QUANTIFYING THE ECONOMIC AND ENVIRONMENTAL LINKAGE AND LEAKAGE OF THE CONSTRUCTION SECTOR IN AN URBAN ECONOMY

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Quantifying the economic and environmental linkage and leakage of the construction sector in an urban economy

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

In the era of globalization, accelerated international trade activates the spatial agglomeration and fragmentation that lead to an increase in worldwide production, trade and also environmental pollutant. Small open economies are forced to undergo economic restructuring with few dominating sectors, and hence, rely on substantial quantities of imported goods and services. Quantification of trans-boundary economic leakage and trans-boundary carbon dioxide (CO_2) emissions are essential, especially for the construction sector which requires great intermediate inputs from upstream sectors both locally and globally.

The dissertation proposes an analytical framework to evaluate the effects of trade and service-dominating economic structure on economic and environmental influence and leakage of the construction sector in an urban economy, using Hong Kong as a case study. Input-output analysis (IOA) is applied to capture the domestic intersectoral linkage, and multi-regional IOA is conducted to measure the economic leakage resulting from international trade, as well as the energy-related CO_2 emissions induced by construction consumption. In the absence of Hong Kong official input-output tables (IOTs), five IOTs during 1995 to 2013 and three multi-regional IOTs for the years 2004, 2007, and 2011 are compiled using the Global Trade Analysis Project (GTAP) database in conjunction with official statistics. Comparisons with other economies are included to disclose the relative influences and leakages of Hong Kong's construction sector.

The analyzed results reveal the declining economic importance of Hong Kong's construction sector in stimulating domestic economic growth, along with increased leakage to the manufacturing sectors abroad. The domestic backward linkage has dropped from 1.74 in 1995 to 1.55 in 2013 per unit of final demand. 38.37–40.55% of the economic contribution has leaked out through international trade. As for the environmental impacts, CO_2 emissions emitted to sustain the local construction consumption are at least 32.37% higher than those estimated by the conventional accounting approach. Yet, the consumption-based CO_2 emissions have witnessed a slight decline from 11.50 Mt in 2004 to 10.19 Mt in 2011. This trend is closely tied to the declining emission intensities of upstream sectors, even with strong growth in construction final demand. 96.61-97.41% of the consumption-based CO_2 are indirect emissions, and 73.50-78.58% are trans-boundary emissions. Utilities, Manufacturing, and Transport & Storage are the main source sectors contributing the most to total CO_2 emissions.

The analyzed outcomes provide a rational basis with which to inform the decision-making of the Hong Kong government in resource allocation and policy planning. Import substitution policy is recommended to ease foreign dependence through local production of construction products. Also, extended emission monitoring beyond municipal boundaries, diversification of import origins, use of low carbon-intensive building materials locally and from nearby regions are proposed to mitigate the CO_2 emissions generated by the construction activities.

PUBLICATIONS ARISING FROM THE STUDY

Much of the dissertation was previously published in two technical papers [1-2]. The listed papers represent the joint work of the co-authors of that paper.

[1] **Hung, C.C.W**., Hsu, S.C., Pratt, S., Chen, P.C., Lee, C.J., and Chan A.P.C. (2019). Quantifying the Linkages and Leakages of Construction Activities in an Open Economy Using Multiregional Input-output Analysis. *Journal of Management in Engineering*, 35(1), 04018054.
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[2] **Hung, C.C.W.**, Hsu, S.C., and Cheng, K.L. (2019). Quantifying City-scale Carbon Emissions of the Construction Sector based on Multi-regional Input-output Analysis. *Resources, Conservation and Recycling*, 149, 75-85.
https://doi.org/10.1016/j.resconrec.2019.05.013

[3] Cheng, K.L., Hsu, S.C., **Hung, C.C.W.**, Chen, P.C., and Ma, H.W. (2019). A Hybrid Material Stock Analysis for Quantifying Multilevel Anthropogenic Resources. Manuscript submitted to *Journal of Industrial Ecology* (under revision).

[4] Lee, C.J., Wang, R., Lee, C.Y., **Hung, C.C.W.**, and Hsu, S.C. (2018). Board Structure and Directors' Role in Preventing Corporate Misconduct in the Construction Industry. *Journal of Management in Engineering*, 34(2), 04017067.
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LIST OF ACRONYMS

AAGR	Average Annual Growth Rate
CBA	Consumption-based Accounting
CGE	Computable General Equilibrium
CO_2	Carbon Dioxide
CO_2-e	Carbon Dioxide Equivalent
EEE	Emissions Embodied in Exports
EEI	Emissions Embodied in Imports
EE-IOA	Environmentally Extended Input-Output Analysis
EE-MRIOA	Environmentally Extended Multi-Regional Input-Output Analysis
EET	Emissions Embodied in Trade
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTAP	Global Trade Analysis Project
GVA	Gross Value Added
IEA	International Energy Agency
IMF	International Monetary Fund
IO	Input-Output
IOA	Input-Output Analysis
IO-LCA	Input-output Life Cycle Assessment
IOTs	Input-Output Tables
IPCC	Intergovernmental Panel on Climate Change
MRIO	Multi-Regional Input-Output
MRIOA	Multi-Regional Input-Output Analysis
MRIOTs	Multi-Regional Input-Output Tables
OECD	Organization for Economic Co-operation and Development
PBA	Production-based Accounting
RoW	The Rest of World
UK	The United Kingdom
US	The United Stats

Chapter 1 INTRODUCTION

1.1 Research Background

The vital role of construction activities in economic growth is well recognized (Hillebrandt, 2000; Giang and Pheng, 2011; Barber Jr. and El-Adaway, 2013; Ho, 2016; Lam and Oshodi, 2016). A positive correlation between construction output and the level of economic output has been confirmed (Turin, 1969; Hosein and Lewis, 2005; Chiang et al., 2015) as capital formation is the crucial driver of economic growth in classical growth theories (Boskin and Lau, 1991; Lopes et al., 2002). At the same time, concerns on the negative effects of construction activities are discussed in recent studies, including air, dust and water pollutions (Gilchrist and Allouche, 2005; Matthews et al., 2015), traffic impacts (Jiang, 1999; Wang, 2011; Matthews et al., 2015), productivity loss (Çelik et al., 2017) and other social impacts (Marx, 2002; Çelik et al., 2017). Carbon dioxide (CO_2) emission has received more attention since buildings and the construction sector are responsible for 39%—28% from building facilities and operations, and 11% from building materials, transport, and construction activities—of the global energy-related CO_2 emissions in 2016 (UNEP, 2017).

Opinions differ as to whether globalization is an opportunity or a threat to urban regions. The general finding is that large cities tend to reap the gains from globalization but at the expense of increasing spatial impacts (Richardson, et al., 2005). Also, the role of cities in the national economy has changed over recent decades. Economic geographers see the scale effect and agglomeration effect of cities and regions as the vital determinants in industrialization and economic growth (Scott, 2001; Findlay and O'Rourke, 2007). With falling trade barriers, lower transaction cost, and increasing blurred national borders in the globalization era, the global connectivity of cities becomes more critical to national economic performance (Taylor, 2004; Sassen, 2006).

The connectivity (or openness) and productivity are claimed to be positively related (Edwards, 1998; McCann and Acs, 2011). Villar (1999) suggests regions with less costly access to foreign markets (for example, border or port regions) appear to have greater benefit from trade liberalization. This efficiency gain from market access can also be facilitated through transport infrastructure and telecommunication network, and thereby increases productivity (Brülhart, 2011). Though the above observations lied in the assumptions that productivity is enhanced with easy access to lower cost intermediate inputs, and/or output level is amplified with easy access to customers, which eventually affect the economic growth with export-led growth hypothesis (Cuadros et al., 2004).

Other studies exploring the relationship between trade openness and economic growth also emphasize the effect of spatial agglomeration and fragmentation. Theories of comparative advantage suggest the market tends to reallocate resources across regions, sectors and production factors to maximize efficiency and profits from the globalization process (Brülhart, 2011). Thus, the trade openness activates geographic concentration of specific sectors (Fujita et al., 1999; Monfort and Nicolini, 2000; Crozet and Koenig, 2004), and leads to spatial fragmentation of production (Feenstra, 1998) and eventually structural change (Uy et al., 2013).

Meanwhile, the interaction between international trade (or globalization) and environmental pressure is increasingly recognized. Some studies suggest that globalization leads to an increase in worldwide trade and demand, which has resulted in the rise in the production and pollution (Coggburn et al, 2007; Baek et al., 2009), including emissions from interregional and international transport (Huwart and Verdier, 2013). Some researchers address the fragmentation and industrial agglomeration cause the geographical separation of production and consumption, hence, alter the associated environmental pressures among economies (Peters and Hertwich, 2008; Davis and Caldeira, 2010). Others note cities are the carrier of economies activities, which accounts for more than 75% of global energy-related greenhouse gas (GHG) emissions (UNEP, 2014).

For a small open economy with a small domestic market, the trade liberalization stimulates the economic restructuring process with few dominating sectors. Without adequate colonial arenas and raw materials, a large share of goods is bought from and sold abroad, and the import content in exports is expected to increase to support the rising production and demand. In other words, as trade openness increases, the magnitudes of domestic intersectoral linkages in the small open economies are reduced (Krugman and Elizondo, 1996) even with expanding economic output. The earned profits through the production process are distributed across cities, regions, and nations. At the same time, carbon emissions are generated along the supply chains as a by-product. Identification of the interconnections between sectors, regions, and nations are necessary to illustrate the economic significance of an urban economy, its dependency on the exterior supply, and its carbon footprint.

As construction is a labor and material-intensive sector, the rising dependency on imported materials and labors is expected to reduce its sectoral economic importance in the era of globalization. The effect is likely to be greater in open urban economies. The recognition of leak out transactions in inputs and final demand with other regions is essential to characterize weaknesses in productivity, interregional and international leakages of the local construction sector, as well as its associated environmental impacts and carbon responsibility.

1.2 Problem Statement

Parts of the economic effects and environmental burdens that an urban economy manifests are associated with interregional and international traded products and services. This suggests that the consumption of imported goods in a city incurs carbon pollutants and economic impacts from other regions and economies. The economic influence and the carbon responsibility of an urban economy, thus, partially rely upon the dependence of imported products and services.

Despite extensive research on investigating the economic contribution of the construction sector at the macro-level, few studies have focused solely on small advanced economies or urban economies, and none of them have addressed the leakage issue in detail. Also, much less is known about leakage of construction-related CO_2 emissions of these urban economies. As one of the leading financial hubs, Hong Kong is used as the case study to represent a small open economy, as well as an urban economy to explore changes in the economic influence and city-scale CO_2 pollutants of the construction sector over a time period.

To obtain a better understanding of the construction sector and other material- and labor-intensive sectors in small open economies undergoing deindustrialization, the joint economic and environmental impacts should be examined, with an emphasis on the sectoral interconnections within the targeted economy and across economies. This dissertation addresses three related questions listed below to explore the economic influence and CO_2 emissions of an urban economy (Hong Kong) in the global supply chains.

(1) To what extent is the economic influence of the construction sector in Hong Kong through time by identifying domestic linkages and leakages from a global perspective?

(2) What is the allocation of carbon emissions originated in fossil fuel combustion for the construction activities in Hong Kong from both production and consumption perspectives, as well as the driving factors on the emission trends for both perspectives?

(3) How different are the interdependence and trade openness effects of Hong Kong's construction sector, comparing to other similar economies?

1.3 Methodologies

The dissertation attempts to answer these questions through the use of input-output analysis (IOA), multi-regional IOA (MRIOA) and environmentally extended MRIOA (EE-MRIOA). The first two models are used to quantify the evolving linkages between domestic production sectors, the impacts of international trade on those linkages over a particular period of time. Direct and embodied emissions analysis is then constructed on the basis of MRIOA to estimate the direct carbon emission and carbon embodiments in trade responding to the final demand of Hong Kong's construction on a global level.

Official Hong Kong input-output tables (IOTs) are yet to be available. The latest IOT of Hong Kong for the fiscal year 1997/1998 (Voon and Ho, 2001) does not cover current conditions. The unavailability of IOTs from official statistics sources poses a challenge to the investigation. Also, the absence of continuing IOTs hampers the study of the evolving contribution of Hong Kong's construction sector over time as the interdependence between the construction sector and other sectors is not static (Bon, 1988).

In the dissertation, a series of IOTs for the years 1995, 2000, 2005, 2010 and 2013, as well as three multi-regional IOTs (MRIOTs) of Hong Kong for the years 2004, 2007, and 2011 are compiled to analyze the ability of the construction sector in stimulating economic growth, the leak-out effect and to reveal its truthful carbon responsibility in a small and import-dependent economy. The IOTs and MRIOTs explicitly incorporate the service-dominating economic structure of Hong Kong and are divided into 10 classified sectors. These tables are constructed using the Global Trade Analysis Project (GTAP) database in conjunction with official statistics in Hong Kong. As the base years of GTAP are different from the proposed Hong Kong IOTs, adjustments are made for updating the transaction tables to the proposed years. Based on the results, the shift of production structure, sectoral interdependence, import dependence, and carbon pollutants incurred over time are identified and explored.

MRIOTs is considered as an extension of the single region IOTs that covers the intraregional and interregional interconnections between Hong Kong's construction sector and other abroad sectors. Within this MRIOA framework, three geographical regions—Hong Kong, China and the rest of the world—are assigned to represent the city, national, and global level, respectively. Then, emission data are combined with MRIOA to include the upstream emission impacts of products and services across international supply chains, as shown in EE-MRIOA. The composition of direct, indirect, and imported economic impacts and CO_2 emissions are identified with a trans-boundary approach. Also, both production-based emissions and consumption-based emissions are estimated to provide full insights on the carbon emissions, including the leakage of emissions.

The results of the economic and environmental consequences of Hong Kong's construction sector in terms of linkage, leakage, and CO_2 emissions, are used in comparing the sectoral performance with other economies throughout time. The potential causes of the changes are then explored. These outcomes are expected to provide a more comprehensive view of the sector-specific and overall economic benefits proceeding from construction activities in Hong Kong. Proper policies and recommendations in expanding the domestic linkages and mitigating carbon emissions are presented.

In sum, the objectives of the study are stated underneath to answer the issues listed in the problem statement.

(1) To construct a series of IOTs and MRIOTs to assess the effects of regional and international trade, as well as the service-dominating economic structure on the economic linkage and leakage of Hong Kong's construction sector through a time frame. The shift of

sectoral interdependence and import dependence are explored to demonstrate the importance of considering intersectoral linkages with abroad upstream sectors in discussing the economic influence of an urban economy.

(2) To investigate Hong Kong's carbon flows induced by local construction final consumption through sectoral flow and trade from 2004 to 2011 by integrating MRIOTs with CO_2 data. The upstream sectors across the globe are emphasized to outline the true carbon responsibility of an urban economy as a consumer. Possible driving factors that influence CO_2 emissions are also discussed.

(3) To compare the linkage and leakage with other economies to provide insights for possible points of intervention and practical policies for Hong Kong and other urban economies.

1.4 Dissertation Outline

After the presentation in this chapter of general background for understanding the research questions, the subsequent chapters are organized as below. Chapter 2 outlines a review of previous studies on macroeconomics models adopted in estimating the economic and environmental impacts of construction investments or activities. Chapter 3 describes the analytical framework of a single region IOA model applied in Hong Kong, by considering its economic structure to illustrate the economic role of Hong Kong's construction sector in stimulating local economic growth. Chapter 4 adopts MRIOA to explore the economic leakage effect from a global perspective. Chapter 5 outlines the direct and embodied CO_2 emissions associated with a downstream consumption in Hong Kong's construction sector from both production and consumption perspectives with EE-MRIOA. In these three chapters, data sources and the procedures for estimating sectoral economic and environmental coefficients are outlined. Possible factors at the regional level which influence the declining economic linkages and leakages are discussed throughout the content. Also, comparisons with selected advanced economies are presented to draw the differences. Chapter 6 summarizes the contributions, limitations, policy implications and proposes possible directions for future research.

Chapter 2 LITERATURE REVIEW

2.1 Introduction

The chapter provides a review of empirical literature in exploring the relationship between construction activities or public capital and economic growth with macro-economic approaches. The findings of previous studies on the economic influence and CO_2 emissions of the construction sector in small and open economies are also presented.

2.2 Construction Activities and Economy Growth

The economic contribution of construction activities has been extensively studied from the 1950s with econometric models. The earlier studies (Turin, 1969; Strassmann, 1970; Turin, 1973; Wells, 1986; Gundes, 2011) suggested there is a positive correlation between measures of construction output and economic output (often as per capita GDP or per capita national income). Yet, Lopes et al. (2002) argued the degree and nature of correlation might vary under different circumstances. Drewer (1980), Ruddock and Lopes (2006) criticized the reliability of those findings in terms of the quality of data, the limitation of coverage, and the employed analysis methods.

Green (1997), Lean (2001), Yiu et al. (2004), Wong et al. (2008), Lewis (2009), Ozkan et al. (2012) applied econometric analysis to test the causality between construction output and GDP. The results of these studies were inconclusive. In the case of Hong Kong, Tse and Ganesan (1997), and Yiu et al. (2004) suggested the real growth of the aggregate economy leads the construction output growth, and not vice versa. In contrast, Wong et al. (2008) indicated the causality runs from the construction sector to GDP, and Chiang et al. (2015) stated a bi-directional causal relationship. Again, the above studies focused more on the static view of the relationship between the construction sector and economic growth in a relatively straightforward manner.

Lakshmanan and Anderson (2002) stated that economic development is mainly influenced by public capital through direct and indirect channels, including ripple effects of infrastructure improvements. They classified the analytical approaches into three categories: microeconomic modeling, macroeconomic modeling and general equilibrium effects of public capital. The microeconomic approach focuses on the direct and indirect micro-level benefits arising from the consequent changes in public capital. Cost-benefit analysis is the most commonly used method, which fails to capture the broader network effects, as well as to provide the information on the mechanisms underlying economic change (Lakshmanan, 2011; Carlsson et al., 2013).

At a macroeconomic level, public capital tends to make an impact on economic growth, either directly and indirectly (Rosenstein-Rodan, 1943; Hirschman, 1958). Investments in public capital contribute to the economy directly as additions to final output and capital stocks, and also lead to new investments and activities from follower sectors within a short period. The services of infrastructure indirectly induce greater efficiency and reduce production cost for a long duration, and eventually lead to output expansion effect. The former short-term effects in causing further economic activities are generally assessed by IOA, and the latter economic consequences deriving from infrastructure operation are evaluated by production function or cost function models with a pre-determined set of assumptions. Yet, the production function and cost function have long been criticized: (1) the mechanisms linking the infrastructure improvement and the broader economy are insufficiently detailed; (2) the direction and causality between infrastructure and output are unclear; (3) the substitutional elasticities between various inputs are constant and equal to unity; (4) findings were not consistent among the previous studies (Hakfoort, 1996; Romp and De Haan, 2005; Lakshmanan, 2011). In contrast, the short-term economic impacts are more certain by depicting the interactions among various economic sectors and economies.

There are numerous influencing factors that may affect the economic impacts of construction activities on the economy: industrialization (Bon and Pietroforte, 1990; Ilhan and Yaman, 2011), scale of economy (Dietzenbacher, 2002; Myers, 2013), technology and labor productivity (Bon, 2000; Sposi, 2015), and domestic resource usage and imports (Polenske and Sivitanides, 1990). Many of these factors are interrelated, and the resultant impacts caused by these variables frequently appear as aggregate outcomes. The aggregated sectoral changes can be observed from the input-output (IO) model, which depicts interdependence between sectors in an economy and between economies, by stimulating trade flows between economic activities. The sectoral interdependence is assessed and presented as linkage indicators.

The significant economic role of the construction sector through a complex set of intersectoral flows with other sectors are highlighted in numerous IOA studies. Sectors with widespread activities throughout the economy tend to have a greater magnitude of linkages (Dietzenbacher, 2002; Reis and Rua, 2009), which is proven to be the case for the construction sector (Polenske and Sivitanides, 1990; Gundes, 2011). The construction sector is also characterized by possessing strong demand pull effect and relatively weak supply push effect, as revealed by backward and forward linkage indicators (Polenske and Sivitanides, 1990; Ilhan and Yaman, 2011; Gregori and Pietroforte, 2015). This demonstrates that construction activities can spur economic activities through intermediate input demand from various supplying sectors.

Based on several studies carried out using IOA, a conclusive statement is derived that the economic contribution of the construction sector in advanced economies has declined over time because of deindustrialization and the declining contribution from the manufacturing sector. Bon and Pietroforte (1990), and Pietroforte and Gregori (2003) reported that the economic influence of the construction and manufacturing sectors declines once the economy enters the stage of deindustrialization in some advanced economies including Australia, Japan, and the US. Pietroforte et al. (2009) suggested that the declining economic importance of the US construction sector from 1947 to 2002 is strongly affected by the shrinking intermediate inputs. The decreasing contribution of manufacturing inputs is partially offset by the steady growth of service inputs. Ilhan and Yaman (2011) documented similar observations in Ireland, the Netherlands, and Sweden from 1998 to 2002. The shift of intermediate inputs has been attributed to the level of industrialization, technology transformation, price fluctuation, and labor productivity (Bon, 2000; Pietroforte et al., 2009; Sposi, 2015). Finally, Wells (1986), Giang and Pheng (2011) emphasized the importance of using locally produced inputs rather than imported inputs for the construction sector to increase the local value-added.

According to Miller and Blair (2009), the smaller the economy, the more dependent that economy is on trade with other areas. The simple IO model is used to represent a national or regional economy with no connection to other regions. Data of imports and exports by sectors are often added to complete a single region IOA with two fundamental assumptions. Firstly, an increase in output in the target region causes an output increase in other regions. Yet, any of the other regions have no influence on the remaining regions. The second assumption is that the production efficiency of imported goods and services is identical to the economy under investigation. The existence of MRIOA permits relaxation of such assumptions. It comprises interregional and international transaction flows among all regions, and allows to evaluate backward effects of the target sectors or regions from a global perspective.

Pietroforte et al. (2000) constructed 18-sector bi-regional IOTs to represent the North and South regions of Italy from national benchmark tables. The results indicated that the economic importance of the construction sector has declined substantially in South Italy because of the lack of a manufacturing base and the regional economy relies heavily on imports from North Italy. That highlights the importance of considering intersectoral linkages with abroad upstream sectors in discussing the regional economic influence.

Overall, conventional IO and multi-regional IO (MRIO) models have been criticized for being static, lack of flexibility in input coefficients, and lack of supply-side feedbacks in price and resource constraint (Bachmann et al., 2014). The linearity assumption implies a rigid proportional relationship between input coefficients (also import coefficients) and output, and there is no substitutability between factors. IO and MRIO models are known as the demand-driven models (Miller and Blair, 2009), which assume the supply of exogenous resources as infinite. In addition, these models achieve equilibrium in supply and demand quantities only, and the effect of price is treated exogenously. Still, Baumol (2000) believed IOA is one of the major accomplishments to economics in the 20th century that IOA mutually supports theory, data, and application. IOA has been applied extensively in various subjects as international trade, environmental economics, as well as productivity based on actual data and trade statistics.

There has been an increased interest in the interactions between trade and environment since the 1970s (Tukker and Dietzenbacher, 2013). The detailed output of IOA or MRIOA enables a connection to the environmental matrix (Suttinon et al., 2013), and combined into EE-IOA or EE-MRIOA. The models have been considered as appropriate top-down techniques to attribute energy use, resource consumption, and GHG emission to sectoral final demand at the regional, national and supranational levels (Miller and Blaie, 2009).

The reviews of Wiedmann (2009a) and Hoekstra (2010) stated a few concerns in EE-IOA and EE-MRIOA. Main concerns for EE-IOA include uncertainties in source data and trade statistics, assumptions of proportionality and homogeneity, aggregation, and temporal discrepancies due to re-exports (Lenzen, 2001; Peters and Hertwich, 2006a; Weber, 2008; Wiedmann, 2009a). The level of sector aggregation, treatment of the rest of world (RoW) region, and monetary exchange rate are the main concerns for EE-MRIOA (Lenzen et al., 2004 ; Weber, 2008; Hoekstra, 2010). Theoretically, a finer level of disaggregation in sectors (Su et al., 2010), as well as the RoW region would be favored. The error associated with aggregation occurs when high and low impacting sectors are merged into a single aggregated sector (Wiedmann, 2009a).

Regarding these concerns, Wiedmann et al. (2008) were the first to conduct a comprehensive uncertainties analysis of a global MRIOA using the Monte-Carlo analysis (Wiedmann, 2009a). The results indicated that the relative standard error of total CO_2 emission estimation for the UK is between 3.3% and 5.5%. The authors concluded the estimation of total embodied emissions is regarded as reliable with MRIOA at the national level.

2.3 Construction Activities in Small and Open Economies

Small countries with limited domestic market size face stronger incentives to remain open to sustain the level of economic activity and productivity (Alesina and Wacziarg, 1998; Ram, 2009). Because an open economy is more subjective to external shocks, and its macroeconomic policy is largely powerless to influence the use of imported inputs, IOA becomes indispensable for rational policy formation to make optimal use of resources (Baumol and Wolff, 1994). Based on the IOA of six European Union (EU) economies in 1985, Dietzenbacher (2002) noted that small economies

(Belgium, Denmark, and the Netherlands) appear to have smaller economic impacts than large diversified economies (Germany, France, and Italy), indicating that the economic activities of small economies generally depend more on imports and exports, with larger leakage effects. The construction sector is no exception. In this study, leakage is defined as the loss of economic output with the use of imported goods and services (Guo and Planting, 2000).

The results from previous studies quantifying the sectoral performance of the construction sector in small open economies do not comply fully with the results from large economies. For the production structure, increasing dependency on the service sectors has been reported for North Cyprus (Mehmet and Yorucu, 2008) and Sri Lanka (Rameezdeen and Ramachandra, 2008). As for the linkage, some studies claimed that there is no difference in the sectoral performance among Denmark, the Netherlands (Pietroforte and Gregori, 2003), and other large economies, whereas some stated that small economies tend to have lower total backward linkages, such as Finland (Bon and Pietroforte, 1990) and Sri Lanka (Rameezdeen and Ramachandra, 2008).

Previous studies on Hong Kong have revealed that one unitary increase in construction final demand led to 1.20–1.31 units of output in the years 1962, 1973, and 1997/1998 (Hsia et al., 1975; Sung, 1979; Voon and Ho, 2001) (Appendix 1). Among all sectors, the backward linkages of Hong Kong's construction sector are less than those from mining and agricultural sectors, but greater than those of labor-intensive sectors (Voon and Ho, 2001). These observations are different from other studies that demonstrated greater backward linkages of the construction sector in other small open economies. Bon and Pietroforte (1990) stated the linkage values for Finland range from

1.70 to 1.9 from 1959 to 1985. Similar findings are reported by Bon and Yashiro (1996), Pietroforte and Gregori (2003), and Ilhan and Yaman (2011) with linkage values larger than 2.0 in Denmark, Finland, Hungary, the Netherlands, Turkey, and Sweden prior to 2002.

2.4 Construction Activities and Carbon Emissions

Previous studies have attempted to quantify GHG emissions generated by the construction sector at the macro-level. IOA and input-output life cycle assessment (IO-LCA) are commonly used methods. Huang et al. (2018) conducted IOA and found that 23% of global CO_2 emissions are contributed by the construction sector, and 94% of construction-related CO_2 emissions are indirect emissions. Chen et al. (2017b), and Chuai et al. (2015) used IOA to investigate the composition of CO_2 emissions emitted by the Chinese construction sector. Both papers suggested the indirect emissions represent over 95% of total emissions. Hong et al. (2013) conducted process-based LCA and IO-LCA approaches and stated material production, transport, and on-site activities are responsible for 95.2%, 1.8% and 3.0% of global warming potential. Huang and Bohne (2012) applied IOA to conclude that an increasing trend in GHG emissions is observed in the Norwegian construction sector from 2003 to 2007, but with decreasing emission intensities. Chang et al. (2010) performed IO-LCA to reveal that the embodied energy and environmental emissions of the Chinese construction sector have gradually increased from 2002 to 2007. Nässén et al. (2007) also applied IO-LCA to quantify the CO_2 emissions from the Swedish building sector. Their results indicated the direct, indirect, and imported emissions account for 23%, 46%, and 31% of total emissions, respectively. Similar findings were reported by Acquaye and Duffy (2010) using IOA, with the share of direct, indirect and imported emissions at 17%, 41%, and 42% respectively in the case of Ireland's construction sector. CO_2 is concluded to be the most dominant emission, with negligible contributions from N_2O and CH_4.

These studies provide several key insights. (1) Although the level of GHG emissions in the construction sector has increased, the emission intensities have remained steady or decreased over time. Those intensities in the developing counties are larger than the values in the developed counties. (2) Emissions generated are dominated by CO_2. (3) Indirect emissions are by far the greatest contributor, ranging from 77% to 95% of total emissions. Yet, the issue of leakage of emissions through trade is less discussed in these studies. Inattention to environmental pollution through international and interregional trades could result in delivering insufficient information on consumption patterns at the regional and sectoral level. Suboptimal policies and strategies for the construction sector may be formulated in the absence of relevant information (Hong et al., 2016).

A number of recent studies have highlighted the substantial role of CO_2 emissions that are embodied in international trade. A study by Peters et al. (2011a) indicated that the CO_2 emissions embodied in trade among 113 economies have reached 7.8 Gt (26% of global emissions) in 2008. Lenzen et al. (2007), Rodrigues and Domingos (2008), Minx et al. (2009), Kanemoto et al. (2011) and Steininger et al. (2014) discussed the shared producer and consumer responsibility in environmental impacts within an IOA or MRIOA framework. The producer (consumer) responsibility of a sector or a region is defined as the downstream (upstream) embodied emissions of the economic flows in the IO framework, for example, primary inputs (final demand). The consumption-based emissions are also referred to as carbon footprint (Steininger et al., 2018).

There are several approaches to quantifying the emissions embodied in international trade (Kanemoto et al., 2011; Sato, 2014; Zhang et al., 2017). Regarding the complexity of trade transactions, with the associated economic and environmental data, MRIOA has been used intensively with well-established methodologies and robust databases (Wiedmann, 2009b; Arto et al., 2014; Steininger et al., 2018). Numerous papers have applied MRIOA to cover the global economy in estimating GHG emissions and carbon leakage (Peters and Hertwich, 2008; Hertwich and Peters, 2009; Wilting and Vringer, 2009; Davis and Caldeira, 2010; Peters et al., 2011a; Wiebe et al., 2012). Other empirical studies have emphasized carbon footprints at the national level through a time-series of MRIOTs, such as for Austria (Muñoz and Steininger, 2010; Steininger et al., 2018), China (Fan et al., 2016; Mi et al., 2017), EU-countries (Kanemoto et al., 2016), Japan (Kanemoto and Tonooka, 2009; Kanemoto et al., 2016), the UK (Baiocchi and Minx, 2010; Wiedmann et al., 2010) and the US (Weber and Matthews, 2007; Fan et al., 2016). Several key findings shared across these studies are summarized as follows. (1) There is an increased flow of GHG emissions from developed economies to developing economies through international trade. Most of the developed economies are recognized as net importers of embodied emissions except for the ones with larger exports of natural resources. (2) Small and trade-exposed economies tend to have a higher value of emissions embodied in imports (EEI) than large and diversified economies. (3) Construction activities account for 10% of GHG emissions globally. GHG emissions at the sectoral level were much less emphasized, and often found as part of the national analysis in most MRIOA studies. The construction sector is frequently quantified as one of the significant contributors of consumption-based emissions (Hertwich and Peters, 2009; Muñoz and Steininger, 2010; Liu et al., 2015; Steininger et al., 2018).

