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Abstract

We examine how the structure of Australian production and trade has been affected by the expansion of global production networks. As conventional measures of international trade do not fully capture the impact of global supply chains, we present complementary estimates of value-added trade for Australia. These value-added trade estimates suggest that the United States and Europe are more important for export demand than implied by conventional trade statistics, as some Australian content is exported to those locations indirectly via east Asia. The estimates also highlight the importance of the services sector to Australian trade, as the services sector is integral to producing goods exports.

We also find that, compared to thirty years ago, Australian production now involves more stages of production, a greater share of production occurs overseas, and more production occurs towards the start of the supply chain. For Australia, these structural adjustments mainly occurred during the 1990s, and we provide evidence that similar adjustments have occurred elsewhere in the world driven by several factors, including lower international trade costs, deregulation of markets that produce intermediate goods and services, and economic development in emerging economies, such as China.

JEL Classification Numbers: D57, E01, F12, F60, L16, L23

Keywords: fragmentation, supply chains, trade costs, value-added trade

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1. Introduction

Structural change in the Australian economy has been a prominent issue in recent years (Connolly and Lewis 2010). We provide a new perspective on structural change by investigating how the domestic supply chain has evolved in recent decades. We also examine how the structure of Australian international trade has evolved in response to the development of global supply networks. The paper is divided into three parts.

First, we investigate how Australian trade has been affected by the growing fragmentation of production across international borders through global supply chains. Australia's trade linkages have been affected by the expansion of global production networks; Australia typically exports commodities that are used to produce goods and services that are, in turn, exported to other markets. We present new estimates of value-added trade for Australia that complement conventional trade statistics. The value-added trade estimates suggest that the United States and Europe are more important for export demand than implied by conventional trade statistics, as some Australian content is indirectly exported there via east Asia. The value-added trade estimates also highlight the extent to which the services sector is integral to the production of goods exports.

Second, we quantify how the Australian supply chain has evolved in recent decades using novel measures based on historical input-output tables. Overall, compared to a few decades ago, the Australian economy now involves more stages of production, with a greater share of production occuring overseas and more domestic production occuring earlier in the supply chain. That is, production in the Australian economy has become more 'vertically fragmented', more 'offshore' and more 'upstream'. Most of these adjustments occurred over the 1990s, which suggests that economic reform and competitive pressures due to 'globalisation' were contributing factors.

Third, we undertake econometric analysis to explore how the level of vertical fragmentation across countries and industries has been affected by factors such as lower international trade costs and deregulation of product markets.

2. The Structure of Australia's International Trade

2.1 Background

The structure of international trade has changed dramatically in recent decades. A key feature of this structural change has been the increasing role of global supply chains. Global supply (or value) chains are production networks that span multiple countries, with at least one country importing inputs and exporting output. The production of a single good, such as a mobile phone or television, typically now takes place across several countries, with each country specialising in a particular phase or component of the final product (Riad *et al* 2012).

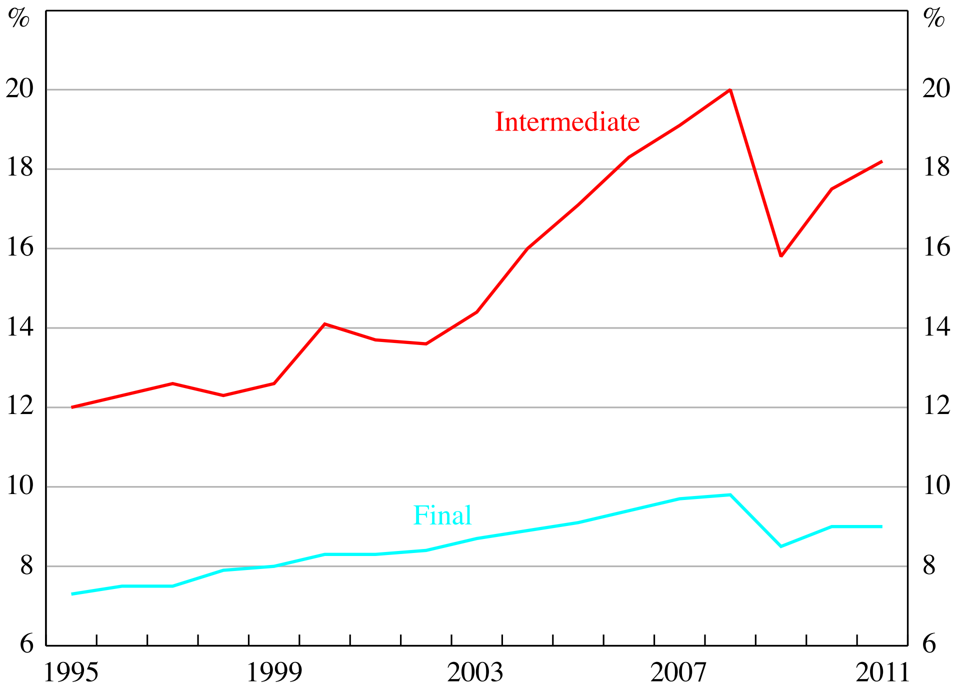
International trade has risen, as a share of world GDP, from less than 20 per cent in the mid 1990s to more than 25 per cent more recently (Figure 1). More notably, the growth in trade has been dominated by trade in intermediate inputs – goods and services that are not consumed directly but are used to produce other goods and services.[1] The rapid growth in trade in intermediate inputs has been facilitated by factors that have lowered the cost of trade, such as: advances in transportation and communication technologies; the liberalisation of trade; the removal of foreign capital controls; and the growing industrial capacity of emerging economies.[2]

A related feature of this structural change in recent decades has been the growth in intraregional trade and the emergence of regional supply networks. This has been particularly apparent in east Asia where a regional supply network has developed that specialises in producing components for computers and other electronic devices (Craig, Elias and Noone 2011). China has played a central

1 The concept of trade in intermediate inputs (or 'supply-chain trade') is closely related to the notion of 'intra-industry trade' (Baldwin and Lopez-Gonzalez 2013). However, we focus on supply-chain trade as we believe it is a broader concept that encompasses both inter-industry and intra-industry trade.

2 Some of the trend increase in the value of intermediate exports relative to GDP over the mid to late 2000s is due to a relative price increase and, in particular, the rise in world commodity prices.

