calculate the average production length of value-added from section j in country d to final products of sector i in country c;[15]

$$plvy^{dc}_{ji,t} = \frac{Xv\_GVC^{dc}_{ji,t}}{V\_GVC^{dc}_{ji,t}} \tag{4.35}$$

where $Xv\_GVC^{dc}_{ji,t}$ is the total output induced by the production chain from country d sector j's value-added and finally absorbed by sector i's final products in country c. $V\_GVC^{dc}_{ji,t}$ is the total value-added of sector j of country d embodied in the final product of sector i in country c.[16].

Aggregating Equation (4.35) over value-added from all sectors j in all countries d that have contributed to the final goods produced by sector i of country c, we can get the backward-looking value-added based downstreamness position of section i in country c

$$POS^{c,b,va}_{i,t} = \frac{\sum_{d=1}^{M}\sum_{j=1}^{N} Xv\_GVC^{dc}_{ji,t}}{\sum_{d=1}^{M}\sum_{j=1}^{N} V\_GVC^{dc}_{ji,t}} = \frac{Xy\_GVC^{c}_{it}}{Y\_GVC^{c}_{it}} \tag{4.36}$$

where b denotes "backward", $Xy\_GVC^{c}_{it}$ stands for total value of value-added induced by final goods production in sector i of country c; and $Y\_GVC^{c}_{it}$ is the value of final output from sector i in country c. Therefore, $POS^{c,b,va}_{i,t}$ measures total intermediate inputs induced by a unit value of particular final product from sector i in country c, throughout all upstream sectors in the economy.

Given the production length measure of value-added of a particular sector in country c, we can construct a country-level measure of position based on value-added decomposition by summing up all sectors in country c.

$$POS^{c,b,va}_{t} = \frac{\sum_{i=1}^{N} Xy\_GVC^{c}_{it}}{\sum_{i=1}^{N} Y\_GVC^{c}_{it}} \tag{4.37}$$

[15]See Wang et al. (2017) for discussion on how to compute production length based position and distance index from forward and backward production linkages.

[16]For detailed construction and calculation of $Xv\_GVC^{cd}_{ij,t}$ and $V\_GVC^{cd}_{ij,t}$, please refer to Wang et al. (2017).

Distances are defined in the same way as before. That is

$$DIS_t^{cd,b,va} = |POS_t^{c,b,va} - POS_t^{d,b,va}| \tag{4.38}$$

4.4.2 Length based distance

In the benchmark theoretical model and empirical analysis in Section 2 and 3, the distance is a simplified version of economic distance proposed by Conley and Dupor (2003), capturing the degree to which two countries differ in their downstreamness positions. It is motivated by the argument that two countries with similar positions tend to have similar production technology or similar supply shocks' downstream transmission effect through backward industrial-linkage, which implies higher output correlation. Another more explicit measure of distance along the global value chain discussed in the literature is to examine how many production steps it takes the goods produced by source country to reach destination countries. The value-added based position discussed above will help us construct such a measure of distance.

To see why, consider there is a positive productivity shock in country A, value-added produced in country A increases and value-added export also increases. Suppose value-added goes through 2 steps to arrive destination country B and 3 steps to country C. Since the impact of the shock weakens with the distance along value chain we can conclude that if it takes more steps for goods from the source country to reach the destination country, business cycle of source and destination may be less comoved. Motivate by this, we directly construct a distance measure between source and destination country based on the value-added based position measure and examine how it affects their business cycle correlation. We refer it as length based bilateral distance.

Specifically, based on $plvy_{ji,t}^{dc}$ defined in Equation (4.35), length based backward bilateral distance between country c and country d is defined by

$$DIS_t^{cd,b,l} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} Xv\_GVC_{ji,t}^{dc}}{\sum_{i=1}^{N}\sum_{j=1}^{N} V\_GVC_{ji,t}^{dc}} \tag{4.39}$$

where intuitively, $DIS_t^{cd,b,l}$ measures the average production length of a unit of value-added from country d to final products in country c.

4.4.3 Comparison

We first check if the distance defined in our theoretical model is correlated with the two distance measures discussed above. The correlation between value-added based distance and benchmark distance is 0.35 while the correlation between length based distance and benchmark distance is around 0.30. It indicates that our distance measure captures some position information based on input-output linkage which is also embodied in the other two distance measures.