A growing body of literature discusses environmental impacts at the urban level due to increasing recognition of the importance of local action in climate change mitigation (Minx et al., 2013), and the nature of urban areas. Cities and metropolitan regions are open systems that rely heavily on the outside world to acquire materials and release wastes. GHG emissions are a prominent example of urban by-products (Bai, 2007). Recent urban studies suggested that consumption-based emissions exceed production-based emissions in most urban areas, mainly located in developed countries, and some are reported in China. Several metropolitan areas are identified to be net importers of embodied GHG emissions, for example, Belgium (77% of GHG emissions are EEI) in 2007 (Athanassiadis et al., 2018), Sydney (71%) and Melbourne (55%) in 2009 (Chen et al., 2017a), Xiamen City (59%) in 2010 (Lin et al., 2015), and Tokyo (53%) in 2011 (Long and Yoshida, 2018).

Some MRIOA studies have expanded the scope to compare the GHG emissions for a series of urban areas. Minx et al. (2013) studied the carbon footprints of 434 municipalities in the UK. Their results showed that 90% of municipalities are net importers of embodied CO_2 emissions, while the averaged carbon footprint of urban areas is lower than that of rural areas. As in China, Feng et al. (2014) reported that over 70% of emissions consumed in the three largest urban areas—Beijing, Shanghai, and Tianjin—are imported from other regions in 2007. The dominant share of EEI is attributed to the construction sector, owing to the continuous demands for urban capital investments. Sudmant et al. (2018) compared the emissions of 45 urban areas in China, the UK, and the US. The results indicated that income level and population density are strong predictors of consumption-based emissions. Higher income levels lead to greater emissions from increasing demand which is usually met by imports. Yet, a different observation was stated in Franzen and Mader (2018) by measuring the ratio of consumption-based emissions to production-based emissions in 110 nations. They claimed the share of industry or services in GDP, and income level do not affect the ratio. Instead, the ratio is found to be greater for economies with high energy efficiency and high import rate.

Chapter 3 HK INPUT-OUTPUT ANALYSIS

3.1 Introduction

Hong Kong is a small and open economy with a high dependence on external trade. The extensive use of imported goods combined with skewed economic structure alters the interdependence of the construction sector through the production process and trading behavior. Despite extensive research on the IOA of the construction sector in numerous developed and developing countries, few studies have focused solely on small developed economies, and none of them have addressed the leakage issue in detail. Yet, the absence of continuing IOA hampers the study of the evolving contribution of Hong Kong's construction sector over time because the interdependence between the construction sector and other sectors is not static (Bon 1988). The unavailability of IOTs as official statistics poses a challenge to the investigation, and the latest IOT of Hong Kong for the fiscal year 1997/1998 does not cover current conditions.

To better understand the up-to-date influence of Hong Kong's construction sector in stimulating economic growth, this chapter involves analyzes performed in three phases including (1) investigate the linkages of the construction sector by compiling a series of IOTs for the years 1995, 2000, 2005, 2010, and 2013; (2) compare outcomes with other economies; and (3) conduct a hybrid 2013/14 IOT for validation. Measures of linkage and leakage are used to quantify interdependence and trade effects for Hong Kong's construction sector, and hence to discuss its changing economic importance from 1995 to 2013. The assessments on the sectoral performance regarding linkages and leakages throughout time in Hong Kong and other economies are reviewed. The shift of production structure, sectoral interdependence, and import dependence over time are discussed with explanations. These outcomes are expected to provide a more comprehensive view of the sector-specific and overall economic benefits proceeding from construction activities in Hong Kong.

3.2 Method and Data

3.2.1 Study Framework

Some studies use population, land area, or gross domestic product (GDP) as the indicators for country (economy) size (Rodríguez and Rodrik, 2000; Ram, 2009), whereas others argue an economy is classified as small in the sense that it has no discernable influence on the world output, price level, and interest rate (Clarida et al., 2001; Dib, 2011). Also, the meaning and measure of trade openness are interpreted differently in empirical studies (Rodríguez and Rodrik, 2000; Yanikkaya, 2003). The share of trade volume (imports plus exports) to the GDP is the most basic measure, whereas others claim the trade barriers, trade orientation, or exchange rate should be used to represent the openness measure (Yanikkaya, 2003).

Hong Kong is selected to represent a small (regarding population, land area, and as a price-taker) and open economy that adopts outward-oriented policies (Rao and Singh, 2010), with trade volume exceeded 340% of the GDP in 2014 (Census and Statistics Dept., 2016a). Its high dependence on external trade with the relocation of manufacturing operations to South China has led to a service-based economy. The share of services comprised

92.7% of the GDP, whereas the manufacturing share of GDP fell to 1.1% in 2015 (Census and Statistics Dept., 2017).

Considering the availability of statistics and the service-dominating economic structure, Hong Kong IOTs have been divided into 10 sectors: (1) Agriculture, (2) Manufacturing, (3) Utilities, (4) Construction, (5) Wholesale & Retail Trade, (6) Transport & Storage, (7) Information & Communication, (8) Financing & Insurance, (9) Professional & Support Activities, and (10) Other Services. Comparisons in sectoral classification between the Hong Kong, GTAP database and other economies are summarized in Table 3-1.

3.2.2 Accounting Framework and Data

IO models can be classified briefly as survey, non-survey and hybrid models, depending on the data sources. Survey-based model obtains most of the data through mailed questionnaires or interviews with regional business firms. Non-survey model employs almost no primary data. It generally obtains data from the database or refers to other similar economies with careful adjustments. The hybrid model relies on surveys for IO intersectoral flow coefficients and applies secondary data for the rest of the table (Otto and Johnson, 1993).

Within the time and resource constraints, this study focuses on the non-survey model and the hybrid model. A series of non-survey IOTs from 1995 to 2013 for Hong Kong was constructed to analyze the ability of the construction sector in stimulating economic growth. Various data sets were used to compile Hong Kong IOTs to ensure accuracy and consistency.

Many of the data sources are listed in Table 3-2. Also, a hybrid 2013/14 IOT is constructed to compare with the non-survey I-O table for validation purpose.

For the compilation of non-survey intersectoral transaction tables in the years 1995, 2000, 2005, 2010, and 2013, the intersectoral flow coefficients were extracted from the GTAP database on the base years 1997, 2001, 2004, 2007, and 2011. The GTAP database comprises balanced, harmonized data (Narayanan and Walmsley, 2008; Peters et al., 2011b) and inclusive sets of accounts outlining the annual flows of goods and services with regional and sectoral detail for 140 regions (Aguiar et al., 2016). Nonetheless, the base years of GTAP are different from the proposed Hong Kong IOTs. Proportional adjustment and standard RAS methods were used for updating the transaction tables by reconciling and balancing the columns and rows. The basic principles and procedures applied are discussed by Parikh (1979) and Toh (1998).

Other input data, such as intermediate consumption, value-added, final demand, imports, and exports, were extracted from official statistics. Parts of the applied secondary data were regrouped or separated into the appropriate classified sectors. The published statistics for imports and exports are incomplete, so estimations and assumptions were applied to fill the gap by referring to the composition of Singapore IOTs because Singapore's economic structure and scale are similar to that of Hong Kong (Young 1992; Zimring et al. 2010).

Table 3-1 Summary of sectoral classification of US, UK, Singapore, GTAP and Proposed HK IOT

<table>
<tr><th>US (2016)
(15 Sectors)</th><th>UK (2014)
(10 Sectors)</th><th>Singapore (2014)
(11 Sectors)</th><th>Proposed HK IOT
(10 Sectors)</th><th>GTAP 9 Data Base
(57 Sectors)</th></tr>
<tr><td>Agriculture, forestry, fishing, and hunting</td><td>Agriculture</td><td>Other Goods</td><td>Agriculture</td><td>(1) Paddy rice; (2) Wheat; (3) Cereal grains nec; (4) Vegetables, fruit, nuts; (5) Oil seeds; (6) Sugar cane, sugar beet; (7) Plant-based fibers; (8) Crops nec; (9) Bovine cattle, sheep and goats, horses; (10) Animal products nec; (11) Raw milk; (12) Wool, silk-worm cocoons; (13) Forestry; (14) Fishing;</td></tr>
<tr><td>Mining</td><td rowspan="3">Production</td><td rowspan="2">Manufacturing (Oil/ Non-Oil)</td><td rowspan="2">Manufacturing</td><td rowspan="2">(15) Coal; (16) Oil; (17) Gas; (18) Minerals nec; (19) Bovine cattle, sheep and goat, horse meat products; (20) Meat products nec; (21) Vegetable oils and fats; (22) Dairy products; (23) Processed rice; (24) Sugar; (25) Food products nec; (26) Beverages and tobacco products; (27) Textiles; (28) Wearing apparel; (29) Leather products; (30) Wood products; (31) Paper products, publishing; (32) Petroleum, coal products; (33) Chemical, rubber, plastic products ; (34) Mineral products nec; (35) Ferrous metals; (36) Metals nec; (37) Metal products; (38) Motor vehicles and parts; (39) Transport equipment nec; (40) Electronic equipment; (41) Machinery and equipment nec; (42) Manufactures nec;</td></tr>
<tr><td>Manufacturing</td></tr>
<tr><td>Utilities</td><td>Utilities</td><td>Utilities</td><td>(43) Electricity; (44) Gas manufacture, distribution; (45) Water;</td></tr>
<tr><td>Construction</td><td>Construction</td><td>Construction</td><td>Construction</td><td>(46) Construction;</td></tr>
<tr><td>Wholesale trade</td><td rowspan="3">Distribution, transport, hotels and restaurants</td><td>Wholesale & Retail Trade</td><td rowspan="2">Wholesale & retail trade (include import/export)</td><td rowspan="2">(47) Trade;</td></tr>
<tr><td>Retail trade</td><td>Accommodation & food services</td></tr>
<tr><td>Transportation and warehousing</td><td>Transportation & Storage</td><td>Transport & storage</td><td>(48) Transport nec; (49) Water transport; (50) Air transport;</td></tr>
<tr><td>Information</td><td>Information & communication</td><td>Information & Communications</td><td>Information & communication</td><td>(51) Communication;</td></tr>
<tr><td rowspan="2">Finance, insurance, real estate, rental, and leasing</td><td>Financial & insurance</td><td>Finance & insurance</td><td>Financing & insurance</td><td>(52) Financial services nec; (53) Insurance;</td></tr>
<tr><td>Real estate</td><td rowspan="2">Business services[a]</td><td rowspan="2">Professional & support activities</td><td rowspan="2">(54) Business services nec;</td></tr>
<tr><td>Professional and business services</td><td>Professional and support activities</td></tr>
<tr><td>Government</td><td rowspan="2">Government, health & education</td><td rowspan="4">Other services[a]</td><td rowspan="4">Other services</td><td rowspan="4">(55) Recreational and other services; (56) Public administration and defense, education, health; (57) Dwellings.</td></tr>
<tr><td>Educational services, health care, and social assistance</td></tr>
<tr><td>Arts, entertainment, recreation, accommodation, and food services</td><td rowspan="2">Other services</td></tr>
<tr><td>Other services, except government</td></tr>
</table>

Note: Aguiar et al. (2016); BEA (2016); ONS (2014); Singapore (2014). [a.] Ownership of dwellings is classified under "other services" in 2007 but shifted to "Business services" after 2010.

Table 3-2 Data sources for comprising HK IOTs (1995-2013)

	Data	
	Year	Data Source
Interindustry coefficients	1997, 2001, 2004, 2007, 2011	GTAP Data Base (Aguiar et al., 2016)
GDP and its expenditure components	1995, 2000, 2005, 2010, 2013	Gross Domestic Product (Yearly) (Census and Statistics Dept., 2005-2013)
Intermediate inputs Value-added (compensation, gross surplus), taxes less subsidies	1995, 2000, 2005, 2010, 2013	Key Statistics on Business Performance and Operating Characteristics of the Building, Construction and Real Estate Sectors (Census and Statistics Dept., 2010-2013a) Report on Annual Survey of Building, Construction and Real Estate Sectors (Census and Statistics Dept., 1995-2005a) Key Statistics on Business Performance and Operating Characteristics of the Industrial Sector (Census and Statistics Dept., 2010-2013b) Report on Annual Survey of Industrial Production (Census and Statistics Dept., 1995-2005b) Key Statistics on Business Performance and Operating Characteristics of the Import/Export, Wholesale and Retail Trades, and Accommodation and Food Services Sectors (Census and Statistics Dept., 2010-2013c) Report on Annual Survey of Wholesale, Retail and Import and Export Trades, Restaurants and Hotels (Census and Statistics Dept., 1995-2005c) Key Statistics on Business Performance and Operating Characteristics of the Transportation, Storage and Courier Services Sector (Census and Statistics Dept., 2010-2013d) Report on Annual Survey of Transport and Related Services (Census and Statistics Dept., 1995-2005d) Key Statistics on Operating Characteristics of the Information and Communications, Financing and Insurance, Professional and Business Services Sectors (Census and Statistics Dept., 2010-2013e) Report on Annual Surveys of Storage, Communication, Banking, Financing, Insurance and Business Services (Census and Statistics Dept., 1995-2005e)
Changes in Inventory	1995, 2000, 2005, 2010, 2013	Table 090: Selected Statistics for All Establishments in the Industry Sections of Import/Export, Wholesale and Retail Trades, and Accommodation and Food Services (Census and Statistics Dept., 2016b) Table 202: Selected Industry Averages and Analytical Ratios for Establishments in the Manufacturing Sector (Census and Statistics Dept., 2016c)
Imports and Exports	1995, 2000, 2005, 2010, 2013	Table 063 : External Merchandise Trade Statistics by End-use Category – Imports (Census and Statistics Dept, 2016d) Table 082 : Exports, Imports and Net Exports of Services by Service Component (Census and Statistics Dept., 2016e) Table 197: Imports of Ten Principal Commodity Divisions (Census and Statistics Dept., 2016f) Table 198: Domestic Exports of Ten Principal Commodity Divisions (Census and Statistics Dept., 2016g) Table199: Re-exports of Ten Principal Commodity Divisions (Census and Statistics Dept., 2016h)

Take IOT of the year 2013 as an example, the data of 10 principle commodities of merchandise trade (Census and Statistics Dept., 2016f) and merchandise trade classified by end-use category (Census and Statistics Dept., 2016d) were used to allocate the imported and exported values in Agriculture, Manufacturing, and Utilities. Data on international trade in services (Census and Statistics Dept., 2016e) that are provided in numerous subgroups were relocated to the proposed sectors. A comparison between Singapore and Hong Kong trade values in ratios was then conducted to identify the missing gap. As for the imported commodities, the remaining values were redistributed to Construction, Professional& Support Activities, and Other Services.

As for the hybrid 2013/14 IOT, the intermediate and final demand of goods and services related to Construction sector in the year 2013/14 were obtained from the survey. The analyzed outcomes from 6 completed questionnaire then transformed into intersectoral flow coefficients to replace the existing coefficients of Construction in the 2013 non-survey IOT with a balancing procedure. The brief procedures and questionnaire template are shown in Appendix 2.

Based on the transaction tables, three matrixes were constructed, namely a technical coefficient matrix ($\mathbf{A}$), the Leontief matrix$(\mathbf{I}-\mathbf{A})$, and the Leontief inverse matrix$(\mathbf{I}-\mathbf{A})^{-\mathbf{1}}$. For an IOT with n sectors, the input coefficient (a_{ij}) is expressed as the ratio of the intermediate deliveries (Z_{ij}) from sector i to sector j over the total input of the latter sector (X_j). The input coefficient can be written as

$$a_{ij} = Z_{ij}(X_j)^{-1} \tag{1}$$

$$Z_{ij} = a_{ij}X_j \tag{2}$$

The estimated input coefficient for each sector is used to construct technical coefficient matrix ($\mathbf{A}$), shown as $\mathbf{A} = [a_{ij}]$ under the assumptions that the structure of production and prices of inputs are fixed. When sectoral linkages are measured by total intermediate transactions, regardless of whether they come from domestic or international producers, they would lead to the overestimation of the linkage effect (Dietzenbacher et al., 2005; Reis and Rua, 2009). In this study, imports are determined exogenously to separate the imported and domestic supplies and demands. Matrix ($\mathbf{A^d}$) is used to represent the domestic coefficients matrix excluding imports. Imported inputs are assigned as a new industry category aside from matrix ($\mathbf{A^d}$), and the final demand entries of imports are computed as a negative value in final demand; thus, the domestic final demand ($\mathbf{Y^d}$) is delivered. The supply-demand balance equation used to represent the transaction flows of an economy in matrix notation is given as

$$\mathbf{X} = \mathbf{A^d X} + \mathbf{Y^d} \tag{3}$$

where $\mathbf{X}$ = vector of domestic gross output; and $\left(\mathbf{A^d X}\right)$ and $\mathbf{Y^d}$ = vectors of domestic intermediate demand and final demand, respectively. The vector of output $\mathbf{X}$ can be solved by

$$\left(\mathbf{I} - \mathbf{A^d}\right)\mathbf{X} = \mathbf{Y^d}$$

$$\mathbf{X} = (\mathbf{I} - \mathbf{A^d})^{-1}\,\mathbf{Y^d} \tag{4}$$

where $\mathbf{I}$= identity matrix; and $(\mathbf{I} - \mathbf{A^d})^{-1}$ = matrix of interdependence coefficients.

Through these processes, the Leontief matrix $(\mathbf{I} - \mathbf{A^d})$ and inverse matrix $(\mathbf{I} - \mathbf{A^d})^{-1}$ of Hong Kong were completed for later analysis. The concepts and methods used in the compilation of IOTs are given in detail in Miller and Blair (2009). The Leontief inverse matrices of Hong Kong in 2013 for both methods are shown as examples in Appendix 3.

3.2.3 Measures of Hong Kong IOA

Common measures derived from IOTs include (1) direct backward and forward linkages, (2) domestic backward and forward linkages, (3) normalized measures of backward and forward linkage, and (4) coefficient of variation (Polenske and Sivitanides, 1990; Reis and Rua, 2009). These indicators are used to examine demand and supply trends of Hong Kong's construction sector. Import and value-added multipliers are also included to illustrate the leakage and value-added generated in local industries induced by the construction activities. The equations and principles for these indicators are presented in Table 3-3.

From the demand side, direct backward linkage is used to indicate the production structure by revealing the intermediate inputs and value-added composition, whereas domestic backward linkage (output multiplier) illustrates the economy-wide effects of a given increase in the final demand of a sector. The configuration of backward linkage (interdependence coefficient) for a sector reveals its dependencies on other sectors. From the supply-side perspective, direct forward linkage highlights the share of total output of a sector accounted as sales to intermediate sectors, whereas domestic forward linkage (input multiplier) measures the direct and indirect effects associated with a unitary change in the primary input of a sector.

Table 3-3 Principles and equations for linkages and multipliers

Indicators	Equations and Definitions			
Direct Linkages based on (**A**)	<u>Direct Backward Linkage</u> Direct $\mathrm{BL}_j = \sum_{i=1}^{n} \frac{z_{ij}}{x_j}$	Ratio of intermediate inputs to total inputs for sector *j*. Input coefficient (Z_{ij} / X_j) indicates the direct intermediate deliveries from sector *i* to sector *j* for one unit of the total inputs of sector *j*.	<u>Direct Forward Linkage</u> Direct $\mathrm{FL}_i = \sum_{j=1}^{n} \frac{z_{ij}}{x_i}$	Ratio of intersectoral sales to total outputs for sector *i*. Output coefficient (Z_{ij} / X_i) indicates the sales of sector *i* to sector *j* for one unit of the total outputs of sector *i*.
Domestic Linkage based on $(\mathbf{I\text{-}A^d})^{-1}$	<u>Domestic Backward Linkage (Output Multiplier)</u> Domestic $\mathrm{BL}_j = \sum_{i=1}^{n} b_{ij}$	Total outputs from all sectors associated with one unit change in final demand of sector *j*. Interdependence (input) coefficient measures the effect for one unit change in final demand of sector *j* on total output of sector *i*.	<u>Domestic Forward Linkage (Input Multiplier)</u> Domestic $\mathrm{FL}_i = \sum_{j=1}^{n} b_{ij}$	Total outputs throughout all sectors of one unit change in primary input from sector *i*. Interdependence (output) coefficient measures the effect on sector *j* output of one unit change in primary inputs from sector *i*.
Normalized Linkages based on $(\mathbf{I\text{-}A^d})^{-1}$	<u>Power of Dispersion</u> $U_j = \dfrac{\sum_{i=1}^{n} b_{ij}}{(\frac{1}{n}) \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij}}$	Measures the relative backward linkages of sector *j* according to the overall measure for the economy.	<u>Sensitivity of Dispersion</u> $U_i = \dfrac{\sum_{j=1}^{n} b_{ij}}{(\frac{1}{n}) \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij}}$	Measures the relative forward linkages of sector *i* according to the overall measure for the economy.
Measure of Dispersion based on $(\mathbf{I\text{-}A^d})^{-1}$	<u>Coefficient of Variation for BL</u> $V_j = \dfrac{\sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (b_{ij} - \frac{1}{n} \sum_{i=1}^{n} b_{ij})^2}}{\frac{1}{n} \sum_{i=1}^{n} b_{ij}}$	Measures the extent to which sector *j* draws evenly from other sectors	<u>Coefficient of Variation for FL</u> $V_i = \dfrac{\sqrt{\frac{1}{n-1} \sum_{j=1}^{n} (b_{ij} - \frac{1}{n} \sum_{j=1}^{n} b_{ij})^2}}{\frac{1}{n} \sum_{j=1}^{n} b_{ij}}$	Measures the extent to which the system of sectors draws evenly upon sector *i*.
Multipliers based on $(\mathbf{I\text{-}A^d})^{-1}$	<u>Value-added Multiplier</u> $\mathrm{VA}^v = \widehat{\mathbf{VA}}(\mathbf{I\text{-}A})^{-1}$	Measures value-added generated in the economy for one unit change in final demand for a given sector.	<u>Import Multiplier</u> $\mathrm{M}^v = \widehat{\mathbf{M}}(\mathbf{I\text{-}A})^{-1}$	Measures import leaked out from the economy for one unit change in final demand for a given sector.

Notations and Explanation:

Z_{ij} = intermediate deliveries from sector *i* to sector *j*

X_i = total output of sector *i*

X_j = total input of sector *j*

n = number of sectors

$\sum_{i=1}^{n} b_{ij}$ = column sums in Leontief Inverse Matrix $(\mathbf{I}-\mathbf{A^d})^{-1}$

$\sum_{j=1}^{n} b_{ij}$ = row sums in Leontief Inverse Matrix $(\mathbf{I}-\mathbf{A^d})^{-1}$

$\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}$ = total sums in Leontief Inverse Matrix $(\mathbf{I}-\mathbf{A^d})^{-1}$

$\mathbf{I}$ = identity matrix

$\widehat{\mathbf{M}}$ = diagonal matrix of import coefficient

$\widehat{\mathbf{VA}}$ = diagonal matrix of sectoral value added-output ratio

As outlined by Boucher (1976), the coefficient of variation for linkages can be used to assess the dispersion of a sector's interdependence with the supply (demand) of other sectors. A greater coefficient of variation implies that a sector depends (connects) largely on a few sectors, whereas a sector with a low coefficient indicates that an expansion of that sector would stimulate the entire economy more evenly.

Value-added and import multipliers represent the value-added generated domestically and the leakage effect for one-unit production, respectively. A sector with a low import multiplier indicates that most of the goods and services that are served by that sector are supplied domestically, and the leak out effect is considered small.

3.2.4 <u>Model Validation</u>

The results of non-survey IOT and hybrid IOT of Hong Kong in 2013 are shown in Table 3-4 (Appendix 2 for details). Since only the intersectoral flow coefficients of Construction were revised, the main differences between two IOTs exist in the interdependence coefficients and output multipliers of Construction, while the figures of other sectors remained roughly the same. The output multiplier of the hybrid IOT (1.70) is slightly higher than that of the non-survey IOT (1.55). The interdependence coefficients of Construction and of Manufacturing in the hybrid IOT are 1.41 and 0.12, whereas the coefficients in the non-survey IOT are 1.00 and 0.36. One possible explanation is that the interviewed contractors hire subcontractors for operations and materials, rather than to provide such services in-house and purchase materials directly from suppliers. The subcontracting activities are revealed in the Construction interdependence coefficient, with lower Manufacturing coefficient in the hybrid IOT.

Table 3-4 2013 Output multipliers for HK

Sector	2013 Output multiplier	
	Non-survey	Hybrid
Agriculture	1.01	1.01
Manufacturing	1.07	1.07
Utilities	1.17	1.17
Construction	**1.55**	**1.70**
Wholesale & Retail Trade	1.63	1.63
Transport & Storage	1.91	1.91
Information & Communication	1.13	1.12
Financing & Insurance	1.54	1.54
Professional and Support Activities	1.38	1.26
Other Services	1.30	1.32

Yet, the lower response rate of the questionnaires (6 out of 112 samples for 22,312 establishments) may affect the validity of survey findings, as well as the hybrid IOT. The results from non-survey IOTs are used as the main findings in the following sections. Nevertheless, the issue of possible underestimation of the non-survey Construction output multiplier is identified. More details are provided in section 3.3.2.

3.3 Results and Discussion

Figure 3-1 displays the direct and domestic linkages of Hong Kong's construction sector from 1995 to 2013. The results indicate that Construction has greater backward linkages than forward linkages, meaning the construction sector has a relatively strong influence in spurring other sectoral activities. The low forward linkages are attributed to the majority of Construction outputs being delivered as final demand (capital investment), rather than intermediate inputs for other sectors.

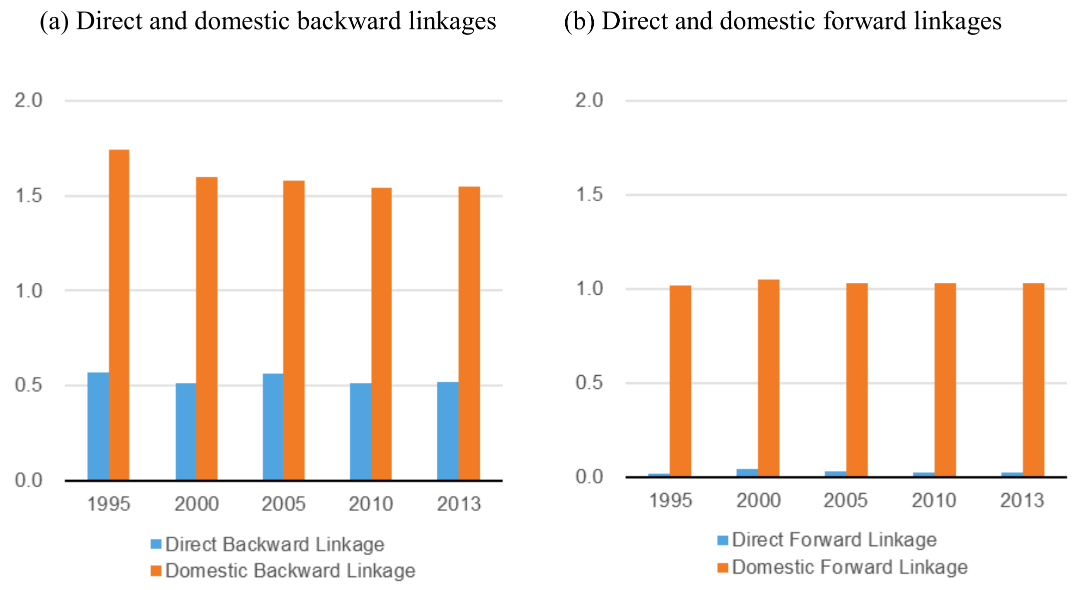


Figure 3-1 Direct and domestic linkages of HK Construction (1995-2013)

The results in Figure 3-1(a) indicate that Construction has experienced a minor decline in intermediate input shares from 0.57 in 1995 to 0.52 in 2013, and its domestic linkages have dropped by 10.92% from 1.74 to 1.55. Among the 10 sectors, Construction ranks first in 1995 but falls to third place by 2005, after Transport & Storage and Wholesale & Retail Trade (Appendix 4 for details), regarding the domestic linkage. Thus, the influence of the construction sector in stimulating Hong Kong's domestic economy has weakened over time. The coefficient of variation for Construction domestic backward and forward linkages, along with key contributors to the domestic backward linkages (with larger interdependence coefficient), are summarized in Table 3-5. Construction has smaller coefficients of variation for backward linkages and ranks the eighth place in the forward linkage. This reflects that Construction has a widespread interrelationship with supplying sectors, but its output products are used in a limited number of sectors.

Table 3-5 Coefficient of variation for HK linkages and key contributors

Year	Coefficient of variation and rank[a]		Key contributors[b] and share of contribution[c]
	Domestic BL	Domestic FL	
1995	2.05 (1/10)	3.11 (9/10)	Con, Manu, Finan (84.50%)
2000	1.99 (1/10)	3.02 (8/10)	Con, Manu, Trans (91.89%)
2005	2.01 (1/10)	3.06 (8/10)	Con, Manu, Trade (92.54%)
2010	2.05 (1/10)	3.07 (8/10)	Con, Manu, Trade (92.10%)
2013	2.04 (1/10)	3.07 (8/10)	Con, Manu, Trade (92.17%)

Note: BL = backward linkage; Con = Construction; Finan = Financing & Insurance; FL = forward linkage; Manu = Manufacturing; and Trans =Transport & Storage.

[a] Figures in parentheses represents the ascending ranking order of Construction.

[b] Top three sectors contributing the largest values in Construction domestic backward linkages

[c] Total percentage of domestic backward linkages generated by the key contributors.

Over 90% of Construction domestic backward linkages are derived from three sectors, and Manufacturing has the largest interdependence coefficient other than Construction itself. Wholesale & Retail Trade outstripped Transport & Storage in 2005 as the third biggest contributor. The remaining seven sectors have contributed 9.36% of the linkages on average. Even though Construction is in a position to induce economic activity in numerous sectors, the main beneficiaries are Construction and Manufacturing.

3.3.1 Selection of Economies for Comparative Analysis

To examine the relative economic significance of Hong Kong's construction sector, an in-depth comparison with economies of similar economic structure, trade openness, fixed capital investment, and government size was conducted. Eight economies were nominated from 36 advanced economies classified by the International Monetary Fund (IMF) in 2014 that compiled with the following criteria: (1) share of service sector exceeds 75% of the GDP (2013 figure), (2) similar merchandise trade (percentage of GDP), (3) similar gross capital formation (percentage of GDP), and (4) similar government final consumption expenditure (percentage of GDP) with Hong Kong (average values from

2010 to 2014). The nominated economies were Belgium, Cyprus, France, Luxembourg, Malta, the Netherlands, Singapore, and the US. Six economies were further selected to represent the small state (Cyprus), large economies (France and the US), and economies in between (Belgium, the Netherlands, and Singapore).

The IOTs of these economies were released by the Organization for Economic Cooperation and Development (OECD) Statistics, the Singapore Department of Statistics, and the US Bureau of Economic Analysis (BEA). Direct and domestic linkages were derived from technical coefficient matrices (total) and inverse matrices (domestic), respectively. As the sectoral classification varies across different data sources, sectoral aggregation and recalculation were performed for consistency and ease of comparison.

Among the selected economies, Singapore is most similar to Hong Kong regarding economic scale, economic structure, and trade volume. Both economies are characterized as free-market economies that are highly dependent on international trade (Zimring et al. 2010). Leakage analysis of Singapore was conducted and compared with Hong Kong in a detailed manner. Here, Singapore's official IOTs for the years 2000, 2005, 2007, and 2010 were used for linkage and leakage comparisons. Sectoral classification for Singapore is similar to Hong Kong's IOTs and remains untouched.

3.3.2 Direct Backward Linkages

As indicated in previous studies, the construction sector performs well in inducing economic growth with its strong pull potentials, but it has relatively weaker push effects (Bon and Pietroforte, 1990; Giang and Pheng, 2011). Hence, the following comparisons primarily focus on the production process, regarding backward linkages. Table 3-6 presents the direct backward linkages from 1995 to 2013 and the average direct inputs from selected sectors for one unit production over the considered period.