Figure 1: World Exports
Current prices, per cent of GDP

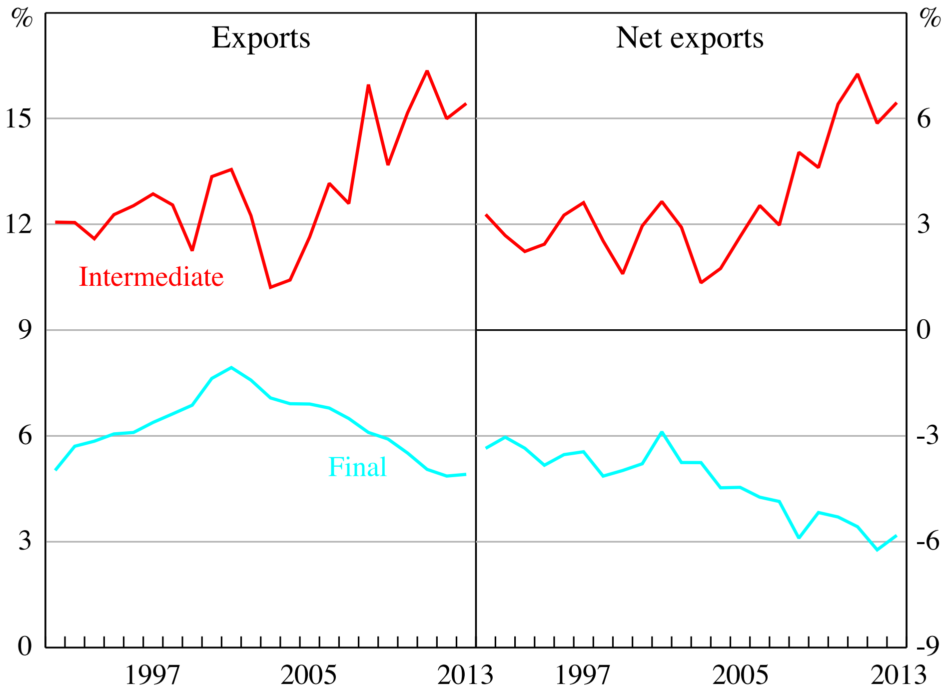


Source: World Input-Output Database

role in the development of this supply network, following its accession to the World Trade Organization (WTO) in 2001. China has experienced large inflows of foreign direct investment and has become a major destination for the outsourcing and offshoring of global manufacturing. It is now a core market for intermediate products, such as resource commodities from Australia and complex manufactured components from Asian countries. These intermediate products are used to produce final goods, many of which are exported to advanced economies.

The growing prevalence of global supply chains, and the related rise of trade in intermediate inputs, has a direct bearing on the structure of Australian trade. Australian exports of intermediate goods and services have consistently exceeded exports of final goods and services over the past two decades (left-hand panel of Figure 2). Moreover, the gap between the two types of trade has widened over recent years. This reflects the resource boom, as a significant share of Australia's resource commodities are exported to east Asia where they are used to produce goods and services that are either sold within east Asia or re-exported to other parts of the world. Australia's growing integration into global supply networks is illustrated by the fact that Australia is increasingly a net exporter of intermediate

Figure 2: Australia – Trade
Current prices, per cent of GDP



Sources: ABS; Authors' calculations

goods and services, and a net importer of final goods and services (right-hand panel of Figure 2).[3]

2.2 Measurement of International Trade

Conventional measures of international trade based on gross flows of exports and imports do not fully capture the impact of global supply chains on Australian trade. We construct estimates of 'value-added trade', which complement conventional measures, and illustrate how the fragmentation of production across international borders has affected Australian trade. Unlike conventional trade statistics, value-added trade statistics identify the contributions of each country and each industry to the final value of an exported good or service. While conventional trade statistics identify the initial destination of a country's exports, value-added measures identify both the initial and effective final export destinations. A comparison of

3 The rise in the value of net exports of intermediate goods and services (relative to GDP) over recent years is also partly due to higher prices for Australia's commodity exports, such as iron ore and coal.

gross trade and value-added trade statistics provides a guide to the extent to which demand shocks stemming from final export destinations indirectly affect Australia.

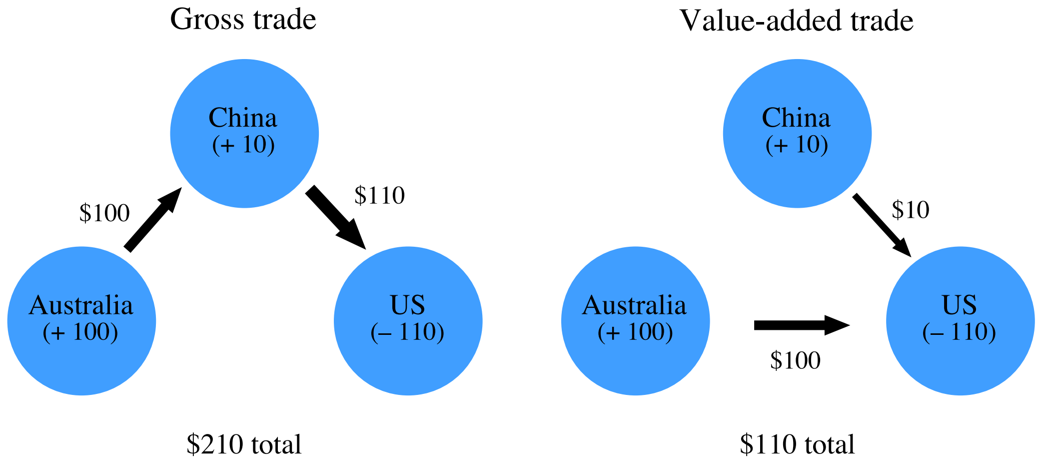
Conventional trade statistics typically measure the value of goods and services each time they cross a border. These estimates form the basis of international trade measured in the national accounts and balance of payments and are the most reliable and timely source of information on imports and exports. But gross trade flows do not necessarily identify the countries and industries that contribute to the production of the traded good or service; instead, the full value is attributed to the last country and industry that shipped the product. A component of an exported good that crosses international borders multiple times in the process of becoming a finished good is counted multiple times under conventional measures. As a result, gross measures of trade flows can inflate the amount of trade (relative to domestic output) and provide a distorted view of a country's bilateral trade flows.

These measures of trade reflect the way in which economic activity is measured within and across national borders. GDP, the most commonly used indicator of a nation's domestic economic activity, records only expenditures on final goods and services (or 'final demand') and excludes expenditures on intermediate goods and services (or 'intermediate consumption'). GDP therefore measures the value-added in the production process. For example, suppose an iron ore miner produces iron ore worth \$100 (without any intermediate inputs) and sells it to another firm, which uses the iron ore as an intermediate input to produce a refrigerator, which is then sold domestically as a finished good for \$110. The 'gross output' of the economy is equal to \$210, while the 'value-added' (as measured by final expenditure) is equal to \$110. The national accounts will record the 'value-added' of the finished good (\$110) as GDP, effectively avoiding counting the value of intermediate inputs multiple times.

To take a similar example, consider the trade flows depicted in Figure 3. Suppose the iron ore producer exports the iron ore, produced entirely within Australia, worth \$100 to a firm in China. The firm in China then processes the iron ore (adding value of \$10) to create a refrigerator which is exported to the United States, where it is sold as a finished good (for a full value of \$110). The conventional measure of trade would record total global exports and imports of \$210, despite only \$110 of value-added being generated in production. The conventional measure would show that the United States has a trade deficit of

$110 with China, and no trade at all with Australia, despite Australia being the chief beneficiary of the final demand of the United States. If, instead, the trade flows were measured in value-added terms, total trade would equal $110. Also, the trade deficit of the United States with China would be only $10, and it would run a deficit of $100 with Australia.

