BRI Infrastructure Development and Economic Growth

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Abstract: *Infrastructure development is a key aspect of the Belt and Road Initiative (BRI). After measuring the infrastructure stocks of China and BRI countries, this paper estimates BRI countries' demand for infrastructure development and verifies its economic growth effects, thus demonstrating the importance of the BRI. We found China's infrastructure stock to be second-highest in the world, next only to that of the United States. While China's infrastructure development is in sync with its economic development, inadequate infrastructure prevents many countries around the world from unlocking their full economic potential. By providing financing for much-needed infrastructure, the BRI exerts positive effects on economic growth in relevant countries. With a mandate of promoting infrastructure interconnectivity, the BRI will serve as a new driving force shaping a community of shared future for humankind.*

Keywords: *infrastructure stock, quadrant chart, Belt and Road Initiative (BRI)*
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1. Introduction

In September 2013, General Secretary Xi Jinping introduced the "Silk Road Economic Belt and the 21st Century Maritime Silk Road" initiative (known as the "Belt and Road Initiative" or BRI) during his visit to Central Asian and Southeast Asian countries. "The key to BRI development is interconnectivity, and infrastructure development is the cornerstone of interconnectivity," remarked General Secretary Xi Jinping on April 26, 2019 at the Second Belt and Road Forum for International Cooperation. Focusing on infrastructure interconnectivity, the BRI promotes coordinated development among BRI countries, bringing common prosperity to the global economy.

After decades of development, China leads most countries in terms of infrastructure stock. Infrastructure development has played a pivotal role in China's transformation over the past four decades from a poor country into the second-largest economy in the world. China's experience may provide important lessons for BRI countries and contribute to creating a community of shared future for humankind.

There is an extensive demand for infrastructure development around the world. Despite high per capita of infrastructure stock, developed countries face the problem of a large number of renovation requirement of aging infrastructure. While for developing countries, they are still in the early stage of economic development, not only with a low stock of infrastructure, but also the insufficiency of corresponding technology, funds and talents for infrastructure construction, which leave a large space

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“一带一路”基础设施建设与经济增长

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***摘　要：**基础设施建设是“一带一路”倡议中不可或缺的一环，本文从实物角度测算了中国及“一带一路”国家的基础设施存量情况，估计了各国基础设施建设的真实需求状况，并通过实证发现基础设施建设对经济增长具有拉动作用，论证了“一带一路”倡议的合理性和必要性。研究发现，中国基础设施存量已跃居世界第二，仅次于美国。同时，中国的基础设施建设与经济发展水平协同程度较高，而相当一部分国家基础设施建设落后于经济发展水平。因此，“一带一路”倡议的提出恰好符合大部分国家当前的发展需求，能够助力沿线各国经济发展。“一带一路”倡议以基础设施互联互通为出发点，将为新一轮全面开放下构建“人类命运共同体”注入新的动力。*

***关键词：**基础设施存量；象限图法；“一带一路”倡议*

JEL 分类号：H54; O19; O50

一、引言

2013年9月，习近平总书记在出访中亚和东南亚国家期间首次提出了共建“丝绸之路经济带”和“21世纪海上丝绸之路”的倡议。2019年4月26日，习近平总书记在第二届“一带一路”国际合作高峰论坛上再次指出：共建“一带一路”，关键是互联互通，而基础设施建设正是“互联互通”的基石。“一带一路”倡议以基础设施互联互通为优先领域和重要着眼点，促进沿线国家协同联动发展，实现全球经济的共同繁荣，在当前全球经济环境下具备极强的合理性。

中国的基础设施建设存量在多年的积累过程中已逐渐领先于全球大部分国家。纵观中国经济发展历程，改革开放四十多年以来，中国从经济发展基础薄弱、基础建设投资落后的人口大国一跃成为全球第二大经济体，基础设施建设在其中发挥了重要的作用。中国四十年基建的成功经验正可以为“一带一路”沿线国家的发展提供重要借鉴，为“人类命运共同体”的构建添加动力。

同时，站在全球其他国家的角度，大部分国家对于基础设施的建设存在大量需求。发达国家虽然基础设施的人均拥有量高，但基础设施使用年限较久，大量基础设施需要修缮及重建；而对于发展中国家，尚处于经济发展的初期，缺乏技术、资金和人才，不仅基础设施存量较低，也缺乏修建基础设施相应的技术、资金和人才，增长空间也较大。随着全球化的不断发展，各个国家在深入参与国际贸易与合作中取得了长足的进步和

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for growth. In today's era of globalization, most countries have benefited greatly from international trade and cooperation. Some, however, have failed to realize the economic dividends of globalization largely due to infrastructure gaps. Without adequate infrastructure, further progress in free trade would be hard to attain.

According to the Asian Development Bank (ADB), Asia needs to invest 26 trillion US dollars by 2030 to bridge their infrastructure gaps. Despite great improvements over the past few decades, infrastructure in Asia has yet to match economic, population, and urban development. Transportation, electric power, water, and health sectors all require massive investments, generating huge business opportunities for China which boasts advantages in the sectors. Interconnectivity under the BRI serves the needs of relevant countries and the interests of world economic development.

Academics have studied BRI-related trade and economic data, extensively. Estimating global import and export data, Zhang (2018) found that BRI countries may gain new ideas and opportunities for economic development by drawing upon China's industrial, infrastructure, and urban development experiences. From an industrial perspective, Yao (2018) found that compared with BRI countries, China's labor- and capital-intensive manufacturing and producer services are well positioned for external support. Using the social network analysis method, Zhang (2019) found that China occupied an intermediate link in international trade, having close trade ties with both developing and developed countries. Yet there are few academic studies on BRI infrastructure connectivity. Despite the importance of BRI infrastructure connectivity, relevant estimations have been inadequate. In particular, gaps exist in estimating the infrastructure stocks of BRI countries. To a large extent, it is not possible to compare infrastructure stock in countries at different economic development stages and experiencing rapid technological progress. Also, as it is based on different estimation methods, the measurement of each country's infrastructure stock may lead to different conclusions, resulting in scholarly contradictions in findings on the relationship between infrastructure development and economic growth. These issues directly impact the effectiveness of BRI infrastructure development. Based on the above considerations, this paper categorizes infrastructure in the temporal dimension, and employs multidimensional data and estimation methods to re-examine infrastructure in the context of the BRI. Our findings are expected to provide references for the implementation of BRI infrastructure connectivity and economic development in BRI countries.

Two types of literature are directly related to this paper. First, the estimation of infrastructure stock; second, the temporal correlation between infrastructure and economic growth. Regarding infrastructure stock, two methods of infrastructure measurement are generally accepted, i.e. monetary measurement and physical measurement. Most studies using monetary measurement, e.g. Rostow (1990), Aschauer *et al*. (1989), are focused on the United States. Research on infrastructure investment in other countries has yet to be carried out due to a lack of data. Using the perpetual inventory method, Kamps (2006) estimated the stock of government capital in OECD countries from 1960 to 2001, which makes a great contribution to addressing the lack of data. Since government capital in OECD countries is mainly invested in infrastructure, this set of data can be seen as an approximation of infrastructure investment in OECD countries. Based on Kamps *et al*. (2006), Jin (2012) defined the scope of domestic infrastructure investment, made necessary supplementation and adjustment to official data, and employed the perpetual inventory method to estimate infrastructure investment stock at national and provincial levels. Based on Kamps's (2006) and Jin's (2012) conclusions, Zhao (2013) believed that the two sets of data were comparable and thus performed comparative analysis. Regarding the physical measurement method, Calderon (2015) employed the principal component analysis (PCA) method to measure the weights of communication, energy, and transportation, using physical assets as the basis for estimating infrastructure investment stock. Due to the universality of physical assets and the availability of data, it becomes feasible to compare infrastructure investment stock globally. Chinese academics have also extensively

发展，然而还有相当一部分国家并未在全球化时代搭上经济快速发展的快车，这很大程度上是因为基础设施短缺或薄弱。没有完善的基础设施建设作为支撑，自由贸易不能得到更为深入的进步和发展。

根据亚洲开发银行的报告，预测到2030年亚洲将需要投资26万亿美元来解决基础设施严重短缺的问题。可以看到，虽然过去20年间，亚洲基础设施已经获得了大幅改善，但是依然无法匹配经济、人口和城镇化快速发展的需要，无论是交通运输、电力还是水、卫生部门均需要较大规模的投资支持，这当然也意味着巨大的市场和投资潜力，而这些领域都是中国目前拥有优势的领域。“一带一路”基础设施建设互联互通的提出，正好切合沿线国家发展的需求，符合世界经济发展的根本利益。

目前，学术界对于“一带一路”倡议涉及的相关贸易经济数据已经做了较多的研究。张辉(2018)通过测算全球进出口贸易数据发现在新型全球化格局中，沿线的国家和地区可以借鉴中国发展过程中积累的工业化、基础设施建设、城镇化等方面的经验，获得经济发展的新思路与新契机。姚星(2018)从产业的角度发现，相对于“一带一路”沿线国家，中国的劳动密集型及资本密集型制造业和生产性服务业的外向支撑地位较高。张辉(2019)通过引入社会网络的分析方法发现中国在国际贸易中处于承上启下的地位，同时与发达国家及发展中国家开展密切的贸易活动。然而，学术界对于“一带一路”相关基础设施联通方面的关注和研究相对较少，虽然对于“一带一路”基础设施联通的重要性达成了共识，但是相应的测算仍有所不足，尤其是对于沿线各国基础设施存量的测算尚存在大量空白。这很重要的一部分原因是由于技术的快速进步以及各国经济阶段的不同，很难将各国的基础设施进行合理的对比。同时，由于测算方法的差异，各国基础设施的度量也存在较多不一致的结论，进而导致了关于基础设施建设与经济增长之间关系的研究存在较多的矛盾之处，对于这些问题的认识将直接影响到“一带一路”基础设施联通建设的成效。本文正是基于如上考虑，试图通过对基础设施在时间维度上进行更为细致的分类，并利用多维度的数据和测算方法，将基础设施置于“一带一路”倡议的大背景下重新考察，为“一带一路”倡议下基础设施联通的推行，为更好地帮助和推动“一带一路”沿线国家发展提供借鉴。

与本文直接相关的文献主要有两类。一是关于基础设施存量的测算，二是基础设施与经济增长之间时间上的联动关系。基础设施存量测算方面，学界普遍认可的基础设施测量方法分为两种：一种是货币计量方式，另一种是实物计量方式。针对货币计量方式的研究主要集中在美国，Rostow(1990)、Aschauer(1989)等学者以基础设施为出发点进行了诸多研究；其他国家对基础设施投资的研究则基本并未展开，主要原因在于数据获取层面的困难。Kamps(2006)对数据的缺失做了卓有成效的贡献，他使用永续盘存法，对OECD国家1960—2001年的公共资本(Government Capital)存量数据进行了估算。因为OECD国家公共资本主要投资于基础设施投资，因此这一套数据可以近似视作OECD国家的基础设施投资数据。金戈(2012)在Kamps(2006)等国内外学者研究的基础上，对国内基础设施投资的范围进行了界定，对官方公布数据进行了必要的补充和调整，并使用永续盘存法对全国层面和分省层面的基础设施投资存量数据进行了估算。赵雷(2013)基于Kamps(2006)和金戈(2012)的研究结论，认为两套数据具有良好的可比性，于是进行对比分析。针对实物计量方式，Calderón(2015)以通信、能源、交通三方面基础设施为代表，通过主成分分析法，对三方面的基础设施投资权重进行了测度，使用实物资产作为基础设施投资存量的估算依据。由于实物资产的通用性和数据的

investigated infrastructure investment. From the perspective of physical assets, Zhang (2007) estimated China's infrastructure stock, but his method of mostly using domestic statistics makes it difficult for international comparison.

Academics have identified two correlation mechanisms between infrastructure and economic growth. Some believed that infrastructure development should lag behind economic growth and others argued that it should stay ahead of economic growth. According to those who believe that infrastructure development should lag behind economic growth, a country must massively invest in such productive sectors as industry and agriculture, and it is not worth investing in infrastructure until economic growth crosses a certain threshold. This generally occurred in poor developing countries. the representative scholar of this theory is Albert O. Hirschman (1958). According to Rosenstein-Rodan (1943), relatively advanced infrastructure development is a key growth driver, and the infrastructure sector can be established by pooling social capital in ways similar to that by which the government disburses fiscal funds. Infrastructure development must keep pace with economic growth to avoid negative effects on socio-economic development. Ahmed (1976) suggested that for most developing countries, the lag in infrastructure construction will affect socio-economic development. Glover (1975) identified infrastructure development as the biggest constraint of economic development for less developed countries. Rostow (1990) identified six stages in the development of human society, highlighting the importance of infrastructure in the early stage of industrialization.