Table 3-6 Direct backward linkage of Construction (1995-2013)

Economy	**Direct backward linkage**[a]								**Average contribution**[b]		
	1995	2000	2005	2007	2010	2011	2012	2013	Manu.	Serv.[c]	Con.
Belgium	0.66	0.68	0.69	0.69	0.71	0.71			0.23	0.20	0.25
Cyprus	0.48	0.49	0.53	0.55	0.58	0.62			0.32	0.13	0.07
France	0.53	0.56	0.56	0.56	0.54	0.54			0.21	0.21	0.12
Hong Kong	0.57	0.52	0.56		0.51			0.52	0.32	0.15	0.00
Netherlands	0.65	0.65	0.63	0.64	0.63	0.63			0.21	0.20	0.21
Singapore		0.54	0.79	0.79	0.73		0.74	0.75	0.26	0.12	0.33
United States		0.48	0.47	0.44	0.44	0.44	0.43	0.43	0.24	0.19	0.00

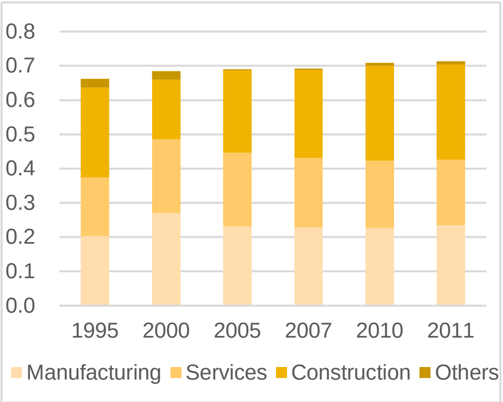
Note: Data for the US from BEA (2018a); for Singapore from Singapore Dept. of Statistics (2010, 2012, 2014, 2017b, 2017c), and for other economies from OECD Statistics (2017b).
[a] The proportion of intermediate inputs over total inputs of a sector.
[b] Average figures of direct inputs (abstract values) from Manufacturing, Service, and Construction.
[c] Consists of Wholesale & Retail Trade, Transport & Storage, Information & Communications, Financing & Insurance, Professional and Support Activities, and Other Services.

On average, the US presents the lowest Construction direct backward linkage of 0.45, whereas Singapore has the highest value at 0.72. Hong Kong lies in between the two with a value of 0.54. There is no discernible pattern of changing direct backward linkages of the seven economies collectively from 1995 to 2013. The results indicate an increase for Belgium and Cyprus; no change for France, the Netherlands, and Hong Kong; and a decrease for Singapore and the US. The upward trends for Belgium and Cyprus are mainly driven by the steady growth of Construction inputs (Construction and Service inputs). The downward trends for Singapore and the US are attributed to the declining Service (Manufacturing) inputs, as shown in Figure 3-2.

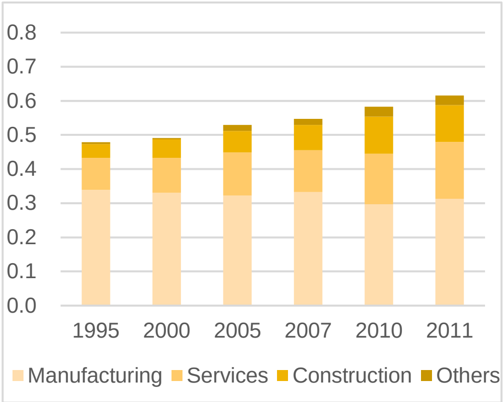
The diverse results for intermediate input composition are inconsistent with those from previous studies (Bon, 2000; Pietroforte and Gregori, 2003; Pietroforte et al., 2009), which claim a constancy or a minor decline trend, along with shrinking contributions from Manufacturing and continuous growth in Service inputs over time (i.e., Demark, France from the 1970s to the 1990s, and the US from the 1950s to 2002).

In this study, there is no obvious decline in Manufacturing inputs (except for the US) or increase in Service inputs (other than Cyprus). The inconsistency between the observed trends with the previous findings is largely related to the examined time frame; for example, France shows a steady decline of Manufacturing inputs (input coefficient drops from 0.30 to 0.21) with the increasing share of Service inputs (from 0.15 to 0.19) from the 1970s to 1990s, as observed by Pietroforte and Gregori (2003). The share of Manufacturing inputs and Service inputs remain steady during 1995–2013 (input coefficients both stay as 0.21) from this study, indicating that the construction sector in France has experienced technological changes in the production process from the 1970s to 1990s, and then appeared to be stabilized after 1995.

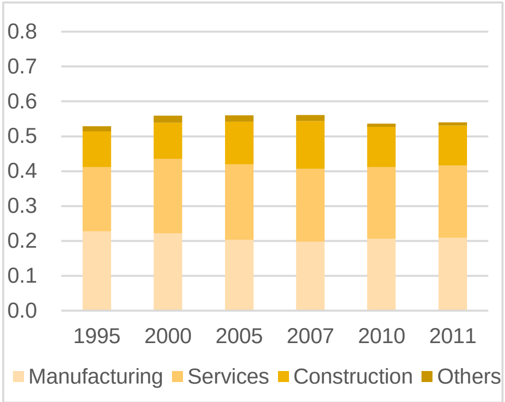
Another noteworthy result is that manufacturing products are no longer the leading intermediate inputs. France and the Netherlands exhibit equal shares of Manufacturing and Service inputs within each of their economies. As suggested by Pietroforte and Gregori (2003), growing inputs from knowledge-based services are required to cope with the increasing complexity of modern construction projects and the shifting trend from in-house to subcontracting for general contractors (Gundes, 2011).



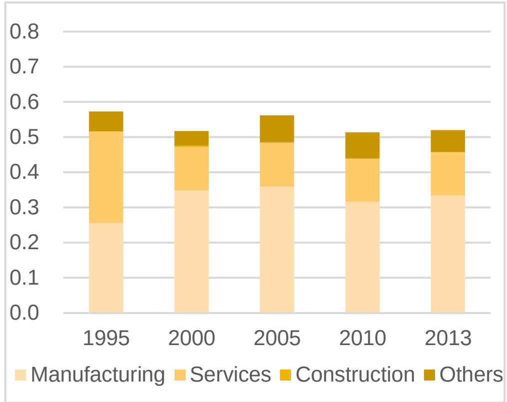
(a) Belgium



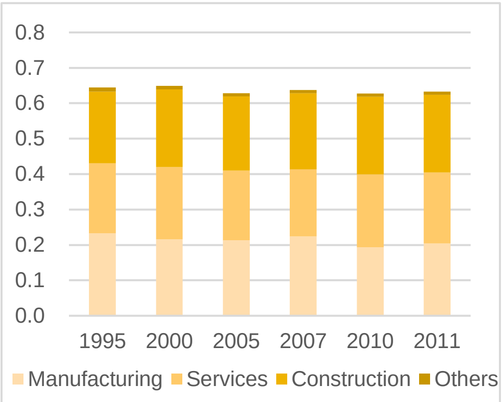
(b) Cyprus



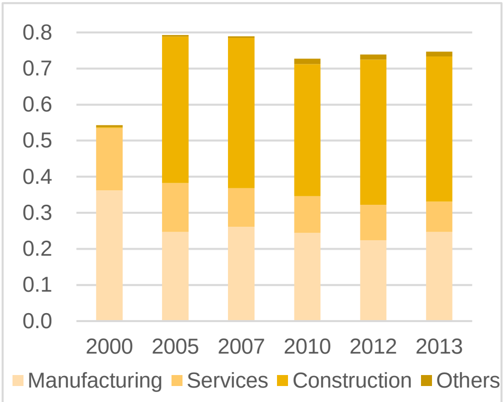
(c) France



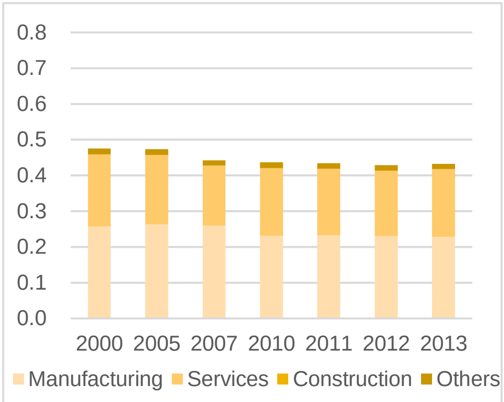
(d) Hong Kong



(e) Netherlands



(f) Singapore



(g) United States

Figure 3-2 Input coefficients in Construction direct backward linkage (1995-2013)

The sum of Manufacturing and Service inputs of each of the seven economies are fairly similar to one another. This means an economy with a larger input coefficient of Construction would eventually have a higher direct backward linkage, as in the case in Belgium and Singapore. However, the underestimation of Construction input coefficient of Hong Kong and the US may relate to the procedures of data collection. Subcontractors are not separated from the main contractors, and the subcontracting activities (depicted by Construction input coefficient) are excluded from the transaction flows in IOTs.

The composition of Hong Kong intermediate inputs has remained steady from 1995 to 2013, indicating more or less hat homogeneous inputs are used. Polenske and Sivitanides (1990) and Pietroforte et al. (2009) outlined a few factors that should be considered in discussing the variability of input structure, including composition of construction activities, differential price movements of inputs, cost structure, and the applied technologies. Nevertheless, these factors are often interconnected and inseparable.

The construction works in Hong Kong can be broadly classified as buildings (including residential, commercial, and industrial buildings) and structures and facilities (including transport, utilities, and other facilities) according to the official statistics. The composition of construction works is dominated by the building subsector, and its market share has reduced gradually from 77.1% in 2000 to 53.1% in 2013 (Appendix 5 for details). Meanwhile, the input coefficients from Manufacturing appear to be slightly larger in the years 2000 and 2005 (0.35) than in other years (0.32) (Figure 3-2). The shifting composition of construction works can be considered to affect the input structure of the construction sector.

Regarding the price variation of construction costs, the overall growth rates in material costs (96.9%) are more incremental than labor costs (35.5%) from 1997 to 2013 compared with the cost indexes (Appendix 6). Although this change has not been reflected in the input structure, the proportion of intermediate inputs (largely related to materials, ranges from 0.57 to 0.51) and value-added (employee compensation is the dominant component) varies slightly over the considered period. The discussion on prices should encompass the effects of productivity and applied technologies to provide a full picture.

Prefabrication techniques have been progressively adopted in Hong Kong's construction sector to enhance productivity and buildability (Jaillon and Poon, 2009; Liu et al., 2017; Li et al., 2018). Based on the case studies in Hong Kong, prefabrication techniques are believed to reduce labor costs (9% in one project), but the overall construction cost is slightly higher than that of conventional construction. This may be due to the higher transportation cost of the precast components (Jaillon and Poon, 2009), and this increase should be revealed as parts of the input coefficient of Wholesale & Retail Trade and Transport & Storage sectors. However, projects adopting prefabrication techniques represent a small portion of the construction sector; hence, the changes in the cost structure of these projects are considered to have minor impacts on the overall input structure of the construction sector. Construction cost breakdown and productivity of other construction work types, along with a more disaggregated IOT, are required to reveal greater variability of input coefficients for the construction sector.

3.3.3 Domestic Backward Linkages

Table 3-7 summarizes the domestic backward linkages from 1995 to 2013 and the leading three sectors that Construction depends on the most. The figures in parentheses represent the percentage of domestic backward linkages that is generated by these sectors. The results reveal an increase for Belgium, Cyprus, and Singapore, static for France and the Netherlands, and a minor decrease for the US and Hong Kong. Similar to direct linkages, these observed trends are somehow inconsistent with previous studies (Bon and Pietroforte, 1990; Pietroforte and Gregori, 2003), which have stated that the economic contribution of the construction sector tends to decline or stay flat over time for developed economies. Again, this variance may relate to the different time frames used in these studies.

Among the seven economies, Belgium and Singapore have higher domestic linkages, exceeding 2.0. Cyprus and Hong Kong have lower values averaging 1.56 and 1.60, respectively. There is no clear distinction between the outcomes of large and small economies because France and the US exhibit lower domestic linkages than Belgium and Singapore and higher than Hong Kong. This observation differs from the findings of Dietzenbacher (2002), which claimed that small economies tend to have a larger dependence on foreign inputs, resulting in smaller domestic backward linkages, although Pietroforte and Gregori (2003) argued that the level of industrialization and the interdependence of Construction on Manufacturing are the main factors affecting the magnitude of Construction output multiplier. Their results revealed that the output multipliers of Germany, Denmark, and the Netherlands are relatively larger than those of France and the US. A similar result is presented by

Ilhan and Yaman (2011), the output multiplier of some small economies (Finland, the Netherlands, and Slovenia) are larger than that of France.

In this study, the results of these seven compared economies are unable to demonstrate the distinctive effect caused by imports and the dependence on the local manufacturing sector because the selected economies are all characterized as service-oriented economies (share of services sectors exceeds 75% of the GDP) with high trade volume. Instead, the results in Table 3-7 show that Construction is the leading contributor to itself, and the influence of subcontracting outperforms the leak out effects of imported intermediate inputs (Appendix 7), as shown in the cases of Belgium, France, the Netherlands, and Singapore.

By referring to the intermediate import ratio, which is used to illustrate the ratio of intermediate import inputs over total intermediate demand for a specific sector, it is possible to investigate the leakage effect. Large economies possess a smaller intermediate import ratio than small economies, especially for the manufacturing sector (Appendix 7). Among the smaller economies, Singapore (0.81 on average) and Hong Kong (0.86) are observed to have much greater intermediate import ratios than the others (from 0.47 to 0.56) in manufacturing goods. Once again, this outcome indicates that the impact of the leakage on the economic influence of the construction sector varies in different economies.

The domestic linkages of Construction are broken down to illustrate the key contributors that Construction depends on most. The results demonstrate that over 84% of the domestic linkages are generated by the top three sectors with larger coefficients. Construction is considered as

Table 3-7 Domestic backward linkage of Construction (1995-2013)

Economy	Share of GDP[a]		Domestic backward linkage[b]								Key contributors[c] & the contribution share[d]
	1995	2013	1995	2000	2005	2007	2010	2011	2012	2013	2010/2011/2013
Belgium	5.27	5.56	2.04	2.00	2.12	2.15	2.18	2.17			Con, Manu, Prof. (86.69%)
Cyprus	9.31	3.58	1.41	1.46	1.55	1.58	1.66	1.69			Con, Manu, Trade (90.77%)
France	5.32	5.94	1.80	1.84	1.86	1.87	1.80	1.81			Con, Manu, Prof. (86.61%)
Hong Kong	5.06	3.97	1.74	1.61	1.59		1.54			1.55	Con, Manu, Trade (92.14%)
Netherlands	5.31	4.50	1.87	1.90	1.92	1.93	1.92	1.92			Con, Manu, Prof. (85.32%)
Singapore	6.31	4.79		1.41	2.18	2.16	2.08		2.14	2.16	Con, Manu, Prof. (91.86%)
United States	4.16	3.84		1.79	1.77	1.72	1.69	1.69	1.68	1.69	Con, Manu, Trade (83.99%)

Note: Data from BEA (2018b); CYSTAT (2017); OECD Statistics (2017a, 2017b); and Singapore Dept. of Statistics (2010, 2012, 2014, 2017a, 2017b, 2017c).
Con = Construction; Manu = Manufacturing; Prof = Professional & Support Activities; and Trade = Wholesale & Retail Trade.

[a] The percentage contribution of Construction to GDP at basic prices.

[b] The direct and indirect effects associated with a unitary change in final demand.

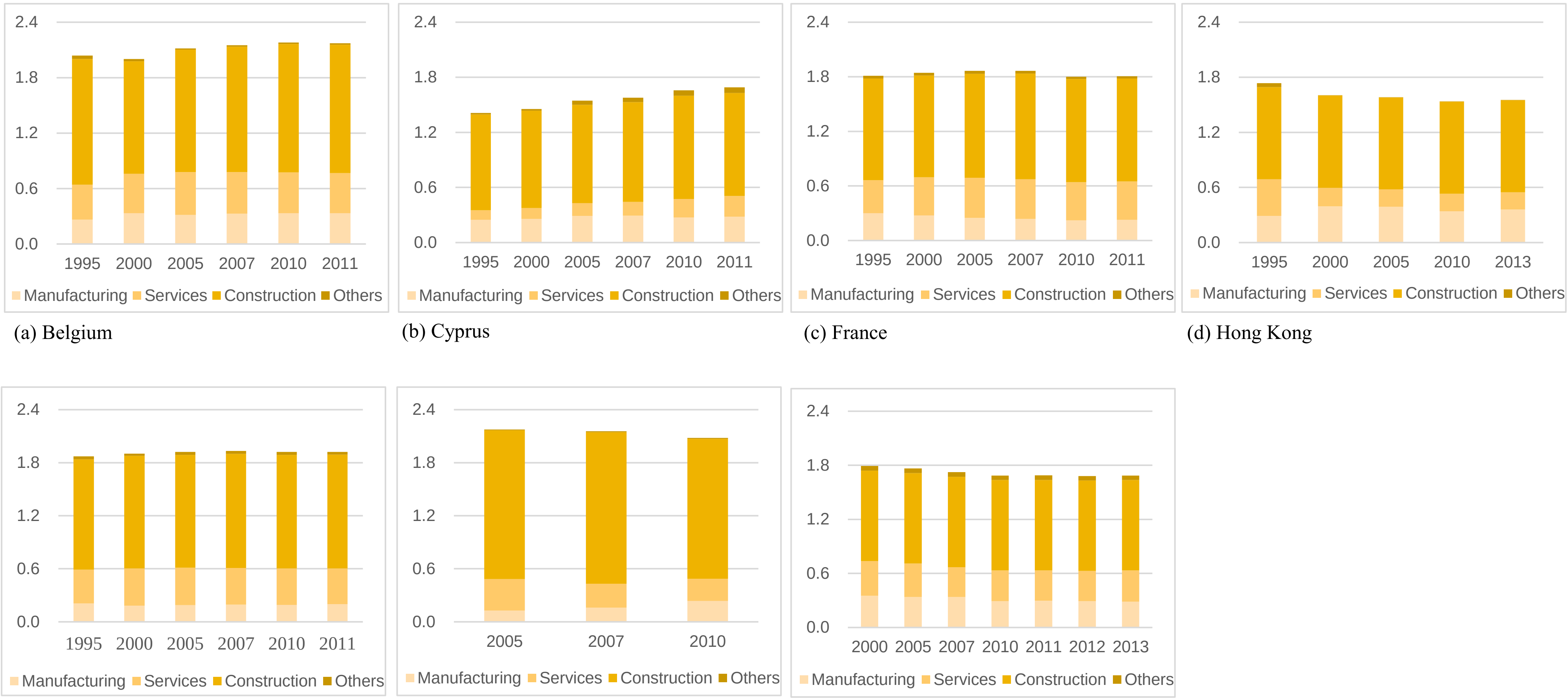
[c] Top three sectors contributing the largest values in Construction domestic backward linkage.

[d] Total percentage of domestic backward linkage generated by the key contributors.

“self-dependent”, or that on average 65.76% of the domestic linkages is generated by itself. The levels of self-dependence in the selected economies are close to each other, ranging from the lowest ratio of 56.04% for the US in 2000 to the highest ratio of 79.56% for Singapore in 2007 (Figure 3-3). Manufacturing is the second key contributor (15.03% on average), and Professional & Support Activities ranks as third (except for Cyprus and Hong Kong, in which Wholesale & Retail Trade ranks as third). These results denote that the production structures of the construction sector exhibit many similarities between the selected economies, regardless of the scale of domestic backward linkages.

A positive relationship between the domestic backward linkages and the input coefficients of Construction is observed (Table 3-6). Economies with larger Construction input coefficients display higher domestic backward linkages, such as for Belgium and Singapore. Because the composition of induced activities is similar to one another, if more construction activities (caused by subcontracting) are involved for the same demand, then the resultant economic effect would be expected to amplify and reflect on the domestic backward linkages.

For Hong Kong, the interdependence coefficients of Construction and of services sectors stay at 1.0 and 0.20 from 1995-2013. This indicates that the dependence on services remains at a lower level. The interdependence coefficient of Manufacturing and Construction domestic backward linkage have experienced minor declines over the years, but despite the share of manufacturing intermediate inputs remain constant. This implies that the leakage of imported goods may be the main cause of the declining influence of Construction in stimulating economic growth.



(a) Belgium (b) Cyprus (c) France (d) Hong Kong

(e) Netherlands (f) Singapore (g) United States

Figure 3-3 Interdependence coefficients in Construction domestic backward linkage (1995-2013)

3.3.4 Leakage Measures

Table 3-8 summarizes the output, import, and value-added multipliers from 1995 to 2013 as parts of the IOA. The import multiplier represents the leak out share, whereas the value-added multiplier denotes the intraregional effect for one-unit production, given that the values of these two multipliers should add up close to one (tax multiplier is negligible and excluded).

Table 3-8 Construction multipliers for HK and Singapore (1995-2013)

Economy	Sector	Multiplier	Year						Average
			1995	2000	2005	2007	2010	2013	
Hong Kong	Construction	Output[a]	1.74	1.60	1.58		1.54	1.55	
		Value-added[b]	0.66	0.59	0.53		0.57	0.56	0.58
		Import[c]	0.33	0.40	0.46		0.43	0.44	0.42
	Manufacturing	Output	1.31	1.17	1.09		1.09	1.07	
		Value-added	0.18	0.09	0.04		0.03	0.02	0.07
		Import	0.81	0.91	0.96		0.97	0.98	0.93
Singapore	Construction	Output		1.41	2.18	2.16	2.08		
		Value-added		0.63	0.55	0.53	0.61		0.58
		Import		0.37	0.45	0.47	0.39		0.42
	Manufacturing[d]	Output		1.23	1.28	1.42	1.42		
		Value-added		0.35	0.37	0.42	0.36		0.38
		Import		0.65	0.63	0.58	0.64		0.62

Note: Data from Singapore Dept. of Statistics (2010, 2012, 2014).
[a] Induced direct and indirect effects associated with a unitary change in final demand, also known as domestic backward linkage.
[b] The value of value-added generated domestically for one unit production.
[c] The value of import leaking out the economy for one unit production.
[d] Figures of Manufacturing in 2000, 2005 and 2007 representing the manufacturing (non-oil) sector.

The results show that the average values of value-added and import multipliers are the same for Hong Kong and Singapore (0.58 and 0.42, respectively). Although the values for Singapore's import multiplier have remained stable, Hong Kong's import multipliers have increased by 33% from 0.33 in 1995 to 0.44 in 2013. The economic influence of Construction in Hong Kong is weaker than in Singapore, according to their output multipliers of 1.54 and 2.08 in 2010, respectively. The results for

Manufacturing are also compared because this sector has the largest interdependence coefficient (other than Construction). Singapore's Manufacturing output multiplier averaging 1.34 surpasses that of Hong Kong at 1.15, whereas Singapore's import multiplier averaging 0.63 is smaller than that of Hong Kong at 0.93. These observations indicate that Hong Kong's construction sector has relied more heavily on imported manufacturing products, and the economic influence of the construction activities has dropped as the leakage amplified from 1995 to 2013.

3.4 Summary

The empirical application is based on the IOTs for Hong Kong during the period 1995–2013. Findings reveal that the influence of Hong Kong's construction sector in stimulating economic growth has decreased by 10.92% from 1995 to 2013 due to the intensifying leakages through international trade. The analyzed outcomes provide a basis for informing the Hong Kong government in resource allocation and strategic planning.

The measures of linkage indicate that the construction sector is one of the most influential sectors in stimulating Hong Kong's economic growth due to its widespread interrelationship with other sectors. The growing importance of the services sectors has no obvious impact on the construction sector's influence. The increase in imported manufacturing goods is anticipated to be the main cause of the declining importance of the construction sector. Its influence in stimulating economic growth has decreased from 1.74 output units in 1995 to 1.55 units in 2013 for one unitary increase in final demand.

Along with the six economies studied for comparison, the analyzed results exhibit similar production structures across each of the country's construction sectors, with over 84% of related transactions coming from three sectors, namely Construction, Manufacturing, and Professional & Support Activities (or Wholesale & Retail Trade). The difference in domestic backward linkages of the construction sector between those economies is that they are mainly influenced by the level of local subcontracting activities. It appears that economies with larger Construction input coefficients in the production process tend to have higher domestic backward linkages.

Chapter 4 LINKAGES VERSUS LEAKAGES

4.1 Introduction

Hong Kong is regarded as a small and open economy with a high dependence on external trade. The ratio of the value of total imports to Hong Kong's GDP was 2.12, while that of the value of exports to GDP was 1.94 in 2014. Moreover, more than 83.08% of the imported goods are for subsequent re-exportation (Census and Statistics Dept., 2016a). As trade openness increases, the extents of domestic intersectoral linkages are expected to be reduced (Krugman and Elizondo, 1996). The earned profits through the production process that induced by local final demand, are distributed across the local economy as well as the trading partners.

With the increasing economic connectivity in the globalized era, there is a need to capture the full economic effects of consumption across international supply chains, and hence to update policies for sustainable consumption and production. Based on the results of Hong Kong IOTs during the period 1995–2013, the increase in imported manufacturing goods is anticipated to be the main cause of the declining importance of Hong Kong's construction sector. Yet, the and composition of the leakage due to imports are uncertain from IOA. Harris and Liu (1998) also argued that lack of trade data and ignorance of relative importance of trade sector make it difficult to evaluate a region's economic performance through IOA.

MRIOA is considered as an extension of the single region IOA that covering interregional and international interconnections between Hong Kong's economic sectors and other abroad sectors. In an MRIO model, regional IOTs and trade flow tables, revealing the exports and imports by sector in other regions, are linked together in one coherent accounting framework (Wiedmann et al., 2011). Here, direct and indirect trade flows from trading partners and feedback effects are tracked and presented (Miller, 1969) from a global perspective.

Despite extensive research on the IOA of the construction sector in numerous developed and developing countries, few studies have addressed the leakage issue in detail. This chapter involves analyzes performed in two phases including (1) investigate the leakages of the construction sector by compiling 3 MRIOTs for the years 2004, 2007, and 2011; (2) compare outcomes of Hong Kong with those of Singapore. In the MRIOA, the backward linkage and leakage are emphasized since the construction sector has a relatively weak supply push effect (Bon and Pietroforte, 1990; Giang and Pheng, 2011). The shift of sectoral interdependence and import dependence across Hong Kong, China, and the other regions are discussed. Finally, along with results from IOA, policy directions are suggested for sustainable economic development in Hong Kong.

4.2 Method and Data

4.2.1 <u>Accounting Framework and Data</u>

MRIOA is applied to provide a more detailed illustration of the Hong Kong economy leakage from a given sector to other sectors in multiple economies. MRIOA traces the impacts of international production and supply chains from a global perspective (Wiedmann et al., 2011). Over the last decade, Mainland China was the largest source of Hong Kong's imports, accounting for 46.4% of total imports on average (Census and Statistics Dept., 2010; 2016a). Within this MRIO framework, supply chains to/from Hong Kong arise from three geographical regions, including Hong Kong (H), China (C) and the rest of world (R, or denoted as RoW). These three regions are assigned to represent the regional, national, and global scales, respectively.

In the absence of Hong Kong official IOTs, the data used in compiling Hong Kong MRIOTs were derived from the GTAP database version 9a for the benchmark year 2004, 2007 and 2011 (Aguiar et al., 2016). GTAP contains balanced, harmonized data (Narayanan and Walmsley 2008; Peters et al., 2011b) and inclusive sets of accounts outlining the annual flows of goods and services with regional and sectoral details for 140 regions and 57 sectors (Aguiar et al. 2016). The data for the 140 regions were aggregated into the 3 regions as proposed, and the 57 sectors were also aggregated into 10 sectors to reflect the service-dominating economic structure of Hong Kong (Table 3-1).

The structure of an MRIOT with *n* sectors is shown in Figure 4-1. The block $\mathbf{Z^{CH}}$ outlines the transaction flows from industry *i* in China to sector *j* in Hong Kong. Its coefficient matrix is written as

$$\mathbf{A^{C}} = \mathbf{Z^{C}}(\mathbf{\hat{X}^{H}})^{-1} \tag{5}$$

where $\mathbf{\hat{X}^{H}}$ = diagonal matrix of sectoral gross input of Hong Kong.

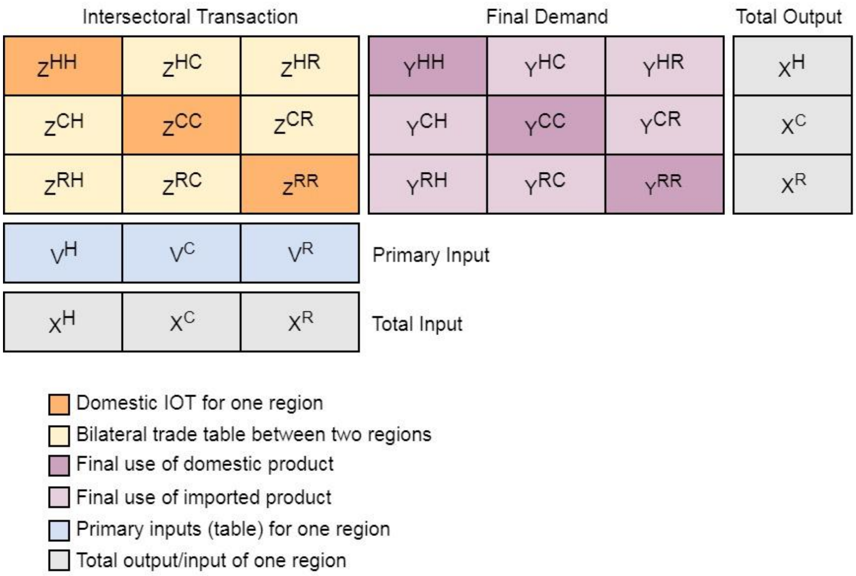


Figure 4-1 Structure of proposed 3-region MRIOT

The diagonal blocks in MRIOT represent the domestic IOTs from GTAP (for example, $\mathbf{Z^{HH}}$), and the off-diagonal blocks are constructed based on the import IOTs with intraregional bilateral trade data (Peters et al., 2011b; Andrew and Peters, 2013). Vectors of trade share were calculated based on the assumption that the bilateral exports are distributed according to the import structure in the importing region (Peters et al. 2011b). Similar procedures were applied to the final demand, which is identified as the **Y** block. Trade shares of final consumption were also calculated using proportional distribution. The trade surplus (deficit) between imports and exports was then included as the margin under primary input (*V*) to retain the balance of the matrix. The expenses of international transport were included and allocated to the regions and suppliers proportionally. The procedures for converting the GTAP database into an MRIOT are described in more detail in Peters et al. (2011b) and Andrew and Peters (2013).

A potential uncertainty is the possible error caused by adjustments made in removing re-exports in GTAP database. Re-exports should be eliminated in GTAP to avoid double-counting from indirect trade flows. Yet, the issue of discrepancies of origin and destination economy in trade statistics was denoted by previous studies (Lenzen et al., 2004; Wiedmann, 2009a; Wiedmann et al., 2011). GTAP also noticed the data discrepancy and proper modifications were made since GTAP database version 7.0 (Gehlhar, 2010). Still, even after re-scaling or re-estimation procedure, major re-exporting economies, such as Hong Kong and Singapore, may still suffer overestimation in domestic exports and/or retained imports (Gehlhar, 2010).

Take 2011 Hong Kong trade statistics as an example, the value of imports is close to the value of exports in the GTAP database. The ratio of domestic exports over imports only accounts for 17.88% based on official statistics (Census and Statistics Dept., 2016a), indicating a potential error in export overestimation. Nevertheless, as this study focuses on the backward linkage which concentrates on imports, the effect of overestimated exports would not largely affect the analyzed results.

4.2.2 Measures of Hong Kong MRIOA

For the MRIOA, the configuration of backward linkage (interdependence coefficient) and total backward linkages are assessed to outline the intraregional effect and the interregional effect, which are (1) the domestic linkage, (2) the spillover effect from Hong Kong to China, and (3) the spillover effect from Hong Kong to the rest of the world. The analyzed results are important for a small open economy to evaluate the impacts of international trade in the construction production process. In addition, the interactions between domestic linkages and leakages can also be identified.