Table 4 gives the result. The first two columns just relisted the baseline estimation results in Table 3 for comparison convenience. In all specifications, the coefficients of all three distance measure remain to be negative and significant (at the 1 percent confidence level), suggesting the negative relationship between distance and comovement is robust to alternative distance measures.

Regarding other controls, consistent with Duval et.al (2016), the coefficient of bilateral trade intensity in gross term is not significant at the 5% level for the specification of value-added based distance and 10% for the specification of length based distance. Results for other control variables, such as the production structure similarities and export structure, and the capital market integration, are all similar to the benchmark result.

5 Robustness check

5.1 Alternative measure of correlation

One potential issue regarding the quasi-correlation used in benchmark regression is that the noise may be particularly high since it is a special case of rolling window correlation with window size equal to 1. We use several alternative measures of correlation to deal with this problem.[17]

Two alternative correlations of output are considered. First, we use the correlation of quarterly output growth rate from alternative source as the dependant variables in the estimation.[18] Second, we use a 5-year moving window correlation of annual

[17]We also, try to use a multivariate GARCH model to compute the dynamic conditional correlation. But our low-frequency annual data and small sample size(16 observations) is not sufficient for the maximum likelihood to find the correct initial value and optimal solution.

[18]Quarterly output data for European countries is extracted from OECD library dataset and that

output growth rate and the standard pairwise correlation for full sample to eliminate the potential noise associated with quasi-correlation.

Another concern about the estimation result is reverse causality between distance and output correlation. Countries with less comoved business cycle may specialize in different production stages, which leads to a longer distance in production chain.[19] To alleviate this concern, in the specifications with 5-year rolling window correlation (annual data) and 5-year non-overlapping correlation (quarterly data), for each explanatory variable, we use its value at the beginning year of each 5-year window. Similarly, in the specification with standard correlation over the full sample, we also use the value of each explanatory variable at the beginning year of the sample. It is very unlikely business cycle comovement in the subsequent period has an impact on one country's production activity at the beginning of the period.

Table 5 reports the results using alternative correlations of output growth rate. In general, the main result that longer distance along the global production chain reduces business cycle comovement remains unchanged when alternative measures of output correlation are used. Out of all specifications, the coefficients of distance on output correlation are negative and significant. Regarding coefficients on other controls, coefficients on country size (absolute difference between log GDP or log GDP per capita) are mainly significantly negative but mixed over different specifications. The effect of bilateral trade (value-added) remains positive and significant for specifications using annual data growth correlations. The result of bilateral trade (gross export) is mixed. Its coefficient is negative and significant when quarterly data are used[20], while positive and significant for correlations using annual growth data. The coefficient on capital market integration turns to be positive in estimations using standard correlation over the full sample, perhaps because of more severe endogeneity problem in these estimations, especially in the cross-section analysis, as discussed in Kalemli-Ozcan et al. (2013).

for China, Bulgaria, Brazil, Cyrus, Lithuania and Romania is taken from IFS. All data series are based on 2005 price expect China with the base year 2010. Correlation of output growth rate is computed over three subsamples (1995Q2-2000Q4, 2001Q1-2006Q4 and 2007Q1-2011Q4).

[19]Some country-specific characteristics may determine the relative positions on the global production chain and the output comovement between two countries simultaneously. But we have introduced the country pair fixed effect in the estimation to address this problem.

[20]This is perhaps because of the use of different data set. Duval et al. (2016) use extrapolated OECD-WTO TiVA database, and we use different data source - OECD library dataset for the quarterly data.

5.2 Alternative aggregation methods for distance

As pointed by Antràs and Chor(2018), different approaches of aggregation may impact the pattern of positioning in global value chain. In this robustness check, we consider an alternative aggregation method suggested by them. We aggregate the sector-level input-output linkage to the country level and obtain country-by-country input-output relationship. We then utilize this country-by-country input-output relationship to obtain country-level position measures and distance directly. This aggregation method is different from that used for our position measure discussed in the benchmark estimation, for which we maintain country-sector dimension information of input-output linkage and compute position measure at country level weighted by gross output or export. Table 6 reports the result when the alternative position measure is used. Alternative measures of correlation are also used. For all specifications, the coefficients of distance on output correlation are negative and significant.