Figure 3: Comparison of Gross Trade and Value-added Trade



This example highlights the two main issues with the conventional measurement approach: gross trade provides an upper-bound estimate of the contribution of trade to economic activity, and the composition of each country's trade balance does not necessarily reflect value-added trade flows. However, while bilateral gross and value-added trade balances can differ, the aggregate level of each country's trade balance is the same when measured in either gross or value-added terms. In the example, Australia has an aggregate surplus of $100, China has an aggregate surplus of $10, and the United States has an aggregate deficit of $110 under either approach to measuring international trade.

2.3 The World Input-Output Database

In recognition of these problems, an alternative measure of trade known as 'value-added trade' has recently been developed (Johnson and Noguera 2012). The measurement of value-added trade requires very detailed information on how exports and imports are used as intermediate inputs by various countries and industries. The World Input-Output Database (WIOD) combines information from national input-output databases with bilateral trade data to construct harmonised annual world input-output tables for 35 industries in 40 countries over the period

1995 to 2011.[4] This database seeks to identify all the input-output linkages between countries and industries and can be used to construct measures of value-added trade. The WIOD can also be used to trace the path of a country's intermediate exports through global supply chains and identify the effective final destination for the domestic content of a country's exports.[5]

Value-added trade estimates complement, but do not replace, conventional trade statistics as the necessary information on inputs and outputs is typically produced with a significant publication lag (the latest WIOD data cover the period up to 2011). Gross trade statistics for Australia, on the other hand, are produced on a monthly basis with a very short publication lag. Gross trade statistics, therefore, provide a timelier indicator of trends in Australian trade. Furthermore, the construction of value-added trade statistics requires several assumptions, which are outlined in Appendix A. The WIOD can also be used to construct measures of the domestic supply chain that will be discussed in Section 4.

3. Value-added Trade and the Australian Economy

Figure 4 presents the value of both final and intermediate exports measured on the conventional gross trade basis, for Australia, the United States, China and the world as a whole.[6] Exports of intermediate goods and services comprise a relatively high share of total exports for Australia. According to the WIOD, Australian intermediate exports have risen from around 75 per cent of total exports in the mid 1990s to more than 80 per cent of exports more recently. A similar pattern can be seen for both the United States and world exports. In contrast, final

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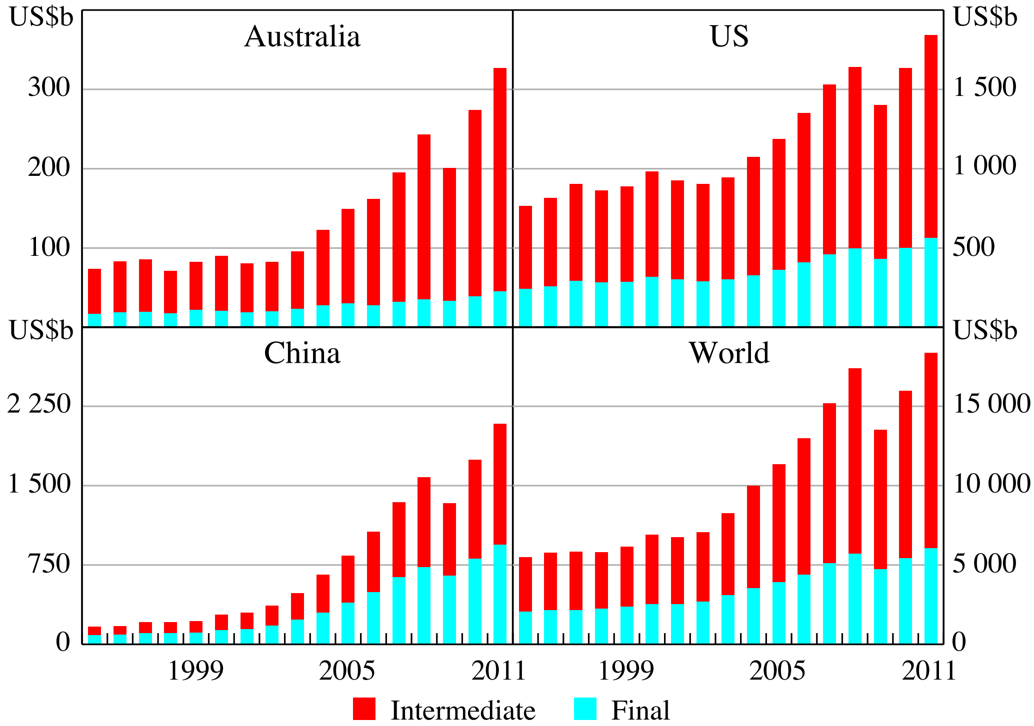
4 Timmer (2012) provides an overview of the contents, sources and methods used in compiling the World Input-Output Database, and the associated database can be found at http://www.wiod.org.

5 A joint OECD-WTO initiative has also developed a database of value-added trade indicators, available at http://www.oecd.org/industry/ind/measuringtradeinvalue-addedanoecd-wtojointinitiative.htm. The OECD-WTO database has a similar coverage of countries and industries as the WIOD, but it currently only covers the individual years 1995, 2000, 2005, 2008 and 2009. For these years, the estimates of value-added trade for Australia are very similar to those obtained from the WIOD.

6 Due to the aggregation of many countries into a 'rest of the world' region, the estimates for world exports understate the total level of world trade (as the estimate does not record trade between countries within this particular region).

goods and services comprise a much higher share of Chinese exports, reflecting China's role as an assembly point in many global supply chains.

Figure 4: Gross Exports



Source: World Input-Output Database

To compare estimates of value-added trade with conventional estimates of gross trade, it is useful to construct a summary indicator known as the 'VAX ratio' (Johnson and Noguera 2012). This is the ratio of value-added exports to gross exports and is an approximate measure of the domestic value-added content of exports. The VAX ratio can be constructed for each bilateral trading pair or each industry of a given country. By definition, the bilateral VAX ratio is less than one when value-added exports are less than gross exports, which can occur either because some of the value of the exports is imported from another country or because the trading partner re-exports the content to another destination. The bilateral VAX ratio is greater than one when value-added exports exceed gross exports. This can occur when some of the country's exports reach the trading partner directly (as measured by gross exports) and the rest indirectly (when domestic value-added is embodied in a third country's exports to that partner). A similar logic applies for understanding variation in the measured VAX ratio across individual sectors of the economy. The VAX ratio for a sector can be greater than one if the sector contributes more as an intermediate input to the value of exports of other sectors than those sectors contribute to the value of its own exports. Conversely, the VAX ratio for a sector can be less than one if intermediate inputs from other sectors, or from imports, contribute more to the value of the sector's exports than it contributes to the exports of other sectors.[7]