4.3 Results and Discussion

MRIOA is used to reveal the domestic linkage and leakage in the construction production process from a global perspective and the interaction between these two indicators over the period 2004–2011. Figure 4-2 (a) shows that one unit increase in the final demand of Hong Kong's construction sector is able to generate 2.89–2.93 units of output. The influence of Construction on Hong Kong economy remains constant with 1.74–1.78 output units, also its influence on other regions through international trades maintains in the range of 1.11–1.19 output units. Overall, 38.37–40.55% of economic output has leaked abroad as spillovers. Regarding leakage composition, 25.00% has flown to China and the remaining has gone to other economies.

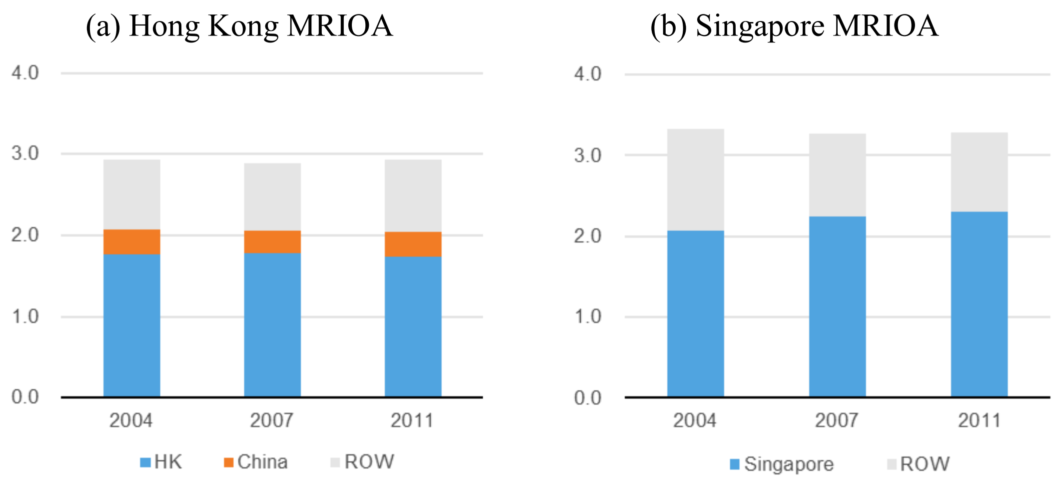
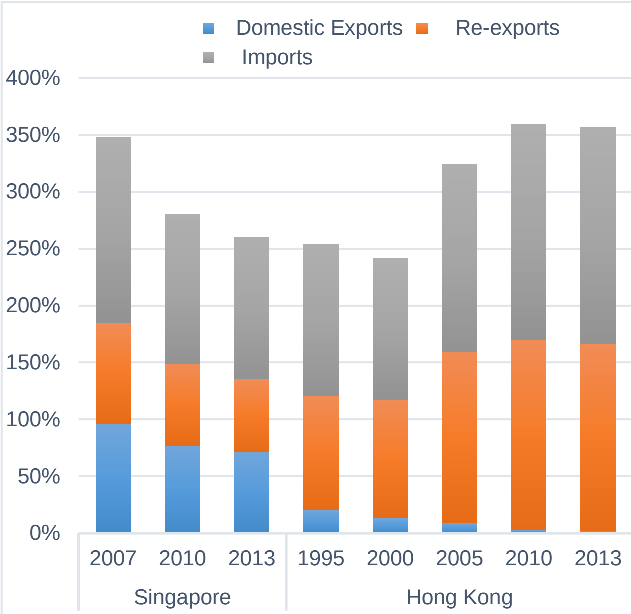


Figure 4-2 Construction output multipliers of MRIOA (2004-2011)

Following the leakage analysis in Chapter 3 , Singapore is used for MRIOA comparison to evaluate the magnitude of leakage induced by local Construction final demand. MRIOTs of Singapore for the years 2004, 2007, and 2011 were converted from GTAP database, with the same procedures as that of Hong Kong. Two regions were proposed as Singapore (S) and RoW for Singapore MRIOA to address the domestic linkage and the spillover effect from Singapore to other economies.

Figure 4-2(b) reveals that Singapore's total backward linkages and the leakages are both greater than that of Hong Kong. One unit of Construction final demand in Singapore can induce 3.27–3.33 units of output globally, and 30.06–37.62% of the economic contribution leaks out to other economies. Yet a decreasing trend in leakage is observed because the output multiplier to the Singapore economy has increased from 2.08 in 2004 to 2.30 in 2011, indicating that more local activities are involved in the construction production process per unit of final demand by 2011. The results echo the trends in merchandise trade in both economies. Although Hong Kong experienced a 40% increase in merchandise trade (as a share of GDP) from 1995 to 2013, a continuous decline in trade is observed in Singapore (Figure 4-3).

The key contributors that Construction depends on the most are outlined in Table 4-1. Construction itself is the leading contributor. Construction coefficient of Singapore outperforms that of Hong Kong by 0.68–0.80 output unit. This is due to the growth of subcontracting activities occurring within Singapore and the underestimated subcontracting transactions in Hong Kong, as discussed in section 3.2.4 and section 3.3.2. Coefficients relating to Manufacturing amount to 26.89% (Singapore) and 38.86% (Hong Kong) of



Note: Data from Census and Statistics Dept. (2005-2016); Singapore Dept. of Statistics (2016b)

Figure 4-3 Merchandise trade (% of GDP) of Singapore and HK (1995-2013)

the total backward linkage on average. For Hong Kong, the reliance on abroad Manufacturing and services sectors have remained relatively stable over time. Whereas in Singapore, the dependence on Manufacturing (RoW) has dropped by 19.63% from 2004 to 2011, and it is substituted by the use of local supplies. In other words, the decreased dependence on imports and the growth of subcontracting activities are the main drivers for the increased economic influence of Singapore's construction sector.

Table 4-1 Interdependence coefficient and key contributors in MRIOA (2004-2011)

Economy	Sector	Interdependence coefficient[a]			Share of sectoral dependencies[b]		
		2004	2007	2011	2004	2007	2011
HK MRIOTs	HK Construction	1.00	1.00	1.00	0.34	0.35	0.34
	RoW Manufacturing	0.57	0.55	0.59	0.20	0.19	0.20
	HK Manufacturing	0.35	0.35	0.34	0.12	0.12	0.11
	CN Manufacturing	0.23	0.21	0.23	0.08	0.07	0.08
	HK Trade	0.18	0.19	0.18	0.06	0.06	0.06
	HK Transport	0.13	0.14	0.13	0.05	0.05	0.04
	RoW Profession	0.08	0.08	0.08	0.03	0.03	0.03
SGP MRIOTs	SGP Construction	1.68	1.77	1.80	0.50	0.54	0.55
	RoW Manufacturing	0.84	0.67	0.66	0.25	0.21	0.20
	SGP Manufacturing	0.14	0.17	0.18	0.04	0.05	0.05
	SGP Profession	0.10	0.11	0.12	0.03	0.03	0.04
	RoW Profession	0.11	0.09	0.08	0.03	0.03	0.02
	RoW Trade	0.09	0.08	0.07	0.03	0.02	0.02

Note: Profession = Professional & Support Activities; Trade = Wholesale & Retail Trade; and Transport = Transport & Storage

[a] The direct and indirect effects contributed from a given sector with a unitary change in Construction final demand.

[b] The percentage of contribution from a given sector to Construction total backward linkage.

Other than Manufacturing, the results demonstrate a relatively stronger interrelationship between Construction and Professional & Support Activities in Singapore, whereas a higher dependence on Wholesale & Retail Trade and Transport & Storage is witnessed in Hong Kong. With regard to the increased reliance on imports, additional expenses in transport and wholesale distribution are incurred and reflected as the dependence on these two sectors in Hong Kong. Cost breakdown analysis of construction works, along with the more disaggregated MRIOTs of Singapore and Hong Kong, would assist in revealing greater variability of interdependence and leakage for the construction sector.

4.4 Summary

The presented analysis is oriented toward understanding the economic leakage of the construction sector in a small and open economy from a global perspective. This is particularly relevant to the declining economic importance of the construction sector resulting from the increasing separation between production and consumption activities in the process of globalization. Based on the MRIOA results, the influence of the construction sector on the Hong Kong economy remained constant at 1.74–1.78 units of output from 2004 to 2011, whereas 1.11–1.19 units of output have leaked out through imports. That is, a minor increase of economic importance of the construction sector over time is suggested, but it is mainly related to imported intermediate inputs. Among the spillover effect, 25.00% of leakage has flown to China because it is the leading trading partner of Hong Kong, and 68.52% of the leakage is interconnected to manufacturing activities directly and indirectly.

From the viewpoint of policy planning, the measures of linkage and leakage illustrate the intersectoral and intercountry dispersion of a stimulus in a specific sector. For a small and open economy with a narrow economic structure, these measures constitute a perspective for understanding the economic interactions between sectors and economies. Risks associated with limited diversification in economic structure and trade can then be identified to undertake strategic planning to ensure macroeconomic stability.

At the macro level, the construction sector of Hong Kong performs well in inducing economic growth among all sectors, but with relatively weaker push effects. At the meso level, investments in Hong Kong's construction sector would initiate economic growth by inducing expansion of other sectors, such as the manufacturing, trade, and transport sectors. Yet, the dependence on the abroad manufacturing suppliers is found to be larger than the local suppliers. Considering the similarity between Hong Kong and Singapore (in terms of economic structure and trade openness), the results from Singapore reveal a larger economic contribution from its construction activities, with 2.08–2.30 units of output remaining within the economy. subcontracting, and the dependence on local professional services in the construction production process from 2004 to 2011. Similar approaches are suggested for Hong Kong and for other small open economies to ease the dependence on foreign inputs. The selection of technologies that favors the use of local resources and labor, combined with import substitution policy, are recommended to increase the domestic transaction and mitigate the leakage. For example, the development of local building material production and prefabricated assembly work may reduce the consumption of foreign intermediate products. Also, the use of outsourcing to distribute knowledge-based services for general contractors is known to enhance the domestic intersectoral transaction. Still, the consequences of import substitution should be anticipated in the decision-making process because the trade and transport sectors would be affected to some extent.

Though IOA and MRIOA have been criticized for being static, lack of flexibility in input coefficients, lack of supply-side feedbacks in price and resource constraint (Bachmann et al., 2014) and lack of timeliness (Wiedmann et al., 2011), IOA and MRIOA are used as descriptive tools for a specific economy, and as a base for further complex modelling procedures (West, 1995). Since there are no Hong Kong official IOTs available, static IOTs and MRIOTs of Hong Kong economy within a reasonable time period are needed to explore the shifting economic role of the construction sector in stimulating economic growth with detailed transaction flows. To allow for sound tend analyses of current and past situations, continuous updated IOTs and MRIOTs are recommended, ideally spanning over several decades. The outcomes and data can be extended for further projection and scenario analysis.

Besides economic accounting, MRIO framework provides the ability to track the environmental and social-economic impacts of international production and supply chains, by linking the trade data to environmental and social-economic accounts on a global scale. The analyzed outcomes are expected to improve knowledge of the relationship between economic growth, environmental and social impacts, and trade. The knowledge is then used to support the goal-oriented policy-making process.

Chapter 5 EMISSION FLOW THROUGH TRADE

5.1 Introduction

Mitigation policies for GHG emissions related to the built environment have received more attention (Huang et al., 2018). Global energy-related CO_2 emissions reached a historic high of 32.5 Gt in 2017 (IEA, 2018). Buildings and construction sector are responsible for 39%—28% from building facilities and operations, and 11% from building materials, transport, and construction activities—of energy-related CO_2 emissions in 2016 (UNEP, 2017). Yet, buildings are expected to deliver smaller emissions savings than other sectors (CCC, 2017; Serrenho et al., 2019). This highlights the critical roles and opportunities of the buildings and construction sector in reducing the threat of climate change.

The construction sector is a carbon-intensive sector (Du, et al., 2018; Zhang and Wang, 2016) the consumes substantial amounts of energy, products, and services from other sectors. Besides, accelerated fragmentation and globalization intensify the geographical separation of production and consumption, hence, lead to a displacement of environmental impacts through trade (Peters and Hertwich, 2008; Wiedmann and Lenzen, 2018) with additional emissions from interregional and international transport (Huwart and Verdier, 2013). The impact displacement might cause ostensible decouple of environmental impacts from economic growth (Wiedmann and Lenzen, 2018) under the conventional accounting approach. Therefore, it is necessary to quantify the source sectors of carbon emissions and identify the driving factors associated with the construction sector from a global perspective as a basis to formulate appropriate mitigating policies.

Some of the previous studies have discoursed the GHG emissions emitted by the construction sector on national or prefectural level evaluation (Acquaye and Duffy, 2010; Chen et al., 2017a, 2017b; Du, et al., 2018; Huang and Bohne, 2012; Lu et al., 2016; Tian et al., 2014). City-scale emissions associated with the construction activities have not been fully addressed by considering upstream supply chains across regional and national boundaries. This is primarily due to the complexity of city responsibility allocation caused by the growing imbalance of the production and consumption structures between cities, regions, and nations.

Under the accounting rule of the Intergovernmental Panel on Climate Change (IPCC) guidelines, national GHG emissions refer to the emissions that are emitted from production and consumption processes within the territorial areas of a nation (IPCC, 2006). This production-based accounting (PBA) framework is built on the concept that the producer should be responsible for the emissions occurred from production. With the ongoing wave of specialization and globalization, production supply chains are now spanning several economies or even regions. The observed emission stabilization in developed economies was more or less related to growing imports from developing economies (Davis and Caldeira, 2010; Peters et al., 2011a). The absence of emissions embodied in international trade may underrate the responsibility of an open economy which exports less than it imports.

Consumption-based accounting (CBA) is offered as an alternative approach that attributes the emitted emissions along the supply chains and distributions to the final users (Munksgaard and Pedersen, 2001; Peters and Hertwich, 2008; Wiedmann, 2009b). PBA and CBA approaches complement each other to fulfil the following purposes: (1) reveal different pictures as producer and consumer for an economy; (2) demonstrate the effects of trade on its emission budget (Wiedmann, 2009b; Steininger et al., 2018); (3) allocate carbon flows of products and services (Hu et al., 2016); and (4) identify structural shifts in consumption patterns (Hertwich and Peters, 2009; Baiocchi and Minx, 2010). The outcome difference between the two methods is known as emissions embodied in trade (EET), including international transport (Peters, 2008; Peters et al., 2011a).

Cities and local authorities are called to increase the efforts in achieving the global CO_2 reduction targets in COP21 and other United Nation initiatives. As the cities are claimed to be responsible for more than 75% of global energy-related GHG emissions (UNEP, 2014). The role of cities for combatting climate change is becoming increasingly important, which indicates city-scale emission flows should be uncovered including EET with other regions.

As one of the leading financial hubs, Hong Kong is used as a case study to explore changes in city-scale CO_2 emissions generated by the construction sector. The government has set a reduction target of 26% to 36% in absolute carbon emissions by 2030 compared with 2005 level (Environment Bureau, 2017). Buildings and construction sector are identified as the crucial sectors in the mitigation action plan. Yet, the current targets and actions are planned based on territorial emissions, that underrate the truthful emission responsibility by disregarding EET.

The following sections are aimed to quantify the direct, indirect and trans-boundary emissions emitted by construction activities in a city. First, the production- and consumption-based emissions are estimated to uncover the discrepancy between these two emissions. Then, the source sectors and driving factors of CO_2 consumption-based emissions are identified. Also, the emission composition of Hong Kong and Singapore are compared to disclose the trend of CO_2 emissions. Finally, a discussion on city emission responsibility allocation and possible mitigation actions is provided.

5.2 Method and Data

5.2.1 Study Framework

Turner et al. (2007) pointed out that MRIOA is an appropriate framework for allocating the total (direct plus indirect) pollution embodiments of final consumption, given this framework's consideration on the interdependence between sectoral activities within an economy. An EE-MRIOA of Hong Kong is conducted in this study to analyze CO_2 emissions generated by the construction sector along the global supply chain.

Within this MRIO framework, supply chains to/from Hong Kong arise from three geographical regions, including Hong Kong (H), China (C) and the rest of world (R, or denoted as RoW). These three regions are assigned to represent the city, national, and global scales, respectively. An MRIOT framework with *n* sectors that defines the transaction flows and embodied emissions related to Hong Kong is depicted in Figure 5-1. The concepts and methods used in the compilation of EE-IOA and EE-MRIOA are given in detail in Miller and Blair (2009), Turner et al. (2007), and Hermannsson and McIntyre (2014).

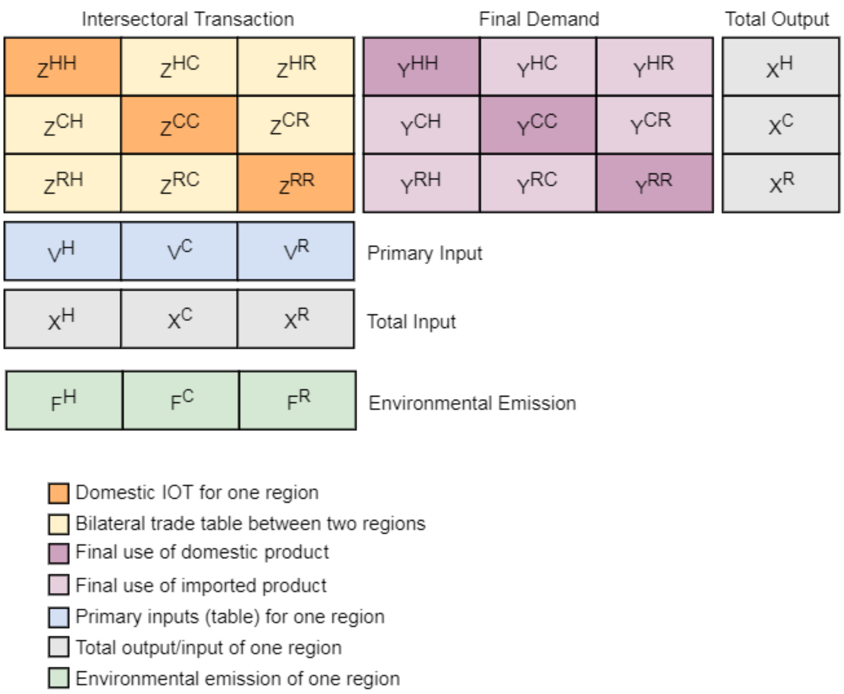


Figure 5-1 Structure of proposed 3-region MRIOT

5.2.2 Accounting Framework and Data

The basic principle of EE-IOA is that the impacts or emissions associated with intersectoral production are generated in response to final demand within an economy (Miller and Blair, 2009). For a single-region economy in an IOA framework, the economic output is determined as:

$$x^r = A^{rr}x^r + y^{rr} + y^{r*} \tag{6}$$

and total impacts or emissions are calculated based on Eq.(6):

$$f^r = F^r x^r = [F^r (I - A^{rr})^{-1}](y^{rr} + y^{r*}) \tag{7}$$

where x^r is the vector of total gross output in region r, $\mathbf{A}^{\mathbf{rr}}$ is a matrix of intermediate demand with each element (a_{ij}) revealing the sectoral inputs from sector i to sector j to produce one unit of output for the latter sector, and $A^{rr}x^r$ is the vector of total intermediate demand. y^{rr} is a vector with elements indicating the domestic final demand in each sector, and y^{r*} represents total exports from region r to other regions. Imports are generally excluded in the framework (Peters, 2008). f^{r} denotes total domestic emissions generated by all production activities in response to domestic consumption (y^{rr}) and exports (y^{r*}). F^r is a vector with vector elements representing the average generation of emissions per unit of sector output (referred to as direct emission intensity). $\mathbf{I}$ is the identity matrix. The matrix $(\mathbf{I{-}A^{rr}})^{-1}$ is known as the Leontief inverse with elements (b_{ij}) describing the amount of output generated in sector i for one unit change in final demand of the sector j. The column sum in the Leontief inverse matrix is known as an output multiplier that depicts the impact of an increase in final demand for sector j upon all sectors within the economy. A vector of total emission intensities is bracketed in Eqs.(7). The elements in that vector represent total direct and indirect emissions generated along supply chains to satisfy a unit increase in the final demand of each sector.

There are two main categories of household emissions. One is the emissions embodied in products and services, and those can be derived from Eqs.(7). The other is the direct emissions that arisen from household activities, for example, combusting transport fuels. Both two emissions should be included to complete the impact estimation. Hence Eqs.(7) is extended to include the direct emissions of household activities.

$$f_t^r = F^r x^r = F^r\ (I{-}A^{rr})^{-1}(y^{rr} +\ y^{r*}) + f_{hh}^r \qquad (8)$$

where f^{r}_{hh} is total direct emissions of household activities. It can be derived from multiplying the direct emission intensity of household (F^{r}_{hh}) with the level of household final demand (y^{r}_{hh}).

A 3-region MRIOT indicating the interregional transactions between Hong Kong, China and RoW is constructed in Figure 5.1. The diagonal blocks in the MRIOT represent the domestic IOTs (i.e. $\mathbf{Z^{HH}}$ for Hong Kong). The off-diagonal blocks (i.e. $\mathbf{Z^{CH}}$) show the intermediate requirements of imported products from one region (China) to the other region (Hong Kong). Exposition of the extension of the standard single-region framework in Eqs.(8) is applied to the 3-region framework and shown in matrix form.

$$\begin{pmatrix} f^{\mathrm{HH}} & f^{\mathrm{HC}} & f^{\mathrm{HR}} \\ f^{\mathrm{CH}} & f^{\mathrm{CC}} & f^{\mathrm{CR}} \\ f^{\mathrm{RH}} & f^{\mathrm{RC}} & f^{\mathrm{RR}} \end{pmatrix} = \begin{pmatrix} \mathbf{F^{H}} & 0 & 0 \\ 0 & \mathbf{F^{C}} & 0 \\ 0 & 0 & \mathbf{F^{R}} \end{pmatrix} \begin{pmatrix} \mathbf{I-A^{HH}} & \mathbf{-A^{HC}} & \mathbf{-A^{HR}} \\ \mathbf{-A^{CH}} & \mathbf{I-A^{CC}} & \mathbf{-A^{CR}} \\ \mathbf{-A^{RH}} & \mathbf{-A^{CR}} & \mathbf{I-A^{RR}} \end{pmatrix}^{-1} \begin{pmatrix} \mathbf{y^{HH}} & \mathbf{y^{HC}} & \mathbf{y^{HR}} \\ \mathbf{y^{CH}} & \mathbf{y^{CC}} & \mathbf{y^{CR}} \\ \mathbf{y^{RH}} & \mathbf{y^{RC}} & \mathbf{y^{RR}} \end{pmatrix}$$

$$+ \begin{pmatrix} f^{\mathrm{HH}}_{\mathrm{hh}} & f^{\mathrm{HC}}_{\mathrm{hh}} & f^{\mathrm{HR}}_{\mathrm{hh}} \\ f^{\mathrm{CH}}_{\mathrm{hh}} & f^{\mathrm{CC}}_{\mathrm{hh}} & f^{\mathrm{CR}}_{\mathrm{hh}} \\ f^{\mathrm{RH}}_{\mathrm{hh}} & f^{\mathrm{RC}}_{\mathrm{hh}} & f^{\mathrm{RR}}_{\mathrm{hh}} \end{pmatrix} \tag{9}$$

where f^{HH} denotes total emissions generated by production activities in Hong Kong to support the local final demand, while f^{CH} is the emissions embodied in China-Hong Kong trade in response to the consumption in Hong Kong.

In that sense, the emissions are allocated to the region of final consumption. For example, the consumption-based emissions of Hong Kong are the emissions incurred from domestic production and imported goods according to local consumption.

$$f^{\mathrm{H}}_{\mathrm{c}} = f^{\mathrm{HH}} + [\, f^{\mathrm{CH}} + f^{\mathrm{RH}} \,] \tag{10}$$

where the sum of the values inside the bracket equal to total emissions embodied in imports and shown as f_{i}^{r} for region r.

Similarly, the production-based emissions of a region can be obtained by summing row values in the total emission matrix ($\boldsymbol{f}$). This allows assigning emissions to the resident regions that emit the emissions in production. The production-based emissions of Hong Kong can be derived from

$$f_{\mathrm{p}}^{\mathrm{H}} = f^{\mathrm{HH}} + [\, f^{\mathrm{HC}} + f^{\mathrm{HR}} \,] \tag{11}$$

where the amounts inside the bracket represent all emissions embodied in exports (EEE) and shown as f_{e}^{r} for region r. Here, exports include goods for both intermediate and final consumption from the domestic supply chain only. The relationship between production and consumption-based emissions for region r can be expressed as

$$f_{\mathrm{c}}^{\mathrm{r}} = f_{\mathrm{p}}^{\mathrm{r}} - f_{\mathrm{e}}^{r} + f_{\mathrm{i}}^{r} \tag{12}$$

In the absence of Hong Kong official IOTs, the data used in compiling Hong Kong MRIOTs were derived from the GTAP database version 9a for the benchmark year 2004, 2007 and 2011 (Aguiar et al., 2016). The GTAP data for the 140 regions were aggregated into the 3 regions as proposed, and the 57 sectors were also aggregated into 10 sectors to reflect the service-dominating economic structure of Hong Kong (Table 3-1).

The CO_2 emissions extension data from GTAP was estimated based on the energy volume data compiled by the International Energy Agency (IEA) and only covered the CO_2 emissions from fossil fuel combustion (Peters et al., 2012). GTAP follows the assumptions from the IEA to convert energy into CO_2 emissions that are then modified to be consistent with the economic data in the GTAP database (Peters et al., 2012). Also, GTAP allocates international transportation emissions (from bunker fuels) to the suppliers and not the consumers. If GTAP is used in analyzing consumption-based emissions, international transportation emissions might be incorrectly allocated especially for economies with large imports or exports (Peters et al., 2009; Peters et al., 2011b).

A potential uncertainty is the overestimation in domestic exports and/or retained imports based on the GTAP database, as denoted in section 4.2.1. The overestimation in domestic exports may lead to overvaluing production-base emissions. Nevertheless, the GTAP database provides complete and consistent data on bilateral trade, intermediate and final consumption, as well as CO_2 emissions. It is regarded as one of the most commonly used databases in contemporary policy-related analyses (Arto et al., 2014).

Other than data source, potential uncertainties and limitations in MRIO model are also summarized. Those include selection of datasets and emission satellite accounts (Weber, 2008; Peters, et al., 2012; Moran and Wood, 2014), different assumptions and approaches used in the datasets (Tukker and Dietzenbacher, 2013), and the sector aggregation effect (Lenzen et al, 2004; Steen-Olsen et al., 2014).

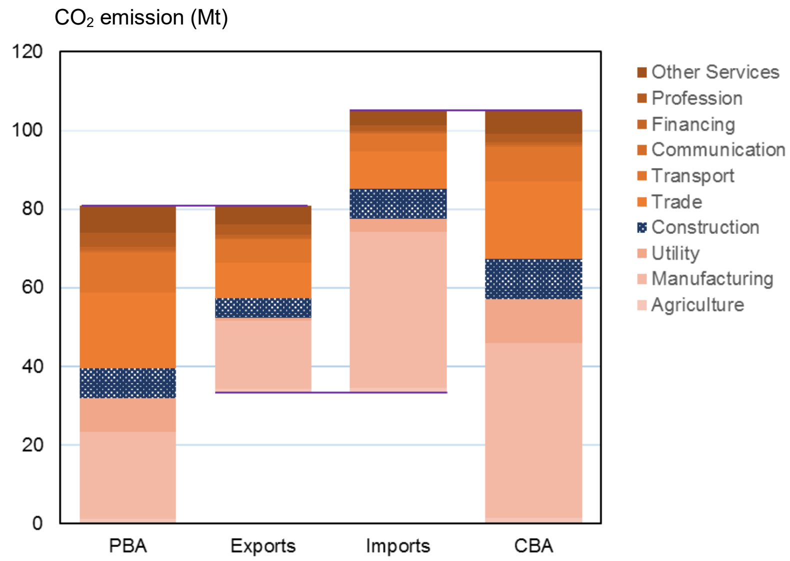
5.3 Results and Discussion

This section provides an overview of Hong Kong's CO_2 emissions under both PBA and CBA approaches, follows with the breakdown of consumption-based CO_2 emissions emitted by Construction across the globe over the period

2004–2011. Based on Eqs.(7) and Eqs. (8), CO_2 emissions generated by an economy or a sector depends on the level of economic activity (driven by final demand), production technology and intersectoral linkage (denoted by output multiplier), as well as emission intensity and import origin. The followings also outline the influences of these factors on the change of CO_2 emissions generated by Hong Kong's construction sector.

5.3.1 Hong Kong's CO_2 emissions

Results revealed that Hong Kong is a net importer of emissions with 23.87 Mt net CO_2 emission inflows in 2011. It generated 80.94 Mt production-based CO_2 or 11.45 tons of CO_2 per capita. The level of emissions increased to 104.82 Mt CO_2 or 14.82 tons of CO_2 per capita from a CBA perspective, as illustrated in Figure 5-2. Among the 10 classified sectors, the top PBA sectoral emitters were Manufacturing (27.37%), Wholesale & Retail Trade (23.74%), Transport & Storage (12.64%), Utilities (10.57%) and Construction (9.51%). The main CBA sectoral emitters were the same as the listed PBA sectoral emitters but in a slightly different order, with Transport & Storage falling to fifth place. The top 5 sectors were responsible for more than 80% of the total CO_2 inventories in both accounting approaches. In comparison, these sectors solely contributed to 1.61% (Manufacturing), 29.42% (Wholesale & Retail Trade), 6.31% (Transport & Storage), 1.78% (Utilities) and 3.44% (Construction) of Hong Kong GDP in 2011 (Census and Statistics Dept. 2016a). Concerning the emissions per unit of value-added, Construction is stated as an emission-intensive sector, falls behind Manufacturing and Utilities.

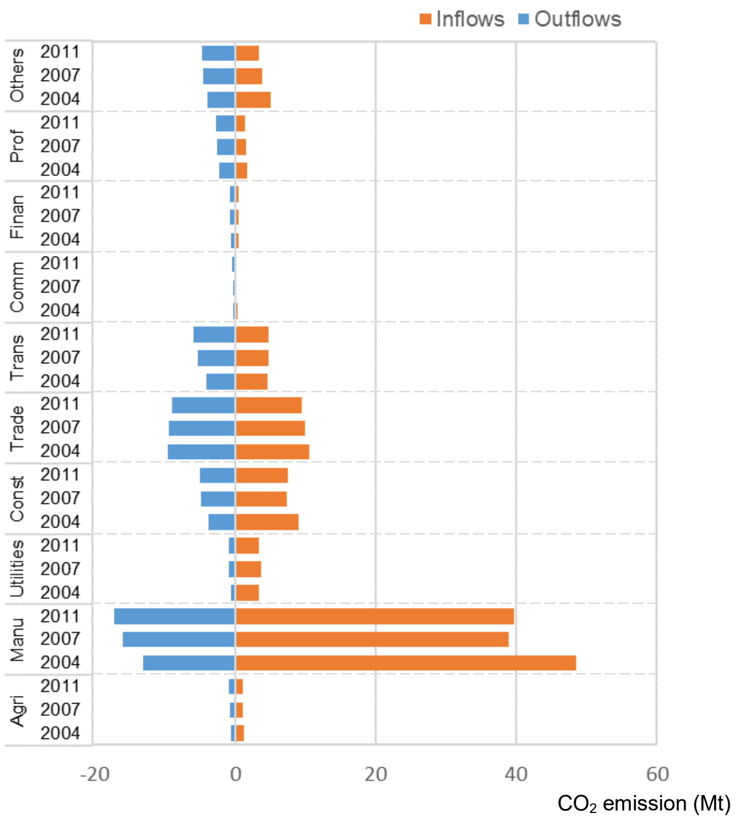


Note: Trade = Wholesale & Retail Trade; Transport = Transport & Storage; Communication = Information & Communication; Financial = Financing & Insurance; Profession = Professional & Support Activities.