5.3 Financial Crisis

Our sample covers the period from 1995-2011, which includes financial crisis episodes (2007-2008). Usually, business cycle correlation increases during turbulent times. It is natural to ask if our baseline result may be due to the inclusion of this episode. Inclusion of time fixed effect partially addresses this problem by capturing time trending effect. But the financial crisis may also play a role through other channels, such as trade credit. To alleviate this concern, we should check if our results still hold during normal periods. Meanwhile, since Wang et al. (2017) show that activities along deeply involved global value chain decrease during financial crisis times, we are also interested in finding out if the impact of distance on business cycle correlation differs during normal times and financial crisis times.

Therefore, we first redo the estimation using subsample before global financial crisis. If coefficients on distance are still significantly negative, it indicates that distance-comovement relationship identified in this paper is not driven by the financial crisis period. We then interact distance measure with time dummies representing financial crisis period, i.e., year dummy for 2007 and 2008 to see if the relationship between distance and business cycle comovement changes during financial crisis.

Table 7 reports the results. One can see that once we focus on the pre-crisis period, the size of the effect of distance on comovement is smaller (Columns 1 and 2 in Table 7), but remains to be negative and significant. This finding suggests that our main finding that longer distance along global value chain leads to smaller comovement holds in normal times. For the second regression, we can observe two facts. First, the coefficient on the distance is still negative and significant. Second, the coefficient on the interaction term is positive, which implies that the effect of distance on comovement is weaker during financial crisis period. This finding, to some extent, is consistent with Wang et al. (2017)'s finding that activities along global value chain decrease during financial crisis times. Since the shock transmission channel through global value chain weakened, distance will have less effect on output comovement across countries. Meanwhile, another explanation for this result is that during financial crisis period, common shocks becomes the major driving force for output fluctuations. So country-specific shocks transmitted along the production network will be less important in explaining business cycle correlation across countries.

6 Conclusion

This paper studies the effect of distance in production network on international business cycle comovement. We first propose a distance measure capturing heterogeneity in the output response to country-specific supply shocks in a theoretical production network framework and then show this distance is negatively correlated with output correlation. We also bring the model to data and investigate the effect of distance in explaining business cycle synchronization empirically. Estimation results show that distance has a significant and negative effect on business cycle correlation, suggesting that a closer distance between two countries in the the global value chain will lead to more business cycle synchronization. This result is robust for the inclusion of a large set of control variables and different fixed effects, alternative measures of business cycle correlation and distance. The significant effect of distance on business cycle correlation sheds light on the importance of shock transmission mechanism.

In short, this paper identifies a new channel through which trade linkage affect business cycle comovement by emphasizing the role of distance in the global value chain in explaining business cycle correlation. This channel enhances our understanding of how production network structure impacts the shock transmission across borders and, therefore, global business cycle comovement.

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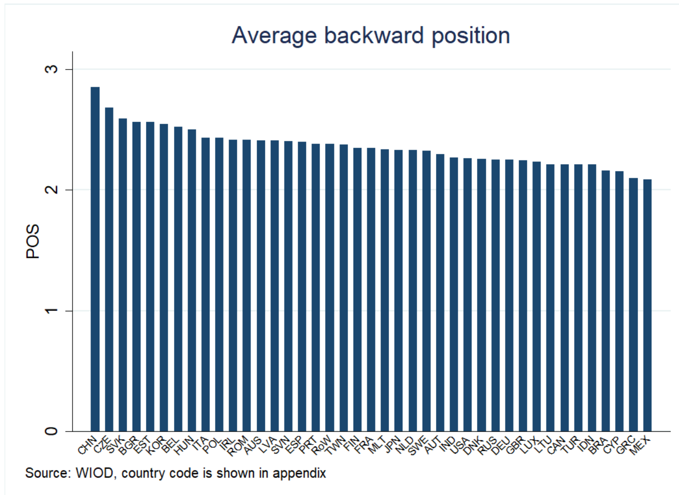
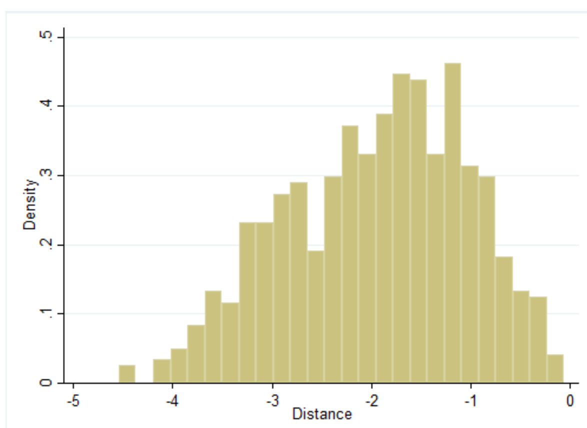
Figures