3.1 Value-added Trade by Trading Partner

In terms of trading partners, the main difference between Australia's gross and value-added exports is the importance of emerging economies relative to the advanced economies. According to the WIOD, between 2002 and 2011, North America and Europe accounted for 23 per cent of Australia's gross exports, but about 32 per cent of value-added exports as some Australian production is exported to the advanced economies indirectly via supply chains in Asia (Table 1). Conversely, exports to China, Indonesia, Korea and Taiwan together accounted for only about 25 per cent of Australia's value-added exports, but around 32 per cent of gross exports, as some of the exports to Asia are used as intermediate inputs to produce final goods and services that are re-exported to other countries.[8]

Looking at how the bilateral VAX ratios have evolved over time, there has been a steady increase in the value-added content of Australia's trade with North America and Europe but a gradual decline in the value-added content of Australia's trade with east Asia (Figure 5). The volume of both gross and value-added exports to east Asia, and particularly China, has grown markedly, but an increasing share of Australian exports to the region is processed and re-exported rather than consumed domestically, which has caused the VAX ratio to trend down. These trends mainly reflect the increasing integration of east Asia into global value chains; the effect is particularly pronounced during the 2000s.

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7 A country's total value-added trade cannot exceed its gross trade, which implies that the overall VAX ratio cannot be greater than one; only bilateral (or sectoral) value-added trade can exceed gross trade.

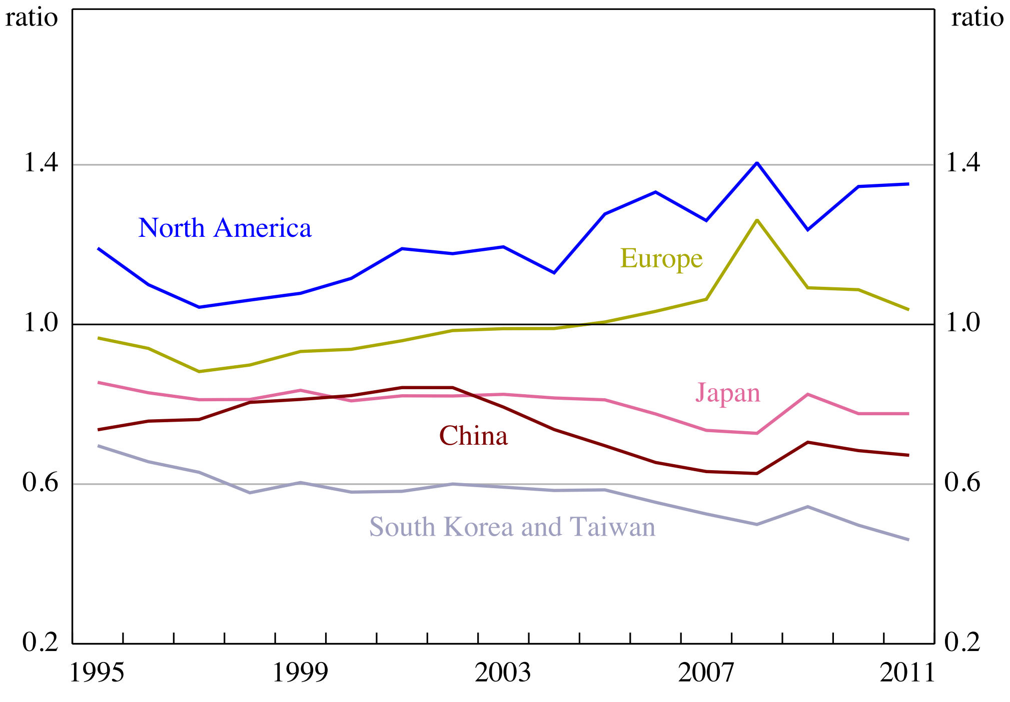
8 These estimates assume that, for each industry, the import content of production is the same for exported and non-exported products. But, due to China's use of export-processing trade zones, Chinese exports tend to have higher imported content than goods and services produced for domestic consumption. This implies that the WIOD estimates may overstate China's share of Australian value-added exports.

Table 1: Australian Exports by Trading Partner
2002–2011 average

Trading partner	Share of gross exports	Share of value-added exports	Difference Per cent	VAX ratio
North America	10.3	15.8	5.6	1.27
Europe	12.3	15.7	3.4	1.05
Japan	15.6	15.0	–0.5	0.79
China	17.9	15.0	–2.9	0.70
South Korea and Taiwan	11.4	7.6	–3.8	0.54
Other trading regions	32.5	30.8	–1.7	0.79
Total	100.0	100.0	0.0	0.82

Source: World Input-Output Database

Figure 5: Australia – VAX Ratio by Destination



Sources: Authors' calculations; World Input-Output Database

3.2 Value-added Trade by Sector

The sectoral mix of Australia's trade is also different when measured in value-added rather than gross terms (Table 2).[9] The sectoral breakdown of Australian exports in value-added terms indicates which sectors ultimately benefit from trade.

Table 2: Value-added Trade by Sector
2002–2011 average

Sector	Share of gross exports	Share of value-added exports	Difference Per cent	VAX ratio
Manufacturing	37.6	18.9	–18.7	0.41
Resources	39.9	37.2	–2.7	0.77
Construction and utilities	0.2	3.1	2.9	11.93
Services	22.3	40.8	18.5	1.51
Total	100.0	100.0	0.0	0.82

Source: World Input-Output Database

Services exports account for a much higher share of Australia's exports in value-added terms (41 per cent) than in gross terms (22 per cent) (Table 2). Australia's exports, therefore, embody a higher share of services than conventionally measured. Most services are non-tradeable so the service sector produces a small share of direct exports as captured by the gross trade statistics. However, services are used extensively as inputs to produce manufactured and resource exports. For example, services, such as marketing and distribution, account for a relatively large share of the final value of manufactured goods. Furthermore, service industries tend to be labour intensive, requiring relatively few intermediate inputs in their own production.