Figure 5-2 Sectoral emissions of production, exports, imports and consumption in HK (2011)

Regarding trans-boundary trade emissions, EEE accounted for 56.40–58.86% of production-based emissions, while EEI equaled 68.17–73.87% of consumption-based emissions (Appendix 8) from 2004 to 2011. This implies the production-based emissions were induced mainly by local consumption, whereas around 70% of consumption-based emissions were associated with imported goods and services. The results are close to several studies, showing that 74% of consumption-based emissions come from EEI in Beijing, 72% in Shanghai (Feng et al, 2014), and 71% in Sydney (Chen et al., 2016; Chen et al., 2017a).

The emission trade balance, known as the net difference between the embodied carbon that an economy gains and losses through its imports and exports (Rodrigues et al., 2010), fell from 46.09 to 23.87 Mt due to a steady increase in EEE with a decline in EEI over the period 2004–2011. Temporal change of emissions embodied in trans-boundary trade at the sectoral level is illustrated in Figure 5-3. Manufacturing (54.30–57.16%), Wholesale & Retail Trade (12.48–13.84%), and Construction (10.16–10.63%) dominated the emission inflows with higher shares.



Note: Agri = Agriculture; Manu = Manufacturing; Const = Construction; Trade = Wholesale & Retail Trade; Trans = Transport & Storage; Comm = Information & Communication; Finan = Financing & Insurance; Prof = Professional & Support Activities.

Figure 5-3 Sectoral emissions embodied in HK traded goods

The share of emissions generated by the construction activities to total urban emissions remained within a range of 9.02% to 9.99% for both PBA and CBA approaches over the examined period. This result echoes the findings of Hertwich and Peters (2009) that construction activities account for an average level of 10% of total GHG emissions from the 87 evaluated regions in 2001, though the same paper reported the share for Hong Kong's construction sector to be around 13%. In the final demand perspective, consumption-based emissions generated by Construction were largely attributed to capital investment, which represented more than 97.77% of its sectoral final demand.

Table 5-1 displays the level of emissions generated by Construction in 2004, 2007, and 2011. The consumption-based CO_2 emissions fluctuated slightly with an average annual growth rate (AAGR) of -1.66% over the considered period, but the production-based CO_2 emissions increased steadily from 6.22 to 7.70 Mt with an AAGR of 3.12%. In contrast, the final demand grew continuously with AAGRs of 5.97% and 6.02% under PBA and CBA approaches, respectively.

As shown in Eqs. (7), CO_2 emissions are measured based on three variables: a flow matrix describing the intersectoral linkage and production structure (denoted by output multiplier), the composition of final demand, as well as direct emissions of production in the individual sector. The economic influence of Construction remained stable with output multiplier of 2.89–2.93 between 2004 to 2011 (Section 4.3 and Table 4-1). The interrelationships between Construction and other sectors also stayed roughly the same, with 68.52% of the economic leakage interconnected to trans-boundary manufacturing activities on average. Based on results, the expanding production-based CO_2 emissions were greatly influenced by Construction final demand. In contrast, the impact from the increased final demand was offset by other factors (mainly from the declining emission intensities of supply chains as explained in Section 5.3.3) to cause the slight decrease of consumption-based CO_2 emissions over time.

As a whole, the discrepancy between the two emissions had witnessed a sharp reduction. The percentage of the excess of consumption-based CO_2 over production-based CO_2 was around 32.37% in 2011, compared to the 84.78% difference in 2004.

Table 5-1 CO_2 emissions induced by HK Construction (2004-2011)

Categories	**2004**	**2007**	**2011**
Emissions embodied in trade (EET) (Mt)	12.80	12.07	12.49
Emissions embodied in exports (EEE) (Mt)	3.76	4.79	5.00
Emissions embodied in imports (EEI) (Mt)	9.04	7.28	7.49
PBA CO_2 emissions (Mt)	6.22	7.29	7.70
CBA CO_2 emissions (Mt)	11.50	9.78	10.19
CBA / PBA ratio	1.85	1.34	1.32

Note: EET = international transfers of CO_2 emissions from exports and imports = EEE+EEI.

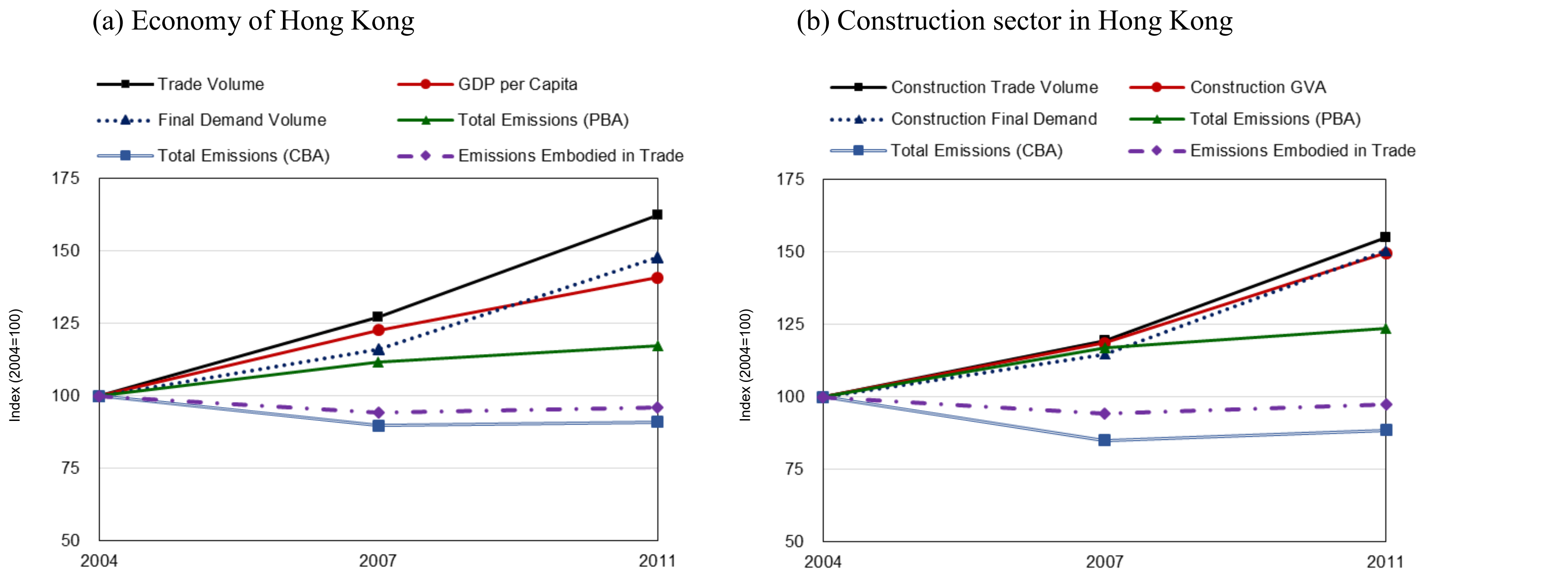
EET for Hong Kong's construction sector remained roughly stable from 12.80 Mt in 2004 to 12.49 Mt in 2011. Again, emissions embodied in exports and imports revealed two opposite trends. The level of EEI dropped from 9.04 to 7.49 Mt with an AAGR of -2.65%, while EEE experienced steady growth with an AAGR of 4.16%. Given that the trade volumes for both exports and imports exhibited rapid growth with AAGRs of 7.30% for exports and 5.97% for imports, the influence of the increased import flows was insignificant to the EEI level. But, the increasing EEE level was positively affected by the growing export volumes.

Figure 5-4 depicts the changes of various economic and emission indicators from 2004 to 2011 that allow comparing the relative performance indicators of Construction and of the overall economy to the 2004 level. For the Hong Kong economy, a slight decrease was observed in EET and consumption-based CO_2, as the trade and demand volume experienced strong growth from 2004 to 2011. Similar trends were shown in Construction with the relatively greater discrepancy between production- and consumption-based emissions. This larger discrepancy was due to the higher share of EEI over total consumption-based emissions in Construction (73.50–78.58%) than that of the Hong Kong average (68.17–73.87%) (Appendix 8). From the results, it is apparent that the economic activity affected the changes in production-based emissions during 2004–2011. Yet, the impacts of economic activities and trade volume were offset by other factors and considered to be insignificant to consumption-based emissions in the case of Hong Kong.

5.3.2 Breakdown of consumption-based emissions by Construction

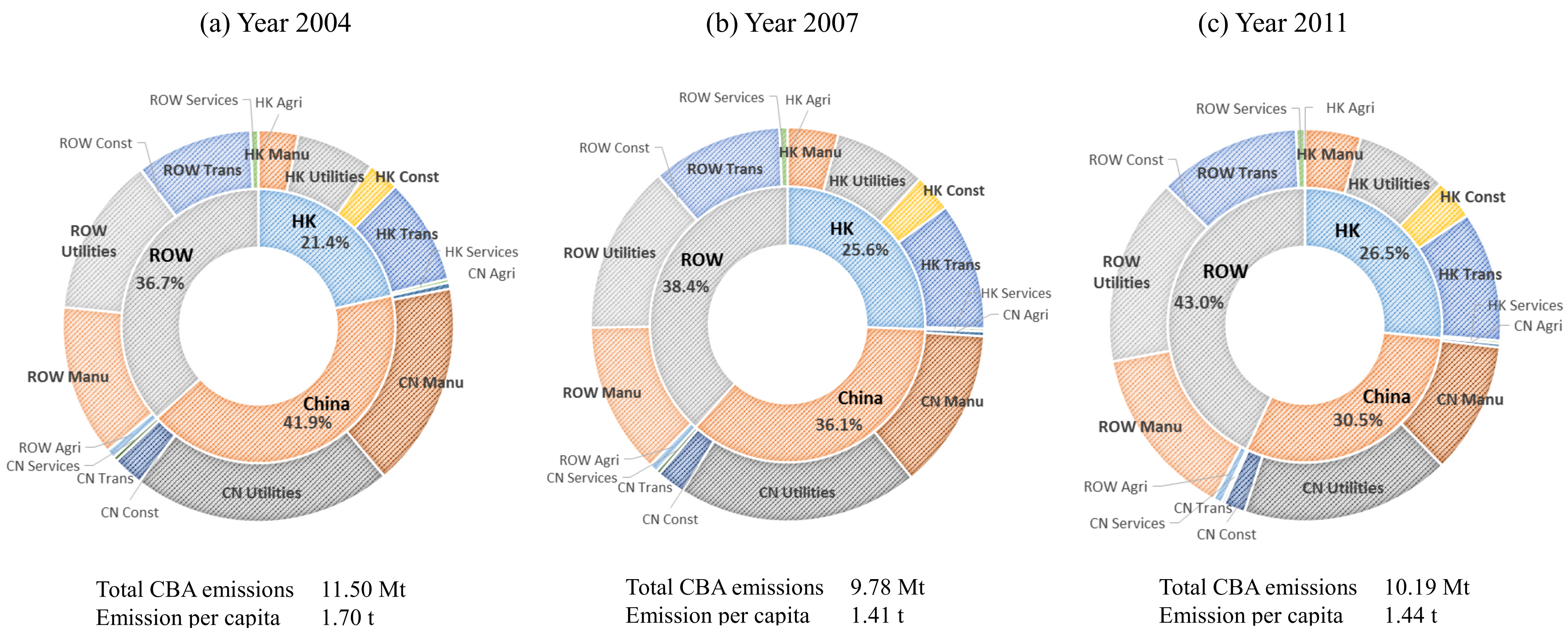
As an emission-intensive sector with substantial emission inflows, allocation of consumption-based emissions for Construction is essential to reveal the emitting regions and the sectors in which emissions take place (source sector) upon the local final demand. Figure 5-5 displays the emission origins induced by Construction final demand along the global supply chains for the years 2004, 2007, and 2011. The direct and indirect consumption-based CO_2 emissions are revealed. Direct emissions refer to those derived from on-site activities. Indirect emissions are those emitted in other sectors in providing products and services for construction operations.

Hong Kong's construction sector was responsible for 9.78–11.50 Mt of CO_2 emissions, or 1.41–1.70 tons of CO_2 per capita from 2004 to 2011. 2.59–3.39% of total emissions were direct emissions, 18.83–23.11% were indirect emissions from other sectors within Hong Kong, with 73.50–



Note: Trade volume = the sum of imports and exports of goods and services for both final consumption and intermediate consumption; PBA = production-based accounting; CBA = consumption-based accounting; emissions embodied in trade = international transfers of CO_2 emissions from imports and exports; CBA emission intensity = ratio of consumption-based CO_2 emissions relative to regional (sectoral) output; GVA = gross value-added.

Figure 5-4 Indices of economic and emission indicators for HK



Note: Agri = Agriculture; Manu = Manufacturing; Const = Construction; Trans = Transport & Storage; Services = all services sectors.

Figure 5-5 Composition of CO_2 emissions induced by HK Construction

78.58% came from EEI. Altogether, the top three source sectors that supported Hong Kong's construction consumption were Utilities (40.30–41.24%), Manufacturing (29.81–32.76%), and Transport & Storage (20.88–24.22%) across the world.

Following the leakage analysis in Chapter 4 , Singapore is used for EE-MRIOA comparison to demonstrate the variance in consumption-based emissions between the two cities. Singapore's top trading partners include a cohort of neighboring Asian countries such as China, Malaysia, and Indonesia. 71% of its merchandise trade came from the Asian region in 2014 (Singapore Dept. of Statistics, 2016b). Here, three regions–Singapore, Asia, and RoW–were proposed for Singapore MRIOA.

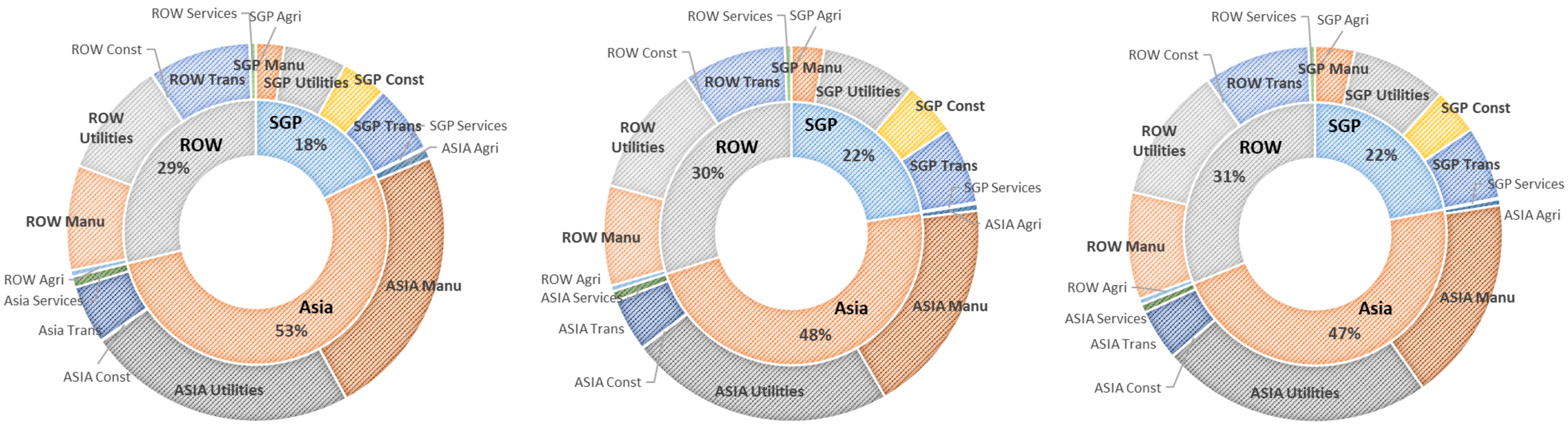
The construction sector in Singapore was responsible for 4.81–7.02 Mt of CO_2 emissions, or 1.16–1.35 tons of CO_2 per capita from 2004 to 2011, as presented in Figure 5-6. The composition of CO_2 emitted in Singapore is similar to that of Hong Kong. 95.33–96.12% of accounted emissions were indirect emissions, which include trans-boundary emissions. Utilities (38.51–43.32%), Manufacturing (30.11–34.89%), and Transport & Storage (19.57–20.03%) were the leading source sectors across the globe.

Previous studies indicated that over 94% of the total CO_2 emissions generated by the construction sector are indirect emissions (Huang et al., 2018). The percentage is even higher in the case of China, ranging from 95.4% to 99.3% (Chang et al., 2010; Chuai et al., 2015; Chen et al., 2017b; Huang et al., 2018). The main source sectors were listed as 'electricity, gas and water supply', 'non-metallic manufacturing', 'primary metal and fabricated metal manufacturing', 'mining' and 'transport, storage and information' from 1995–2010 (Chuai et al., 2015; Chen et al., 2017b). The results are similar to those of Hong Kong and Singapore, with Utilities and Manufacturing being the dominant contributors. Yet, the share of Transport & Storage is greater than the reported figures in China (within a range between 2.7% and 4.5%). The distant location from trade partners including China, and the high dependence on imported products are two possible explanations for the significant emissions caused by transport.

For both Hong Kong and Singapore, the local emissions generated had witnessed a steady increase over time. The level of local emissions ranged from 2.46 to 2.70 Mt in Hong Kong, and from 0.85 to 1.54 Mt in Singapore in 2004– 2011. Transport & Storage was the leading source sector in Hong Kong, and its share over total emissions increased from 8.74% to 10.70%, followed by Utilities (7.52%) and Manufacturing (4.62%). The sequence of source sectors was slightly different in Singapore, that Utilities (8.19%) ranked first, followed by Transport & Storage (6.29%), Construction (4.00%) and Manufacturing (3.42%) in 2011.

Regarding trans-boundary emission inflows, its share of consumption-based emissions experienced a slight decline in both economies from 2004 to 2011. The percentage of EEI dropped from 78.58% to 73.50% in Hong Kong, as the share fell from 82.27% to 77.99% in Singapore. Still, these ratios are regarded to be high compared to other studies. The share of EEI in consumption-based emissions was found to be 63% in Perth (Chen et al., 2016), and 42% and 31% for Irish and Swedish construction sectors, respectively (Nässén et al., 2007; Acquaye and Duffy, 2010).

(a) Year 2004 (b) Year 2007 (c) Year 2011



	(a) Year 2004	(b) Year 2007	(c) Year 2011
Total CBA emissions	4.82 Mt	5.31 Mt	7.02 Mt
Emission per capita	1.16 t	1.16 t	1.35 t

Note: Agri = Agriculture; Manu = Manufacturing; Const = Construction; Trans = Transport & Storage; Services = all services sectors.

Figure 5-6 Composition of CO_2 emissions induced by Singapore Construction

The ranking of the main source sectors for EEI in Hong Kong remained roughly the same over the years. Utilities and Manufacturing were the leading source sectors of EEI, occupying 32.78% and 25.17% of total emissions in 2011. Among these trans-boundary sectors, emission inflows of Transport & Storage reached a high peak at 13.52%, particularly from the RoW region (11.75%). This increase is highly related to rapid growth of trade volumes (intermediate and final consumptions between Hong Kong and the RoW region), which climbed up from 4.93 to 7.75 billion USD over the period 2004–2011 with an AAGR of 6.68%. In general, China was the leading trading partner of Hong Kong, as well as the dominant contributor to the emission inflows, even as the share fell from 41.87% in 2004 to 30.50% in 2011.

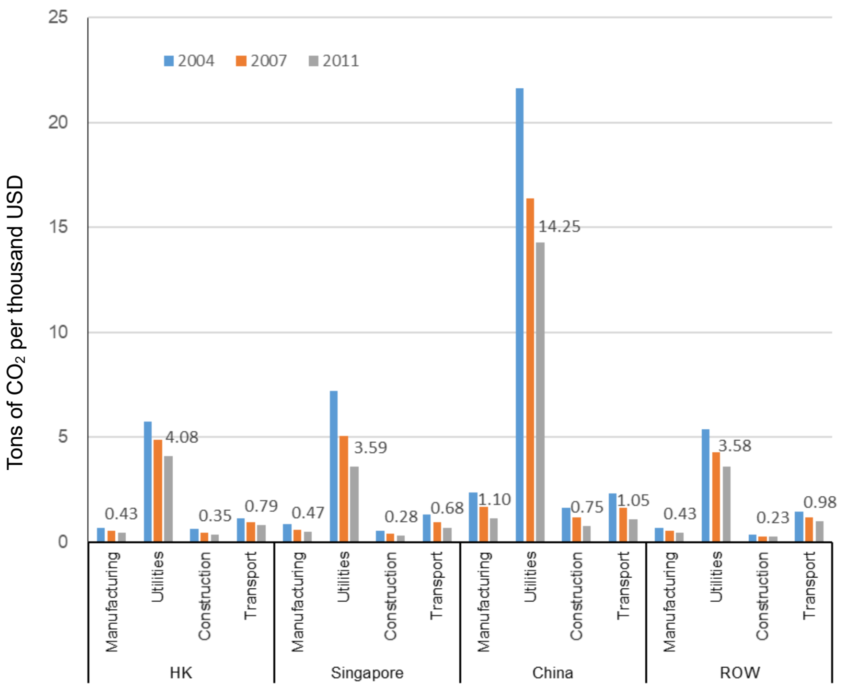
5.3.3 Sectoral emission intensities

As discussed in previous sections, the effect of the increment of final demand was not apparent on consumption-based emissions in Hong Kong. Besides, the intersectoral linkages and production structure of Construction stayed stable. Hence, the decreasing sectoral emission intensities should be the crucial driver for the downward volume and share of EEI in total emissions. Both direct emission intensity ($\mathrm{F^r}$) and total emission intensity ($F^r\ (I–A^{rr})^{-1}$) of the main source sectors are analyzed to depict the changes in emission intensities over the examined period. Also, the emission intensities of Singapore are included as comparative values.

Direct emission intensity is applied to derive estimates of CO_2 emissions directly relative to the production level of a specific sector. Total emission intensity is often used as a measure of the energy efficiency of a given sector, as it reflects product mix, production technology, sectoral structure, and pricing regime in the aggregated sectors (Peters and Hertwich, 2006b). It is defined as the CO_2 emissions generated to satisfy a unitary final demand of a specific sector.

As shown in Figure 5-7, total emission intensities of the main source sectors in 4 regions all experienced a steady decline from 2004 to 2011. The rates of decrease varied within a range of 29.05% and 54.01% when compared to the 2004 level (Appendix 9). On average, energy-intensive sectors located in China had higher total emission intensities than those of Hong Kong and Singapore, although those intensities had witnessed a sharp fall during the period. On the contrary, the declining rates of sectoral emission intensities in Hong Kong had been more modest than other economies, indicating the emission reductions through improved efficiency and structural shift in Hong Kong were relatively ineffective over the examined period.

For the construction sector, a higher value in total emission intensity in Hong Kong (0.35 tonnes of CO_2 per thousand USD) was witnessed compared to that of Singapore (0.28) and RoW (0.23) in 2011. As indirect and trans-boundary emissions accounted for 96.00% and 77.99% of total emissions emitted by Hong Kong's construction sector through transaction flows, direct emission intensities of upstream sectors should be examined to uncover the influence of source sectors on the emission change.



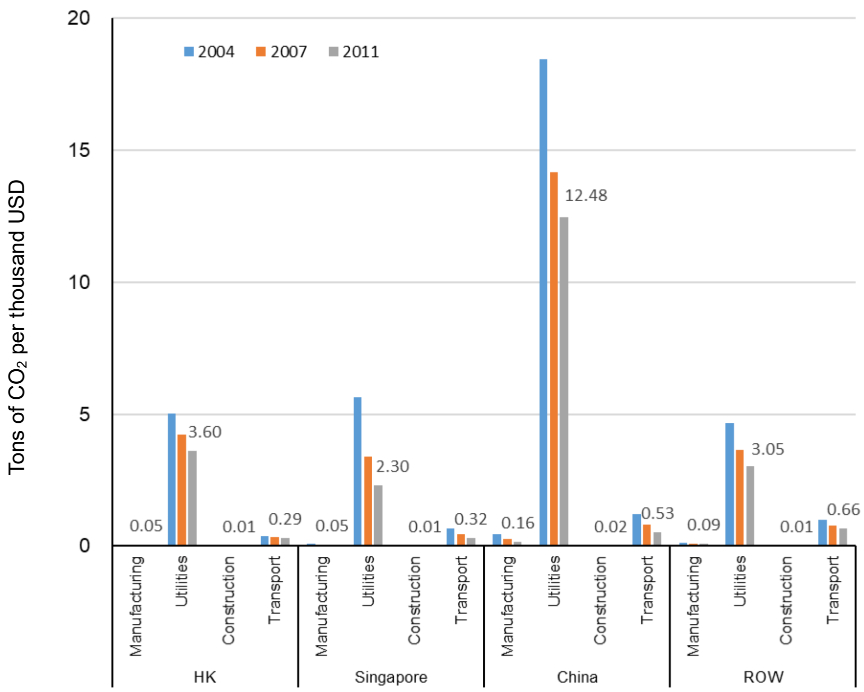
Note: China = Mainland China, RoW = all economies exclude HK and China.

Figure 5-7 Total emission intensities of main source sectors (2004-2011)

Similar trends in total emission intensities were evident in direct emission intensities, as presented in Figure 5-8. The direct emission intensities in the energy-intensive sectors declined steadily at rates ranging from 14.47% to 67.37% (Appendix 9). Again, a modest declining trend of direct emission intensity in Hong Kong was witnessed comparing to other regions. In general, the sectoral levels of direct emission intensities in Hong Kong were found similar to those of Singapore, implying the resultant efficiencies from the production process, technology and management level between those two urban economies are close to each other.

As for Hong Kong Construction, the declining rate of direct emission intensity (22.95%) was nearly half of the rate of total emission intensity

(41.11%) over the period (Appendix 9). In other words, the reduction of CO_2 emissions emitted by Construction was largely relied on the improvements from upstream sectors, and partially from Construction itself. This observation aligns with local construction activities' heavy reliance on import products mainly from China, and those products might be produced through a less energy efficient process with greater use of coal (Chen et al., 2017b; Yuan et al., 2018).



Note: China = Mainland China, RoW = all economies exclude HK and China.

Figure 5-8 Direct emission intensities of main source sectors (2004-2011)

As a whole, with the alike composition of consumption-based emissions induced by Construction final demand, Singapore possessed lower direct and total emission intensities, as well as per capita CO_2 emissions of 1.16–1.35 tons than Hong Kong (1.41–1.70). Cleaner energy sources and more diversified import origins are the possible explanations for the lower emissions in Singapore. Take electricity energy mix as an example, natural gas and petroleum products accounted for 77% and 20% of Singapore fuel mix in 2011 (Singapore Dept. of Statistics, 2016a), whereas coal (53%) dominated the Hong Kong fuel mix, followed by nuclear electricity (23%) and natural gas (22%) in 2012 (Environment Bureau, 2015). The dependence on coal in electricity generation was even higher in China. Coal steadily accounted for 80% during 1980–2010, and the share fell to 62% in 2014 (Yuan et al., 2018). The high ratio of coal consumption affects the sectoral emission intensities in China, and hence influence the consumption-based CO_2 emissions level in Hong Kong with the usage of imported products from China.

To demonstrate the impact of diversification of import origins, the averaged direct emission intensities of Asian region (including China) are used to replace the intensities of China economy while other settings remained unchanged in Hong Kong MRIOA (The emission intensities in the revised RoW region–exclude Asian economies–are slightly lower than the existing figures. Here existing emission intensities are applied to provide a conservative estimate). The revised consumption-based emissions generated by Construction in 2011 is then reduced by 9.62%, or as 9.21 Mt in Hong Kong.

5.3.4 Variability of consumption-based emissions between data source

A concern for policymakers is the results that used in policy formation should be consistent and robust. Common causes for the variability of estimated emissions are sectoral aggregation, data source, assumptions, and approaches. Comparing with previous studies, the variance for Hong Kong production-based emissions ranged from 17.29% to 66.36%, and the variance for consumption-based emissions ranged from 10.11% to 106.99% (Davis and Caldeira, 2010; Steininger et al., 2016; Peters et al., 2011b) (Appendix 10). Studies of Arto et al. (2014), Tukker and Dietzenbacher (2013) also stated that quite different values can be calculated with different data sources.

A comparison of GTAP- and Eora-based consumption-based CO_2 emissions using homogenous MRIOA framework is provided as shown in Figure 5-9. An aggregated 26-sector-per-country resolution (Eora26) (Lenzen et al., 2013) was further aggregated to the 10-sector and 3-region resolution as proposed in the study. Direct emission intensities were calculated with two inventory satellite accounts provided: CDIAC and EDGAR. Then the consumption-based CO_2 emissions generated by Construction in Hong Kong were recalculated by replacing the per-sector direct emission intensities. The scopes of these inventory satellite accounts are slightly different. CO_2 emissions from fossil-fuel burning, cement production, and gas flaring are included in CDIAC, while EDGAR accounts for fossil-fuel burning and cement production.

For Hong Kong Construction, the estimated consumption-based emissions with GTAP are lower than that calculated with CDIAC and EDGAR. The differences have gradually reduced from 20.66% in 2004 to 7.25% with CDIAC, and from 23.94% to 9.80% with EDGAR (Appendix 10). Yet, the trends of consumption-based emissions are evident in all three data sources, that the total CO_2 emissions fell from 2004 to 2007, then rebounded slightly in 2011.

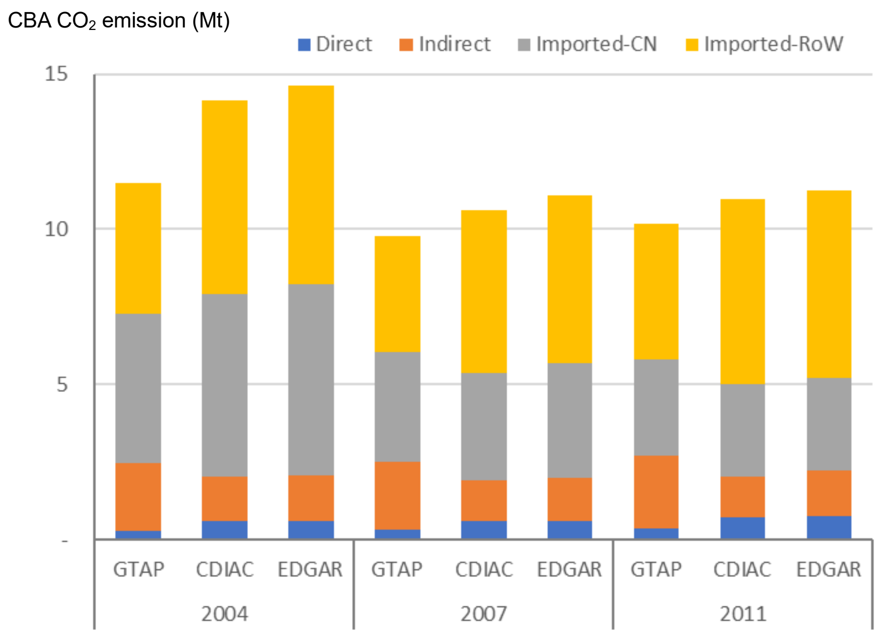


Figure 5-9 Comparisons of CBA emissions from three data sources

5.3.5 Policy Implications

Hong Kong economy relies on substantial quantities of imported goods and services to operate, but its GHG mitigation policies are based on the conventional PBA approach. Although Hong Kong is not bounded in international cooperation on climate change mitigation, the government is committed to reducing per capita emissions from 6.2 tonnes CO_2-e in 2014 down to 3.3–3.8 tonnes CO_2-e in 2030 (Environment Bureau, 2017). According to the results from Hong Kong EE-MRIOA, the production-based emissions should be recalculated to become 10.17–11.45 tonnes CO_2 per capita by including emissions from shipping and intersectoral transaction flows. The figure climbs to 14.82–16.96 tonnes CO_2 per capita when applying a CBA approach for the years 2004, 2007, and 2011.

For cities or metropolitan areas that have a large discrepancy between the production- and consumption-based emissions, in addition to a high proportion of embodied emissions, should adopt a CBA approach in mitigation policy (Harris et al., 2012; Chen et al., 2016). Hence, consumption-based inventories provide a direction for formulating mitigation strategies by identifying main source sectors other than Construction itself. Recommended measures include extending the monitoring of CO_2 emissions along the supply networks beyond municipal boundaries, diversification of import origins, implementation of import substitution, use of low carbon-intensive materials, and enhancement in electricity generation towards low-carbon fuels.