Most academics endorse the view that infrastructure should precede economic development. Aschauer (1989) observed a decline in US productivity around 1973. Based on the US time series data of 1945-1985, he created a C-D production function and discovered positive economic growth effects of roads and other infrastructure. Specifically, Button (1976) believed that two mechanisms were at play - the direct transportation input effect and the indirect multiplier effect. According to the World Bank, each percent of growth in infrastructure stock leads to a one percentage point growth in GDP. Using India's railway data of 1861-1930, Donaldson (2018) verified that upfront infrastructure development could drive regional economic growth by reducing trade costs. This paper also empirically verifies the positive growth effects of early infrastructure investment and found that infrastructure development could significantly drive mid- and long-term economic growth.

Both developed and developing countries have a huge demand for infrastructure development, for which, over the past four decades, China has developed sufficient experiences and resources, which may provide lessons for other countries. As it is growth-enhancing, infrastructure development may drive further economic growth. With a focus on infrastructure investment, the BRI will help relevant countries build much-needed infrastructure.

The rest of this paper is structured as follows: Section 2 measures global and BRI countries' infrastructure stocks and evaluates infrastructure development in each country; Section 3 examines BRI countries' actual infrastructure demand based on their respective economic development stages; Section 4 demonstrates the BRI's rationality based on empirical analysis. Section 5 provides conclusions.

2. Analysis of Each Country's Infrastructure Stock

For a straightforward evaluation of China's infrastructure development, this section compares infrastructure development in China with those of other countries, especially BRI countries, using physical measurement.

2.1 Data Sources and Methodologies

Two methods of infrastructure measurement are recognized in academia. First, monetary measurement of each country's infrastructure stock in US dollar terms. The other method is the physical measurement of each country's infrastructure stock based on universal and comparable physical assets

易获取性，使得在世界范围内进行基础设施投资存量比较具有了可行性。国内学者对基础设施投资也进行了诸多研究，张军(2007)从实物资产的角度对基础设施投资存量进行了分析估算，但由于过多采用国内数据的统计特点，使得国际比较存在客观困难。

而关于基础设施与经济增长联动方面，学术界认为其联动机制主要有两种，即滞后论和超前论。滞后论认为一国经济体需对工业、农业等生产性部门进行大规模投资，直到突破经济增长水平的门槛时，投资基础设施建设等才具有促进价值。其描述的现象多发生于穷困的发展中国家，该思想的代表学者为Albert O. Hirschman(1958)。超前论的代表学者为Rosenstein-Rodan(1943)，其提出相对超前的基础设施建设是经济增长的重要来源，而基础设施部门可通过筹集大量不可分割的社会分摊资金(类似政府运用财政资金)组建。此外，由于基础设施建设前期投入大、产出回报高，需配合经济增长预测有计划性进行投资与建设，否则相对滞后的基础设施建设可能导致电力供给不足、道路不便，进而限制生产部门扩大生产，拖累经济增速。Ahmed(1976)提出对于大部分发展中国家而言，基础设施建设的滞后将影响社会经济发展。Glover (1975)提出对于不发达国家，制约经济发展最核心的因素为基础设施建设。Rostow(1990)通过梳理人类社会发展的六个阶段，阐明了起飞阶段的工业化开端需要重视基础设施建设。

两种理论中，超前论获得较多的认可。Aschauer(1989)观察到1973年前后美国生产率下降的情形，通过美国1945-1985年时间序列的数据，建立C-D生产函数，发现道路等基础设施对经济增长具有拉动作用。具体的机制作用方面，Button(1976)认为有两种作用机制，包括直接的运输投入效应和间接的乘数效应。世界银行测算表明，基础设施存量每增长1%，GDP相应增长1%。Donaldson(2018)用印度1861-1930年的铁路数据，证实前置的基础设施建设可通过降低贸易成本带动地区经济增长。本文亦通过实证分析验证了超前论的存在性，发现基础设施的建设能够显著拉动未来中长期经济的增长。

综上，无论发达国家还是发展中国家，目前基础设施建设仍存在巨大的需求，而中国在过去四十年的基础设施发展历程中积累了足够的经验和资源，正好能够为其他国家的基础设施建设提供思路和参考。同时，由于基础设施建设与经济增长存在正向相关关系，基础设施的发展可拉动经济进一步增长。因此，以基础设施建设投资为重点的"一带一路"倡议的推出正当时，恰应景。

本文整体结构如下：第二章从实物层面首先对全球和"一带一路"沿线各国的基础设施存量进行测算，评估各国的基础设施发展状况；第三章从相对量角度出发，结合"一带一路"沿线各国的经济阶段，分析各国对于基础设施建设的真实需求程度；第四章论证了"一带一路"倡议提出的合理性；第五章为全文结论。

二、各国基础设施建设存量分析

为直观评估中国在基础设施建设方面的发展情况，比较中国与全球多个国家，特别是和"一带一路"沿线国家的基础设施发展差异，本章将通过实物计量方式对世界各经济体的基础设施存量进行相应测算。

(一)数据来源和方法

目前，学界普遍认可的基础设施测量的方法分为两种：一种是货币计量方式。在以美元计价条件下，研究

and extensively available data. With limited samples, most of which are developed countries, monetary measurement offers little comparability for China. Hence, this paper employs the physical measurement method to compare the infrastructure stocks of various countries, especially BRI countries. The data span for the physical measurement is 1990-2014, and the main data source for the country comparison is the World Bank's World Development Indicators (WDI) database.

2.2 Measurement of Infrastructure Investment Stock Based on Physical Assets

This paper compares each country's infrastructure investment volume relative to that of other countries. Considering the representativeness, comparability, and availability of data, measuring infrastructure investment stock by means of physical assets is a good option. In this section, we employ multidimensional data to depict the "infrastructure investment stock index." Referencing domestic and international literature, Calderon (2015) employed the principal component analysis (PCA) method to estimate the physical assets of 59 countries and regions, as well as each physical asset indicator as a share of the "per capita infrastructure investment stock index." In this manner, physical assets are divided into the three sectors of electric power, telecom, and transportation. In measuring physical assets, we use the proxy variables of "electric power consumption" for the electric power sector, "the number of landline telephones per 100 persons" from 1990 to 2000, and "the number of broadband internet subscriptions per 100 persons" after 2001 for the telecom sector, reflecting broadband data as a better indicator for telecom infrastructure in the internet era,[1] and "railway length per thousand persons" for the transportation sector. All data is from the World Bank's World Development Indicators (WDI) database.[2] Following the PCA method, this paper has estimated global and BRI countries' physical asset data as much as possible, reflecting each physical asset indicator as a share of the "per capita infrastructure investment stock index."

With the rapid development of telecom technologies and the penetration of new technologies since the 1990s, the dimension of infrastructure measurement was extended to the internet sphere after 2000. We divide the data period into Stage I (1990-2000) without broadband data and Stage II (2001-2014) with broadband data for a PCA analysis.

2.2.1 Data treatment process

When conducting an infrastructure assessment for sample countries, researchers are faced with the problem of data availability. For most developing countries, in particular, the lack of data is extremely severe, which explains the paucity of relevant literature. To ensure fair estimation and to retain as many sample countries as possible for analysis, this paper carries out the following treatment for missing data based on previous literature and data attributes.

i. Explanations on raw data. All four indicators selected in this paper are from the World Bank's database, which contains data about physical infrastructures in 215 countries in 1960-2017. In this paper, our general principle is to retain as many samples and countries as possible.

ii. Treatment of missing data

According to the availability of data, the analysis covers duration between 1990 and 2014. And considering the accuracy and comparability of the data, the missing data are processed as follow: deleting sample countries if any of four indicators is/are completely missing and those with missing values for more than five years, and using the mean value method to interpolate the missing samples. In the next section, we will use the renovated data for comprehensively comparative study of infrastructure development with BRI countries and global samples.

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[1] Data also indicates a rapid increase in broadband usage after 2001 for most countries and slowing, stagnant or falling telephone usage.

[2] For the repeatability of estimation and the universality of data acquisition, this paper employs the World Bank's database.

者基于货币资产测度各国基础设施存量水平。另一种是实物计量方式。通过实物资产的通用性、可比性和数据的广泛性，测度世界各国基础设施投资存量大小。从方法上来看，货币计量的方式由于样本有限，并大都属于发达国家序列，对中国的对比借鉴意义有限，而实物计量的方式其数据的可获得性和可比性更好，因此，本文主要将基于实物计量的方式进行测度，对全球各国，特别是“一带一路”沿线国家的基础设施存量进行一个全面系统的比较。实物计量方式数据时间跨度为1990−2014年，国别比较数据主要来源于世界银行世界发展指标（WDI）数据库。

（二）基于实物资产角度的基础设施投资存量测度

本文的关注点在于基础设施投资规模的国际相对比较，考虑到数据的代表性、可比性和易获得性，以实物资产估算基础设施投资存量成为一个相对优良的比较途径和方法。本节使用多维度的数据来刻画“基础设施投资存量指数”。参考Calderon（2015）采用主成分分析法对59个国家和地区实物数据进行了估算测度，并估计了各实物指标在构成“人均基础设施投资存量指数”时所占的比重。本文将实物估算分为三个领域：电力能源领域，以“电力消耗量”为刻画依据。通信领域，1990−2000年以“每百人所拥有的固定电话线路”为刻画依据；2001年后，考虑到互联网革命的冲击，我们认为，宽带数据能够更好地衡量通信情况，因此将通信领域的代表数据更替为“每百人使用宽带的人数”[1]。交通领域，以“每千人拥有的铁路里程”为刻画依据。所有数据均来源于世界银行数据库（WDI）[2]。通过主成分分析法，本文尽可能多地对全球以及“一带一路”相关国家和地区实物数据进行了估算测度，估计了各实物指标在构成“人均基础设施投资存量指数”时所占的比重。

由于20世纪90年代以来通信领域技术的快速发展和新技术的逐渐普及，2000年后衡量基础设施的维度扩展到了互联网领域。本文将时间跨度分为1990−2000年不包含宽带数据的第一阶段，和2001−2014年包含宽带数据的第二阶段，分别对其进行主成分分析。

1.数据处理过程

在对全球样本国家的基础设施进行评估的时候，研究者面临的最大困难就是数据的可获得性，尤其是对于大多数的发展中国家，数据缺失情况极为严重，这也是为何相关文献缺乏的重要原因。为了尽可能保证测算的公允和保留尽可能多的样本国家进行分析，本文在结合前人文献和数据特征的基础上对缺失数据进行了如下处理：

（1）关于原始数据的说明。本文所选取的四个指标全部来源于世界银行数据库，世界银行提供了全球215个国家1960−2017年的相关实物基础设施的数据。本文的处理总的原则是在保证科学合理的前提下，尽量保存多的样本和国家。

（2）缺失数据的处理

根据本文研究数据的可得性，本文测算的年份为1990−2014年，且考虑到数据的准确性和可比性，本文对

[1] 数据中也显示大多数国家在2001年之后宽带数据开始了快速的上涨，而电话数据开始增长放缓进而停滞甚至下降。
[2] 为了测算的可重复和数据的可获得性，本文选取了世界银行数据库作为数据来源。

2.2.2 Estimating the infrastructure stock index

i. Estimation of infrastructure stock index in Stage I. We performed a PCA analysis of infrastructure investment data from 1990 to 2000 to measure the composite infrastructure stock indexes for the three infrastructure sectors, including the following variables:

Communication sector: "Total length of landline telephones"; electric power sector: "Annual total electric power consumption"; transportation sector: "Total railway length." Hence, the "infrastructure investment stock index" for the period of 1990-2000 can be expressed as:

$$GINFR_{it} = 0.6453 \times GTEL_{it} + 0.4336 \times GPW_{it} + 0.6289 \times GTR_{it} \quad (1)$$

Where, $GINFR_{it}$ is the composite infrastructure stock index, $GTEL_{it}$ is the total length of telephone lines, GPW_{it} is the total annual electric power consumption, and GTR_{it} is the total railway length.

ii. Estimation of infrastructure stock index in Stage II. We performed a PCA analysis for infrastructure investment data in 2001-2014 to measure the composite infrastructure stock index for the three sectors, including the following variables:

Telecom sector: "Total length of landline telephone lines" is replaced with "broadband subscribers"; electric power sector: "Annual electric power consumption"; transportation sector: "Total railway length." The calculation of the "total infrastructure investment stock index" for 2001-2014 is shown as follows:

$$GINFR_{it} = 0.6266 \times GTB_{it} + 0.4264 \times GPW_{it} + 0.6524 \times GTR_{it} \quad (2)$$

Where, $GINFR_{it}$ is the composite infrastructure stock index, GTB_{it} is broadband penetration, GPW_{it} is annual electric power consumption, and GTR_{it} is total railway length.

2.2.3 Composite infrastructure development status for global samples

Based on the physical asset measurement method, this paper estimates the composite infrastructure index for global sample data in 1990-2014, selecting data of four temporal cross-sections, including 1990, 2000, 2001, and 2014, with results shown below:

The United States is the most advanced on all four temporal cross-sections from 1990 to 2014. In 1990, China ranked 11th among 59 countries in terms of the composite infrastructure stock index. By 2000, China's ranking jumped to second, but its absolute gaps with the US were still significant. In 2001, global composite infrastructure stock decreased substantially due to the replacement of "per capita landline telephone lines" with "per capita broadband subscriptions." Back then, China's internet infrastructure was far less sophisticated, causing its ranking to decline to eighth place. With rapid progress in infrastructure development after 2001, China's ranking on the composite infrastructure stock index returned to second place on the cross-section of 2014, and gaps with the US further narrowed. China and the US eclipsed the 57 other countries in terms of infrastructure development. Russia ranked third on this list, but its infrastructure stock was only 1/4 that of China's.