Figure 1: Country Position



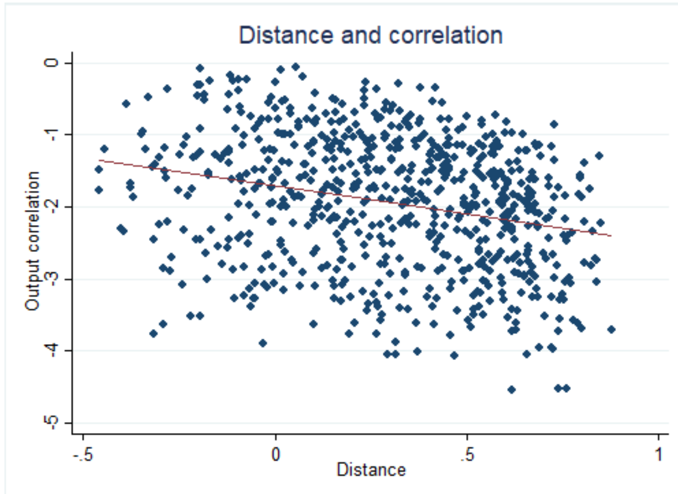
Note: Backward position measure in this figure is defined in Equation (3.24). For each country we take the sample mean across time.

Figure 2: Histogram of distance



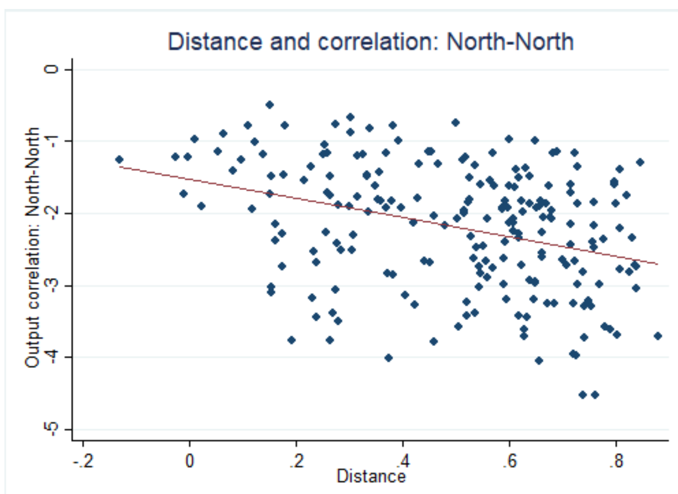
Note: Distance measure in this figure is defined in Equation (3.25): absolute difference between two countries' downstreamness position (weighted by gross output). For each country pair we take the sample mean from 1995 to 2011.

Figure 3: Distance and Output Correlation



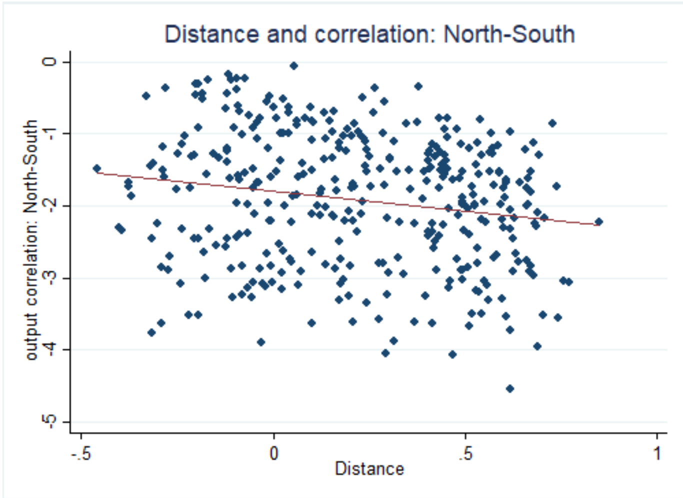
Note: Distance and output growth correlation (full sample mean) from 1995 to 2011.