Building materials are responsible for the majority of embodied emissions from the construction sector (Giesekam et al., 2016, Huang et al., 2018). According to the Hong Kong MRIOT data, the imports counted 42.25–44.78% of intermediate input values for the construction sector. 87.38% to 91.06% of these imports were from trans-boundary manufacturing sectors. As a result, the production of building materials and machines abroad emitted 25.17–29.46% of total CO_2 emissions. The development and use of less carbon-intensive building materials and energy efficient machines are encouraged. Increment of import products, i.e. cement and steel, from other Asian economies with clean fuel mix is recommended to reduce the dependence on China supplies.

Additionally, CO_2 emissions caused by transport account for 20.88–24.22% of total CO_2 emissions during the period 2004–2011, largely owing to the increasing trade volume. To reduce the emissions from shipping, products could be imported from the Pearl River Delta, East Asia, and other nearby regions, rather than other distant economies. Besides, promotion of prefabrication and local assembly manufacturing by financial incentives are advised to further mitigate the emissions.

Though direct emission accounts for 2.59–3.39% of total emissions emitted from the construction sector, policies on the adjustment of local final energy mix and reduction on transmission loss are required to decrease the local emissions, especially on the substitution of coal power. On a larger scale, information sharing and collaborative actions among cities or regions are advised to provide up-to-date data to accurately quantifying upstream emissions.

5.4 Summary

Cities such as Hong Kong, with a skewed economic structure and few natural resources, depends largely on imported goods and services. Without sufficient information on CO_2 emissions from upstream sectors could lead to ineffective climate policies and actions in carbon mitigation. This study has extended Hong Kong MRIOTs to explore the flow and composition of CO_2 emissions emitted by the local construction activities from both PBA and CBA perspectives.

The construction sector in Hong Kong contributed 4.43 – 4.84% of GDP in 2004, 2007, and 2011. Comparatively, construction activities are responsible for 9.78 – 11.50 Mt of CO_2 emissions, accounting for 9.46 – 9.99% of total consumption-based urban emissions. It is worth noting that the reported emission volume represents the construction sector during a period of historically low output, with an average level of $13,080 million USD in

2000 prices. The construction output has increased to $19,117 million USD in 2017 with no provision for inflation (Census and Statistics Dept., 2018a), and is projected to expand at an AAGR of 1.28% for the upper bound or maintain its current level during the 2017 to 2026 period (CIC, 2018). This implies that the CO_2 emissions emitted by the construction sector will continue to increase gradually in the short term if emission intensities remain unaffected or decrease at a slower rate than that of the final demand.

PBA and CBA offer complementary perspectives in understanding the sectoral responsibilities in CO_2 emissions and the influences of driving factors on the change of those emissions. During 2004–2011, the production-based CO_2 emissions increased steadily from 6.22 to 7.70 Mt, driven by the growth of final demand volume. Meanwhile, the consumption-based CO_2 emissions fluctuated from 11.50 to 10.19 Mt. Reductions in emission intensity of trans-boundary utilities and manufacturing sectors were the main inhibitory factor driving the downward trend of consumption-based CO_2 emissions, while production structure remained roughly the same and has little effect over the same period.

The results also reveal that the CO_2 emissions generated by Hong Kong's construction sector were largely attributed to trans-boundary upstream sectors, ranging from 73.50–78.58%. Yet, these indirect CO_2 emissions are currently left out of the practices and policy-making processes in Hong Kong. A CBA approach is advised to be adopted to truthfully reveal the CO_2 emissions induced by local construction final demand. Mitigation strategies and emission monitoring should be extended beyond municipal boundaries. As Manufacturing and Transport & Storage sectors were responsible for over 50% of total consumption-based CO_2 emissions, the use of low carbon-intensive materials and energy efficient machines in Hong Kong and nearby regions are encouraged to stabilize or to mitigate CO_2 emissions based on the construction activities.

This study focuses on analyzing the trend of CO_2 emissions in Hong Kong's construction sector during the period between 2004 and 2011. Further studies can be extended by taking other GHG emissions, pollutants, and resources into account with available data sets. A finer level of geographical or sectoral aggregation is recommended to assess the embodied emissions via trade from major trading partners, as well as to explore the effects associated with current fuel mix in Hong Kong and the trade partners. Besides, comparative analysis between urban economies can be extended to explore the trend of CO_2 emissions in relation to other factors, such as geographical location, income level, and population density, as well as economic structure.

Chapter 6 CONCLUSION

6.1 Contribution

In summary, the dissertation compiled a series of Hong Kong IOTs, MRIOTs, and EE-MRIOTs to address the effects of trade and economic structure on economic influence and CO_2 emissions of the construction activities for an urban economy. It contributed to the existing literature in three ways. Firstly, Hong Kong IOTs for the years 1995, 2000, 2005, 2010, and 2013 were constructed to illustrate the intersectoral linkages within the Hong Kong economy since the official IOTs are yet to be available. The increase in imported manufacturing products was suggested to be the main cause of the declining importance of the construction sector with modest production structure shift over the examined period.

Moreover, Hong Kong MRIOTs for the year 2004, 2007 and 2011 were formulated to identify the spatial distribution of economic activities to satisfy Hong Kong's construction final demand on a global scale. Results indicate a minor increase in the economic influence of Hong Kong's construction sector across the worldwide supply chains. Yet, 38.37–40.55% of the economic output has leaked abroad as spillovers, and 68.52% of the leakage is interconnected to the manufacturing activities.

Secondly, Hong Kong EE-MRIOTs for the year 2004, 2007 and 2011 were extended to quantify the role of trade in CO_2 emission growth for the construction activities by allocating the emission flows of products and services globally. Results reveal that the emissions emitted to sustain the local construction consumption are at least 32.37% higher than those estimated by the conventional PBA approach. The driving factors for the change of emissions under PBA and CBA approaches are also different in the case of Hong Kong. During 2004–2011, the production-based CO_2 emissions increased steadily from 6.22 to 7.70 Mt, driven by the growth of final demand. Meanwhile, the consumption-based CO_2 emissions fluctuated slightly from 11.50 to 10.19 Mt. Reductions in emission intensity of trans-boundary utilities and manufacturing sectors were the main inhibitory factor driving the downward trend of consumption-based emissions.

Besides, the significance of trans-boundary CO_2 emissions from upstream sectors is identified as the EEI accounted for 73.50–78.58% of the consumption-based emissions, as the economic leak out effects represented 38.37–40.55% of the output. That is the slow growth in consumption-based CO_2 emissions in Hong Kong was partially due to growing imports of energy-intensive products and services.

Thirdly, the relative economic influence of Hong Kong with other economies are identified to explore the potential causes for such difference. It appears that economies with larger construction input coefficients (involving more subcontracting activities) in the production process tend to have higher domestic backward linkages. The economic leakage can be mitigated through the use of local products and services, and subcontracting activities, as demonstrated in the case of Singapore.

6.2 Limitations and Extensions

One key limitation of this study is that the Hong Kong IOTs are constructed based on a 10-sector classification system, which may be suboptimal due to the unavailability of detailed sectoral data published by the Hong Kong government. A finer level of sectoral and regional aggregation is recommended to assess the interdependence of the construction sector upon the local and trans-boundary manufacturing and utility sectors, as well as to the explore the trade effect in CO_2 emissions associated with current fuel mix in Hong Kong and leading trade partners.

Information on the productivity and cost structure of major construction works should be included for further investigation, along with the verification of detailed imported manufacturing inputs and trade pattern, to accurately identify the leakage regarding the composition of construction deliverables. In the study, input and output in each sector output are both confined to a single commodity. A more detailed level of sectoral aggregation with key commodities should be included in the future analysis to assure more accurate sectoral structure and sectoral interdependence are presented. For example, the construction sector might comprise several commodities, i.e. buildings, transport, other utilities & plant, as the input structure, economic influence of these commodities are slightly different from one another.

Currently, the transaction flows of subcontractors are included as parts of contractors in Hong Kong IOTs and MRIOTs, which may have led to an underestimation of the economic contributions of Hong Kong's construction sector. Another concern is the potential overestimation of Hong Kong domestic exports based on the GTAP database. Future research addressing these limitations is suggested to better reflect the true economic contribution and CO_2 emissions of the construction activities in Hong Kong.

As for the environmental impact analysis, EE-MRIOA can be extended by taking other GHG emissions, pollutants, and resources into account with available data sets. Also, comparative analysis between urban economies can be extended to explore the trend of CO_2 emissions in relation to other factors, such as geographical location, income level, and population density.

Furthermore, the compiled Hong Kong IOTs and MRIOTs are recommended to use as a base for further complex modelings. IOA and MRIOA assume fixed proportions between coefficients with unlimited resources. Such assumptions are acceptable to depict the shift of production structure, sectoral interdependence and import dependence of an economy but may be insufficient for detailed policy analysis or scenario analysis which involve the behaviors of agents (i.e. firms, households and government) that change the coefficients. In these cases, Computable General Equilibrium (CGE) modeling can be extended based on the IOTs with behavioral equations for calibration. Yet, the solution of a CGE model entails finding numerous parameters and elasticity values to feed the model equations. This usually involves rigorous and up-to-date data gathering to reflect the real structure of the economy.

6.3 Policy Implications

From the viewpoint of policy planning, the measures of linkage and leakage in IOA and MRIOA illustrate the intersectoral and interregional dispersion of a stimulus in a specific sector. For a small open economy with a narrow economic structure, these measures constitute a perspective for understanding the economic interactions between sectors, regions, and economies. Risks associated with limited diversification in economic structure and trade can then be identified to undertake strategic planning to ensure macroeconomic stability.

At the macro level, the construction sector of Hong Kong performs well in inducing economic growth among all sectors, but with relatively weaker push effects. At the meso level, investments in Hong Kong's construction sector would initiate economic growth by inducing expansion of other sectors, such as the manufacturing, trade, and transport sectors. Yet, the dependence on the abroad manufacturing suppliers is found to be larger than the local suppliers. Import substitution and subcontracting are suggested for Hong Kong and for other small open economies to ease the dependence on foreign inputs.

The selection of technologies that favors the use of local resources and labor, combined with import substitution policy are recommended to increase the domestic transaction and mitigate the leakage. Also, the use of outsourcing to distribute knowledge-based services for general contractors is known to enhance the domestic intersectoral transaction. Still, the consequences of import substitution should be anticipated in the decision-making process because the trade and transport sectors would be affected to some extent.

In the era of globalization, the transfer of carbon pollutant between economies and regions through trade, either physically or embodied in production, represent a substantial fraction of total CO_2 emissions. Without sufficient information on CO_2 emission flows in trade may underrate the responsibility of an urban economy as a consumer, and hence, lead to inefficient climate policies and actions in carbon mitigation. PBA and CBA approaches offer complementary perspectives in understanding the sectoral responsibilities in CO_2 emissions, as well as quantifying influences of driving factors on the change of those emissions with EE-MRIOA.

The analyzed results indicated two opposite trends for PBA and CBA approaches in Hong Kong from 2004 to 2011. The production-based CO_2 emissions were driven by the growth of final demand and increased steadily from 6.22 to 7.70 Mt. Meanwhile, the consumption-based CO_2 emissions fluctuated slightly from 11.50 to 10.19 Mt, which was influenced by the declining emission intensities of upstream sectors. With growing imports of energy-intensive products and services over time, the mitigating effects relied largely on the efficiency improvements in the trans-boundary upstream sectors, but not much from the improved efficiency and structural shift in Hong Kong.

Recommended measures include extending the monitoring of CO_2 emissions along the supply networks beyond municipal boundaries, diversification of import origins, implementation of import substitution and enhancement in electricity generation towards low-carbon fuels. In addition, to allow for sound trend analyses of current and past situations, continuous updated IOTs and MRIOTs are recommended, ideally spanning over several decades.

APPENDICES

Appendix 1 Studies Relating to Hong Kong IOT

A few studies have constructed IO transactions tables of the Hong Kong region in the past, and brief summaries of the selected studies are listed as follows.

(A) 1962 IOT

This IOT was established in the base year 1962, in which 32 sectors were chosen. Among these sectors, 3 referred to agriculture and mining-related sectors, 23 related to manufacturing, 4 related to services industries, as well as the construction sector and power & fuel & water sector. In the 1960s, the published statistics and quantitative data of Hong Kong were incomplete or absent. According to the study, data derived from both published and unpublished sources were supplemented by interviews and surveys. However, the response rate of the survey was found to be unsatisfactory. The productivity of diversified production structure and scale of firms were difficult to reconcile. Estimations and assumptions were then applied to fill the gap (Hsia et al., 1975).

The main sources of data came from the 1962 survey of manufacturing industries, Hong Kong Annual Report 1962, Hong Kong Trade Statistic, and Report on the Consumer Expenditure Survey. Input coefficients of some particular industries in various nations with similar production conditions were chosen to fill in the gaps. These estimates were combined with costing statements submitted to the Commerce and Industry Department (the current

Trade and Industry Department). Statistics or data from Japan, Norway, Italy, and the United Kingdom were applied. For instance, input coefficients in trade and services sectors were extracted from IOTs of Japan, Italy, and the United Kingdom. For the construction sector, input requirements were estimated based on the interviews and from historical data of construction materials, as well as applied input coefficients of the United Kingdom (Hsia et al., 1975). The results of the IOA are shown in Table A-1.

Table A-1 Output multiplier of 32 sectors in Hong Kong (1962)

Category	Sector		Output Multiplier	Proportion of Output by own sector (%)
High Multiplier	3	Mining	1.730	58
	8	Miscellaneous textiles & made-up textiles	1.682	62
	6	Textiles, cotton	1.665	92
	2	Agriculture & fishery, not else specified	1.600	63
	16	Non-metallic mineral products	1.461	70
	20	Transport equipment	1.447	84
	10	Clothing, cotton	1.445	69
	11	Clothing, not cotton	1.425	70
Medium Multiplier	19	Machinery, non-electrical	1.381	83
	17	Basic metal industries	1.379	82
	12	Clothing accessories	1.370	73
	13	Wood product, furniture & fixtures	1.363	87
	5	Beverage & Tobacco	1.329	87
	14	Paper & printing	1.328	86
	27	**Construction**	**1.313**	**76**
	30	Trade	1.307	77
	9	Footwear	1.303	77
	15	Chemical Products	1.295	81
	4	Processed and manufactured food	1.276	84
	22	Electric products, not else specified	1.256	82
	18	Metal products	1.250	81
	23	Toys	1.233	81
	26	Leather, rubber & all other manufactures	1.227	83
	21	Electric components & equipment	1.213	88
Low Multiplier	29	Transport & communication	1.204	87
	24	Plastic products, not else specified	1.201	84
	31	Building & property rental	1.166	93
	7	Textiles, not cotton	1.115	93
	1	Agriculture & fishery, foodstuffs	1.128	89
	25	Wigs	1.111	90
	28	Power, fuel & water	1.055	96
	32	Services, not else specified	1.000	100

Note: Data from Hsia et al. (1975)

The output multipliers ranged from 1.000 to 1.730 in 32 sectors. The study had divided multipliers into three categories; multipliers above 1.40 were regarded as high, those ranged between 1.21 to 1.40 as medium and those below 1.21 were marked as low (Hsia et al., 1975). The construction sector fell into the medium range. For the supply column, the local intermediate coefficient was 0.2456, with value-added content 0.4844 and imports content 0.2700. For the use row, around 0.9494 of demand went to investment (or known as capital formation) and the rest went to government consumption. The assumption was based on that the products or works provided by the construction industry were all accounted as capital investments, but not operating costs.

(B) 1973 IOT

Sung (1979) used purely secondary data to construct non-survey IOT of the year 1973. These national data came from Hong Kong official statistics department, so some private sources of regional economic data. Some data were not available, and estimations and assumptions were applied based on the earnings, employment, income, and other indicators. The 1973 transaction table consisted of 70 sectors. Among these sectors, 2 referred to agriculture and mining-related sectors, 63 related to manufacturing sub-sectors, 3 related to services industries, plus the construction and the power & fuel & water sector.

(C) 1977/78 IOT

Voon and Ho (2001) conducted a study investigating the economic importance of logistics, and the linkages between the logistics industry and other sectors of the Hong Kong economy. An updated IOT of 1977/78 was constructed based on IOT developed by Sung (1979) in conjunction with the one by Hsia et al. (1975). 8 sectors were classified, and the non-survey method was applied. Similar to the previous two IOTs, secondary data from the official statistics department and private sources of economic data were applied with certain assumptions. For example, the coefficients between sectors corresponding to the year 1997/98 were updated according to the changes in GDP shares of various sectors, based on the 1973 IOT constructed by Sung (1979).

In the 1997/98 IOT, sections of final demands, exports were excluded. Household consumption and imports (included in the payment sector) were used for later multiplier calculations. Take the construction sector as an example, the 1997/98 local intermediate coefficient was 0.1702, with value-added content 0.4845 and payment sector (including imports) content 0.3453 (Voon and Ho, 2001). The results of 1997/98 IOA are shown in Table A-2.

Table A-2 Output Multiplier of 8 sectors in Hong Kong (1997/98)

Sector	Output Multiplier
Manufacturing	1.19
Agriculture	1.21
Mining	1.26
Utilities	1.11
Construction	**1.20**
Trade	1.33
Transport	1.17
Services	1.15

Note: Data from Voon and Ho (2001)

(d) 1979 IO table

Lin and Sung (1984) also updated a 1979 IOT based on IOTs developed by Sung (1979) and Hsia et al. (1975). The study was targeted to assess the role of the tourism sector in the Hong Kong economy, by comparing the performance with 3 classified manufacturing sectors. Output multipliers and import multipliers of these 4 sectors were presented to indicate the extent of linkage and leakage. In sum, the tourism sector was proven to have relatively smaller linkage and lower leakage effects than those of the manufacturing sectors.

Appendix 2 Hybrid Questionnaire Survey

Considering the time and resource constraints, a questionnaire survey focused on the construction sector in Hong Kong is proposed to collect the primary data. There were 22,312 establishments in the construction sector, and around 98.0% engaged less than 50 persons (Census and Statistics Dept. 2014). A total of 112 approved contractors for public works (group C) were selected to be the candidates, as they represented the leading contractors in Hong Kong. The questionnaire survey was commenced on 5th October 2015. The proposed questionnaire distributed to leading construction companies is shown below.

After four-round follow up phone calls, a total of 6 completed questionnaires were received. These completed questionnaires were checked to ensure the compliance and accuracy of data. The figures relating to sale and purchase activities of the local contractors were summed and blow up to the scale proportionally. These figures were then used to replace the sale and purchase figures of the construction sector in 2013 non-survey IO transactions table, and to complete 2013/14 hybrid IOT.

Survey on Economic Benefits of Construction Investment

The specific focus of the Survey is to obtain data from the business operation of individual firm's purchases and sales in the year 2013-2014, occurring in Hong Kong region.

The information will be handled in strictest confidence. Individual company figures will not be revealed. Your responses will be aggregated with those of other firms within the same economy sector, consisting of at least 30-50 individual firms.

1. Participation on the Survey is voluntary. The Survey is recommended to be completed by financial controller or/and accounting manager.
2. Please provide the feedbacks in dollar amounts (current price) or percentages depends on the request content. Data for the fiscal or calendar years 2013-2014 is preferred.
3. When exact data are not available, please use estimates. If it is not possible to provide information for certain questions, please indicate for later identification. [M = "not applicable / do not exist"; L = "not available / exist but not collected or not transmitted"; Z = "exist but value is zero or considered as zero"]

General Information

Name of Company: ______________________

Name of Sender: ______________ ; Position: ______________

Contact Number: ______________ ; E-mail : ______________

Date: ______________

Number of establishments/entities covered by this Survey: ______________

(Relate to construction works or services; exclude consulting, surveying, designing or real estate services)

What was the total number of employees that the company had at any one time in 2013-2014?

Full time: ______________ ; Part time: ______________

What is the average compensation of employees?

Full time: ______________ ; Part time: ______________

Section I - Annual Sales

1. What was the Hong Kong dollar value of construction or services provided by your facilities in the Hong Kong region for the fiscal year 2013-2014 and categories indicated? Please include the value of subcontracts let by your firm, as well as the construction works done for your own facilities.

	Fiscal Year 2013-2014 (HK$000)
(A) New Construction put in place in: (Include material, employee compensation, profit, overhead, architectural and engineering service, excavation and demolition costs associated to the construction of new structures / alternation / addition)	
Hong Kong Region	$__________
Foreign Regions	$__________
Subtotal	$__________
(B) Maintenance and Repair Construction in:	
Hong Kong Region	$__________
Foreign Regions	$__________
Subtotal	$__________
(C) Other Services provided: (Please specify __________)	
Hong Kong Region	$__________
Foreign Regions	$__________
Subtotal	$__________
(D) Other Operating Revenue: (Values of any "Other operating income" recorded in the profit and loss statement and/or income statement. Include interest, insurance claim, donation, rental income etc.)	$__________
(E) Total Sales Amount = (A)+(B)+(C)+(D)	$__________
(F) Percent (or dollar value) done by Sub-Contractors over annual revenue	__________%

2. **Based on Question 1, please show the percentage of the value falling into each of the following categories:**

Fiscal Year 2013-2014	New	Maintenance & Repair
(A) Private Works		
1 **Residential** (Exclude public housing)	_____%	_____%
2 **Commercial**	_____%	_____%
3 **Industrial** (Include factory, warehouse, ship yard)	_____%	_____%
4 **Private founded Infrastructure** (Include utilities, telecommunication, school, hospital, power plant and other facilities)	_____%	_____%
(B) Public Works (Infrastructure)		
1 **Building** (Include public housing)	_____%	_____%
2 **Structure & Facility**	_____%	_____%
(C) Others : (Please specify and indicate as private/public works)		
_____	_____%	_____%
_____	_____%	_____%
_____	_____%	_____%
_____	_____%	_____%
TOTAL	100%	100%

3. **Based on Question 1, what was the value of sub-contractors let by your firm to:**
(If the founder(s) of sub-contractors are from companies or/ investors based on foreign countries and Mainland China, should categorized as "located in foreign region")

	Fiscal Year 2013-2014 (HK$000)
Located in the Hong Kong Region	$_____
Located in foreign Regions	$_____
Subtotal	$_____

Section II - Expenditure of Components, Supplies, Fuels and Other Services

- The estimated expenditure in Section II of the whole company includes project cost and general administration expense in headquarter and regional offices but does not include items purchased for your own capital equipment (other than section (D) & (F)).
- Section II deals with the annual expenditure of construction material, component, electricity, fuel and repair part (for new construction, maintenance and repair construction, as well as administration and general operating of the company) in the following three categories:
  - from producers in the Hong Kong region (either direct or through brokers),
  - from wholesalers or retailers in the Hong Kong region,
  - from all kinds of suppliers located outside the Hong Kong region.
- All expenditure should be reported at delivered cost (which may include transport cost, warehousing, taxes on products (less subsidies)). If it is not feasible to include transportation and warehousing costs, please indicate when these are excluded.
- The list below is by no means an exhaustive list, and if the purchased products for 2013-2014 do not fall into these classifications, please list the products/costs in the blank spaces along with the dollar amount of purchase.

4. **What was the Hong Kong dollar value of purchase of components and supplies for the fiscal years 2013-2014?**

No.	Product Description	Purchase in 2013-2014 (HK$000) (A) From producers in HK (directly or through brokers)	(B) From whole-salers or retailers in HK	(C) From foreign regions	(D) = (A)+(B)+(C)
(A) Components and Supplies					
1	Raw material and building material (Include cement, steel, glass, paint & other petroleum products etc.)	$_____	$_____	$_____	$_____
2	Electric equipment, pluming fitting & fixture, including office and household furniture & appliance	$_____	$_____	$_____	$_____
3	Machinery & equipment, include construction, mining, material handling and unspecialized machinery (as escalator, lift, crane, air conditioner, pump etc.)	$_____	$_____	$_____	$_____
	Other (Please specify):				
4	_____	$_____	$_____	$_____	$_____
5	_____	$_____	$_____	$_____	$_____
6	_____	$_____	$_____	$_____	$_____
7	Replacement part, tire, gas, oil etc. for construction machinery & automobile (replaced by employee).	$_____	$_____	$_____	$_____
	(i) TOTAL PURCHASE OF MATERIAL, COMPOMENTS & SUPPLIES	$_____	$_____	$_____	$_____
	(ii) PURCHASES OF GOODS FOR RESALE	$_____	$_____	$_____	$_____

Note:
1. The sum of items (1) to (7) should equals to (i) + (ii)
2. The sales of item (ii) goods for resale should record as **(D) Other Operating Revenue** in Section I Question 1.

5. **If the majority of estimated purchase amount of building material, machinery, part and replacement in Question 4 were outsourced to subcontractors. Please indicate the percentage of the expenditure value falls into each of the following categories based on your previous experience for any two major work types (in both private and public works, referring to categories in Section I Question 2):**

Type I:____________________

		Percentage
1	Raw materials and building materials	______%
2	Electric equipment, pluming fittings & fixture	______%
3	Machinery & equipment (installed on-site)	______%
4	Overhead & general expenses (include administration, site office setup)	______%
5	Fuel, water and electric energy	______%
Others (Please specify):		
6	____________________	______%
7	____________________	______%
8	____________________	______%
	TOTAL	100%

Type II:____________________

		Percentage
1	Raw materials and building materials	______%
2	Electric equipment, pluming fittings & fixture	______%
3	Machinery & equipment (installed on-site)	______%
4	Overhead & general expenses (include administration, site office setup)	______%
5	Fuel, water and electric energy	______%
Others (Please specify):		
6	____________________	______%
7	____________________	______%
8	____________________	______%
	TOTAL	100%

Note:
Type of works may include transportation work (road, bridge, railway and tunnel), industrial warehouse or facilities, telecommunication, commercial building, residential building, repair and maintenance etc.

6. **What was the Hong Kong dollar value of the purchase of following expenditure categories for the fiscal years 2013-2014, including construction project expenses, office administration and overhead cost.**

No.	Product Description	Purchase in 2013-2014 (HK$000) (A) From suppliers in HK	(B) From foreign regions	(c) = (A)+(B)
(B)	**Fuels, Electric Energy**			
1	Coal and Coke	$______	$______	$______
2	Gas, fuel, petroleum (exclude for motor vehicles)	$______	$______	$______
3	Electric Energy	$______	$______	$______
	SUBTOTAL			$______
(C)	**Purchased Services**			
1	Transportation & warehousing charge (Import & export)	$______	$______	$______
2	Communication (telephone, internet etc.)	$______	$______	$______
3	Water & Sanitary Supply & Construction Waste Disposal	$______	$______	$______
4	Advertising & Marketing (outsourcing)	$______	$______	$______
5	Insurance, financial charges (Include interest)	$______	$______	$______
6	Rent	$______	$______	$______
7	Business services (Include legal, engineering, architectural, accounting, management consulting, data processing, traveling agent, human resource function etc.)	$______	$______	$______
8	Hiring, leasing or renting machinery and vehicles	$______	$______	$______
9	Cost of auto & truck repair done by outside repair shop	$______	$______	$______
10	Services to building by outside contractor (Include window & site cleaning, exterminating etc.)	$______	$______	$______
	SUBTOTAL			$______
(D)	**Repair & Maintenance on Own Facilities** (If not account as cost, but capitalized, report to section (F)			
1	Repair to building & structure			
	a) By outside contractor	$______	$______	$______
	b) By own work force (Show supplies & materials here, and compensations as part of (E) below)	$______	$______	$______
2	Repair to equipment by outside contractors (if done by own workforce, please go to section (A) for material cost and show compensation as part of (E))	$______	$______	$______
	SUBTOTAL			$______
(E)	**Other Costs**			
1	Wages & Salaries (compensations of employee)			$______
2	Taxes (Include property tax, license fee etc.)			$______
3	Depreciation on plant and equipment			$______
	SUBTOTAL			$______
(F)	**Capital Expenditure for Own Facilities**			
1	Construction (Include building, plant, warehouse etc.)			$______
2	Equipment (Include delivered cost)			$______
	SUBTOTAL			$______

Notes To Help You Complete the Survey

Please read these notes before completing this Survey

1. **Annual Sales**

Give the vales of all sales made in the year whether or not the goods were produced in the year. The values given are equals to the amount of the invoices charged to customers during the financial period, and may include transport and delivery, insurance, indirect taxes and duties, as well as margins.

Include

- Value of work done on customers' materials (service fee);
- Upgrade and alternation works of building, facility should be include in **"New construction put in place"**;
- Interest and dividends received and other similar incomes from renting properties, donations and fundraising activities, insurance claims etc. that recorded as "other operating income" in the accounts should be separated and marked under "**Other Operating Revenue**".

Exclude

- Output for own final use (office building or warehouse registered under company's name);
- Amounts received from the sales of fixed capital assets, vehicles, patents, copyrights etc.

2. **Examples of Private Works and Public Works.**

Upgrade and alternation works of building, facility, structure should be included as part of construction works (opposite to "Repair and Maintenance").

(a) Private Works

- **"Residential"** may include apartment, single dwelling, town house etc. For residential commercial complex project, if the gross floor area of residential units not exceeding 70% of the total floor area and unable to separate the proportion under two categories respectively. Please mark under **"Residential"** section. Exclude public housing projects that founded by the government.
- **"Commercial"** may include office building, retail, restaurant, hotel, healthcare, sports facility etc.
- **"Industrial"** may include industrial facility, factory, warehouse, garage, distribution center etc.
- **"Private founded Infrastructure"** may include power plant, telecommunication, waste treatment facility, school, hospital, health center, jail etc.

(b) For Public Works (Infrastructure)

- "**Structure & Facility**" refers as civil engineering works, power plant, telecommunication, waste treatment facility, green park, open space etc.
- "**Building**" refers to office building, public housing, school, health center, communication center etc.

3. Expenditure

(a) Components and Supplies

Give the vales of expenditures related to the goods and materials used in the construction works, or/and in the running of the business made in the year. The values given are equals to amount of the invoices charged upon your company(s), and may include transport and delivery, insurance, indirect taxes and duties.

Include

- The cost of raw material, building material, component, fixture, machinery, machine spares charged to you;
- Any imports of goods should be valued as Free on Board(FOB);
- The cost of materials you have supplied for works done by you or your subcontractors;
- The cost of materials or equipment purchased in the installation, repair or maintenance of customers' goods or/and as parts of the construction works;
- Building materials you have purchased for your own use.

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Exclude

- Transport or delivery costs on purchase paid to a third party. Include these in section II (C).
- Amounts charged to capital account. Include these in Section II (F);

(b) Fuels, Electric Energy

Include

- The cost of fuels, electric energy charged to you on construction site and in business operating.

(c) Purchase Services

Include

- The cost of services charged to you on construction site and in business operating.
- Amounts paid for licensing, inspection and monitoring under **"business service"**;
- Staff travelling and subsistence expenses under **"business service"**;
- Outsourced labor recruitment administration costs under **"business service"**.

Exclude

- Mortgage loan payments and interest payments;
- Bad debts;
- Fines and penalties except those related to congestion charges;
- Market research, public relation activities, labor recruiting activities carried out by your own staff.

(d) Capital Expenditure for Own Facilities

The amounts entered should include the purchase costs and disposal proceeds of fixed assets, together with any other amounts treated as capital items for taxation purposes.

Include

- Expenditure on new construction work constructed by you, including the construction of new facilities, extensions and improvements to existing facilities (covers fixtures and machineries such as lift, heating and ventilation system) ;
- All work of a capital nature carried out by your own staff. The relevant employment costs and the cost of purchases consumed in the work should be included in **section II (A) and (E)** ;
- Expenditure on assets acquired for hiring, renting and other leasing purposes (other than assets acquired in order to leases to others under finance leasing arrangements) ;
- All additions, alternations, improvements and renovations which prolong the service life or increase the productive capacity of existing capital goods;

Exclude

- Assets like goodwill, patents or license fees;
- The proceeds from an insurance claim against the loss of fixed assets. Should be included in **Section I (D) "Other Operating Revenue"**.
- Rental charged for assets leased by you through operational leasing facilities;
- Assets located outside Hong Kong region.