2.2.4 Composite infrastructure development in BRI sample countries

We estimated the aggregate infrastructure indexes for investigating differences in infrastructure development between China and BRI countries by using physical assets meaures based on 44 countries data during 1990-2014. Then, time cross-section data of 1990, 2000, 2001,and 2014 are selected respectively, for further comparative analysis, with results shown below:

Among the 44 sample BRI countries, China ranked third in terms of aggregate infrastructure index in 1990, behind Russia and India, but followed a stable growth trajectory afterward and overtook Russia and India in 2000, with the highest aggregate infrastructure index among the sample BRI countries. After introducing the "per capita broadband subscriptions" index in 2001, China's aggregate infrastructure index ranking slipped to third place after Russia and India. However, China's infrastructure stock

缺失数据进行了如下处理：删除四个指标完全缺失的样本国家、删除数据缺失时间连续超过5年的国家、利用均值法对缺失样本进行插补。后文将利用填补完善的数据对全球样本及“一带一路”相关国家样本的基础设施状况进行综合比较和分析。

2.基础设施总量综合指数估计

(1)第一阶段基础设施总量综合指数估计。对1990−2000年基建投资数据进行主成分分析，衡量三个基础设施服务领域的基础设施总量综合指数，包括：①通信领域：“固定电话线路总长”；②电力能源领域：“年电力消耗总量”；③交通运输领域：“铁路总里程”。由此1990−2000年阶段的“基础设施总量综合指数”的计算方式为：

$$GINFR_{it} = 0.6453 \times GTEL_{it} + 0.4336 \times GPW_{it} + 0.6289 \times GTR_{it} \quad (1)$$

其中$GINFR_{it}$是基础设施总量综合指数，$GTEL_{it}$是固定电话线路总长，GPW_{it}是年电力消耗总量，GTR_{it}是铁路总里程。

(2)第二阶段基础设施总量综合指数估计。我们对2001−2014年基建投资数据进行主成分分析，衡量三个基础设施服务领域的基础设施总量综合指数，包括：①通信领域：将“固定电话线路总长”变量换为“宽带普及人数”；②电力能源领域：“年电力消耗总量”；③交通运输领域：“铁路总里程”。由此，2001−2014年的“基础设施总量综合指数”的计算方式为：

$$GINFR_{it} = 0.6266 \times GTB_{it} + 0.4264 \times GPW_{it} + 0.6524 \times GTR_{it} \quad (2)$$

其中$GINFR_{it}$是基础设施总量综合指数，GTB_{it}是宽带普及人数，GPW_{it}是年电力消耗总量，GTR_{it}是铁路总里程。

3.全球样本综合基础设施建设情况

基于实物资产测度方法，本文对1990−2014年的全球样本数据进行了基础设施总量综合指数的测算，其中分别选取1990年、2000年、2001年与2014年四个时间截面年份的数据作进一步比较分析，结果如下：

在1990−2014年的四个时间截面上，美国均领先。与此相对，中国在1990年时基础设施总量综合指数得分相对落后，在59个国家排名第十一；而在2000年时，中国的基础设施总量综合指数已经跃升至第二名，但与美国仍存在较大差距；2001年时，由于“固定电话线路总长”替换为“宽带的普及人数”指标，全球基础设施总量综合指数整体水平都大幅下滑，而彼时中国的互联网基础设施建设尚处于较为落后的水平，因此相较于2000年，中国的排名又下滑至第八名；但在2001年后中国基础设施建设快速发展，总量增速迅猛，在2014年的横截面上，中国基础设施总量综合指数得分已经重新回到全球第二的位置，与美国的差距进一步缩小，同时中美基础设施建设水平远超剩余57个国家，排名第三的俄罗斯指数得分仅约为中国的1/4。

4.“一带一路”相关样本综合基础设施建设情况

为进一步考察中国与“一带一路”相关国家基础设施发展水平的差异，本文利用1990−2014年44个国家的基础设施投资数据，基于实物资产测度的方法计算了其基础设施投资总量综合指数，然后分别选取1990年、

Table 1: Comparison of Infrastructure Stock Indexes for 59 Countries

Country	1990	Country	2000	Country	2001	Country	2014
The United States	8.62	The United States	9.62	The United States	4.46	The United States	9.06
Russia	2.41	China	4.22	Russia	1.49	China	8.01
Japan	1.75	Russia	2.52	Sweden	1.17	Russia	2.53
Germany	1.65	Japan	2.14	Finland	1.03	Japan	1.64
Sweden	1.43	Germany	2.02	Germany	0.66	Germany	1.62
France	1.30	France	1.58	Japan	0.54	France	1.44
Finland	0.80	Sweden	1.42	France	0.53	India	1.07
The United Kingdom	0.71	India	1.34	China	0.40	Republic of Korea	1.03
India	0.59	Finland	1.18	India	0.39	Finland	1.03
Italy	0.46	The United Kingdom	1.06	The United Kingdom	0.09	Sweden	0.95
China	0.45	Italy	0.75	Republic of Korea	0.09	Britain	0.81
Ukraine	0.31	Republic of Korea	0.47	Belgium	0.07	Italy	0.47
Switzerland	0.10	Spain	0.40	Switzerland	0.02	Spain	0.43
Kazakhstan	0.10	Belgium	0.25	Austria	0.00	Saudi Arabia	0.27
South Africa	0.09	South Africa	0.20	Italy	-0.01	Austria	0.18

Note: In the interest of length, only the top 15 countries for various years are listed.

increased swiftly, overtaking Russia's in 2014. As a result, China's aggregate infrastructure index is more than twice that of the second-ranking country. In aggregate terms, China already boasts the largest infrastructure stock among BRI countries.

During 1990-2000, most BRI sample countries except China recorded slower growth rates in infrastructure development. After introducing the broadband subscription indicator, all sample scores slid, to some extent, but China's infrastructure investment started to increase rapidly, resulting in significant strengths over other BRI sample countries by 2014.

In comparing global and BRI countries' samples, we found that China was far ahead of most economies in terms of aggregate infrastructure stock and growth. With advanced technologies and experiences, China is well-positioned to assist economies in meeting their robust demand for infrastructure development. Given their disparate levels of economic development, such demand is heterogeneous. Countries with modest infrastructure stocks may not always have a strong demand for infrastructure development. The following section will investigate each country's infrastructure relative to their level of economic development and assess their future infrastructure development potential.

3. Relationship between Infrastructure Development and Economic Growth in BRI Countries

The amount of infrastructure is subject to the level of a country's economic development. By reducing logistical costs and facilitating the flow of information, infrastructure development is conducive to economic prosperity, which in turn means more resources available for building infrastructure. In assessing a country's real demand for infrastructure development, we must take into account its economic attributes. It can be learned from the above estimations that China is ahead of most other countries in terms of both aggregate infrastructure stock and growth rate. The question is twofold: Is China's infrastructure development sufficient to meet its own needs and are there significant infrastructure gaps in BRI countries? To answer these questions, this paper employs the quadrant chart

表1 全球59个国家基础设施总量综合指数分年对比

国家	1990年	国家	2000年	国家	2001年	国家	2014年
美国	8.62	美国	9.62	美国	4.46	美国	9.06
俄罗斯联邦	2.41	中国	4.22	俄罗斯	1.49	中国	8.01
日本	1.75	俄罗斯	2.52	瑞典	1.17	俄罗斯	2.53
德国	1.65	日本	2.14	芬兰	1.03	日本	1.64
瑞典	1.43	德国	2.02	德国	0.66	德国	1.62
法国	1.30	法国	1.58	日本	0.54	法国	1.44
芬兰	0.80	瑞典	1.42	法国	0.53	印度	1.07
英国	0.71	印度	1.34	中国	0.40	大韩民国	1.03
印度	0.59	芬兰	1.18	印度	0.39	芬兰	1.03
意大利	0.46	英国	1.06	英国	0.09	瑞典	0.95
中国	0.45	意大利	0.75	大韩民国	0.09	英国	0.81
乌克兰	0.31	大韩民国	0.47	比利时	0.07	意大利	0.47
瑞士	0.10	西班牙	0.40	瑞士	0.02	西班牙	0.43
哈萨克斯坦	0.10	比利时	0.25	奥地利	0.00	沙特阿拉伯	0.27
南非	0.09	南非	0.20	意大利	−0.01	奥地利	0.18

注：由于篇幅所限，只列出了历年排名前十五的国家。

2000年、2001年与2014年四个时间截面年份的数据作进一步比较分析，结果如下。

从与“一带一路”沿线国家对比情况来看，中国的基础设施总量综合指数得分在1990年位于“一带一路”44个相关样本国家中的第三位，落后于俄罗斯与印度，但此后呈现稳定的增长趋势，并在2000年反超印度与俄罗斯，成为“一带一路”样本国家中基础设施总量综合指数得分最高的国家。2001年引入“宽带普及人数”指标后，中国的基础设施总量综合指数排名有所下滑，落后于俄罗斯、印度，位于样本国家中的第三位。但此后中国基础建设存量快速上升，2014年中国反超印度与俄罗斯，基础设施总量综合指数得分是第二名的两倍以上，从总量上来看，中国已经成为“一带一路”样本国家中基础设施存量规模的首位。

从时间序列纵向对比看，1990−2000年这一时间区间上，除了中国以外实际上绝大部分“一带一路”样本国家的基础设施建设都处于缓慢增长状态，而在2001年引入宽带指标后，样本得分均出现了一定程度下滑，但此后基础建设投资开始加大，尤其中国在2001年后基础建设投入飞速增长，在2014年其相对于其他“一带一路”样本国家基建优势已经相当明显。

至此，本文发现在全球范围内，无论是同全球样本还是同“一带一路”相关国家样本对比，中国的基础设施总量及其增长速度均遥遥领先其余大部分经济体，可以认为，中国基础设施建设取得了巨大进步，在基础设施建设中积累的技术和发展经验较为充足，有能力为基础设施建设落后、基建设施需求旺盛的经济体提供帮助。然而，由于各国经济发展水平差异较大，对基础设施建设存量的需求具有异质性，基础设施存量较低并不一定代表存在旺盛需求。因此，接下来，本文将对各国基础设施建设相对于其经济发展水平的相对超前、滞后关系做相应的探究，讨论各国基础设施建设是否存在发展空间。

Table 2: Comparison of Annual Infrastructure Stock Indexes for 44 BRI Countries

Country	1990	Country	2000	Country	2001	Country	2014
Russia	4.49	China	10.48	Russia	3.04	China	10.44
India	2.00	Russia	5.07	India	1.73	Russia	4.16
China	1.76	India	3.74	China	1.65	India	2.53
Ukraine	0.93	Republic of Korea	1.37	South Africa	0.46	Republic of Korea	1.05
Poland	0.68	Poland	1.01	Ukraine	0.34	Poland	0.60
South Africa	0.57	Ukraine	0.93	Poland	0.28	Ukraine	0.53
Kazakhstan	0.31	Turkey	0.77	Republic of Korea	0.19	South Africa	0.45
Republic of Korea	0.29	South Africa	0.75	Czech Republic	0.08	Kazakhstan	0.36
Czech Republic	0.10	Czech Republic	0.24	Austria	0.06	Czech Republic	0.24
Austria	0.09	Austria	0.22	Kazakhstan	0.05	Turkey	0.23
Romania	-0.01	Iran	0.13	Romania	-0.16	Austria	0.20
Turkey	-0.02	Kazakhstan	0.07	Hungary	-0.20	Saudi Arabia	0.19
Bulgaria	-0.15	Romania	0.01	Slovak Republic	-0.22	Iran	0.06
Belarus	-0.17	Hungary	-0.02	Israel	-0.22	Romania	0.03
Slovak Republic	-0.20	Greece	-0.04	Slovenia	-0.23	Hungary	-0.03

Note: In the interest of length, only the top 15 countries for various years are listed.

method[3] to compare each country's infrastructure stock measured by physical assets with their level of economic development for a standardized assessment of whether their infrastructure development is ahead of, in sync with, or lags behind their economic development. The results of the assessment will help identify the real demand of BRI countries for infrastructure development.

3.1 Quadrant Chart Method

The quadrant chart method defines the areas divided by X- and Y-axes as quadrants. The division by X- and Y-axes forms four quadrants. The specific method and steps are explained below:

i. Select two indicators for various countries from 1990 to 2014: Per capita GDP ($AGDP_{it}$) and per capita infrastructure investment stock index ($INFR_{it}$).

ii. Perform *Z-Score* standardization treatment for the $AGDP_{it}$ and $INFR_{it}$ indicators. Meanwhile, the origin of the Cartesian coordinate system is moved to the average center of the sample dataset, which is particularly important for model identification and the evaluation of dynamic evolution over time.