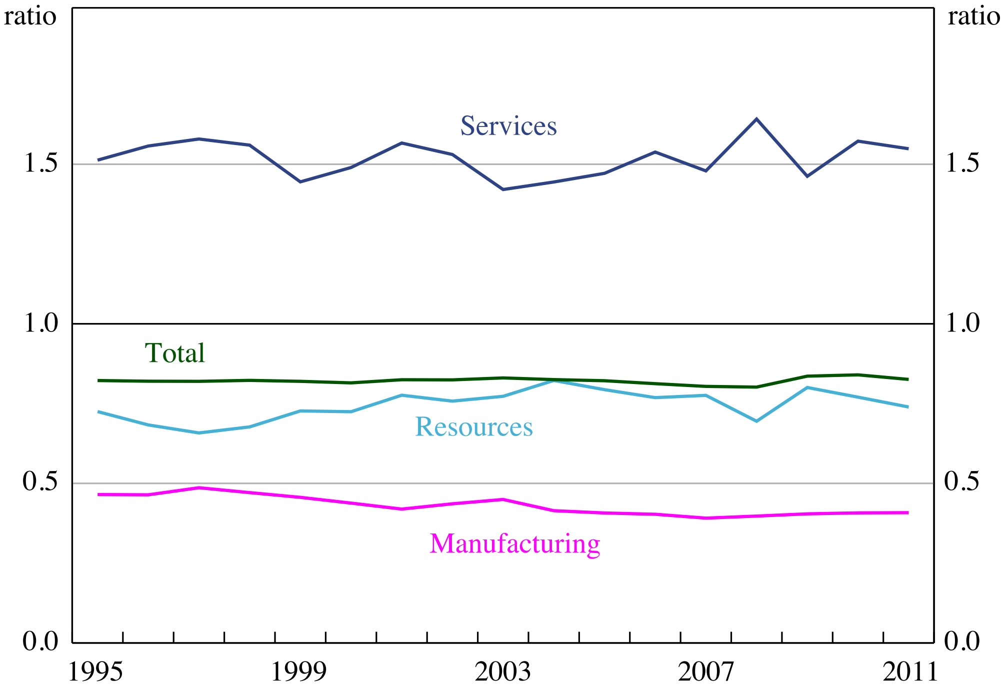
Conversely, the manufacturing sector comprises a much smaller share of value-added trade (19 per cent) than of gross trade (38 per cent) (Table 2). These estimates indicate that about half of the value-added in Australia's manufacturing

9 The WIOD classification of industries is very similar to that of the 2-digit Australian and New Zealand Standard Industrial Classification (ANZSIC) system, which is used by the Australian Bureau of Statistics (ABS). Australian gross exports of resources and manufactured goods are slightly higher, on average, based on the WIOD measure compared with the ABS measure, but these differences are unlikely to have a significant effect on the sectoral VAX ratios. Reclassifying industries into the manufacturing and resources sectors based on the split used by Rayner and Bishop (2013) has little effect on the measured VAX ratios.

exports comes from either imported inputs or the inputs of other domestic sectors. For the resource sector, the share of value-added trade (37 per cent) is similar to that of gross trade (40 per cent). Production in the resource sector extensively uses intermediate inputs from other sectors, but the sector also produces a large share of the intermediate inputs used by other sectors, in the form of raw materials. These two effects largely offset each other.

The sectoral VAX ratios have been fairly constant over time, although there has been a slight decline in the manufacturing VAX ratio over the past couple of decades (Figure 6).

Figure 6: Australia – VAX Ratio by Sector



Sources: Authors' calculations; World Input-Output Database

3.3 Aggregate Value-added Trade

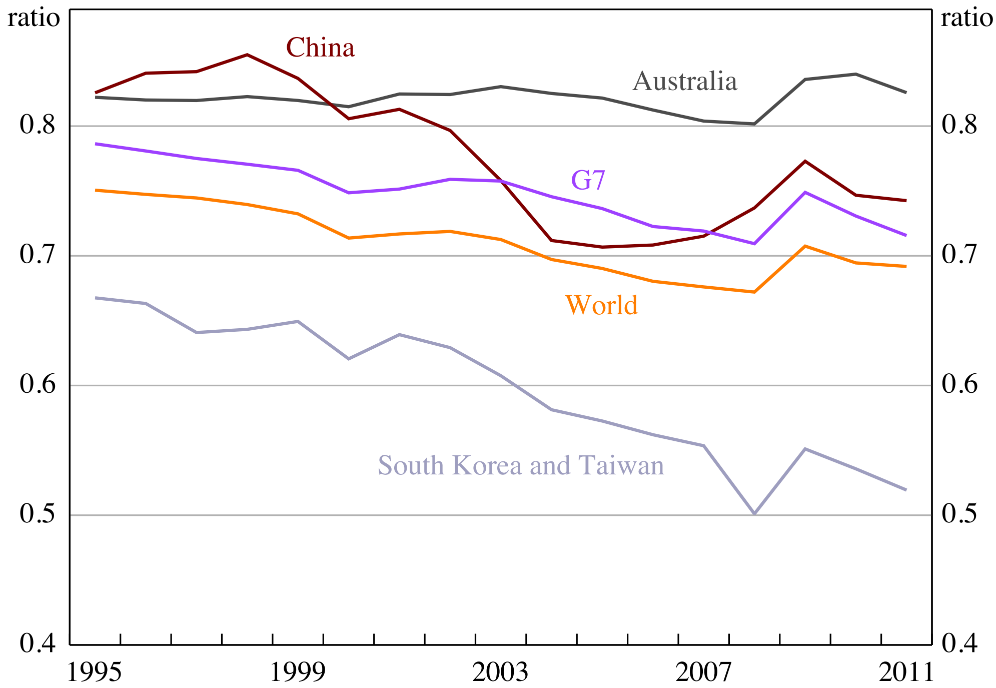
The VAX ratio can also be constructed for Australia's aggregate trade by comparing total value-added exports to total gross exports. The aggregate VAX ratio implies that the share of value-added in Australian exports is about 82 per cent (Figure 7).[10] This is relatively high by international standards; the share of value-added in world exports is about 69 per cent. The high share of value-added content in Australia's trade mainly reflects two factors – the country's geographic isolation and its large endowment of natural resources. First, Australia's geographic isolation means that it is rarely involved in the intermediate processing stages of most global supply chains.[11] Second, the export of natural resources requires few imported inputs so the high share of resources in Australia's export base implies that most of the value-added of Australian exports is due to domestic production. In contrast, the value-added content of trade is typically low for countries close to production hubs that are heavily involved in production sharing, such as those in east Asia, Europe and North America. These factors also largely explain why the value-added content of Australian trade has declined by much less than it has for most other countries since the mid 1990s.[12]

10 Total value-added exports are not simply the domestic content of total gross exports, but the amount of domestic content that is ultimately consumed as final demand outside the country. Value-added exports exclude 'reflected exports', that is, the estimates exclude domestic content that is processed outside the country and then imported (e.g. Australia importing a Japanese car that contains Australian iron ore). But reflected exports represent only a small share of Australia's overall trade, so the VAX ratio provides a reasonable guide to the proportion of domestic content in overall exports.

11 These factors also contribute to the country's relatively low level of trade as a share of GDP (Guttmann and Richards 2004).

12 The VAX ratio is measured in nominal terms and can, therefore, be affected by changes in the prices of intermediate inputs and gross outputs. For example, there is a clear downward spike in the aggregate VAX ratios of most countries in 2008. This pattern is, at least in part, due to large fluctuations in commodity prices around that time. For instance, commodity prices rose sharply in 2008, which would have boosted the relative price of intermediate inputs, and reduced the value-added content of exports for most countries and industries.

Figure 7: Aggregate VAX Ratios



Sources: Authors' calculations; World Input-Output Database

4. The Structure of Australia's Domestic Supply Chain

4.1 Measuring the Domestic Supply Chain

The fragmentation of production across firms and industries within the domestic economy has also been an important feature of structural change in Australia. To the best of our knowledge, there has been no research into the structure and evolution of the domestic supply chain in Australia.