Figure 4: Distance and Output Correlation: North-North



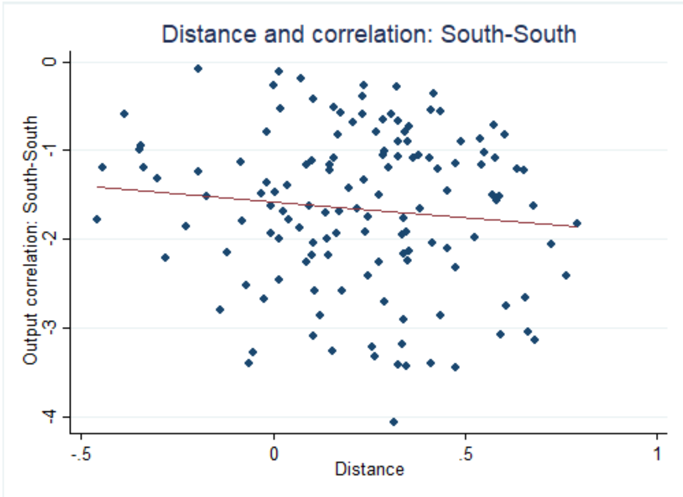
Note: This figure show the correlation of distance and output growth within North countries. North countries refer to developed countries based on definition of World Bank. All the values take sample mean from 1995 to 2011.

Figure 5: Distance and Output Correlation: North-South



Note: This figure show the correlation of distance and output growth between North and South countries. North countries and south countries refer to developed and developing countries, respectively, based on definition of World Bank. All the values are sample mean from 1995 to 2011.

Figure 6: Distance and Output Correlation: South-South



Note: This figure show the correlation of distance and output growth within South countries. All the values are sample mean from 1995 to 2011.

Table 1: Definition of variables

Variable	Definition	Source
Quasi correlation	Time varying correlation for annual data sample	Pen world table 8.0
5-year rolling window correlation	Time varying correlation with rolling window size 5 for annual data sample	Pen world table 8.0
Quarterly correlation	Correlation during 1995-1999, 2000-2004 and 2005-2011 for quarterly data sample	IFS and OECD online library
Standar correlation	Correlation during 1995-2011 for annual data	Pen world table 8.0
Distance	Distance defined in definition 1	WIOD and authors' calculation
Value added based distance	Distance defined in Equation (4.38)	WIOD and authors' calculation
Length based distance	Distance defined in Equation (4.39)	WIOD and authors' calculation
Bilateral trade (VA)	Log of bilateral value added trade intensity	WIOD
Bilateral trade (Gross export)	Log of bilateral gross trade intensity	WIOD
isa	Similarity of overall production structure	WIOD
tsa3	Similarity of bilateral trade structure	WIOD
Low-skilled share	Lower skilled worker share	WIOD
High-skilled share	High skilled worker share	WIOD
kaopen	Capital market integration	Chinn and Ito idex
K/L	Absolute difference in capital-labor ratio	Pen world table 8.0
log GDP	Absolute difference in log GDP	Pen world table 8.0
log GDP per capita	Absolute difference in log GDP per capita	Pen world table 8.0

Note: The table lists the definition and source for control variables in country level regression.

Table 2: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Quasi correlation	0.304	1.148	-7.487	10.791	11248
5-year rolling window correlation	0.322	0.524	-0.998	0.999	8436
Quarterly correlation	0.195	0.304	-0.654	0.915	1859
Standard correlation	0.325	0.321	-0.487	0.938	703
Distance	0.222	0.186	0	1.237	11248
Value added based distance	0.288	0.227	0	1.615	11248
Length based distance	4.051	0.541	2.853	6.365	11248
Bilateral trade(VA)	-6.939	1.473	-11.493	-3.373	11248
Bilateral trade(Gross output)	-6.039	1.711	-16.05	-1.761	11248
kaopen	2.927	1.927	-3.05	4.844	10656
isa	0.508	0.153	-0.152	0.845	11248
tsa3	-0.112	0.372	-0.997	0.86	11244
K/L	0.868	0.747	0	4.051	11248
Low-skilled share	0.12	0.1	0	0.577	9842
High-skilled share	0.085	0.066	0	0.402	9842
log GDP	2.052	1.468	0	7.643	11248
log GDP Per Capita	0.747	0.624	0	3.35	11248