We adopted the *Z-Score* standardization method, i.e. standardization of standard deviation:

$$Z = \frac{(x_i - \bar{x})}{s} \tag{3}$$

$$\bar{x} = \sum \frac{x}{n} \tag{4}$$

Where, i is sample observations (1,2,...,n); $\bar{x}$ is the mean value of x_i, and s is the sample standard deviation:

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{(n-1)}} \tag{5}$$

[3] Chen Mingxing (2010) developed the quadrant method for the analysis of the relationship of being ahead of, in sync or lagging behind. This method is relatively straightforward with a vivid form of presentation and boasts the advantages of quantitative measurement.

表2 “一带一路”44个相关国家基础设施总量综合指数分年对比

国家	1990年	国家	2000年	国家	2001年	国家	2014年
俄罗斯	4.49	中国	10.48	俄罗斯	3.04	中国	10.44
印度	2.00	俄罗斯	5.07	印度	1.73	俄罗斯	4.16
中国	1.76	印度	3.74	中国	1.65	印度	2.53
乌克兰	0.93	大韩民国	1.37	南非	0.46	大韩民国	1.05
波兰	0.68	波兰	1.01	乌克兰	0.34	波兰	0.60
南非	0.57	乌克兰	0.93	波兰	0.28	乌克兰	0.53
哈萨克斯坦	0.31	土耳其	0.77	大韩民国	0.19	南非	0.45
大韩民国	0.29	南非	0.75	捷克共和国	0.08	哈萨克斯坦	0.36
捷克共和国	0.10	捷克共和国	0.24	奥地利	0.06	捷克共和国	0.24
奥地利	0.09	奥地利	0.22	哈萨克斯坦	0.05	土耳其	0.23
罗马尼亚	−0.01	伊朗	0.13	罗马尼亚	−0.16	奥地利	0.20
土耳其	−0.02	哈萨克斯坦	0.07	匈牙利	−0.20	沙特阿拉伯	0.19
保加利亚	−0.15	罗马尼亚	0.01	斯洛伐克共和国	−0.22	伊朗	0.06
白俄罗斯	−0.17	匈牙利	−0.02	以色列	−0.22	罗马尼亚	0.03
斯洛伐克共和国	−0.20	希腊	−0.04	斯洛文尼亚	−0.23	匈牙利	−0.03

注：由于篇幅所限，只列出了历年排名前十五的国家。

三、“一带一路”国家基础设施建设与经济增长的前后置关系

基础设施数量的多寡受限于一国经济发展水平，两者存在密切的联动关系。基础设施的发展能够通过降低物流成本、加快信息流通等方式促进经济的发展和繁荣，而经济的繁荣亦能反作用于基础设施的建设，促进基础设施存量的进一步扩大，因此，在判断一国的基础设施建设的真实需求时，必须结合其经济发展特性加以分析。通过前文的测算可知，中国在基础设施建设存量方面无论是总量还是增速均领先于大部分国家，那么中国的基础设施建设是否已能满足国内经济发展的真实需求？“一带一路”相关国家是否存在较大的基础设施建设缺口呢？为回答以上问题，本文引入象限图法[3]，在充分考虑各国经济发展阶段的基础上，利用实物衡量的基础设施存量，与经济增长发展水平进行比较，给出标准化的前后置关系的判断，来分析“一带一路”沿线各国对于基础设施建设的真实需求。对于两变量超前、协同、滞后关系进行研究和识别。

（一）象限图法

象限图法将X轴和Y轴分割的区域称为象限。通过原点，以X轴和Y轴为划分的依据，分割形成四个象限。具体方法和步骤如下：

1．选择1990−2014年多个国家的两个指标：人均GDP（$AGDP_{it}$）和人均基础设施投资存量指数（$INFR_{it}$）。

2．对$AGDP_{it}$和$INFR_{it}$两个指标进行*Z-Score*标准化处理，分别对应生成两个新变量：$ZAGDP_{it}$和$ZINFR_{it}$。同时将笛卡尔坐标系的原点移动到样本数据集平均中心的位置，这一点对于模型的判别和分析随时间进展的

[3] 陈明星（2010）提出了象限图法来分析判断超前、协同、滞后关系，该方法逻辑相对简明，分析展现形式直观，也兼具了定量度量的优点。

iii. New sequence after standardization treatment: With $ZINFR_{it}$ as X-axis and $ZAGDP_{it}$ as Y-axis, data from different countries will form a set of points ($ZINFR_{it}$, $ZAGDP_{it}$), with which the corresponding scatter diagram can be drawn on the coordinate axis.

After completing the above steps, we may determine the relationship between the two with processed data. The principles for determination are specified and explained as follows:

Principle 1: Create indicator $ZINFR_{it}-ZAGDP_{it}$ and determine its sign. $ZINFR_{it}$ is the extent to which the country sample point deviates from the total sample center of indicator *ZINFR*. $ZAGDP_{it}$ is the extent to which the country sample point deviates from the total sample center of indicator *ZAGDP*. Therefore, the indicator's positive or negative sign denotes the coordination of a country's two indicators jointly deviating from the sample center. When a country's standardized data is projected to the quadrant chart, if indicator $ZINFR_{it}-ZAGDP_{it}<0$, coordinate point ($ZINFR_{it}$, $ZAGDP_{it}$) will fall into the upper left zone of the chart (Zone II), i.e. the region ranks relatively high in terms of per capita GDP but lags behind others in terms of per capita infrastructure stock.

However, if indicator $ZINFR_{it}-ZAGDP_{it}>0$, coordinate point ($ZINFR_{it}$, $ZAGDP_{it}$) will fall into the lower right zone (Zone I), i.e. the region lags behind others in terms of per capita GDP but is ahead of others in terms of per capita infrastructure stock, falling into the category of infrastructure investment ahead of economic development. When $ZINFR_{it}-ZAGDP_{it}=0$, coordinate point ($ZINFR_{it}$, $ZAGDP_{it}$) is exactly on the straight line of the coordinate axis $y=x$, i.e. the region ranks roughly the same in terms of per capita GDP and per capita infrastructure. At this moment, infrastructure investment is fully in sync with economic development by international comparison. It should be noted that in this section, "coordination" describes the relationship between infrastructure investment and economic development by examining whether one is ahead of or lags behind the other. The state of coordination does not mean the optimal state.

Principle II: Measure the size of $|ZINFR_{it}-ZAGDP_{it}|$. The result is the absolute difference between the two indicators, as manifested in the extent to which the two factors in the sample points ($ZINFR_{it}$, $ZAGDP_{it}$) deviate from their respective sample centers. We referenced Chen's (2010) criteria in classifying the numerical values. $0\leq|ZINFR_{it}-ZAGDP_{it}|\leq0.1$ means infrastructure investment is generally in sync with economic development. If $0.1\leq|ZINFR_{it}-ZAGDP_{it}|\leq0.5$, there is a slight deviation of infrastructure investment from economic development. If $0.5\leq|ZINFR_{it}-ZAGDP_{it}|\leq1$, infrastructure investment moderately deviates from economic development. If $|ZINFR_{it}-ZAGDP_{it}|\geq1$, infrastructure investment highly deviates from economic development.

Based on the above two principles, the relationship between infrastructure investment and economic development can be divided into seven types: IC: highly advanced infrastructure investment; IB: moderately advanced infrastructure investment; IA: slightly advanced infrastructure investment; O: infrastructure investment in sync with economic development; IIA: infrastructure investment lagging slightly behind economic development; IIB: infrastructure investment lagging moderately behind economic development; IIC: infrastructure investment lagging severely behind economic development.

Based on BRI countries' relevant data and estimation in the previous section, we analyzed and compared the coordination between economic growth and infrastructure investment. We found that infrastructure investment boosted economic development, and different stages of economic development corresponded to certain levels of infrastructure investment. The results of our analysis are as follows:

3.2 Comparison of BRI Country Samples

Considering the sufficiency of samples and the comparability of subjects, we also selected 44 BRI countries for comparison, and calculated China's indicator $ZINFR_{it}-ZAGDP_{it}$ as shown in the following table:

Judging by the sign of the indicator, China's infrastructure investment lagged moderately behind

动态演变尤为关键。

本文标准化的方法采用*Z-Score*标准化法，也就是标准差标准化法，即为：

$$Z = \frac{(x_i - \bar{x})}{s} \tag{3}$$

$$\bar{x} = \sum \frac{x}{n} \tag{4}$$

在该式中，i是样本的观测值（1，2，⋯，n）；$\bar{x}$是x_i的平均值，s是样本标准差，其中：

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{(n-1)}} \tag{5}$$

3．使用经过标准化处理的新序列，以$ZINFR_{it}$为X轴，以$ZAGDP_{it}$为Y轴，不同国家的数据不尽相同，因此会形成点集（$ZINFR_{it}$, $ZAGDP_{it}$），依此即可在坐标轴上绘制出对应的散点图。

完成以上步骤之后，通过处理完成的数据即可对二者关系进行判别。判别的原则做如下规定和解释：

原则I：构造指标$ZINFR_{it} - ZAGDP_{it}$，并判断此指标的符号。$ZINFR_{it}$表示该国家样本点偏离$ZINFR$指标总样本中心位置的程度，$ZAGDP_{it}$表示该国家样本点偏离$ZAGDP$指标总样本中心位置的程度。因此，该指标符号的正负性实质上就代表了一个国家的两个指标共同偏离样本中心的协同程度，也就是协同性。换而言之，当某一个国家的数据经过标准化处理后，映射到象限图上时，如果指标$ZINFR_{it} - ZAGDP_{it} < 0$，那么坐标点（$ZINFR_{it}$, $ZAGDP_{it}$）就会落入图中左上半区（II区），这说明该地区的人均GDP排名相对靠前，但人均基础设施投资存量相对落后，据此将其定义为基础设施投资滞后类型。但如果指标$ZINFR_{it} - ZAGDP_{it} > 0$，那么坐标点（$ZINFR_{it}$，$ZAGDP_{it}$）就会落入右下区域（I区），这说明该地区的人均GDP排名相对落后，人均基础设施投资存量相对靠前，也就是基础设施投资超前类型。显然，当$ZINFR_{it} - ZAGDP_{it} = 0$时，坐标点（$ZINFR_{it}$，$ZAGDP_{it}$）就正好在坐标轴的$y=x$这条直线上，这说明该地区的人均GDP和人均基础设施投资存量在样本中拥有较为一致的排名，此时基础设施投资与经济发展水平的协同程度对比国际水平，则是完全协同状态。需要注意的是，本节测算的基础设施投资与经济发展水平的协同程度描绘的是两者间的前、后置关系，协同状态并不代表最优状态。

原则II：衡量 $|ZINFR_{it} - ZAGDP_{it}|$ 的大小。这是两个指标差的绝对值，表征的意思实际上是样本点（$ZINFR_{it}$，$ZAGDP_{it}$）中的两元素偏离各自样本中心的协同程度。数值的划分参照陈明星（2010）的标准：$0 \leqslant |ZINFR_{it} - ZAGDP_{it}| \leqslant 0.1$，则说明基础设施投资与经济发展水平的关系处于基本协同状态。$0.1 \leqslant |ZINFR_{it} - ZAGDP_{it}| \leqslant 0.5$，那么基础设施投资与经济发展水平的关系属于轻微偏离。$0.5 \leqslant |ZINFR_{it} - ZAGDP_{it}| \leqslant 1$，则属于中度偏离；$|ZINFR_{it} - ZAGDP_{it}| \geqslant 1$，那么基础设施投资与经济发展水平的关系为高度偏离。

因此，根据上述两原则，可以将基础设施投资和经济发展水平协同关系划分为7种类型：IC：基础设施投资高度超前、IB：基础设施投资中度超前、IA：基础设施投资轻微超前、O：基础设施投资协同、IIA：基础设施投资轻微滞后、IIB：基础设施投资中度滞后、IIC：基础设施投资高度滞后。

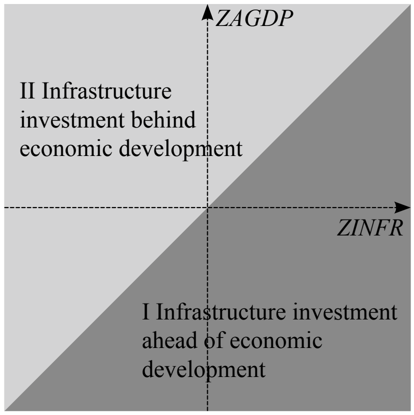

Figure 1: Relationship between Infrastructure Investment and Economic Development

economic development in 1990, 2001, and 2005, i.e. infrastructure development was insufficient relative to China's economic growth. In 2000, China's infrastructure investment lagged slightly behind economic development, but $ZINFR_{it}-ZAGDP_{it}$ was still close to -0.5.[4] By 2014, however, China's infrastructure development was highly in sync with economic growth, and the absolute value of $ZINFR_{it}-ZAGDP_{it}$ was 0.02 and very close to 0. Despite some volatility, China's infrastructure development had outpaced economic growth and gradually became more or less in sync with economic development.

We drafted the following four charts to show the relative positions of BRI countries and changes in coordination between China's infrastructure investment and economic development. Since there are numerous BRI sample countries, black triangles in the following charts indicate China's position relative to that of other BRI sample countries.