Ideally, to measure changes in the structure of the Australian supply chain we would have information on transactions at the plant-level between buyers and suppliers. Unfortunately, these data are not available for Australia. Nonetheless, we can extract useful information on the length of supply chains and an industry's position along a supply chain from industry-level input-output tables.

The most conventional measure of inter-industry linkages and supply chains is the ratio of intermediate consumption to gross output. As mentioned earlier, gross output is the total market value of goods and services produced in an economy, which can be divided into value-added and the cost of intermediate inputs (or intermediate consumption). Value-added reflects the returns to labour and capital used by the industry. The higher the share of output that is accounted for by intermediate consumption, the more of the industry's value is added outside of the industry. A high share of intermediate consumption indicates that production in the industry is 'vertically fragmented'.

While the ratio of intermediate consumption to gross output is easily estimated, it does not account for the full complexity of inter-industry linkages involved in production, nor the length of the supply chain between a good's production and its consumption. More sophisticated measures have been developed to describe the relative position of an industry in the value-added chain – 'fragmentation' and 'upstreamness' (Fally 2012).

The 'fragmentation' statistic measures the number of stages involved in the production of a good or service and how the overall value-added of the product is distributed along these stages. Fragmentation is calculated using a good or service's *inputs*. Fragmentation is defined as one plus a weighted sum of the number of stages involved in the production of good i's intermediate inputs, where the weight corresponds to the value added by each input. The index takes the value of one if there is a single production stage in the final industry and increases with the length of the production chain.

For example, if half of the value of industry A's gross output is accounted for by intermediate inputs from industry B, and the inputs from industry B do not require any inputs themselves, then the 'fragmentation' measure of industry A will be $1+0.5 = 1.5$. If, however, half of the value of industry B's output is spent on intermediate inputs from industry C (which themselves do not require any intermediate inputs) then the fragmentation measure of industry A will be $1+0.5\times(1+0.5) = 1.75$.

An industry's supply chain will, therefore, be more (or less) fragmented depending on the extent to which the production of its final output depends on intermediate goods which are themselves more (or less) fragmented. Low fragmentation does not necessarily mean a 'short' supply chain, but could indicate that the bulk of value-added is concentrated at only one or two stages of a long supply-chain, rather than being dispersed across the length of the chain.

The fragmentation measure is mathematically comparable to the measure of *total backward linkages* of a sector in traditional input-output theory, first proposed in the late 1950s and equivalent to measures of sector-to-economy 'output multipliers' (Miller and Blair 2009). The interpretation of fragmentation as a sector's weighted average number of production stages clarifies the definition of backward linkages, while avoiding the shortcomings of the 'multiplier' interpretation.[13]

The 'upstreamness' statistic measures the average number of stages occurring between production and final demand of a good or service. Upstreamness is calculated using the good or service's *outputs*. It is defined as one plus a weighted sum of the number of stages between production of the goods that take output from industry i as an input and these goods' own final demand, where the weight corresponds to the fraction of industry i's total production going to each use.

For example, if half of the gross output of industry A is used for final consumption and half is used as intermediate inputs by industry B, which produces entirely for final consumption, then the measured upstreamness of industry A will be $1+0.5=1.5$. If, however, only half of the value of industry B's output is used for final consumption, with the other half used as intermediate inputs by industry C (which produces entirely for final consumption), then the upstreamness measure of industry A will be $1+0.5\times(1+0.5)=1.75$.

Industries with low measured upstreamness produce largely for final consumption. An industry that mainly produces for intermediate use will be more upstream, particularly if it produces for other industries that are also upstream.[14] The measurement of fragmentation and upstreamness requires detailed input-output data, giving the relative values of the intermediate inputs that each industry requires for production. We use a combination of ABS input-output tables and

13 For details on these inherent problems in deriving sector-to-economy output multipliers from input-output tables see Gretton (2013).

14 The upstreamness measure is mathematically comparable to the measure of *total forward linkages* of a sector in traditional input-output theory (see Jones (1976)), which have also been interpreted as 'supply-driven' or 'cost-push' multipliers, as opposed to the 'demand-driven' multipliers which are mathematically related to the fragmentation measure (see Miller and Blair (2009)). Antràs *et al* (2012) show how an equivalent measure of distance to final demand can be reached using an alternative derivation.

the WIOD to estimate the supply chain statistics. The calculations are explained in Appendix B.

4.2 The Domestic Supply Chain in Australia

The two supply chain measures indicate that the Australian domestic supply chain involves about two stages of production, on average, and most of this production occurs two stages away from final demand. However, there is significant variation in the degree of vertical fragmentation and upstreamness across different sectors of the economy (Table 3). The manufacturing, construction and utilities sectors tend to be the most fragmented, while the resource sector is the most upstream. In contrast, the services sector tends to be the least fragmented and most downstream.[15]

Table 3: Fragmentation and Upstreamness by Sector
2000–2010 average

Sector	Fragmentation	Upstreamness
Manufacturing	2.6	2.5
Resources	2.0	3.6
Construction and utilities	2.6	1.9
Services	1.9	1.9
Total	2.1	2.2

Source: ABS

This can be seen even more clearly if we decompose these sectoral estimates and examine the variation in fragmentation and upstreamness across individual industries (Table 4). The most fragmented industries tend to have long supply chains along which little value-added occurs at each stage. The most fragmented industries are typically in the manufacturing sector, including meat, dairy and basic metals manufacturing. In contrast, the least fragmented industries are typically services industries, such as education, finance and insurance, and health and community services.

15 The estimated level of fragmentation and upstreamness across sectors is somewhat sensitive to the level of sectoral aggregation used in the calculations. However, the estimated trends for fragmentation and upstreamness are little affected when we calculate each statistic based on different degrees of sectoral aggregation. See Appendix B for more details on the issue of aggregation.

The most upstream industries are typically in the resource sector, although the property and business services industry is quite upstream too. Manufacturing industries that produce mainly primary commodities, such as basic metals, also occupy very upstream positions. In contrast, the most downstream industries are generally in the service sector, such as education, health and community services, and retail trade. Some manufacturing industries, such as motor vehicles and clothing, are also downstream.