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Appendix 3 Leontief Inverse Matrices of Hong Kong in 2013

Table A-3 Leontief Inverse Matrix of Hong Kong in 2013 (Non-survey method)

	Sector	1	2	3	4	5	6	7	8	9	10
1	Agriculture	1.000	0.000	0.000	0.001	0.014	0.002	0.000	0.001	0.001	0.004
2	Manufacturing	0.002	1.037	0.134	0.359	0.116	0.162	0.024	0.047	0.055	0.142
3	Utilities	0.000	0.001	1.001	0.002	0.017	0.006	0.002	0.009	0.005	0.015
4	Construction	0.000	0.000	0.000	1.002	0.002	0.002	0.003	0.004	0.006	0.010
5	Wholesale & Retail Trade	0.001	0.012	0.009	0.070	1.207	0.177	0.011	0.039	0.055	0.050
6	Transport & Storage	0.001	0.010	0.018	0.050	0.162	1.466	0.009	0.037	0.033	0.046
7	Information & Communication	0.000	0.000	0.000	0.003	0.009	0.008	1.032	0.018	0.008	0.003
8	Financing & Insurance	0.000	0.002	0.001	0.030	0.026	0.022	0.011	1.220	0.018	0.008
9	Professional and Support Activities	0.000	0.003	0.002	0.035	0.065	0.060	0.029	0.147	1.056	0.023
10	Other Services	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
	Output Multiplier	**1.01**	**1.07**	**1.17**	**1.55**	**1.62**	**1.91**	**1.12**	**1.52**	**1.24**	**1.30**

Table A-4 Leontief Inverse Matrix of Hong Kong in 2013 (Hybrid method)

	Sector	1	2	3	4	5	6	7	8	9	10
1	Agriculture	1.000	0.000	0.000	0.000	0.014	0.003	0.000	0.001	0.002	0.004
2	Manufacturing	0.002	1.037	0.134	0.121	0.118	0.164	0.024	0.051	0.052	0.140
3	Utilities	0.000	0.001	1.001	0.064	0.017	0.006	0.003	0.010	0.006	0.016
4	Construction	0.000	0.000	0.002	1.411	0.003	0.001	0.001	0.007	0.032	0.029
5	Wholesale & Retail Trade	0.001	0.012	0.009	0.023	1.209	0.179	0.012	0.044	0.054	0.050
6	Transport & Storage	0.001	0.010	0.018	0.008	0.163	1.467	0.010	0.040	0.032	0.045
7	Information & Communication	0.000	0.000	0.000	0.002	0.010	0.008	1.032	0.018	0.007	0.003
8	Financing & Insurance	0.000	0.002	0.001	0.014	0.027	0.023	0.011	1.221	0.024	0.008
9	Professional and Support Activities	0.000	0.003	0.002	0.053	0.067	0.063	0.030	0.151	1.052	0.025
10	Other Services	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
	Output Multiplier	**1.01**	**1.07**	**1.17**	**1.70**	**1.63**	**1.91**	**1.12**	**1.54**	**1.26**	**1.**32

Appendix 4 Domestic Linkages of Hong Kong (1995-2013)

Table A-5 Summary of Domestic Linkages of Hong Kong (1995-2013)

	Sector	Domestic Linkage										Domestic Linkage (normalized)									
		Domestic Backward Linkage[a]					Domestic Forward Linkage[b]					Power of Dispersion[c]					Sensitivity of Dispersion[d]				
		1995	2000	2005	2010	2013	1995	2000	2005	2010	2013	1995	2000	2005	2010	2013	1995	2000	2005	2010	2013
01	Agriculture	1.01	1.01	1.01	1.01	1.01	1.02	1.03	1.02	1.02	1.02	0.74	0.74	0.76	0.75	0.75	0.74	0.75	0.77	0.76	0.76
02	Manufacturing	1.31	1.17	1.09	1.09	1.07	1.71	2.14	2.06	2.02	2.08	0.95	0.86	0.82	0.81	0.79	1.25	1.57	1.54	1.50	1.54
03	Utilities	1.20	1.18	1.17	1.17	1.17	1.53	1.04	1.05	1.06	1.06	0.88	0.87	0.88	0.87	0.86	1.12	0.77	0.79	0.79	0.78
04	Construction	1.74	1.61	1.59	1.54	1.55	1.02	1.05	1.03	1.03	1.03	1.27	1.18	1.19	1.15	1.15	0.74	0.77	0.77	0.77	0.76
05	Wholesale & Retail Trade	1.67	1.66	1.59	1.61	1.62	1.61	1.61	1.63	1.64	1.63	1.21	1.22	1.19	1.20	1.20	1.17	1.18	1.22	1.22	1.21
06	Transport & Storage	1.56	1.73	1.79	1.83	1.91	1.42	1.94	1.79	1.82	1.83	1.13	1.26	1.34	1.36	1.41	1.03	1.42	1.34	1.35	1.36
07	Information & Communication	1.22	1.32	1.18	1.15	1.12	1.30	1.15	1.10	1.09	1.08	0.89	0.97	0.89	0.85	0.83	0.95	0.84	0.82	0.81	0.80
08	Financing & Insurance	1.44	1.40	1.43	1.51	1.52	1.77	1.27	1.28	1.34	1.34	1.05	1.03	1.07	1.12	1.13	1.29	0.93	0.96	1.00	0.99
09	Professional and Support Activities	1.17	1.23	1.21	1.23	1.24	1.10	1.42	1.40	1.42	1.42	0.85	0.90	0.91	0.92	0.92	0.80	1.04	1.04	1.06	1.05
10	Other Services	1.42	1.35	1.30	1.31	1.30	1.25	1.00	1.00	1.00	1.00	1.04	0.99	0.98	0.97	0.96	0.91	0.73	0.75	0.75	0.74

[a] Domestic backward linkage is defined as total direct and indirect effects associated with a change in final demands.
[b] Domestic forward linkage is defined as total direct and indirect effects associated with a change in value-added.
[c] Power of dispersion is defined as normalized total backward linkage
[c] Sensitivity of dispersion is defined as normalized total forward linkage

Appendix 5 Composition of Hong Kong's Construction Works

The composition and volume of construction works performed in Hong Kong are largely affected by public expenditure and policies. Projects under the Airport Core Programmer (ACP) enter into full swing during 1994-1996 (Census and Statistics Dept., 2000), followed with construction works for public housing from 1997 to 2002 in response to the housing policy (Chiu, 2010). The volume of construction works has dropped by nearly 60% in 2006 compared to the peak point in 1998, due to the termination of the home ownership policy in 2002 and completion of ACP projects. After the announcement of Ten Major Infrastructure Projects (TMIPs) in 2007, the volume has gradually increased until 2013. As for the composition of construction works, a clear shift from building works to civil works is noticed from 2000 to 2013.

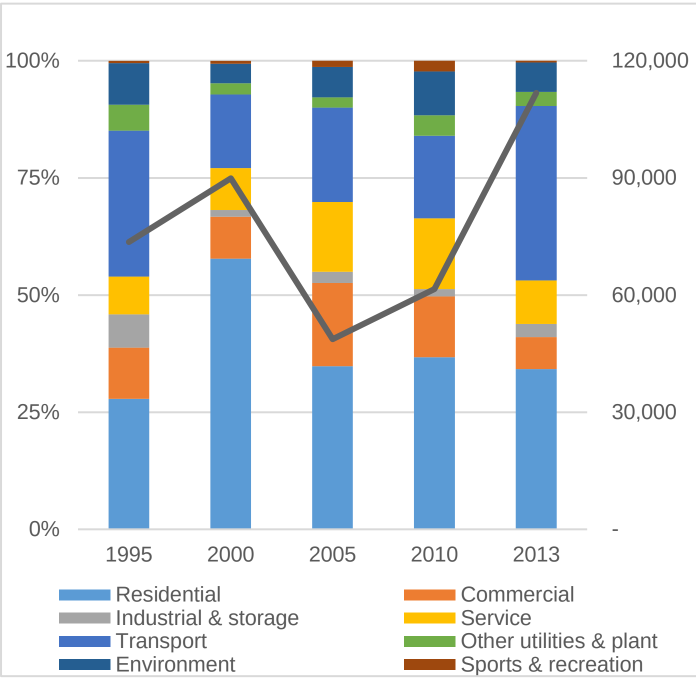

Figure A-1 Gross Value of Construction Works by Main Contractors (1995-2013)

Note: Data from Census and Statistics Dept. (2018b)

Appendix 6 Annual Changes of Construction Cost Indexes

Annual change of the Construction Cost Index for material and labor in Hong Kong from 1997 to 2013 are reported in Table A-6. The overall increase rate of material cost index is nearly 2.7 times the rate of labor cost index over the 1997-2013 period.

Table A-6 Annual Changes of the Construction Cost Indexes (1995-2013)

Annual Change[a]	**1997**	**2000**	**2005**	**2010**	**2013**	**1997-2013**
Material Cost Index	0.87%	3.94%	5.19%	9.90%	-2.58%	96.9%
Labor Cost Index	12.78%	2.17%	-2.60%	0.13%	12.03%	35.5%
Construction Cost Index[b]	8.78%	2.62%	-0.19%	-0.19%	5.73%	54.6%

Note: Data from Civil Engineering and Development Dept. (2017)

[a] Refer to the difference between the cost index of a given year and that of the previous year.

[b] Construction cost index = 0.6 × material cost index + 0.4× labor cost index.

Appendix 7 Import Content of Selected Economies

Table A-7 summarizes the input coefficients in Construction direct backward linkage which relates to direct imports from 1995 to 2013. The coefficient represents the (additional) proportion of intermediate import inputs are directly purchased by Construction sector to produce one (additional) unit of its output. That is, it reflects the dependence of Construction upon direct import inputs in the production process. On average, Cyprus and Singapore present larger coefficients, while France, Hong Kong, and the United States have smaller coefficients ranging from 0.04 to 0.08. Yet, for these imported products that are purchased through other channels (i.e. distributors, wholesalers or subcontractors) would be excluded in the estimation of input coefficients, and the magnitude of intermediate import inputs may be underestimated. Another related indicator, intermediate import ratio, is used to illustrate the proportion of intermediate import inputs over total intermediate demand for Construction sector and other sectors as shown in Table A-8.

Table A-7 Import Input Coefficients in Construction Direct Backward Linkage (1995-2013)

Economy	Year								Average
	1995	2000	2005	2007	2010	2011	2012	2013	
Belgium	0.11	0.14	0.11	0.11	0.11	0.12			0.12
Cyprus	0.19	0.18	0.17	0.17	0.16	0.17			0.17
France	0.07	0.08	0.08	0.09	0.09	0.09			0.08
Hong Kong	0.04	0.04	0.08		0.07			0.06	0.06
Netherlands	0.13	0.13	0.11	0.11	0.11	0.11			0.12
Singapore		0.24	0.18	0.20	0.14	0.14	0.14		0.17
United States		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Note: Data from BEA (2018a, 2018b); OECD Statistics (2017b); Singapore Dept. of Statistics (2010, 2012, 2014, 2017b, 2017c)

Table A-8 Intermediate Import Ratio of Selected Economies (1995-2005)

Economies		Mid-1990	Early-2000	Mid-2000	2010	2013
Belgium	Total	0.31	0.35	0.34		
	Manufacturing[a]	0.53	0.58	0.56		
	Service[b]	0.12	0.15	0.16		
	Construction	0.02	0.02	0.02		
Cyprus	Total	0.34	0.34	0.32		
	Manufacturing	0.55	0.50	0.54		
	Service	0.12	0.16	0.16		
	Construction	0.01	0.03	0.01		
France	Total	0.16	0.18	0.18		
	Manufacturing	0.30	0.35	0.37		
	Service	0.04	0.05	0.05		
	Construction	0.00	0.00	0.00		
Netherlands	Total	0.29	0.30	0.29		
	Manufacturing	0.50	0.51	0.47		
	Service	0.11	0.12	0.16		
	Construction	0.01	0.01	0.02		
Singapore	Total	0.55	0.58	n.a.		
	Manufacturing	0.79	0.83	n.a.		
	Service	0.17	0.26	n.a.		
	Construction	0.09	0.11	n.a.		
United States	Total[c]	0.07	0.09	0.09		
	Manufacturing	0.14	0.20	0.21		
	Service	0.00	0.01	0.01		
	Construction	0.00	0.00	0.00		
Hong Kong	Total	0.63	0.66	0.72	0.73	0.74
	Industry[d]	0.81	0.84	0.88	0.89	0.89
	Service	0.17	0.15	0.19	0.24	0.25
	Construction		0.09	0.09	0.02	0.11

Note: Data from Census and Statistics Dept. (2016d, 2016e); OECD Statistics (2017c)

[a] Consists of Manufacturing sector, based on the sector classification of OECD database.

[b] Consists of Construction, Wholesale & Retail Trade, Transport & Storage, Information & Communications, Financing & Insurance, Professional and Support Activities, and Other Services. The classification is based on the sector classification of OECD database.

[c] The data for the US is in producer's price.

[d] Consists of Agriculture, Manufacturing, and Utilities. There are no detailed breakdown figures by sectoral classification for the official export and import statistics, hence, two main groups are used here as industry and service sector (including Construction sector).

The figures shown in Table A-8 are extracted from the OECD database (use STAN 2012 edition, some figures are slightly different from the estimated ratios using data from the current version of IOTs) except Hong Kong's. Overall, a clear distinction can be made between large economies (France and the US) and the small economies (Belgium, Cyprus, Netherlands, Singapore and Hong Kong). The smaller economies have larger intermediate import ratio especially for Manufacturing sector, indicating that their production process depends more on imports to fulfill the domestic demands. This echoes the findings of Alesina and Wacziarg (1998), Ram (2009) that a negative relationship exists between country size and trade openness. Among all, Singapore and Hong Kong are observed to have remarkably larger intermediate import ratios than others.

Appendix 8 Emissions Embodied in Imports (2004-2011)

Table A-9 Emissions embodied in imports, and % of EEI to consumption-based emissions by sector

Emitting Sector	2004			2007			2011		
	EEI (tonnes)	% of total EEI	% of total consumption-based emissions	EEI (tonnes)	% of total EEI	% of total consumption-based emissions	EEI (tonnes)	% of total EEI	% of total consumption-based emissions
Agriculture	1.21	1.42%	85.41%	1.13	1.58%	83.64%	1.14	1.59%	83.56%
Manufacturing	48.59	57.16%	91.46%	38.90	54.30%	89.03%	39.67	55.52%	89.01%
Utilities	3.42	4.03%	34.89%	3.68	5.14%	34.24%	3.45	4.83%	31.10%
Construction	9.04	10.63%	78.58%	7.28	10.16%	74.43%	7.49	10.48%	73.50%
Wholesale & Retail Trade	10.61	12.48%	53.86%	9.92	13.84%	50.20%	9.44	13.21%	47.86%
Transport & Storage	4.54	5.34%	53.39%	4.69	6.54%	53.25%	4.71	6.59%	52.43%
Information & Communication	0.28	0.33%	78.88%	0.23	0.32%	73.68%	0.22	0.30%	71.23%
Financing & Insurance	0.46	0.54%	66.47%	0.50	0.70%	67.15%	0.49	0.68%	65.19%
Professional & Support Activities	1.72	2.03%	69.56%	1.54	2.15%	65.88%	1.45	2.03%	63.05%
Other Services	5.14	6.04%	68.49%	3.77	5.27%	64.88%	3.41	4.77%	61.49%
Sub-totals	**85.00**	**100.00%**	**73.87%**	**71.64**	**100.00%**	**69.32%**	**71.46**	**100.00%**	**68.17%**

Appendix 9 Direct Emission Intensities (2004-2011)

Table A-10 Total Emission Intensities for Source Sectors (2004-2011)

Emitting Sector		2004	2007	2011	The rate of decrease (%)
HK	Manufacturing	0.663	0.530	0.429	-35.29%
	Utilities	5.752	4.865	4.081	-29.05%
	Construction	0.596	0.442	0.351	-41.11%
	Transport	1.122	0.939	0.788	-29.78%
Singapore	Manufacturing	0.840	0.594	0.472	-43.80%
	Utilities	7.194	5.046	3.594	-50.04%
	Construction	0.530	0.374	0.279	-47.30%
	Transport	1.314	0.941	0.678	-48.37%
China	Manufacturing	2.375	1.691	1.099	-53.72%
	Utilities	21.624	16.364	14.255	-34.08%
	Construction	1.601	1.147	0.754	-52.92%
	Transport	2.291	1.622	1.053	-54.05%
RoW	Manufacturing	0.647	0.518	0.432	-33.33%
	Utilities	5.389	4.268	3.576	-33.65%
	Construction	0.334	0.274	0.231	-30.61%
	Transport	1.441	1.180	0.979	-32.06%

Table A-11 Direct Emission Intensities for Source Sectors (2004-2011)

Emitting Sector		2004	2007	2011	The rate of decrease (%)
HK	Manufacturing	0.057	0.053	0.049	-14.47%
	Utilities	5.041	4.243	3.595	-28.68%
	Construction	0.015	0.014	0.012	-22.95%
	Transport	0.387	0.335	0.292	-24.38%
Singapore	Manufacturing	0.093	0.065	0.054	-41.67%
	Utilities	5.642	3.403	2.299	-59.25%
	Construction	0.012	0.010	0.006	-49.75%
	Transport	0.686	0.467	0.316	-53.96%
China	Manufacturing	0.448	0.283	0.164	-63.46%
	Utilities	18.450	14.188	12.483	-32.34%
	Construction	0.063	0.040	0.021	-67.37%
	Transport	1.205	0.831	0.528	-56.19%
RoW	Manufacturing	0.131	0.101	0.086	-34.43%
	Utilities	4.657	3.650	3.047	-34.58%
	Construction	0.021	0.017	0.013	-36.83%
	Transport	0.980	0.796	0.656	-33.07%

Appendix 10 Variance in CBA Emissions

Table A-11 Variance with Previous Studies

	Previous Studies				GTAP 9a	
	Data source	Year	Approach	Result	Result	Var %
Davis & Caldeira (2010)	GTAP with updated CDIAC	2004	PBA	38.9	68.98	55.77%
			CBA	103.0	115.07	11.07%
Peters et al. (2011)	GTAP 7.1	2004	PBA	58.0	68.98	17.29%
			CBA	104.0	115.07	10.11%
Steininger et al. (2016)	UNDESA (2013)	2011	PBA	40.6	80.94	66.36%
			CBA	345.95	104.82	106.99%

Note: Variance % = |(a-b)|/((a+b)/2)×100

Table A-12 Variance in CBA Emissions of GTAP, CDIAC, and EDGAR (2004-2011)

		GTAP	CDIAC	EDGAR	CGIAC-GTAP Variance (%)	EDGAR-GTAP Variance (%)
2004	Total CBA CO2 emissions (Mt)	11.50	14.15	14.63	20.66%	23.94%
	HK Direct (%)	2.59%	4.26%	4.23%	48.73%	48.02%
	HK Indirect (%)	18.83%	10.00%	9.92%	61.25%	61.93%
	Imported (%)	78.58%	85.74%	85.85%	8.71%	8.84%
2007	Total CBA CO2 emissions (Mt)	9.78	10.62	11.09	8.26%	12.52%
	HK Direct (%)	3.13%	5.59%	5.59%	56.32%	56.30%
	HK Indirect (%)	22.44%	12.56%	12.56%	56.44%	56.46%
	Imported (%)	74.43%	81.85%	81.86%	9.50%	9.50%
2011	Total CBA CO2 emissions (Mt)	10.19	10.96	11.24	7.25%	9.80%
	HK Direct (%)	3.39%	6.45%	6.81%	62.22%	67.03%
	HK Indirect (%)	23.11%	12.19%	12.87%	61.86%	56.97%
	Imported (%)	73.50%	81.36%	80.33%	10.15%	8.88%

Note: Variance % = |(a-b)|/((a+b)/2)×100

REFERENCES

Acquaye, A. A., and A. P. Duffy. 2010. “Input–output analysis of Irish construction sector greenhouse gas emissions.” *Build. Environ.* 45(3): 784-791.

Aguiar, A., B. Narayanan, and R. McDougall. 2016. “An overview of the GTAP 9 data base.” *J. Global Econ. Anal.* 1 (1): 181–208. https://doi.org/10.21642/JGEA.010103AF.

Alesina, A., and R. Wacziarg. 1998. “Openness, country size and government.” *J. Public Econ.* 69 (3): 305–321.

Andrew, R. M., and G. P. Peters. 2013. “A multi-region input–output table based on the global trade analysis project database (GTAP-MRIO).” *Econ. Syst. Res.* 25 (1): 99–121. https://doi.org/10.1080/09535314.2012.761953.

Arto, I., J. M. Rueda-Cantuche, and G. P. Peters. 2014. “Comparing the GTAP-MRIO and WIOD databases for carbon footprint analysis.” *Econ. Syst. Res.* 26(3): 327-353.

Athanassiadis, A., M. Christis, P. Bouillard, A. Vercalsteren, R. H. Crawford, and A. Z. Khan. 2018. “Comparing a territorial-based and a consumption-based approach to assess the local and global environmental performance of cities.” *J. Clean Prod.* 173(1): 112-123.

Bachmann, C., C. Kennedy, and M.J. Roorda. 2014. “Applications of random-utility-based multi-region input-output models of transport and the spatial economy.” *Transp. Rev.* 34: 418–440.

Baek, J., Y. Cho, and W. W. Koo. 2009. “The environmental consequences of globalization: A country-specific time-series analysis.” *Ecol. Econ.* 68(8-9): 2255-2264.

Bai, X. 2007. “Industrial ecology and the global impacts of cities.” *J. Ind. Ecol.* 11(2): 1-6.

Baiocchi, G., and J. C. Minx. 2010. “Understanding changes in the UK’s CO_2 emissions: A global perspective.” *Environ. Sci. Technol.* 44(4): 1177–1184.

Barber Jr., H. M., and I. H. El-Adaway. 2013. “Economic performance assessment for the construction industry in the southeastern United States.” *J. Manage. Eng.* 31 (2): 05014014. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000272.

Baumol, W. J. 2000. “What Marshall didn't know: on the twentieth century's contributions to economics.” *Q. J. Econ.* 115(1): 1-44.

Baumol,W. J., and E. N.Wolff. 1994. “A key role for input–output analysis in policy design.” *Reg. Sci. Urban Econ.* 24 (1): 93–113. https://doi.org/10.1016/0166-

0462(94)90021-3.

BEA (US Bureau of Economic Analysis). 2016. “Industry by industry total requirements tables 1997-2015 (15 industries).” Accessed March 2017. https://www.bea.gov/industry/xls/io-annual/IxI_TR_1997-2015_Sector.xlsx.

BEA (US Bureau of Economic Analysis). 2018a. “Commodity by industry direct requirements, after redefinitions, 1997-2016 (15 industries).” Accessed August 2018. https://apps.bea.gov/industry/xls/io-annual/CxI_DR_1997-2016_Sector.xlsx.

BEA (US Bureau of Economic Analysis). 2018b. “Industry by industry domestic requirements, after redefinitions, 1997-2016 (15 industries).” Accessed August 2018. https://apps.bea.gov/industry/xls/io-annual/IxI_Domestic_1997-2016_Sector.xlsx.

Bon, R. 1988. “Direct and indirect resource utilisation by the construction sector: The case of the USA since World War II.” *Habitat Int.* 12 (1): 49–74. https://doi.org/10.1016/0197-3975(88)90039-2.

Bon, R. 2000. *Economic structure and maturity: Collected papers in input–output modelling and applications*. Aldershot, UK: Ashgate Publishing Ltd.

Bon, R., and R. Pietroforte. 1990. “Historical comparison of construction sector in the United States, Japan, Italy and Finland using input–output tables.” *Constr. Manage. Econ*. 8 (3): 233–247. https://doi.org/10.1080/01446199000000021.

Bon, R., and T. Yashiro. 1996. “Some new evidence of old trends: Japanese construction, 1960–1990.” *Constr. Manage. Econ.* 14 (4): 319–323. https://doi.org/10.1080/014461996373395.

Boskin, M. J., and L. J. Lau. 1991. “Capital formation and economic growth.” In *“Technology & economics: Papers commemorating Ralph Landau’s service to the National Academy of Engineering”*, 47–56. Washington, DC: National Academy Press.

Boucher, M. 1976. “Some further results on the linkage hypothesis.” *Q. J. Econ*. 90 (2): 313–318. https://doi.org/10.2307/1884633.

Brülhart, M. 2011. “The spatial effects of trade openness: a survey.” *Rev. World Econ.* 147(1): 59-83.

Carlsson, R., A. Otto, and J. W. Hall. 2013. “The role of infrastructure in macroeconomic growth theories.” *Civ. Eng. Environ. Syst.* 30, 263-273.

CCC (Committee on Climate Change) (2017). *Meeting carbon budgets: Closing the policy gap*. London, UK: UK Committee on Climate Change.

Çelik, T., S. Kamali, and Y. Arayici. 2017. “Social cost in construction projects.” *Environ. Impact Assess. Rev.* 64: 77-86.

Census and Statistics Dept. 1995-2005a. *Report on annual survey of building, construction & real estate sectors*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 1995-2005b. *Report on annual survey of industrial production*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 1995-2005c. *Report on annual survey of wholesale, retail & import & export trades, restaurants & hotels*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 1995-2005d. *Report on annual survey of transport & related services*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 1995-2005e. *Report on annual survey of storage, communication, financing, insurance & business services*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2000. *Review of construction industry in Hong Kong." Hong Kong Monthly Digest of Statistics (January 2000*). Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2005-2013. *Gross domestic product (yearly)*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2010-2013a. *Key statistics on business performance and operating characteristics of the building, construction and real estate sectors*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2010-2013b. *Key statistics on business performance and operating characteristics of the industrial sector*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2010-2013c. *Key statistics on business performance and operating characteristics of the import/export, wholesale and retail trades, and accommodation and food services sectors*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2010-2013d. *Key statistics on business performance and operating characteristics of the transportation, storage and courier services sector*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2010-2013e. *Key statistics on business performance and operating characteristics of the information and communications, financing and insurance, professional and business services sectors*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2005-2016. *Hong Kong annual digest of statistics*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2010. *Hong Kong annual digest of statistics 2010*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2014. *Key statistics on business performance and operating characteristics of the building, construction and real estate sectors.* Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2016a. *Hong Kong annual digest of statistics 2016*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2016b. "Table 090: Selected statistics for all establishments in the industry sections of import/export, wholesale and retail trades, and accommodation and food services." Accessed June 2016. www.censtatd.gov.hk/hkstat/sub/sp320.jsp?tableID=090&ID=0&productType=8.

Census and Statistics Dept. 2016c. "Table 202: Selected industry averages and analytical ratios in the industry sections of import/export, wholesale and retail trades, and accommodation and food service." Accessed June 2016. www.censtatd.gov.hk/hkstat/sub/sp320.jsp?tableID=200&ID=0&productType=8.

Census and Statistics Dept. 2016d. "Table 063: External merchandise trade statistics by end-use category-imports." Accessed June 2016. www.censtatd.gov.hk/hkstat/sub/sp230.jsp?tableID=063&ID=0&productType=8.

Census and Statistics Dept. 2016e. "Table 082: Exports, imports and net exports of services by service component." Accessed June 2016. www.censtatd.gov.hk/hkstat/sub/sp240.jsp?tableID=082&ID=0&productType=8.

Census and Statistics Dept. 2016f. "Table 197: Imports of ten principal commodity divisions." Accessed June 2016. www.censtatd.gov.hk/hkstat/sub/sp230.jsp?tableID=197&ID=0&productType=8.

Census and Statistics Dept. 2016g. "Table 198: Domestic exports of ten principal commodity divisions." Accessed June 2016. www.censtatd.gov.hk/hkstat/sub/sp230.jsp?tableID=198&ID=0&productType=8.

Census and Statistics Dept. 2016h. "Table 199: Re-exports of ten principal commodity divisions." Accessed June 2016. www.censtatd.gov.hk/hkstat/sub/sp230.jsp?tableID=199&ID=0&productType=8.

Census and Statistics Dept. 2017. *Hong Kong annual digest of statistics 2017*. Hong Kong: Census and Statistics Dept.

Census and Statistics Dept. 2018a. “Table 104: Gross value of construction works performed by main contractors analyzed by broad trade group (at constant (2000) market prices).” Accessed August 2018. www.censtatd.gov.hk/hkstat/sub/sp330.jsp?tableID=104&ID=0&productType=8.

Census and Statistics Dept. 2018b. “Table 110: Gross value of construction works performed by main contractors at construction sites analyzed by broad end-use group (in nominal terms).” Accessed March 2018. www.censtatd.gov.hk/hkstat/sub/sp330.jsp?tableID=110&ID=0&productType=8.

Chang, Y., R. J. Ries, and Y. Wang. 2010. “The embodied energy and environmental emissions of construction projects in China: an economic input–output LCA model.” *Energy Policy*, 38(11): 6597-6603.

Chen, G., M. Hadjikakou, and T. Wiedmann. 2017a. “Urban carbon transformations: Unravelling spatial and inter-sectoral linkages for key city industries based on multi-region input–output analysis.” *J. Clean Prod.* 163: 224-240.

Chen, G., T. Wiedmann, M. Hadjikakou, and H. Rowley. 2016. “City carbon footprint networks.” *Energies*, 9(8): 602.

Chen, J., L. Shen, X. Song, Q. Shi, and S. Li. 2017b. “An empirical study on the CO_2 emissions in the Chinese construction industry.” *J. Clean Prod.* 168: 645-654.

Chiang, Y. H., L. Tao, and F. K. W. Wong. 2015. “Causal relationship between construction activities, employment and GDP: The case of Hong Kong.” *Habitat Int.* 46 (Apr): 1–12. https://doi.org/10.1016/j.habitatint.2014.10.016.

Chiu, R. L. 2010. “The transferability of Hong Kong's public housing policy.” *International Journal of Housing Policy*, 10(3), 301-323.

Chuai, X., X. Huang, Q. Lu, M. Zhang, R. Zhao, and J. Lu. 2015. “Spatiotemporal changes of built-up land expansion and carbon emissions caused by the Chinese construction industry.” *Environ. Sci. Technol.* 49(21): 13021-13030.

CIC (The Construction Industry Council) 2018. “Construction expenditure forecast.” Accessed August 2018. www.cic.hk/eng/main/research_data_analytics_/expenditure_forecast/

Civil Engineering and Development Dept. 2017. “Construction cost indices.” Accessed March 2018. www.cedd.gov.hk/eng/publications/construction/index.html.

Clarida, R., J. Gali, and M. Gertler. 2001. “Optimal monetary policy in open versus closed economies: An integrated approach.” *Am. Econ. Rev.* 91(2): 248–252. https://doi.org/10.1257/aer.91.2.248.

Coggburn, J. D., K. V. Thai, and D. Rahm. 2007. *Handbook of Globalization and the Environment*. New York: Routledge.

Crozet, M., & Koenig, P. (2004). EU enlargement and the internal geography of countries. *J. Comp. Econ.* 32(2): 265–278.

Cuadros, A., V. Orts, and M. Alguacil. 2004. “Openness and growth: Re-examining foreign direct investment, trade and output linkages in Latin America.” *J. Dev. Stud*. 40(4): 167-192.

CYSTAT (Cyprus Ministry of Finance, Statistical Service). 2017. “National accounts, 1995–2016.” Accessed July 2017. http://www.mof.gov.cy/mof/cystat/statistics.nsf/economy_finance_11main_keyfarchive_en/economy_finance_11main_keyfarchive_en?OpenForm&yr=1995-2016C67FD0ACA1564CF496C787647D9F06E6&n=1995-2016.

Davis, S. J., & K. Caldeira. 2010. “Consumption-based accounting of CO_2 emissions.” *Proc. Natl. Acad. Sci. U. S. A.* 107(12): 5687-5692.