The following conclusions can be drawn from the above charts:

i. After reform and opening up, China made great progress in various economic indicators. Compared with other sample countries, China's economic growth and infrastructure investment stock ranking increased significantly. As can be seen from the charts, China's coordinate points ($ZINFR_{it}$, $ZAGDP_{it}$) rose from a relatively low level in the third quadrant in 1990 to the proximity of the quadrant chart origin in 2014. Given China's huge population and weak economic fundamentals in the early years of reform and opening up, this achievement is extremely significant and hard-won.

ii. Judging by the positions of quadrant chart points for the 44 BRI countries in various years, there is a positive correlation between infrastructure investment and economic growth. Infrastructure investment is often accompanied by a rise in the level of economic development.

iii. As can be seen from the chart, China's coordinate point was close to the quadrant chart origin in 2014, i.e. nearly complete coordination between infrastructure development and economic growth. From 1990 to 2014, China's infrastructure investment outpaced economic growth. With coverage expanding nationwide, China's infrastructure development lagged less behind and became more in sync with economic development.

3.3 Identification of Sample BRI Countries with Infrastructure Gaps

Based on the results of the estimation, we identified BRI countries with the biggest infrastructure gaps for more targeted policy advice on infrastructure connectivity under the BRI. With great

[4] Here, change primarily stems from change in the estimation indicators.

图1 基础设施投资与经济发展水平关系划分图示

本文选取"一带一路"沿线国家相关数据，在前文测算的基础上，通过五个时间节点的计算对各国经济增长和基础设施投资程度的协同关系进行分析和比较。基础设施投资对经济发展起到了重要的支持作用，不同经济发展水平阶段所对应的基础设施投资程度也相应有所不同。

（二）"一带一路"沿线国家样本对比

考虑到样本的充足性和对象的可比性，本文同样选用了44个"一带一路"沿线国家进行了对比，中国的$ZINFR_{it}-ZAGDP_{it}$指标计算结果以表格形式展现如下：

从计算结果来看：1990年、2001年、2005年中国的基础设施投资相对于经济增长处于中度滞后，意味着在这个阶段，基础设施的建设相较于中国的经济增长还处于短缺的状态。2000年两者之间表现为轻度滞后，但$ZINFR_{it}-ZAGDP_{it}$依然接近−0.5[4]。然而，到2014年，中国的基础设施建设与经济增长已呈现较协同的状态，$ZINFR_{it}-ZAGDP_{it}$的绝对值为0.03，已经极为接近0。因此，总体而言，中国基础设施建设发展速度虽偶有波动，但总体向好，其增长态势明显领先于经济增长的速度，随着时间的推移二者逐渐呈现出较为协同的状态。

为了更清晰的展现"一带一路"沿线国家所处的相对位置和中国的协同程度变化，本文绘制了如下四张图。由于"一带一路"样本国家的数量较多，图中黑色三角形标注出了中国的相对位置。

由图2可以得出如下几方面的结论：

1.改革开放后，中国经济各方面指标都获得了长足的发展，相较于其他样本而言，中国的经济增速和基础设施投资存量排名均得到显著的提升。从图中看，中国的坐标点（$ZINFR_{it}$，$ZAGDP_{it}$）从1990年位处第三象限的较低水平，上升到2014年的接近象限图原点。再考虑到中国巨大的人口总量和改革开放初期薄弱的经济发展基础，这样的提升极为显著和不易。

2.从"一带一路"沿线44国的象限图点在各年份的整体形态特征上来看，基础设施投资与经济增长之间

[4] 这里的变化主要是由于测算指标的变化引起。

Table 3: Coordination between China's Infrastructure Investment and Economic Growth

Variable	1990	2000	2001	2005	2014
$ZINFR_{it}$	-1.60	-1.16	-1.37	-1.20	-0.47
$ZAGDP_{it}$	-0.84	-0.67	-0.67	-0.67	-0.45
$ZINFR_{it} - ZAGDP_{it}$	-0.76	-0.49	-0.70	-0.53	-0.03
Type of coordination	IIB	IIA	IIB	IIB	O

infrastructure potential, these countries should be priorities for BRI infrastructure programs. After comparing infrastructure with GDP data, we found 20 countries out of the 44 BRI countries with infrastructure lagging behind economic development. Among them, infrastructure lags moderately or highly behind economic development in five countries and slightly behind economic development in 15 countries. Most of the relevant countries with infrastructure lagging behind economic development are in West Asia, South Asia, and Africa. In most parts of West Asia, the climate is arid, water is scarce, and the topography is primarily plateau. Infrastructure is underdeveloped, and the economy is dominated by agriculture and oil exports. Situated in the tropical zone, South Asia is the largest production area for tropical cash crops such as rubber, palm oil and coconuts, and relies on labor-intensive manufacturing, and agricultural and mining exports. With a dry and hot climate, Africa is

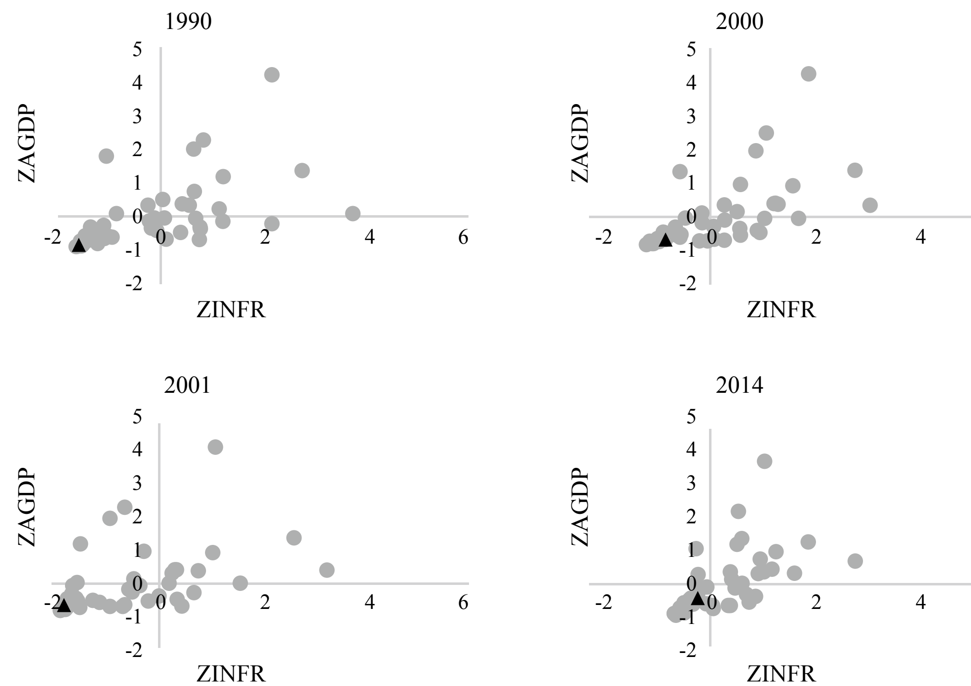

Figure 2: Coordination between Infrastructure Development and Economic Growth in BRI Countries

表3 一带一路沿线国家样本下中国基础设施投资存量与经济增长水平率的协同关系

变量	1990	2000	2001	2005	2014
$ZINFR_{it}$	−1.60	−1.16	−1.37	−1.20	−0.47
$ZAGDP_{it}$	−0.84	−0.67	−0.67	−0.67	−0.45
$ZINFR_{it}-ZAGDP_{it}$	−0.76	−0.49	−0.70	−0.53	−0.03
协同关系类型	IIB	IIA	IIB	IIB	O

存在正相关的关系。基础设施投资的扩张往往伴随着经济发展水平的提高。

3.从图像中判断，2014年中国在象限图中的坐标点趋近于原点，中国基础建设和经济增长水平已呈现出几乎完全协同的状态。从变化趋势来看，自1990年至2014年，中国基础设施投资发展速度快于经济增长水平，可知快速的基建发展已逐步覆盖国内的基建需求，二者逐渐由相对滞后变为相对协同状态。

（三）基于"一带一路"相关国家样本的领先、滞后关系分析

为了对"一带一路"倡议"基础设施联通"提供更具针对性的政策参考，在本节，我们根据测算结果列出了当前"一带一路"沿线国家基础设施最为滞后的国家，这些国家基础设施建设存在较大发展空间，应当是"一

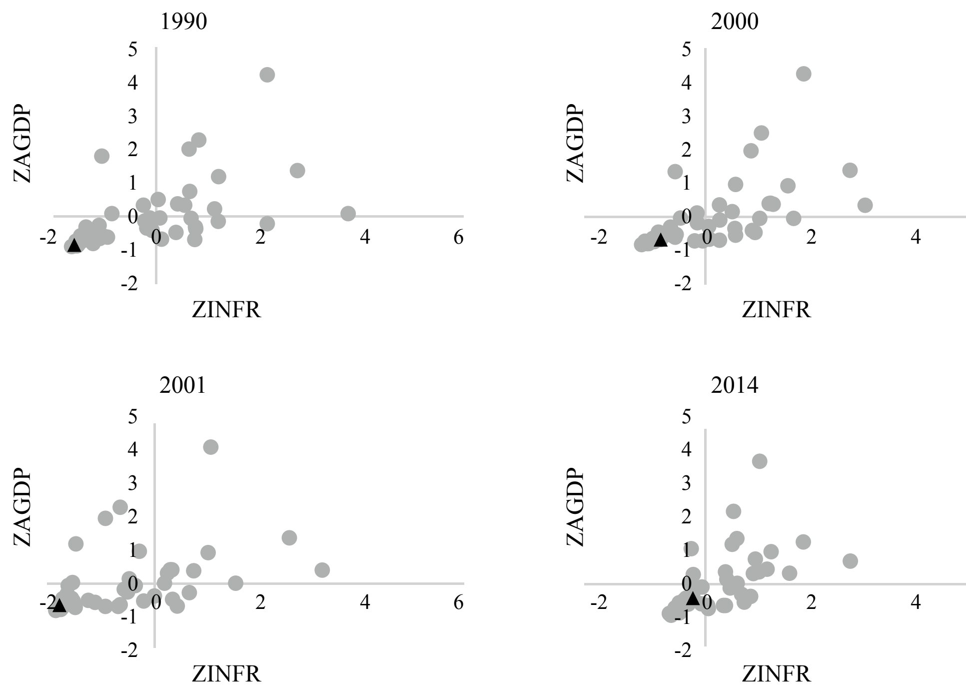

图2 "一带一路"相关国家基础设施建设协同程度

economically less developed.

Among the 44 BRI sample countries, infrastructure was ahead of economic development in 20 countries, including 15 countries with highly advanced infrastructure. Most of these countries are in Central and Eastern Europe - an economically more developed region. With moderate temperature and primarily hilly and plain topography, Central and Eastern Europe are the main grain-producing regions in Europe. Heavy industry is also a key driver of their economies.

Among the BRI country samples, West Asia, South Asia and Africa are economically less developed and are dependent on agricultural and labor-intensive exports. Infrastructure is less developed in most countries in these regions relative to their economic development. Given their dependence on exporting labor-intensive goods and raw materials, infrastructure investment in these regions will help them reduce the cost of transportation, raise labor productivity, boost economic growth, and increase coordination between infrastructure and economic development. For these reasons, we believe great economic potential can be unlocked by infrastructure investment in these regions. Most Central and Eastern European economies are developed, with advanced infrastructures, and thus have less potential for infrastructure investment.