Table 4: Industry Ranking of Fragmentation and Upstreamness
2009/10

Rank	Highest	Lowest
	Fragmentation	
1	Basic metals	Finance and insurance
2	Meat and dairy	Education
3	Other food	Health and community services
4	Transport equipment	Personal and other services
5	Construction	Mining
	Upstreamness	
1	Mining	Health and community services
2	Basic metals	Education
3	Forestry and fishing	Personal and other services
4	Property and business services	Public administration
5	Non-metallic minerals	Retail trade

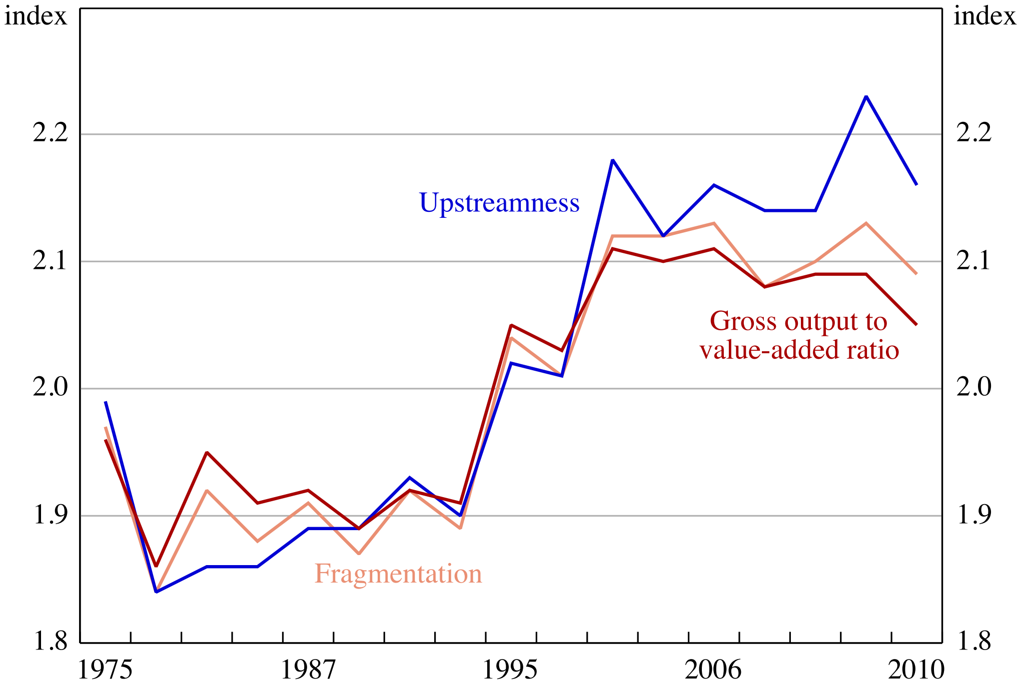
Source: ABS

We can construct time-series indicators of the domestic supply chain for the aggregate economy using historical input-output tables at roughly three-year intervals back to the mid 1970s. These supply chain indicators suggest that the Australian economy has become more fragmented and more upstream since the 1970s (Figure 8), while there was a notable increase in both measures over the 1990s.[16] Methodological changes to the input-output tables by the ABS appear

16 These longer-run trends for the Australian economy are in stark contrast to those of the United States; the US economy has become progressively less fragmented and less upstream over the same period (Antràs *et al* 2012; Fally 2012). Fally attributes this to a shift towards a more service-oriented, and hence downstream, economy.

to explain at least some of this 'jump'.[17] Given this, for much of the subsequent analysis, we focus on the WIOD data and the period since the mid 1990s. This is also the period for which we have comparable international data.

Figure 8: Aggregate Supply Chain Indicators



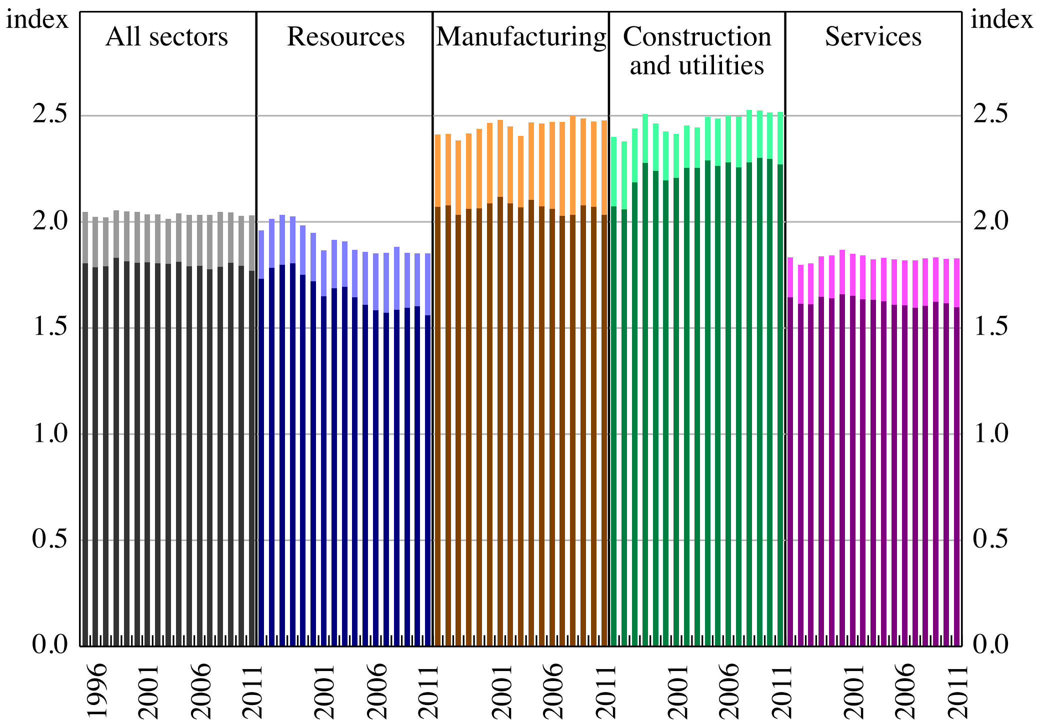
Sources: Authors' calculations; World Input-Output Database

The WIOD data also indicate that, for the Australian economy in aggregate, the degree of fragmentation has been relatively unchanged over the past decade (Figure 9) while the extent of upstreamness has increased (Figure 10). The increase in aggregate upstreamness reflects two factors: i) an increase in the value of aggregate output accounted for by the resource sector (which is the most upstream sector) and ii) an increase in the level of upstreamness within

17 The ABS input-output tables are constructed from supply and use (S-U) tables, which detail industries' production and uses of goods and services and are compiled as part of the Australian System of National Accounts (SNA). While past S-U tables are revised for all periods when historical revisions are made (like other national accounts measures such as GDP), previously published input-output tables are not revised, and therefore do not form a consistent time series. Significant methodological changes were undertaken in the 1990s, including those associated with the implementation of SNA93. For details, see Gretton (2005) and Australian Bureau of Statistics (2013).

the resource sector.[18] The first factor reflects the economy's response to the global commodities boom. The second factor is more subtle and appears to reflect a change in the composition of Australia's supply chain. While, on average, about 85 per cent of Australian production occurs domestically, the upstreamness indicator suggests that the foreign share of the production line has been gradually increasing over the past decade, particularly in the resource sector. This, in turn, reflects two overseas developments highlighted earlier: i) Australian resource production is becoming further removed from the source of final demand (e.g. Europe and North America) as its exported content is increasingly re-directed via intermediate suppliers, such as China; and ii) the Chinese supply chain itself has become more upstream.