Dib, A. 2011. “Monetary policy in estimated models of small open and closed economies.” *Open Econ. Rev.* 22 (5): 769–796. https://doi.org/10.1007/s11079-010-9173-1.

Dietzenbacher, E. 2002. “Interregional multipliers: Looking backward, looking forward.” *Reg. Stud.* 36 (2): 125–136. https://doi.org/10.1080/00343400220121918.

Dietzenbacher, E., V. Albino, and S. Kuhtz. 2005. “The fallacy of using US-type input–output tables.” In *Proc., 15th Int. Conf. on Input–Output Techniques*. Beijing, China: Renmin University of China.

Drewer, S. 1980. “Construction and development: a new perspective.” *Habitat Int.* 5(3/4): 395-428.

Du, Q., X. Lu, Y. Li, M. Wu, L. Bai, and M. Yu. 2018. “Carbon emissions in China’s construction industry: Calculations, factors and regions.” *Int. J. Environ. Res. Public Health*. 15(6): 1220.

Edwards, S. 1998. “Openness, productivity and growth: what do we really know?” *Econ. J.* 108(447): 383-398.

Environment Bureau. 2015. *Report on the Public Consultation on Future Fuel Mix for Electricity Generation in Hong Kong.* Hong Kong: Environment Bureau.

Environment Bureau. 2017. *Hong Kong Climate Change Action Plan 2030+*. Hong Kong: Environment Bureau.

Fan, J. L., Y. B. Hou, Q. Wang, C. Wang, and Y.M. Wei. 2016. "Exploring the characteristics of production-based and consumption-based carbon emissions of major economies: A multiple-dimension comparison." *Appl. Energy*, 184: 790-799.

Feenstra, R. C. 1998. "Integration of trade and disintegration of production in the global economy." *J.Econ. Perspect.* 12(4): 31-50.

Feng, K., K. Hubacek, L. Sun, and Z. Liu. 2014. "Consumption-based CO_2 accounting of China's megacities: the case of Beijing, Tianjin, Shanghai and Chongqing." *Ecol. Indic.* 47: 26-31.

Findlay, R., and O'Rourke. 2007. *Power and Plenty: Trade, War, and the World Economy in the Second Millennium*. Princeton : Princeton University Press.

Franzen, A. and S. Mader. 2018. "Consumption-based versus production-based accounting of CO 2 emissions: Is there evidence for carbon leakage?." *Environ. Sci. policy*, 84: 34-40.

Fujita, M., P. Krugman, and A. Venables. 1999. *The spatial economy: Cities, regions and international trade*. Cambridge, MA: MIT Press.

Gehlhar M. 2010. "Re-Export Trade for the Netherlands and Singapore" in *GTAP 7 Data Base Documentation*. Indiana: Center for Global Trade Analysis.

Giang, D. T. H., and L. S. Pheng. 2011. "Role of construction in economic development: Review of key concepts in the past 40 years." *Habitat Int.* 35 (1): 118–125. https://doi.org/10.1016/j.habitatint.2010.06.003.

Giesekam, J., J. R. Barrett, and P. Taylor. 2016. "Construction sector views on low carbon building materials." *Build. Res. Informat.* 44(4): 423-444.

Gilchrist, A., and E.N. Allouche. 2005. "Quantification of social costs associated with construction projects: state-of-the-art review." *Tunn. Undergr. Space Technol.* 20 (1):89–104.

Green, R.K. 1997. "Follow the leader: how changes in residential and non-residential investment predict changes in GDP." *Real Estate Econ.* 25: 253-270.

Gregori, T., and R. Pietroforte. 2015. "An input–output analysis of the construction sector in emerging markets." Constr. Manage. Econ. 33 (2):134–145. https://doi.org/10.1080/01446193.2015.1021704.

Gundes, S. 2011. "Input structure of the construction industry: A cross-country analysis, 1968–90." *Constr. Manage. Econ.* 29 (6): 613–621. https://doi.org/10.1080/01446193.2011.563787.

Guo, J., and M. A. Planting. 2000. "Using input–output analysis to measure U.S. economic structural change over a 24 year period." Accessed March 2016. https://www.bea.gov/papers/pdf/strucv7all.pdf.

Hakfoort, J. 1996. “Public capital, private sector productivity and economic growth: A macroeconomic perspective.” In: D. F. Batten and C. Karlsson (Eds). *Infrastructure and the Complexity of Economic Development*. 61-72. Berlin, Heidelberg: Springer.

Harris, P. G., A. S. Chow, and J. Symons. 2012. “Greenhouse gas emissions from cities and regions: international implications revealed by Hong Kong.” Energy Policy, 44: 416-424.

Harris, R. I., and A. Liu. 1998. “Input-output modelling of the urban and regional economy: the importance of external trade.” *Reg. Stud.* 32(9): 851-862.

Hermannsson, K., and S. G. McIntyre. 2014. “Local consumption and territorial based accounting for CO_2 emissions.” *Ecol. Econ.* 104: 1-11.

Hertwich, E. G., and G. P. Peters. 2009. “Carbon footprint of nations: A global, trade-linked analysis.” *Environ. Sci. Technol.* 43(16): 6414-6420.

Hillebrandt, P. M. 2000. *Economic theory and the construction industry*. 3rd ed. Basingstoke, UK: Palgrave Macmillan.

Hirschman, A. 1958. *The Strategy of Economic Development.* New Haven : Yale University Press.

Ho, P. 2016. “Analysis of competitive environments, business strategies, and performance in Hong Kong’s construction industry.” *J. Manage. Eng.* 32 (2): 04015044. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000399.

Hoekstra, R. 2010. “Towards a complete overview of peer-reviewed articles on environmentally input-output analysis.” In *18th International Input-output Conference, Sydney, Australia*.

Hong, J., G. Q. Shen, S. Guo, F. Xue, and W. Zheng. 2016. “Energy use embodied in China′ s construction industry: A multi-regional input–output analysis.” *Renew. Sust. Energ. Rev.* 53: 1303-1312.

Hong, T., C. Ji, M. Jang, and H. Park. 2013. “Assessment model for energy consumption and greenhouse gas emissions during building construction.” *J. Manage. Eng.* 30(2): 226-235.

Hosein, R., and T. M. Lewis. 2005. “Quantifying the relationship between aggregate GDP and construction value added in a small petroleum rich economy–A case study of Trinidad and Tobago.” *Constr. Manage. Econ.* 23 (2): 185–197. https://doi.org/10.1080/0144619042000287741.

Hsia, R., H. Ho, and E. Lim. 1975. *The structure and growth of the Hong Kong economy*. Wiesbaden, Germany: Otto Harrassowitz.

Hu, Y., J. Lin, S. Cui, and N. Z. Khanna. 2016. “Measuring urban carbon footprint from carbon flows in the global supply chain.” *Environ. Sci. Technol.* 50(12):

6154-6163.

Huang, L., and R. A. Bohne. 2012. “Embodied air emissions in Norway's construction sector: input-output analysis.” *Build. Res. Informat.* 40(5): 581-591.

Huang, L., G. Krigsvoll, F. Johansen, Y. Liu, and X. Zhang. 2018. “Carbon emission of global construction sector.” *Renew. Sust. Energ. Rev.* 81: 1906-1916.

Huwart, J. Y., and L. Verdier. 2013. “What is the impact of globalization on the environment?” In *Economic globalization: origins and consequences*. OECD Publishing, Paris. https://doi.org/10.1787/9789264111905-8-en.

IEA (International Energy Agency) 2018. *Global energy and CO_2 status report 2017*. Accessed June 2018. https://www.iea.org/geco/emissions/

Ilhan, B., and H. Yaman. 2011. “A comparative input–output analysis of the construction sector in Turkey and EU countries.” *Eng. Constr. Archit. Manage.* 18 (3): 248–265. https://doi.org/10.1108/09699981111126160.

IPCC (Intergovernmental Panel on Climate Change) 2006. *2006 IPCC guidelines for national greenhouse gas inventories*. IPCC, IGES, Japan.

Jaillon, L., and C. S. Poon. 2009. “The evolution of prefabricated residential building systems in Hong Kong: A review of the public and the private sector.” *Autom. Constr.* 18 (3): 239–248. https://doi.org/10.1016/j.autcon.2008.09.002.

Jiang, Y., 1999. “A model for estimating excess user costs at highway work zones.” *Transp. Res. Rec.* 1657 (1):31-41.

Kanemoto, K., M. Lenzen, G. P. Peters, D. D. Moran, and A. Geschke. 2011. “Frameworks for comparing emissions associated with production, consumption, and international trade.” *Environ. Sci. Technol.* 46(1), 172-179.

Kanemoto, K., D. Moran, and E. G. Hertwich. 2016. “Mapping the carbon footprint of nations.” *Environ. Sci. Technol.* 50(19): 10512-10517.

Kanemoto, K. and Tonooka, Y. 2009. “Embodied CO_2 emissions in Japan’s international trade.” *Journal of Japan Society of Energy and Resources,* 30(2): 15–23.

Krugman, P., and R. L. Elizondo. 1996. “Trade policy and the third world metropolis.” *J. Deve. Econ.* 49(1): 137-150.

Lakshmanan, T. R. 2011. “The broader economic consequences of transport infrastructure investments.” *J. Transp. Geogr.* 19(1), 1-12.

Lakshmanan, T. R., and W. P. Anderson. 2002. “Transport infrastructure, freight services sector and economic growth: A white paper for the US Department of Transportation.” *Washington DC*.

Lam, K., and O. Oshodi. 2016. “Using univariate models for construction output forecasting: Comparing artificial intelligence and econometric techniques.” *J. Manage. Eng*. 32 (6): 04016021. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000462.

Lean, S.C. 2001. “Empirical tests to discern linkages between construction and other economic sectors in Singapore.” *Constr. Manage. Econ.* 13: 253-262.

Lenzen, M. 2001. “Errors in conventional and input–output-based life-cycle inventories.” *J. Ind. Ecol.* 4 (4): 127–148.

Lenzen, M., D. Moran, K. Kanemoto, and A. Geschke. 2013. “Building Eora: a global multi-region input–output database at high country and sector resolution.” *Econ. Syst. Res.* 25(1): 20-49.

Lenzen, M., J. Murray, F. Sack, and T. Wiedmann. 2007. “Shared producer and consumer responsibility—Theory and practice.” *Ecol. Econ.* 61(1): 27-42.

Lenzen, M., L. L. Pade, and J. Munksgaard. 2004. “CO_2 multipliers in multi-region input-output models.” *Econ. Syst. Res*. 16(4): 391–412.

Lewis, T. M. 2009. “Quantifying the GDP-construction relationship.” In: L.Ruddock (Ed.) *Economics for the modern built environment*. 34-59. London: Taylor & Francis.

Li, X., G. Shen, P. Wu, H. Fan, H. Wu, and Y. Teng. 2018. “RBL-PHP: Simulation of lean construction and information technologies for pre-fabrication housing production.” *J. Manage. Eng.* 34 (2): 04017053. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000577.

Lin, J., Y. Hu, S. Cui, J. Kang, and A. Ramaswami. 2015. “Tracking urban carbon footprints from production and consumption perspectives.” *Environ. Res. Lett.* 10(5): 054001.

Lin, T. B., and Y. W. Sung. 1984. “Tourism and economic diversification in Hong Kong. Ann. Touris. Res. 11(2): 231-247.

Liu, G., K. Li, D. Zhao, and C.Mao. 2017. “Business model innovation and its drivers in the Chinese construction industry during the shift to modular prefabrication.” *J. Manage. Eng.* 33 (3): 04016051. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000501.

Liu, H., W. Liu, X. Fan, and W. Zou. 2015. “Carbon emissions embodied in demand–supply chains in China.” *Energy Econ.* 50: 294-305.

Long, Y., and Y. Yoshida. 2018. “Quantifying city-scale emission responsibility based on input-output analysis–Insight from Tokyo, Japan.” *Appl. Energy*, 218: 349-360.

Lopes, J., L. Ruddock, and F. L. Ribeiro. 2002. “Investment in construction and economic growth in developing countries.” Build. Res. Inf. 30 (3): 152–159. https://doi.org/10.1080/09613210110114028.

Lu, Y., P. Cui, and D. Li. 2016. “Carbon emissions and policies in China's building and construction industry: evidence from 1994 to 2012.” Build. Environ. 95: 94-103.

Marx, A. 2002. “Uncertainty and social impacts: A case study of a Belgian village.” *Environ. Impact Assess. Rev.* 22(1):79-96.

Matthews, J.C., E.N. Allouche, and R.L. Sterling. 2015. “Social cost impact assessment of pipeline infrastructure projects.” *Environ. Impact Assess. Rev.* 50:196-202. http://dx.doi.org/10.1016/j.eiar.2014.10.001.

Mehmet, O., and V. Yorucu. 2008. “Explosive construction in a micro-state: Environmental limit and the Bon curve: Evidence from North Cyprus.” *Constr. Manage. Econ.* 26 (1): 79–88. https://doi.org/10.1080/01446190701708272.

Mi, Z., J. Meng, D. Guan, Y. Shan, M. Song, Y. M. Wei, Z. Liu, and K. Hubacek. 2017. “Chinese CO_2 emission flows have reversed since the global financial crisis.” Nat. Commun. 8(1): 1712. https://doi.org/10.1038/s41467-017-01820-w.

Miller, R. E. 1969. “Interregional feedbacks in input-output models: Some experimental results.” *Econ. Inq.* 7(1): 41-50.

Miller, R. E., and P. D. Blair. 2009. *Input–output analysis: Foundations and extensions.* 2nd ed. New York: Cambridge Univ. Press.

Minx, J. C., G. Baiocchi, T. Wiedmann, J. Barrett, F. Creutzig, K. Feng, M. Förster, P. P. Pichler, H. Weisz, and K. Hubacek. 2013. “Carbon footprints of cities and other human settlements in the UK.” *Environ. Res. Lett.* 8(3): 035039. https://doi.org/10.1088/1748-9326/8/3/035039.

Minx, J. C., T. Wiedmann, R. Wood, G. P. Peters, M. Lenzen, A. Owen, K. Scott, J. Barrett, K. Hubacek, G. Baiocchi, A. Paul, E. Dawkins, J. Briggs, D. Guan, S. Suh, and F. Ackerman. 2009. “Input–output analysis and carbon footprinting: an overview of applications.” *Econ. Syst. Res.* 21(3): 187-216.

Monfort, P., and R. Nicolini. 2000. “Regional convergence and international integration.” *J. Urban Econ.* 48(2): 286–306.

Moran, D., and R. Wood. 2014. “Convergence between the Eora, WIOD, EXIOBASE, and Open EU's consumption-based carbon accounts.” *Econ. Syst. Res.* 26(3): 245-261.

Munksgaard, J., and K. A. Pedersen. 2001. “CO_2 accounts for open economies: producer or consumer responsibility?” *Energy policy*, 29(4): 327-334.

Muñoz, P., and K. W. Steininger. 2010. “Austria's CO_2 responsibility and the carbon content of its international trade.” *Ecol. Econ.* 69(10): 2003-2019.

Myers, D. 2013. *Construction economics: A new approach*. 3rd ed. New York: Routledge.

Nässén, J., J. Holmberg, A. Wadeskog, and M. Nyman. 2007. “Direct and indirect energy use and carbon emissions in the production phase of buildings: an input–output analysis.” *Energy*, 32(9): 1593-1602.

Narayanan, B., and T. L. Walmsley. 2008. *Global trade, assistance, and production: The GTAP 7 data base*. Indiana: Center for Global Trade Analysis.

OECD Statistics. 2017a. “Gross domestic product (GDP).” Accessed March 2017. https://www.stats.oecd.org/index.aspx?queryid=60702.

OECD Statistics. 2017b. “Input–output tables.” Accessed March 2017. https://stats.oecd.org/Index.aspx?DataSetCode=IOTS.

OECD Statistics. 2017c. “STAN input-output intermediate import ratio, 2012.” Accessed March 2018. https://stats.oecd.org/Index.aspx?DataSetCode=STAN_IO_INTERM_M.

ONS (U.K. Office for National Statistics) 2014. “United Kingdom input-output analytical tables 2010.” Accessed March 2016. www.ons.gov.uk/ons/rel/input-output/input-output-analytical-tables/2010/index.html.

Otto, D. M., and T.G. Johnson, Eds. 1993. *Microcomputer-based input-output modeling: Applications to economic development*. Boulder: Westview Press, Inc.

Ozkan, F., O. Ozkan, and M. Gunduz. 2012. “Causal relationship between construction investment policy and economic growth in Turkey.” Technol. Forecast. Soc. Chang. 79(2): 362-370.

Parikh, A. 1979. “Forecasts of input–output matrices using the R.A.S. method.” *Rev. Econ. Stat.* 61 (3): 477–481. https://doi.org/10.2307/1926084.

Peters, G. P. 2008. “From production-based to consumption-based national emission inventories.” *Ecol. Econ.* 65(1): 13-23.

Peters, G. P., R. Andrew, and J. Lennox. 2011b. “Constructing an environmentally-extended multi-regional input–output table using the GTAP database.” *Econ. Syst. Res.* 23(2): 131-152. https://doi.org/10.1080/09535314.2011.563234.

Peters, G.P., S.J. Davis, and R. Andrew. 2012. “A synthesis of carbon in international trade.” *Biogeosciences*, 9(8): 3247-3276.

Peters, G. P., and E. G. Hertwich. 2006a. “The application of multi-regional input-output analysis to industrial ecology: Evaluating trans-boundary environmental impacts”. In: Suh, S. (Ed.), *Handbook of Input-Output Analysis for Industrial*

Ecology. Springer, Dordrecht, p. Forthcoming.

Peters, G. P., and E. G. Hertwich. 2006b. "The importance of imports for household environmental impacts." *J. Ind. Ecol.* 10(3): 89-109.

Peters, G. P., and E. G. Hertwich. 2008. "CO_2 embodied in international trade with implications for global climate policy." *Environ. Sci. Technol.* 42(5): 1401-1407.

Peters, G.P., G. Marland, E.G. Hertwich, L. Saikku, A. Rautiainen, and P.E. Kauppi. 2009. "Trade, transport, and sinks extend the carbon dioxide responsibility of countries." *Clim. Change*, 97: 379–388.

Peters, G. P., J.C. Minx, C. L. Weber, and O. Edenhofer. 2011a. "Growth in emission transfers via international trade from 1990 to 2008." *Proc. Natl. Acad. Sci. U. S. A.* 108(2): 8903-8908. https://doi.org/10.1073/pnas.1006388108.

Pietroforte, R., R. Bon, and T. Gregori. 2000. "Regional development and construction in Italy: an input-output analysis, 1959-1992." *Constr. Manage. Econ.* 18(2): 151-159. https://doi.org/10.1080/014461900370780.

Pietroforte, R., and T. Gregori. 2003. "An input–output analysis of the construction sector in highly developed economies." *Constr. Manage. Econ.* 21 (3): 319–327. https://doi.org/10.1080/0144619032000056153.

Pietroforte, R., T. Gregori, and M. Falagario. 2009. "The changing input structure of the US construction industry: A longitudinal analysis." *Constr. Manage. Econ.* 27 (11): 1089–1098. https://doi.org/10.1080/01446190903280443.

Polenske, K. R., and P. Sivitanides. 1990. "Linkages in the construction sector." *Ann. Reg. Sci.* 24 (2): 147–161. https://doi.org/10.1007/BF01579729.

Ram, R. 2009. "Openness, country size, and government size: Additional evidence from a large cross-country panel." *J. Public Econ.* 93 (1–2): 213–218. https://doi.org/10.1016/j.jpubeco.2008.04.009.

Rameezdeen, R., and T. Ramachandra. 2008. "Construction linkages in a developing economy: The case of Sri Lanka." *Constr. Manage. Econ.* 26 (5): 499–506. https://doi.org/10.1080/01446190802017706.

Rao, B. B., and R. Singh. 2010. "Effects of trade openness on the steady-state growth rates of selected Asian countries with an extended exogenous growth model." *Appl. Econ.* 42 (29): 3693–3702. https://doi.org/10.1080/00036840802534468.

Reis, H., and A. Rua. 2009. "An input–output analysis: Linkages versus leakages." *Int. Econ. J.* 23 (4): 527–544. https://doi.org/10.1080/10168730903372323.

Richardson, H. W., and C. H. C. Bae, (Ed.). 2005. *Globalization and urban development*. Germany: Springer-Verlag Berlin Heidelberg.

Rodrigues, J. F., and T. M. Domingos. 2008. “Consumer and producer environmental responsibility: Comparing two approaches.” *Ecol. Econ.* 66(2-3): 533-546.

Rodrigues, J. F., T. M. Domingos, and A. P. Marques. 2010. *Carbon responsibility and embodied emissions: Theory and measurement*. London, UK: Routledge.

Rodríguez, F., and D. Rodrik. 2000. “Trade policy and economic growth: A skeptic’s guide to the cross-national evidence.” *NBER Macroecon. Ann.* 15: 261–325. https://doi.org/10.1086/654419.

Romp, W.E., and J. De Haan. 2005. “Public capital and economic growth: A critical survey.” EIB Papers. 10: 41-70.

Rosenstein-Rodan, P. N. 1943. “Problems of industrialization of eastern and south-eastern Europe.” *Econ. J.* 53: 202-211. http://dx.doi.org/10.2307/2226317.

Ruddock, L., and J. Lopes. 2006. “The construction sector and economic development: the ‘Bon curve’.” *Constr. Manage. Econ.* 24(7): 717-723.

Sassen, S. 2006. *Cities in a World Economy*. Thousand Oaks, California: Pine Forge Press.

Sato, M. 2014. “Embodied carbon in trade: a survey of the empirical literature.” *J. Econ. Surv.* 28(5): 831-861.

Serrenho, A. C., M. Drewniok, C. Dunant, and J. M. Allwood. 2019. “Testing the greenhouse gas emissions reduction potential of alternative strategies for the English housing stock.” *Resour. Conserv. Recy.* 144: 267-275.

Scott, A.J. (Ed.) 2001. *Global City-Regions: Trends, Theory, Policy*. Oxford :Oxford University Press.

Singapore Dept. of Statistics. 2010. *Singapore input–output tables 2005*. Singapore: Dept. of Statistics, Ministry of Trade & Industry.

Singapore Dept. of Statistics. 2012. *Singapore input–output tables 2007*. Singapore: Dept. of Statistics, Ministry of Trade & Industry.

Singapore Dept. of Statistics. 2014. *Singapore supply and use, and input–output tables 2010*. Singapore: Dept. of Statistics, Ministry of Trade & Industry.

Singapore Dept. of Statistics. 2016a. *Singapore Energy Statistics 2016*. Singapore: Dept. of Statistics, Ministry of Trade & Industry.

Singapore Dept. of Statistics. 2016b. *Yearbook of statistics Singapore 2015*. Singapore: Dept. of Statistics, Ministry of Trade & Industry.

Singapore Dept. of Statistics 2017a. "M014541-GDP at current market prices, by industry (SSIC 2015), annual." Accessed July 2017. http://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=12360.

Singapore Dept. of Statistics 2017b. "Singapore supply, use and input–output tables 2012." Accessed March 2017. https://www.singstat.gov.sg/-/media/files/find_data/economy/io2012.xls.

Singapore Dept. of Statistics 2017c. "Singapore supply, use and input–output tables 2013." Accessed March 2017. https://www.singstat.gov.sg/-/media/files/find_data/economy/io2013.xls.

Sposi, M. J. 2015. "Evolving comparative advantage, sectoral linkages, and structural change." Federal Reserve Bank of Dallas Globalization and Monetary Policy Institute. Accessed May 2017. https://www.dallasfed.org/assets/documents/institute/wpapers/2015/0231.pdf.

Steen-Olsen, K., A. Owen, E. G. Hertwich, & M. Lenzen. 2014. "Effects of sector aggregation on CO_2 multipliers in multiregional input–output analyses." *Econ. Syst. Res.* 26(3): 284-302.

Steininger, K., C. Lininger, S. Droege, D. Roser, L. Tomlinson, and L. Meyer. 2014. "Justice and cost effectiveness of consumption-based versus production-based approaches in the case of unilateral climate policies." *Global Environ. Change*, 24:75-87.

Steininger, K., C. Lininger, L. H. Meyer, P. Muñoz, and T. Schinko. 2016. "Multiple carbon accounting to support just and effective climate policies." Nat. Clim. Change. 6(1): 35.

Steininger, K. W., P. Munoz , J. Karstensen, G. P. Peters, R. Strohmaier, & E. Velázquez. 2018. "Austria's consumption-based greenhouse gas emissions: Identifying sectoral sources and destinations." *Glob. Environ. Change-Human*, 48: 226-242.

Strassmann, P. 1970. "The construction sector in economic development." *Scot. J. Polit. Econ.* 17: 391-409.

Su, B., H. C. Huang, B. W. Ang, and P. Zhou. 2010. "Input–output analysis of CO_2 emissions embodied in trade: the effects of sector aggregation." *Energy Economics*, *32*(1): 166-175.

Sudmant, A., A. Gouldson, J. Millward-Hopkins, K. Scott, & J. Barrett. 2018. "Producer cities and consumer cities: Using production-and consumption-based carbon accounts to guide climate action in China, the UK, and the US." *J. Clean Prod.* 176: 654-662.

Suttinon, P., S. Nasu, T. Ihara, N. Bongochgetsakul, and K. Uemoto. 2013. "Water resources management in shikoku region by inter-regional input–output table." In *Review of Urban & Regional Development Studies: Journal of the Applied Regional Science Conference*. 25(2): 107-127.

Sung, Y. W. 1979. “Input-output table of the Hong Kong economy (1973).” *Hong Kong Series*. Shatin, Hong Kong: Economic Research Centre, Chinese Univ. of Hong Kong.

Taylor, P.J. 2004. *World City Network: A Global Urban Analysis*. London, UK: Routledge.

Tian, X., M. Chang, F. Shi, and H. Tanikawa. 2014. “How does industrial structure change impact carbon dioxide emissions? A comparative analysis focusing on nine provincial regions in China.” *Environ. Sci. Policy*. 37: 243-254.

Toh, M. H. 1998. “The RAS approach in updating input–output matrices: An instrumental variable interpretation and analysis of structural change.” *Econ. Syst. Res.* 10 (1): 63–78. https://doi.org/10.1080/09535319800000006.

Tse, R. Y. C., and S. Ganesan. 1997. “Causal relationship between construction flows and GDP: evidence from Hong Kong.” *Constr. Manage. Econ.* 15: 371-376.

Tukker, A., & E. Dietzenbacher. 2013. “Global multiregional input–output frameworks: an introduction and outlook.” *Econ. Syst. Res.* 25(1): 1-19.

Turin, D. A. 1969. *The construction industry: Its economic significance and its role in development.* London: Univ. College, Environmental Research Group.

Turin, D. A. 1973. *Construction and development (2nd ed.)*. London: University College, Environmental Research Group.

Turner, K., M. Lenzen, T. Wiedmann, & J. Barrett. 2007. “Examining the global environmental impact of regional consumption activities—Part 1: A technical note on combining input–output and ecological footprint analysis.” *Ecol. Econ.* 62(1): 37-44.

UNEP (United Nations Environment Programme) 2014. *Climate finance for cities and buildings - a handbook for local governments*. UNEP Division of Technology, Industry and Economics (DTIE), Paris.

UNEP (United Nations Environment Programme) 2017. *Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Status Report 2017*. United Nations Environment Programme, Paris.

Uy, T., K. M. Yi, and J. Zhang. 2013. “Structural change in an open economy.” *J. Monetary Econ.* 60(6): 667-682.

Villar, O. A. 1999. “Spatial distribution of production and international trade: a note.” *Reg. Sci. Urban Econ.* 29(3): 371-380.

Voon, T. J., and L. S. Ho. 2001. *Economic impacts of logistics infrastructure development: The case of Hong Kong*. Huntington, NY: Nova Science Publishers.

Wang, R. 2011. “Autos, transit and bicycles: comparing the costs in large Chinese cities." *Transp. Policy*. 18 (1):139-146.

Weber, C. L. 2008. "Uncertainties in constructing environmental multiregional input-output models." In *International input-output meeting on managing the environment*, Seville, Spain.

Weber, C. L., and H. S. Matthews. 2007. "Embodied environmental emissions in US international trade, 1997− 2004." *Environ. Sci. Technol.* 41(14): 4875-4881.

Wells, J. 1986. *The Construction Industry in Developing Countries: Alternate Strategies for Development*. London: Croom Helm Ltd.

West, G. R. 1995. "Comparison of input–output, input–output + econometric and computable general equilibrium impact models at the regional level." *Econ. Syst. Res.* 7(2): 209-227.

Wiebe, K. S., M. Bruckner, S. Giljum, and C. Lutz. 2012. "Calculating energy-related CO_2 emissions embodied in international trade using a global input–output model." *Econ. Syst. Res.* 24(2): 113-139.

Wiedmann, T. 2009a. "A review of recent multi-region input–output models used for consumption-based emission and resource accounting." *Ecol. Econ.* 69(2): 211-222.

Wiedmann, T. 2009b. "Carbon footprint and input-output analysis-an introduction." *Econ. Systems Res*. 21: 175–186.

Wiedmann, T., and M. Lenzen. 2018. "Environmental and social footprints of international trade." *Nat. Geosci.* 11(5): 314-321.

Wiedmann, T., H. C. Wilting, M. Lenzen, S. Lutter, and V. Palm. 2011. "Quo vadis MRIO? Methodological, data and institutional requirements for multi-region input–output analysis." *Ecol. Econ.* 70 (11): 1937–1945. https://doi.org/10.1016/j.ecolecon.2011.06.014.

Wiedmann, T., R. Wood, J. C. Minx, M. Lenzen, D. Guan, & R. Harris. 2010. "A carbon footprint time series of the UK–results from a multi-region input–output model." *Econ. Syst. Res.* 22(1): 19-42.

Wiedmann, T., R. Wood, J. Minx, M. Lenzen, R. Harris. 2008. "Emissions embedded in UK trade—UK-MRIO model results and error estimates." In *International Input–Output Meeting on Managing the Environmen*t, Seville, Spain.

Wilting, H. C., & K. Vringer. 2009. "Carbon and land use accounting from a producer's and a consumer's perspective–an empirical examination covering the world." *Econ. Syst. Res.* 21(3): 291-310.

Wong, J. M., Y. H. Chiang, and T. S. Ng. 2008. "Construction and economic development: the case of Hong Kong." *Constr. Manage. Econ.* 26(8): 815-826.

Yanikkaya, H. 2003. “Trade openness and economic growth: A cross-country empirical investigation.” *J. Dev. Econ.* 72 (1): 57–89. https://doi.org/10.1016/S0304-3878(03)00068-3.

Yiu, C. Y., X. H. Lu, M. Y. Leung, and W. X. Jin. 2004. “A longitudinal analysis on the relationship between construction output and GDP in Hong Kong.” *Constr. Manage. Econ.* 22(4): 339-345.

Young, A. 1992. “A tale of two cities: Factor accumulation and technical change in Hong Kong and Singapore.” *NBER Macroecon. Ann.* 7: 13–54. https://doi.org/10.1086/654183.

Yuan, J., C. Na, Q. Lei, M. Xiong, J. Guo, and Z. Hu. 2018. “Coal use for power generation in China.” *Resour. Conserv. Recy.* 129: 443-453.

Zhang, X., and F. Wang. 2016. “Hybrid input-output analysis for life-cycle energy consumption and carbon emissions of China’s building sector.” *Build. Environ.* 104: 188-197.

Zhang, Z., Y. Zhao, B. Su, Y. Zhang, S. Wang, Y. Liu, and H. Li. 2017. “Embodied carbon in China’s foreign trade: An online SCI-E and SSCI based literature review.” *Renew. Sust. Energ. Rev.* 68: 492-510.

Zimring, F. E., J. Fagan, and D. T. Johnson. 2010. “Executions, deterrence, and homicide: A tale of two cities.” *J. Empirical Legal Stud.* 7 (1): 1–29. https://doi.org/10.1111/j.1740-1461.2009.01168.x.