In a nutshell, most BRI countries are short of and stagnant on aggregate infrastructure stock, as are their infrastructure growth rates on a per capita basis. In relative terms, infrastructure lags behind economic development in about half of the BRI countries, which shows great potential for infrastructure development. Hence, we reckon that huge infrastructure gaps exist in BRI countries. As the world's

Table 4: BRI Countries with Infrastructure Lagging behind Economic Development

Country	*ZINFR*	*ZAGDP*	*ZINFR-ZAGDP*	Type of coordination	Region
Austria	2.05	3.97	-1.91	IIC	Central Europe
Saudi Arabia	-0.54	1.15	-1.69	IIC	West Asia
Israel	1.07	2.36	-1.29	IIC	West Asia
Turkey	-0.47	0.31	-0.78	IIB	West Asia
Malaysia	-0.58	0.01	-0.59	IIB	ASEAN
Cameroon	-1.37	-0.94	-0.43	IIA	Central Africa
Cote d'Ivoire	-1.37	-0.94	-0.42	IIA	West Africa
Algeria	-1.00	-0.60	-0.40	IIA	North Africa
Morocco	-1.15	-0.76	-0.39	IIA	North Africa
India	-1.29	-0.92	-0.38	IIA	South Asia
Sudan	-1.24	-0.90	-0.34	IIA	North Africa
Pakistan	-1.30	-0.97	-0.33	IIA	South Asia
Egypt	-1.14	-0.81	-0.32	IIA	North Africa
Bangladesh	-1.31	-0.99	-0.32	IIA	South Asia
Iran	-0.74	-0.44	-0.30	IIA	West Asia
Thailand	-0.79	-0.50	-0.29	IIA	ASEAN
Republic of Korea	1.19	1.48	-0.28	IIA	East Asia
Greece	1.01	1.29	-0.28	IIA	South East Europe
Jordan	-0.95	-0.74	-0.21	IIA	West Asia
South Africa	-0.48	-0.29	-0.19	IIA	South Africa

带一路”基础设施联通项目对接的重点国家。根据基础设施投资建设及GDP数据对比，我们发现在44个“一带一路”相关国家中，有21个国家存在基础设施投资建设滞后经济发展的情况，其中，有5个国家属于中度或重度滞后，16个国家属于轻度滞后。另外，基建滞后经济发展的国家大多集中在西亚、南亚及非洲地区。西亚地区大部分气候干旱、水资源缺乏，地形以高原为主，基建设施发展较为落后，经济发展主要依靠农业及石油输出；南亚地区处于热带，是橡胶、油棕、椰子等热带经济作物的最大产区，经济发展主要依赖劳动密集的轻工制造业及农矿出口；非洲地区气候干热，经济较为落后。

在44个“一带一路”样本国家中，有20个国家存在基建领先于经济发展的情况，其中，有15个国家属于重度领先，且大部分属于中东欧地区。中东欧地区以丘陵及平原为主，气温适中，属于经济较为发达的地区，拥有广袤的耕地面积，是欧洲粮食主产地之一，另外，重工业也是其经济发展动力之一。

总体而言，在“一带一路”相关国家样本中，西亚、南亚及非洲地区经济较为落后，经济发展主要依赖劳动密集型轻工业及原材料出口，大多属于滞后型关系，引入基建投资可使其降低贸易运输成本，提高劳动生产效率，从而进一步拉动经济增长，提高基建与经济的协同程度。因此基建投资有很大提升空间，可通过进一步发展基础设施建设拉动经济发展。中东欧地区经济较为发达，基础设施建设相对较为完备，大多属于领先型

表4 “一带一路”相关国家中基建滞后国家数据

国家名称	*ZINFR*	*ZAGDP*	*ZINFR-ZAGDP*	协同关系	所属地区
奥地利	2.05	3.97	−1.91	IIC	中欧
沙特阿拉伯	−0.54	1.15	−1.69	IIC	西亚
以色列	1.07	2.36	−1.29	IIC	西亚
土耳其	−0.47	0.31	−0.78	IIB	西亚
马来西亚	−0.58	0.01	−0.59	IIB	东盟十国
喀麦隆	−1.37	−0.94	−0.43	IIA	中非
科特迪瓦	−1.37	−0.94	−0.42	IIA	西非
阿尔及利亚	−1.00	−0.60	−0.40	IIA	北非
摩洛哥	−1.15	−0.76	−0.39	IIA	北非
印度	−1.29	−0.92	−0.38	IIA	南亚
苏丹	−1.24	−0.90	−0.34	IIA	北非
巴基斯坦	−1.30	−0.97	−0.33	IIA	南亚
埃及	−1.14	−0.81	−0.32	IIA	北非
孟加拉国	−1.31	−0.99	−0.32	IIA	南亚
伊朗	−0.74	−0.44	−0.30	IIA	西亚
泰国	−0.79	−0.50	−0.29	IIA	东盟十国
大韩民国	1.19	1.48	−0.28	IIA	东亚
希腊	1.01	1.29	−0.28	IIA	东南欧
约旦	−0.95	−0.74	−0.21	IIA	西亚
南非	−0.48	−0.29	−0.19	IIA	南非

second-largest economy, China has made great progress in infrastructure development and is ahead of most countries in terms of infrastructure stock. The BRI will support infrastructure development in relevant countries and deepen China's opening up for win-win cooperation with BRI countries.

4. BRI's Significance for China and the World

Since reform and opening up in 1978, China has made great progress in infrastructure development, leading the world in terms of aggregate infrastructure stock and growth rate. Rapid infrastructure development has caught up with and is now in sync with economic growth. In many countries, however, infrastructure gaps remain. In this context, General Secretary Xi Jinping put forth the "Silk Road Economic Belt and the 21st Century Maritime Silk Road" initiative (Belt and Road Initiative, or BRI), focusing on infrastructure and industrial cooperation. The BRI not only helps revitalize China's economy by facilitating industrial transition but also compensates for development gaps in BRI countries for mutual benefit. In this sense, the BRI is conducive to deepening China's opening up and promoting world prosperity.

4.1 Infrastructure and Economic Development

By advancing infrastructure development, the BRI is expected to promote prosperity in countries along the BRI route. A key question is whether infrastructure will drive economic development in these countries. Based on per capita infrastructure investment stock, this section creates the following

Table 5: BRI Countries with Advanced Infrastructure Development

Country	*ZINFR*	*ZAGDP*	*ZINFR-ZAGDP*	Type of coordination	Region
Poland	0.76	0.40	0.36	IA	Central and Eastern Europe
Albania	-0.16	-0.62	0.46	IA	Central and Eastern Europe
Russia	0.81	0.16	0.65	IB	CIS
Armenia	0.08	-0.69	0.77	IB	CIS
Ukraine	0.10	-0.78	0.88	IB	CIS
Romania	0.94	-0.12	1.06	IC	Central and Eastern Europe
Slovak Republic	1.89	0.81	1.08	IC	Central and Eastern Europe
Kazakhstan	1.21	0.03	1.17	IC	Central Asia
Mongolia	0.67	-0.68	1.35	IC	East Asia
Czech Republic	2.48	1.06	1.43	IC	Central and Eastern Europe
Georgia	0.75	-0.68	1.44	IC	West Asia
Croatia	1.81	0.35	1.46	IC	Central and Eastern Europe
Hungary	2.03	0.40	1.63	IC	Central and Eastern Europe
Bulgaria	1.37	-0.32	1.69	IC	Central and Eastern Europe
Lithuania	2.34	0.49	1.85	IC	Central and Eastern Europe
Kingdom of Macedonia	1.47	-0.57	2.04	IC	Central and Eastern Europe
Belarus	1.71	-0.39	2.09	IC	CIS
Slovenia	3.70	1.36	2.34	IC	Central and Eastern Europe
Latvia	3.19	0.36	2.83	IC	Central and Eastern Europe
Estonia	5.49	0.75	4.74	IC	Central and Eastern Europe

关系,因此基础设施投资发展空间较为有限。

综上,从总量来看,大部分"一带一路"沿线国家基础设施总量水平较低,且并未随时间推移出现明显的增长趋势,同时其人均基础设施存量增长率也相对较低或处于停滞状态。从相对量来看,约半数"一带一路"沿线国家存在基础设施建设落后于经济发展的情况,其基础设施建设存在较大提升空间。因此可以推断"一带一路"沿线国家存在较为明显的基础设施建设需求缺口。中国作为全球第二大经济体,其基础设施增速较快,基础设施建设存量水平逐年攀升,已领先于全球大部分国家。通过"一带一路"倡议的推行,沿线各国的基础设施投资建设需求能够得到更好的支撑,同时也能推动中国实行更深层次、更高水平的对外开放,与沿线各国合作共赢、共同发展。

四、"一带一路"倡议的合理性分析

改革开放以来,中国基础设施建设的发展取得了长足的进步,无论是基础设施建设总量还是增速均跃居世界领先地位,快速的基建发展已逐步覆盖国内的基建需求,基建与经济发展水平亦由相对滞后变为相对协同状态。与此同时,很多国家的基础设施建设仍面临较大缺口。在此背景下,2013年,习近平总书记提出建设

表5 "一带一路"相关国家中基建领先国家数据

国家名称	*ZINFR*	*ZAGDP*	*ZINFR-ZAGDP*	协同关系	所属地区
波兰	0.76	0.40	0.36	IA	中东欧
阿尔巴尼亚	−0.16	−0.62	0.46	IA	中东欧
俄罗斯联邦	0.81	0.16	0.65	IB	独联体
亚美尼亚	0.08	−0.69	0.77	IB	独联体
乌克兰	0.10	−0.78	0.88	IB	独联体
罗马尼亚	0.94	−0.12	1.06	IC	中东欧
斯洛伐克共和国	1.89	0.81	1.08	IC	中东欧
哈萨克斯坦	1.21	0.03	1.17	IC	中亚
蒙古	0.67	−0.68	1.35	IC	东亚
捷克共和国	2.48	1.06	1.43	IC	中东欧
格鲁吉亚	0.75	−0.68	1.44	IC	西亚
克罗地亚	1.81	0.35	1.46	IC	中东欧
匈牙利	2.03	0.40	1.63	IC	中东欧
保加利亚	1.37	−0.32	1.69	IC	中东欧
立陶宛	2.34	0.49	1.85	IC	中东欧
马其顿王国	1.47	−0.57	2.04	IC	中东欧
白俄罗斯	1.71	−0.39	2.09	IC	独联体
斯洛文尼亚	3.70	1.36	2.34	IC	中东欧
拉脱维亚	3.19	0.36	2.83	IC	中东欧
爱沙尼亚	5.49	0.75	4.74	IC	中东欧

regression equation referencing the classical cross-national economic growth model to verify infrastructure's positive growth effects:

$$growth_{it}^{n}=\alpha_0+\beta lninf_{it}+\gamma CV_{it}+\mu_i+\varphi_t+\varepsilon_{it} \quad (6)$$

Where, $growth_{it}^{n}$ is the per capita GDP growth rate of country (region) i for future n periods at time t. $lninf_{it}$ is the logarithmic value of per capita infrastructure investment stock of country (region) i at the beginning of period t. CV_{it} is a host of control variables[5] for country (region) i at the beginning of period t. μ_i is the individual effect, φ_t is the time effect, and ε_{it} is the time disturbance term. The selected variable CV_{it} includes:

i. Per capita GDP (gdp_{it}): According to the neoclassical growth theory, economies will converge to the steady state at different velocities due to differences in their initial production factors. In the process of convergence, poor economies grow at a faster pace, making it necessary to control for the economic growth effects of initial per capita GDP in the model.

ii. Investment as a share of GDP ($invest_{it}$): In Solow'smodel(Solow, 1956), the investment rate is a key determinant of a country's prosperity or poverty. There is a positive correlation between a country's investment rate and its steady-state capital stock and income level. Investment may induce economic growth until the investment rate reaches beyond the golden rate. Hence, this paper controls for the economic growth effects of investment by considering investment as a share of GDP.

iii. Government spending as a share of GDP ($gover_{it}$): As a means of macroeconomic regulation, government spending stimulates economic growth by such means as injecting liquidity and inducing economic progress. On the other hand, government spending also restrains economic growth by crowding out firm investment and raising the tax burden. This paper adopts government spending as a share of the GDP to describe government spending.

iv. Export as a share of the GDP (exp_{it}): Both David Ricardo's competitive advantage theory and subsequent more modern international trade theories have demonstrated the economic growth effects of opening up, i.e. a country will become more productive and induce economic growth by participating in trade and specializing in manufacturing products for which it has a comparative advantage. In this paper, a country's level of openness is denoted by the share of its export in GDP. Variable statistical descriptions are shown in Table 6.

Table 7 reports regression results, where Columns (1)-(3) use the five-year per capita GDP growth rate as the explained variable, and Columns (4)-(6) list the 10-year per capita GDP growth rate as the explained variable and gradually control for time and individual fixed effects and relevant control variables. According to the results, the coefficient of the logarithmic value of per capita infrastructure investment stock is significantly positive at around 1%, and the coefficient for long-term (10-year per capita GDP growth rate) is more significant. That is to say, infrastructure has extremely significant pulling effects on economic growth performance.

4.2 Analysis of Global Infrastructure Demand

The BRI meets the needs of global economic development by providing financing for much-needed infrastructure. The World Bank estimates global annual infrastructure investment to be in the range of from 700 to 800 billion US dollars, including some 550 billion US dollars invested in emerging markets. Emerging economies account for a lion's share of future infrastructure investment while infrastructure spending in advanced economies is limited. Since 2000, the United States and Japan have made few investments in new infrastructure. Despite similar land areas with China, Australia and Canada have seen limited annual growth in infrastructure investment over the past years.

[5] Relevant data about control variables in this paper is from Penn World Table 9.1.