Table 3: Distance and output correlation, benchmark result

VARIABLES	ρ	ρ	ρ	ρ	ρ	ρ	ρ
Distance			-0.706***	-0.653***	-0.648***	-1.090***	-1.067***
			(0.128)	(0.129)	(0.132)	(0.175)	(0.169)
kaopen	-0.0343***	-0.0537***			-0.0273**	-0.0516***	-0.0536***
	(0.0113)	(0.0144)			(0.0113)	(0.0137)	(0.0143)
Bilateral trade	0.162***	0.141***				0.153***	0.145***
(VA)	(0.0384)	(0.0502)				(0.0494)	(0.0498)
Bilateral trade		0.0698*				0.0581	0.0686*
(Gross export)		(0.0376)				(0.0379)	(0.0376)
isa	2.008***	3.131***			1.892***	3.072***	3.022***
	(0.315)	(0.395)			(0.321)	(0.401)	(0.395)
tsa3		0.185***					0.160**
		(0.0684)					(0.0679)
Low-skilled share		1.223***				1.109***	1.130***
		(0.421)				(0.420)	(0.419)
High-skilled share		2.156***				2.078***	2.014***
		(0.747)				(0.750)	(0.747)
K/L		-0.268***		-0.209***	-0.157**	-0.294***	-0.293***
		(0.100)		(0.0743)	(0.0745)	(0.104)	(0.0996)
Log GDP	-0.276***	-0.618***		-0.257***	-0.210**	-0.499***	-0.512***
	(0.0853)	(0.113)		(0.0839)	(0.0869)	(0.117)	(0.114)
Log GDP per capita	0.163*	0.542***		0.0845	0.197**	0.469***	0.478***
	(0.0910)	(0.118)		(0.0921)	(0.0944)	(0.118)	(0.117)
Constant	0.628*	0.746	0.123***	0.790***	-0.362	0.841	0.925*
	(0.379)	(0.505)	(0.0435)	(0.199)	(0.273)	(0.516)	(0.502)
Observations	10,656	9,320	11,248	11,248	10,656	9,324	9,320
R-squared	0.347	0.369	0.355	0.357	0.348	0.372	0.373
Number of countries	666	666	703	703	666	666	666
Country-pair Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: Dependent variable is quasi-correlation of output growth. Backward distance is defined in definition 1. Bilateral trade (VA) and Bilateral trade (Gross export) are bilateral trade intensity measure based on value-added and gross export, as discussed in Section 4.2.1. tsa3 is measure of similarity of bilateral trade structure mentioned in Section 4.2.2. isa is similarity in overall production structure and kaopen represents capital market integration. Low-skilled share and high-skilled share are defined in 4.2.4. K/L stands for absolute difference in capital-labor ratio, while log GDP and log GDP per capita represent absolute difference between log GDP and log GDP per capita, respectively. Standard error is shown in parentheses which is generated from bootstrapping sampling method with replication 1000 times and clustered at country-pair level.
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Distance and output correlation, alternative distance

	Benchmark distance		Value added distance		Length based distance	
VARIABLES	ρ	ρ	ρ	ρ	ρ	ρ
Distance	-0.653***	-1.067***	-0.281***	-0.401***	-0.119**	-0.174**
	(0.129)	(0.169)	(0.0918)	(0.126)	(0.0475)	(0.0750)
kaopen		-0.0536***		-0.0586***		-0.0522***
		(0.0143)		(0.0143)		(0.0143)
Bilateral trade(VA)		0.145***		0.140***		0.143***
		(0.0498)		(0.0502)		(0.0501)
Bilateral trade(Gross export)		0.0686*		0.0677*		0.0196
		(0.0376)		(0.0375)		(0.0435)
isa		3.022***		3.144***		3.169***
		(0.395)		(0.396)		(0.395)
tsa3		0.160**		0.183***		0.186***
		(0.0679)		(0.0683)		(0.0685)
Low-skilled share		1.130***		1.086***		1.183***
		(0.419)		(0.421)		(0.421)
High-skilled share		2.014***		2.189***		2.136***
		(0.747)		(0.747)		(0.748)
K/L	-0.209***	-0.293***	-0.201***	-0.266***	-0.205***	-0.281***
	(0.0743)	(0.0996)	(0.0742)	(0.100)	(0.0742)	(0.100)
Log GDP	-0.257***	-0.512***	-0.303***	-0.597***	-0.321***	-0.624***
	(0.0839)	(0.114)	(0.0833)	(0.113)	(0.0838)	(0.113)
Log GDP per capita	0.0845	0.478***	0.0847	0.511***	0.116	0.542***
	(0.0921)	(0.117)	(0.0926)	(0.118)	(0.0923)	(0.117)
Constant	0.790***	0.925*	0.825***	0.838*	1.235***	1.154**
	(0.199)	(0.502)	(0.201)	(0.506)	(0.277)	(0.538)
Observations	11,248	9,320	11,248	9,320	11,248	9,320
R-squared	0.357	0.373	0.356	0.370	0.355	0.370
Number of country pairs	703	666	703	666	703	666
Country-pair Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes

Note: Definition of dependent variables can be found in the footnote of Table 3. Value added based distance and length based distance are defined in section 4.4.1 and 4.4.2 respectively.Standard error is shown in parentheses which is generated from bootstrapping sampling method with replication 1000 times and clustered at country-pair level.

*** p<0.01, ** p<0.05, * p<0.1

Table 5: Distance and output correlation, alternative correlation

	Quarterly correlation		Standard correlation		5-Year rolling correlation	
VARIABLES	ρ	ρ	ρ	ρ	ρ	ρ
Distance	-0.376***	-0.435***	-0.546***	-0.281***	-0.555***	-0.630***
	(0.0838)	(0.0905)	(0.0556)	(0.0650)	(0.0717)	(0.0745)
kaopen		-0.00389		0.0535***		0.0482***
		(0.0104)		(0.00888)		(0.00590)
Bilateral trade(VA)		0.0669**		-0.00274		0.0579***
		(0.0305)		(0.00633)		(0.0219)
Bilateral trade(Gross export)		-0.0489**		0.0404***		0.0627***
		(0.0239)		(0.0106)		(0.0174)
isa		0.246		0.205*		0.0874
		(0.230)		(0.115)		(0.158)
tsa3		0.0197		0.0381		0.119***
		(0.0451)		(0.0450)		(0.0298)
Low-skilled share		0.150		-0.193*		-0.0910
		(0.307)		(0.103)		(0.210)
High-skilled share		0.291		-0.186		0.0528
		(0.385)		(0.164)		(0.311)
K/L	0.0286	0.0431	0.0769*	0.158***	-0.257***	-0.288***
	(0.0453)	(0.0493)	(0.0400)	(0.0382)	(0.0371)	(0.0390)
Log GDP	0.0336	0.0409	0.000642	0.0345***	-0.156***	-0.164***
	(0.0547)	(0.0570)	(0.00679)	(0.00889)	(0.0478)	(0.0482)
Log GDP per capita	0.102*	0.0630	-0.361***	-0.350***	-0.0329	-0.00371
	(0.0537)	(0.0589)	(0.0478)	(0.0476)	(0.0493)	(0.0539)
Constant	-0.0510	-0.0220	0.639***	0.434***	0.809***	1.548***
	(0.130)	(0.328)	(0.0204)	(0.101)	(0.118)	(0.227)
Observations	1,893	1,785	703	663	8,436	7,988
R-squared	0.512	0.519	0.376	0.501	0.261	0.270
Number of country pairs	703	666			703	666
Country-pair Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes

Note: Definition of dependent variables can be found in the footnote of Table 3. Quarterly correlation denotes five-year non-overlapping standard correlation of real GDP growth rate. Standard correlation refers to standard correaltion of real GDP growth rate over the entire annual data sample. 5-year rolling correlation refers to standard correlation of real GDP growth rate with 5-year rolling window for annual data sample. Standard error is shown in parentheses which is generated from bootstrapping sampling method with replication 1000 times and clustered at country-pair level. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Distance and output correlation, alternative country-level distance