“丝绸之路经济带”和“21世纪海上丝绸之路”重大倡议，以基础设施等重大项目建设和产能合作为重点的基础设施互联互通便成为了“一带一路”合作平台的重要着力点和依托。“一带一路”倡议的推行不仅有助于中国在产业结构升级的大背景下提振经济，也能弥补沿线国家发展缺陷，促进各国共同互利互惠发展，推动中国实施更深层次、更高水平的对外开放，促进世界各国共同繁荣。

（一）基础设施建设与经济发展

“一带一路”倡议中一个重要着力点便是希冀通过基础设施建设带动沿线各国共同繁荣发展。那么，一个核心问题便是：基础设施的建设是否能够拉动经济的发展？为验证这一假设，本节基于人均基础设施投资存量进行回归分析，借鉴经典的跨国经济增长模型，构建回归方程如下：

$$growth_{it}^{n}=\alpha_0+\beta lninf_{it}+\gamma CV_{it}+\mu_i+\varphi_t+\varepsilon_{it} \quad (6)$$

其中，$growth_{it}^{n}$表示国家（地区）i在时间t的未来n期人均GDP增长速率，$lninf_{it}$表示国家（地区）i在第t期期初的人均基础设施投资存量对数值，CV_{it}表示国家（地区）i在第t期期初的一系列控制变量[5]，μ_i表示个体固定效应，φ_t表示时间固定效应，ε_{it}表示干扰项。选取的控制变量CV_{it}包括：

1.人均GDP（gdp_{it}）。根据新古典增长理论，由于初始生产要素存在差别，各经济体将以不同的速率收敛至稳态，那么在收敛过程中较穷经济体将增长得更快，因此有必要在模型中控制住期初的人均GDP对经济增速的影响效应。

2.投资占比（$invest_{it}$）。在索罗模型（1956）中，投资率是决定一国富裕或者贫穷的关键因素，一国的投资率越高，其稳态的资本存量和收入水平也就越高。投资率在达到黄金率水平之前增加投资能够促进经济增长，因此本文采取投资占GDP份额控制住投资对经济增长的作用。

3.政府支出占比（$gover_{it}$）。政府支出作为宏观调控手段，一方面通过注入流动性、促进技术进步等方式刺激经济增长，另一方面通过挤压企业投资、增加税负等方式抑制经济增长，本文采取政府支出占GDP份额来描述政府支出水平。

4.出口份额（exp_{it}）。李嘉图的比较优势理论及之后更现代的国际贸易理论均论证了开放对经济增长的促进作用，开展对外贸易并通过专业化生产具有比较优势的产品能够达到更高的生产效率，从而促进一国经济增长，本文用出口份额来代表一国的开放程度。各变量的描述统计如表6所示。

表7汇报了回归估计结果，其中（1）列至（3）列以5年人均GDP增长速率为被解释变量，（4）列至（6）列以10年人均GDP增长速率为被解释变量，并逐步控制时间、个体固定效应及相关控制变量。结果显示，人均基础设施投资存量对数值的系数均在1%的水平显著为正，且其对长期（10年人均GDP增长速率）的系数更大，可知基础设施的建设对经济增长表现出极为显著的拉动作用。

（二）全球基建需求分析

从全球基建的需求来看，“一带一路”倡议的提出迎合了全球经济发展的需要。据世界银行估计，全球每

[5] 本文控制变量相关数据源自Penn World Table 9.1。

Infrastructure demand in emerging economies far exceeds current levels of investment. According to the estimate of theWorld Bank, infrastructure investment demand as a share of GDP is the highest in low-income countries from an income perspective, as shown in Table 8. With modest per capita infrastructure stock, low-income countries boast a higher marginal return on capital, which means greater economic growth effects of infrastructure investment. In contrast, high-income countries with more adequate infrastructures have a smaller investment demand for capital expansion. However, significant infrastructure stock in high-income countries requires hefty investments for maintenance, causing aggregate investment demand to be high. In South Asia, infrastructure investment demand is strong and represents a significant share of GDP, which is consistent with our analysis. Infrastructure development in South Asia lags far behind its level of economic development, which explains the robust demand for infrastructure investment. With smaller economic volumes, African countries have a smaller demand for infrastructure investment. With greater economic growth effects, the transportation and electric power sectors have a strong demand for infrastructure investment. In comparison, infrastructure investment demand is smaller in the water and health sectors.

According to our estimates, both developed and developing countries have a robust demand for infrastructure investment. With modest aggregate infrastructure stocks, BRI countries have great potentials for infrastructure development as a driver of future economic growth. As the world's largest

Table 6: Variable Statistical Descriptions

Variable	Sample size	Mean	Standard error	Min.	Max.
$grow5_{it}$	1151	1.15	0.18	0.29	1.91
$grow10_{it}$	886	1.37	0.35	0.41	2.87
$lninf_{it}$	1151	0.37	0.80	-1.54	1.86
$lngdp_{it}$	1151	8.94	1.33	5.99	11.24
$inverst_{it}$	1151	0.23	0.08	0.001	0.51
$gover_{it}$	1151	0.20	0.08	0.03	0.64
exp_{it}	1151	0.26	0.21	0.00	1.00

Table 7: Regression Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	$grow5_{it}$	$grow5_{it}$	$grow5_{it}$	$grow10_{it}$	$grow10_{it}$	$grow10_{it}$
$lninf_{it}$	0.06*** (0.02)	0.11*** (0.03)	0.14*** (0.02)	0.28*** (0.03)	0.27*** (0.03)	0.29*** (0.03)
$inverst_{it}$			-0.28*** (0.07)			-0.44*** (0.13)
$gover_{it}$			-0.94*** (0.07)			-0.65*** (0.10)
exp_{it}			-0.07 (0.05)			-0.16 (0.12)
$lngdp_{it}$	-0.09*** (0.01)	-0.44*** (0.03)	-0.47*** (0.03)	-0.30*** (0.02)	-1.14*** (0.04)	-1.06*** (0.05)
Yeat fixed effects	No	Yes	Yes	No	Yes	Yes
Country fixed effects	No	Yes	Yes	No	Yes	Yes
Observations	1,151	1,151	1,151	866	866	866
R-squared	0.13	0.40	0.50	0.29	0.55	0.58

年基础设施投资约为7000亿–8000亿美元，其中约5500亿美元投资于新兴发展市场，而发达国家的基础投资支出相对较低。2000年以来美国、日本新增基础设施建设几近停滞不前甚至有倒退趋势，澳大利亚、加拿大等发达国家与中国土地面积相似，但年新增基础设施投资始终处于低位。

虽然全球大部分基础设施投资均流向了新兴发展市场，但仍然不能覆盖其需求。根据世界银行的估算，如表8所示，从收入的角度来看，低收入国家基础设施投资需求占GDP比例最高，这类国家人均基础设施存量较低，资本的边际产出相对更高，因而投资基础设施建设能更为有效地拉动经济增长。反之，高收入国家由于其基础设施存量较高，因此资本扩张的需求相对较低，但维护的需求则相对较高，这也导致总投资需求的高涨。从地区的角度来看，南亚地区对基建投资需求相对较高，且对GDP占比较大，这与本文的分析相契合，南亚地区基础设施建设相对于经济发展水平而言存在较大程度的滞后，因此其对基础设施投资的需求也相对更高，而非洲国家由于其整体经济规模较小，因此其投资需求相对较低。从行业的角度来看，由于交通部门和电力部门的投资和发展一方面能够显著降低生产部门的原材料运输成本和产品的生产成本，另一方面能够降低消费端居民的出行和日常生活成本，对经济增长的拉动作用相对更大，因此对基础建设投资需求较高，

表6 变量统计描述

变量	样本容量	均值	标准差	最小值	最大值
$grow5_{it}$	1151	1.15	0.18	0.29	1.91
$grow10_{it}$	886	1.37	0.35	0.41	2.87
$lninf_{it}$	1151	0.37	0.80	-1.54	1.86
$lngdp_{it}$	1151	8.94	1.33	5.99	11.24
$inverst_{it}$	1151	0.23	0.08	0.001	0.51
$gover_{it}$	1151	0.20	0.08	0.03	0.64
exp_{it}	1151	0.26	0.21	0.00	1.00

表7 回归结果

变量	(1)	(2)	(3)	(4)	(5)	(6)
	$grow5_{it}$	$grow5_{it}$	$grow5_{it}$	$grow10_{it}$	$grow10_{it}$	$grow10_{it}$
$lninf_{it}$	0.06*** (0.02)	0.11*** (0.03)	0.14*** (0.02)	0.28*** (0.03)	0.27*** (0.03)	0.29*** (0.03)
$inverst_{it}$			−0.28*** (0.07)			−0.44*** (0.13)
$gover_{it}$			−0.94*** (0.07)			−0.65*** (0.10)
exp_{it}			−0.07 (0.05)			−0.16 (0.12)
$lngdp_{it}$	−0.09*** (0.01)	−0.44*** (0.03)	−0.47*** (0.03)	−0.30*** (0.02)	−1.14*** (0.04)	−1.06*** (0.05)
年份固定效应	否	是	是	否	是	是
国家固定效应	否	是	是	否	是	是
Observations	1,151	1,151	1,151	866	866	866
R-squared	0.13	0.40	0.50	0.29	0.55	0.58

developing country, China has made rapid progress in infrastructure development and is ahead of most countries in terms of infrastructure stock. By providing financing for global infrastructure development, the BRI will promote interconnectivity and win-win development.

4.3 China's Infrastructure Development Experiences and Comparative Advantages

Most BRI countries are developing countries that are in the early stage of economic development and lack sufficient capital and experience for infrastructure development. In this respect, China's experience can be helpful. As the world's largest developing country, China's vast experience in infrastructure development can be shared to help other countries build their infrastructure.

Over the past four decades, China has developed infrastructure technologies and business models. Jiang (2015) identified three effective modes of infrastructure development in China, i.e. introducing market-based mechanisms for the supply of public goods, diversifying investment entities, and applying development finance to infrastructure projects. China's experience and practices may help BRI countries address their robust infrastructure demand. For instance, market-based mechanisms may increase efficiency in the allocation of public goods and resources. The costs and return of infrastructure development can be shared among various stakeholders.

For multilateral development institutions and funds, infrastructure investment in BRI countries will generate steady returns in the long run. For BRI countries, financing for infrastructure development will boost their economic growth potential and promote international connectivity and coordinated regional development. Sound, diverse and sustainable financing systems should be fostered according to the realities of BRI countries and the needs for global public goods.

In African infrastructure aid programs, China's technology and business models have shown great strengths. A key element of infrastructure cooperation between China and South Africa, for instance, is the establishment of local manufacturing facilities and technology transfer allowing some

Table 8: Annual Average Infrastructure Investment Demand from Developing Countries in 2014-2020 (by 2015 Price)

	Investment demand for capital expansion		Investment demand for infrastructure maintenance		Aggregate investment demand	
	In million US dollars	% of GDP	In million US dollars	% of GDP	In million US dollars	%GDP
Low-income countries	176,217	7.10	172,089	6.90	348,306	14.10
Middle-income countries	35,821	1.10	72,063	2.30	107,884	3.40
High-income countries	160,251	2.00	203,047	2.60	363,298	2.60
South Asia Region (SAR)	159,074	7.80	144,427	7.10	303,501	14.90
Sub-Saharan Africa (SSA)	28,946	3.20	27,108	3	56,054	6.20
East Asia and Pacific (EAP)	115,897	2.00	96,244	1.70	212,140	3.70
Middle East and North Africa (MENA)	14,826	1.10	32,244	2.50	47,070	3.70
Latin America and the Caribbean (LAC)	65,828	1.70	74,450	1.90	140,277	3.60
Europe & Central Asia (ECA)	24,178	0.80	36,267	1.10	60,445	1.90
Electric power sector	152,577	1.10	167,754	1.20	320,331	2.40
Transportation sector	76,201	0.60	178,818	1.30	255,019	1.90
Communication sector	123,351	0.90	63,755	0.50	187,105	1.40
Water and health sector	20,160	0.10	36,873	0.30	57,033	0.40

而水和卫生部门对基础建设投资需求相对较低。

结合本文的测算数据，可以看出不论是发达国家还是发展中国家，其基础设施建设需求均较为旺盛，特别是“一带一路”沿线国家，由于其基础设施建设总量相对较低，未来的经济增长有望通过基础设施建设进行拉动。中国作为最大的发展中国家，基础设施建设发展速度很快，基础设施存量亦领先于大部分国家。因此，面对全球基础设施投资缺口较大的现状，可通过“一带一路”倡议互联互通，实现共赢发展。

（三）中国基建经验及比较优势分析

纵观“一带一路”沿线国家，大部分是仍处于经济发展初期的发展中国家，一方面缺乏充足的基础设施建设来推动经济发展，另一方面，也缺乏充足的资金和经验进行基础设施建设，而中国基建的快速发展经验正可以为沿线发展中国家提供支持。结合前文数据可知，中国的基础设施存量及增速均遥遥领先大部分发达国家，作为最大的发展中国家，中国在基础设施建设发展中积累的经验及其发展模式具备更强的借鉴作用。

总结过去四十多年的发展经验，本文认为中国在基础设施建设中积累的经验集中体现在技术和模式两方面。在模式方面，中国积累了成熟的基础设施建设及运营经验，根据姜安印(2015)的梳理，中国形成了三种较为有效的基础设施建设方式，即将市场机制引入公共产品供给领域、多元投资主体不断完善与发挥开发性金融对基础设施建设的带动作用。因此，在较为旺盛的基建需求背景下，“一带一路”沿线国家和地区可以向中国借鉴较为成熟的发展经验和模式，一方面，引入市场机制，提高公共产品资源的配置效率，并建立起一套基于产权、多方共享的成本收益分摊机制。另一方面，打通融资渠道，通过多边开发机构及开发基金为“一带

表8 2014-2020发展中国家年均基础投资需求(以2015年价格计)

	资本扩张投资需求		基建维护投资需求		总投资需求	
	百万美元	%GDP	百万美元	%GDP	百万美元	%GDP
低收入国家	176217	7.10	172089	6.90	348306	14.10
中等收入国家	35821	1.10	72063	2.30	107884	3.40
高收入国家	160251	2.00	203047	2.60	363298	2.60
南亚国家SAR	159074	7.80	144427	7.10	303501	14.90
非洲国家SSA	28946	3.20	27108	3	56054	6.20
东亚/太平洋国家EAP	115897	2.00	96244	1.70	212140	3.70
中东国家MENA	14826	1.10	32244	2.50	47070	3.70
拉美国家LAC	65828	1.70	74450	1.90	140277	3.60
欧洲/中亚ECA	24178	0.80	36267	1.10	60445	1.90
电力部门	152577	1.10	167754	1.20	320331	2.40
交通部门	76201	0.60	178818	1.30	255019	1.90
通信部门	123351	0.90	63755	0.50	187105	1.40
水和卫生部门	20160	0.10	36873	0.30	57033	0.40

infrastructure equipment to be manufactured locally. A combination of gratuitous aid, interest-free loans and preferential loans have helped African countries ease financial pressures for infrastructure projects. Also, training programs have been carried out to help recipient countries improve project management. By drawing upon Chinese experience, BRI countries may explore infrastructure development modes according to their national conditions.

Moreover, China's unique position in the global value chain (GVC) may also benefit the implementation of infrastructure projects under the BRI. With external economic integration deepening from 1990 to 2013, China has become a major trading partner with most countries around the world and a key driver of global economic growth.

New features have emerged in the GVC as dual circulations take the place of traditional "center-periphery" circulation dominated by advanced economies. Emerging Asian economies including China maintain traditional economic ties with advanced economies in Europe and North America, forming the upper circulation of the GVC. Through economic cooperation with resource-rich and less industrialized developed countries in Asia, Africa and Latin America, fast-growing emerging economies led by China spearhead industrial development in various countries and expand local markets through trade, forming the lower circulation of the GVC. The dual GVC circulations are illustrated below.

As can be learned from Zhang's (2019) description of the international trade network, China has close trade ties with developed countries for intermediate inputs and mainly acts as an exporter of intermediate inputs. On the other hand, China exports finished goods to many developing countries. In this manner, China maintains close financial and trade exchanges with both the upper and lower circulations of the GVC. The BRI is a natural response to the "dual circulations" of the global production network. In the context of global dual circulations, China is well-positioned to provide technology and capital to developing countries and initial capital to developed countries. Despite their hefty infrastructure stocks, developed countries also face an urgent need for the cost-efficient maintenance of aging infrastructures.

According to the 2017 Report Card for America's Infrastructure released by the American Society of Civil Engineers (ASCE), the United States needs to invest 3.32 trillion US dollars in infrastructure from 2016 to 2025, with a funding gap estimated to reach 1.44 trillion US dollars. This funding gap would cost the US some 2.55 million jobs and 3.96 trillion dollars in GDP. The same is true for Europe. The European Investment Bank (EIB) invests over 100 billion US dollars in infrastructure each year, but the implementation of infrastructure projects is far from adequate. The developed world is challenged by infrastructure financing and project implementation. After four decades of reform and opening up, China has developed the capital strength to meet the US demand for infrastructure capital. In 2015, China had a net capital outflow to the US, including a flow of funds worth 9.45 billion US dollars to infrastructure projects in the US.

In the rail transportation sector, China and Japan possess technology strengths for cooperation with developed countries. Developing countries face dual challenges of capital shortage and technological thresholds, especially in the water conservancy, information technology, telecom, and road transportation sectors. Despite their technological strengths, developed countries face significant funding gaps and import capital and intermediate inputs from China. For developing countries less experienced in infrastructure development, China may provide both capital and technology to assist in their infrastructure development and form complementary trade ties.

Aside from infrastructure investment, the BRI has also led to closer trade ties in other sectors and enhanced China's pivotal role among BRI countries. The BRI has expedited value circulation between developed and developing countries and helped relevant countries defuse systemic risks from excess liquidity and jumpstart their sluggish economy. By providing financing for much-needed

一路”沿线国家提供资金支持，为资金供给方带来长期稳定的资金收益，并推动资金需求方形成经济发展的造血机制，提高“一带一路”建设的国际融通性和区域发展协同性，形成既适应“一带一路”沿线国家和地区实际，又符合全球公共产品投资大趋势的新投融资机制。中国此前针对非洲的基建援助就集中体现了技术与模式两方面的优势：技术上以南非为例，中国在同南非的基础设施合作过程中，通过投资建厂与技术转让、转移等方式开展部分产品的南非本地化生产，进一步加快南非制造业尤其是其高端制造业的发展。模式上，一方面中国采用多种资金并用的方式，尝试将无偿援助、无息贷款及优惠贷款等多类援助相关资金组合使用，同时适当放宽优惠贷款条件，扩大其规模，帮助非洲国家缓解项目资金压力；另一方面通过人力资源培训等方式，帮助受援国提高项目管理能力，保证项目的长期稳定运行。通过中国经验的输出和帮助，“一带一路”沿线国家和地区基础设施建设可以借鉴中国经验，发展出适合本国特色的基础设施建设模式，为自身的发展打下坚实的基础。

除了拥有基建技术和发展模式的先进经验，中国在全球价值链中的独特地位亦能为“一带一路”倡议的推动及基础设施投资项目的发展提供助益。从当前全球生产网络的价值链来看，两个重大特征值得关注：

第一，1990−2013年随着中国对外开放的程度不断加深，我们在全球经济贸易循环中所处地位越来越重要，已逐渐成为大多数国家的贸易产品主要进出口对手国。且随着中国贸易体量的不断增大，我们已成为全球经济增长的新引擎之一。

第二，全球价值链的表现形式由以发达国家为核心的“中心—外围”这一单循环模式转变为更为复杂的双环流模式。一方面，中国等亚洲新兴国家与欧美发达国家保持着传统的经济往来关系，形成了价值链的上环流；另一方面，中国等新兴国家与资源丰富、工业化程度相对较低的亚非拉发展中国家开展经济合作，通过直接投资带动各国工业化发展扩展当地市场，形成价值链的下环流。具体如图3所示。

根据张辉(2019)关于国际贸易网络的梳理可知，中国与发达国家存在密切的中间品贸易往来并主要扮演中间品出口方的角色。此外，中国向发展中国家主要以出口最终品为主。可以看到，中国与上、下环流经济圈均保持密切的资金、贸易往来，“一带一路”倡议也正是这种全球生产网络“双环流”模式下资金流动的必然结果。因此，在全球双环流的经济结构背景下，中国在基础设施建设方面可以为发展中国家提供技术与资本，为发达国家主要提供启动资金。详细看，发达国家基础设施存量相对较高，但由于建设年限较长，年久失修，维护成本较高。据美国土木工程师协会(ASCE)测算的2017年美国基础设施综合评测报告，2016−2025年，美国预计仍需投资3.32万亿美元的资金，由于资金不足产生的缺口将达到1.44万亿美元，而该缺口预计对总体经济增长将产生254.6万就业缺口、3.96万亿美元GDP缺口的负面影响。欧洲亦然，尽管欧洲投资银行每年在基础设施领域投入超过1000亿美元，但其真正资金的落实度、基础设施的执行力度亦处于较低水平。可见，发达国家的难题在于筹措资金方面及落实度方面，而中国经过改革开放四十多年的高速发展，恰可从资本方面满足美国的需求，典型的表现为中国企业与美国企业的投资往来在2015年实现了净流出，其中94.5亿美元的资金流向基础设施投资项目。除了资本的合作外，在轨道交通领域，中国与日本在该领域已有较强的技术先发优势，因此还可与发达国家进行技术合作。就发展中国家而言，存在资金与技术双门槛，尤其是在水资源开发、信息技术、通信业和道路交通等领域技术储备不足。总结来看，发达国家具有成熟的基础设施建设技术体

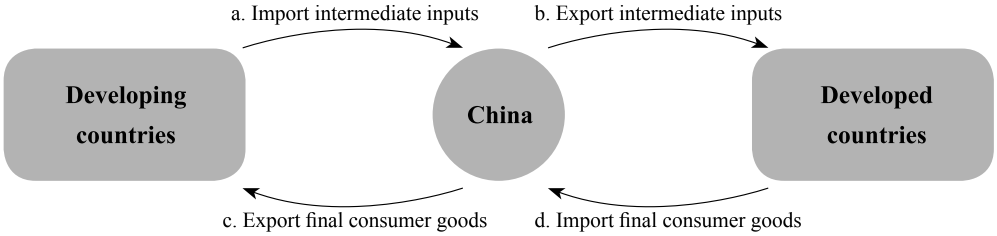

Figure 3: Dual Circulations Model from the Chinese Perspective

infrastructure, the BRI participates in the trade circulation of countries along the route under the "dual circulations" model.

5. Conclusions

At the absolute and relative levels, this paper conducted a quantitative estimation of global and BRI countries' infrastructure development. Based on an estimation of global infrastructure stock, this paper found that over the past two decades, infrastructure development in most developed countries has been stagnant, and global infrastructure growth has been primarily driven by developing countries, especially China. Since 2001, China's infrastructure stock has increased sharply. By 2014, China boasted the world's second-largest infrastructure investment stock, next only to the United States.

Over the past two decades, China has steadily invested in infrastructure at a pace compatible with its rapid economic growth. Unlike in the 1990s when China's infrastructure was underdeveloped and hindered economic growth, China's current infrastructure development is far more advanced and in sync with its economic growth. However, the positive economic growth effects of infrastructure development are yet to be shared among developing countries along the BRI route. According to our study, infrastructure investment lags behind economic development in numerous BRI countries. In this context, the BRI is intended to meet countries' robust demand for infrastructure based on China's experience. Focusing on infrastructure interconnectivity, the BRI provides developed countries with much-needed initial capital and developing countries with both technology and capital for infrastructure development. Such cooperation is consistent with China's current stage of economic development. Under the principles of cooperation, openness and inclusiveness, and mutual benefit, China's BRI vision to build a "community of shared future for humankind" will exert a profound influence on the world economy in the coming two decades.

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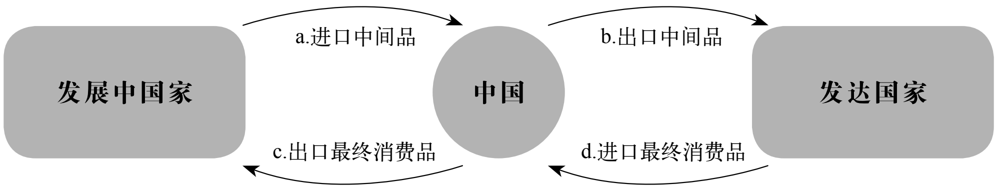

图3 基于中国视角的双环流模型示意

系，但目前资本缺口较大，因此中国向其净流出资本等中间品；对于发展中国家，中国在提供资本支持外，同时输出技术，帮助其完成基础设施建设，形成贸易互补关系，共同发展。

在基建投资之外，通过"一带一路"倡议，沿线国家在其它产业的贸易联系也更加紧密，进一步强化了中国在"一带一路"沿线国家中的枢纽作用，加速了发达国家与发展中国家之间的价值循环，帮助沿线国家化解由流动性过剩带来的系统风险集聚、经济发展低迷等风险。因此，"一带一路"的推出可谓正当时、恰应景。"一带一路"以基础设施建设投资为核心出发点，以"双环流"模式参与"一带一路"沿线国家的贸易循环，正是势所必然、大势所趋。

五、结论

本文从基础设施建设的绝对层面与相对层面对全球和"一带一路"国家基础建设情况进行数量化的测算和分析。基于全球基础设施实物存量的测算，本文发现发达国家的基础设施建设在近二十年的发展中，大多陷入了停滞和滞后，世界范围内的基础设施增长主要由发展中国家驱动。这其中，中国发挥了巨大的作用。中国在2001年之后基建存量大幅增长，在2014年时，已成为基础设施建设投资存量第二大国家，仅次于美国。而且，从基础设施与其经济发展的相对水平看，经过近20年的发展，中国基础设施投资存量和经济增长水平都获得了长足的进步，中国基础设施投资相对经济增长水平，已经逐渐由20世纪90年代初期的相对滞后变为当前的相对协同态势。然而，这种基础设施建设带来的对经济增长的推动作用还没有为广大"一带一路"沿线发展中国家所共享，根据本文的研究，还有相当多的"一带一路"沿线国家，其基础设施投资正严重滞后于其经济发展阶段，并进而制约了其经济发展的潜力。通过实证分析，本文发现基础设施建设能够显著拉动中长期经济增长，因此，在中国基础设施建设发展迅速、世界各国基础设施需求旺盛的背景下，"一带一路"倡议的推出恰逢其时。"一带一路"倡议以基础设施互联互通为核心，为发达国家提供启动资金，为发展中国家提供技术与资金，恰好满足发达国家与发展中国家基础设施建设的痛点，也符合中国当前的经济发展阶段。可以预期的是，既契合时代背景又"秉持和平合作、开放包容、互学互鉴、互利共赢的理念"的"一带一路"共建"人类命运共同体"的愿景，将对世界未来近20年经济发展产生重要、深远的作用。

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