	Quasi correlation	Quarterly correlation	Standard correlation	5-Year rolling correlation
VARIABLES	ρ	ρ	ρ	ρ
Distance	-1.174***	-0.525***	-0.295***	-0.730***
	(0.196)	(0.117)	(0.0671)	(0.0849)
kaopen	-0.0540***	-0.00308	0.0535***	0.0479***
	(0.0143)	(0.0103)	(0.00883)	(0.00590)
Bilateral trade(VA)	0.148***	0.0722**	-0.00324	0.0597***
	(0.0497)	(0.0306)	(0.00630)	(0.0218)
Bilateral trade(Gross export)	0.0735*	-0.0468**	0.0411***	0.0656***
	(0.0376)	(0.0238)	(0.0106)	(0.0174)
isa	3.055***	0.301	0.198*	0.0987
	(0.394)	(0.231)	(0.116)	(0.158)
tsa3	0.165**	0.0202	0.0339	0.122***
	(0.0679)	(0.0455)	(0.0447)	(0.0298)
Low-skilled share	1.114***	0.181	-0.193*	-0.106
	(0.420)	(0.310)	(0.103)	(0.210)
High-skilled share	2.094***	0.440	-0.195	0.0873
	(0.748)	(0.386)	(0.164)	(0.310)
K/L	-0.293***	0.0447	0.158***	-0.286***
	(0.0995)	(0.0491)	(0.0380)	(0.0389)
Log GDP	-0.513***	0.0450	0.0351***	-0.164***
	(0.114)	(0.0579)	(0.00885)	(0.0483)
Log GDP per capita	0.473***	0.0620	-0.351***	-0.00828
	(0.117)	(0.0588)	(0.0476)	(0.0540)
Constant	0.974*	-0.0134	0.440***	1.591***
	(0.502)	(0.325)	(0.101)	(0.227)
Observations	9,320	1,785	663	7,988
R-squared	0.372	0.518	0.502	0.270
Number of country pairs	666	666		666
Country-pair Fixed effect	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes

Note: Definition of dependent variables can be found in the footnote of Table 3. The four colums differ in correlation measures. Quasi correlation refers to benchmark quasi-correlation of real GDP growth rate. Quarterly correlation denotes five-year non-overlapping standard correlation of real GDP growth rate. Standard correlation refers to standard correaltion of real GDP growth rate over the entire annual data sample. 5-Year rolling correlation refers to standard correlation of real GDP growth rate with 5-year rolling window for annual data sample. Standard error is shown in parentheses which is generated from bootstrapping sampling method with replication 1000 times and clustered at country-pair level.

*** p<0.01, ** p<0.05, * p<0.1

Table 7: Distance and output correlation, financial crisis and normal times

	Normal times		Full Sample	
VARIABLES	ρ	ρ	ρ	ρ
Distance	-0.470***	-0.622***	-0.853***	-1.543***
	(0.159)	(0.185)	(0.133)	(0.179)
Distance*GFC dummy			0.854***	1.378***
			(0.142)	(0.164)
kaopen		0.0561***		-0.0605***
		(0.0122)		(0.0142)
Bilateral trade(VA)		0.0585		0.123**
		(0.0460)		(0.0494)
Bilateral trade(Gross export)		0.101***		0.0495
		(0.0324)		(0.0377)
isa		1.218***		3.161***
		(0.373)		(0.395)
tsa3		0.0857		0.167**
		(0.0670)		(0.0674)
Low-skilled share		0.743*		1.128***
		(0.400)		(0.420)
High-skilled share		0.103		1.820**
		(0.590)		(0.742)
K/L	-0.223**	-0.257***	-0.196***	-0.250**
	(0.0898)	(0.0934)	(0.0745)	(0.0996)
Log GDP	-0.0374	-0.0321	-0.275***	-0.566***
	(0.106)	(0.110)	(0.0840)	(0.113)
Log GDP per capita	-0.0772	0.0392	0.0867	0.494***
	(0.111)	(0.111)	(0.0921)	(0.117)
Constant	0.426	0.632	0.854***	0.763
	(0.261)	(0.477)	(0.199)	(0.499)
Observations	7,733	7,322	11,248	9,320
R-squared	0.041	0.054	0.359	0.380
Number of country pairs	703	666	703	666
Country-pair Fixed effect	Yes	Yes	Yes	Yes
Year Fixed effect	Yes	Yes	Yes	Yes

Note: Definition of dependent variables can be found in the footnote of Table 3. This table displays the result for subsample prior to 2007 and financial crisis time. The first two columns are results for normal times before 2007 and the last two columns are results for full sample with interaction of financial crisis dummy and distance.Standard error is shown in parentheses which is generated from bootstrapping sampling method with replication 1000 times and clustered at country-pair level.
*** p<0.01, ** p<0.05, * p<0.1