Figure 9: Fragmentation by Sector

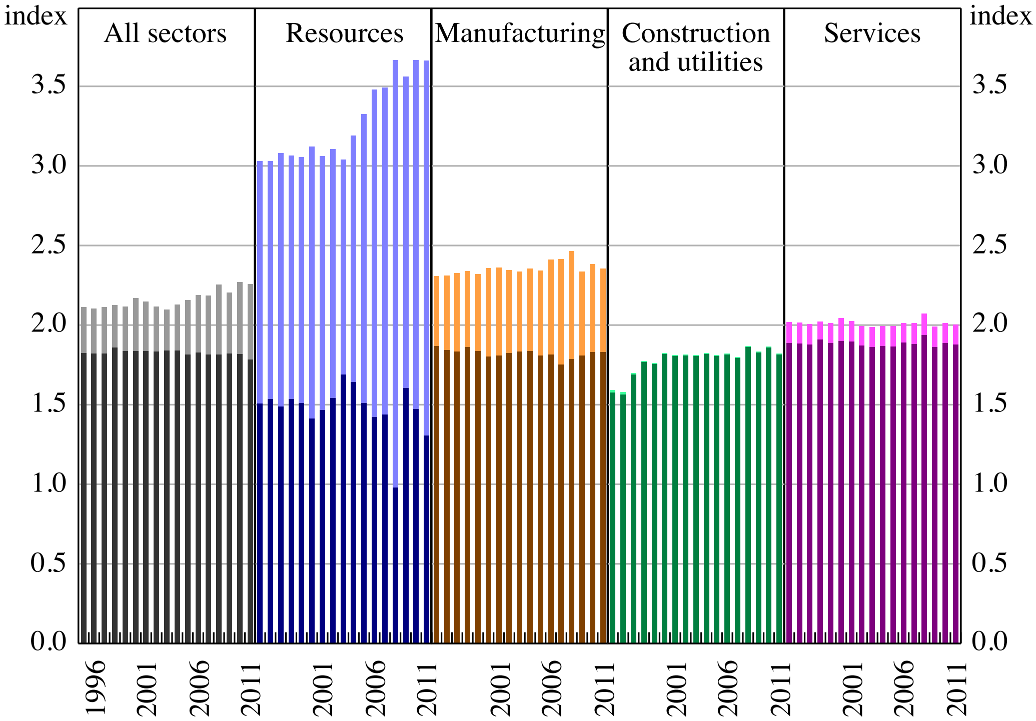


Notes: Lighter shade bars indicate foreign component; darker shade bars indicate domestic component

Sources: Authors' calculations; World Input-Output Database

18 In Appendix C, we conduct a more detailed 'shift-share analysis' to examine the factors driving the aggregate changes in fragmentation and upstreamness.

Figure 10: Upstreamness by Sector



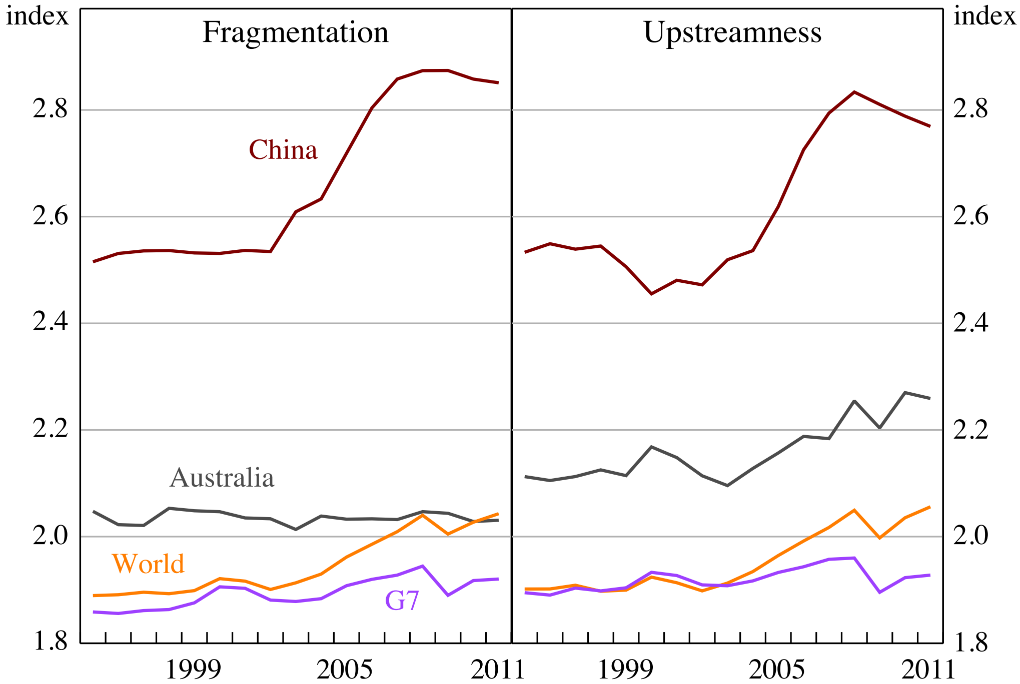
Notes: Lighter shade bars indicate foreign component; darker shade bars indicate domestic component

Sources: Authors' calculations; World Input-Output Database

International comparisons based on the WIOD data allow us to put the Australian estimates into context. Australia's degree of vertical fragmentation and upstreamness is higher than in the rest of the world, on average (Figure 11). This is particularly true in terms of upstreamness due to Australia's relatively large resource sector. In contrast, the supply chains of the G7 countries tend to be relatively downstream and less fragmented by international standards. Clearly, China stands out in international comparisons as a country that has a particularly long and upstream aggregate supply chain.

In fact, Australia has bucked a global upward trend of rising fragmentation since the early 2000s (left-hand panel, Figure 11). This increase in fragmentation around the world has been particularly pronounced in the emerging economies and especially China. On the other hand, the WIOD estimates imply that the degree of upstreamness has risen in Australia over the past decade at about the same rate as the world average, and much less quickly than in China.

Figure 11: Supply Chain Indicators by Region



Sources: Authors' calculations; World Input-Output Database

5. Regression Analysis

In this section we undertake econometric analysis to examine the determinants of the Australian supply chain. In particular, we assess the extent to which changes over time in vertical fragmentation have been driven by exogenous domestic forces (e.g. product market deregulation) and external forces (e.g. falling international transport costs).

5.1 Hypotheses

Jones, Kierzkowski and Lurong (2005) provide a useful conceptual framework for studying the determinants of vertical fragmentation. Suppose a firm produces a particular final good in a vertically integrated process, in which all activity takes place in one location. As the scale of production increases, the firm may find it optimal to divide the production line into different fragments that may be located elsewhere. The total cost of production may be lowered by outsourcing, for example, a stage that makes relatively high use of unskilled labour, to another location in which the unit labour costs of unskilled labour are relatively low. But the fragmentation of production is costly as it also requires services that link each production stage, such as transportation and communication activities.

In this framework, it is optimal for the firm to fragment production if the lower costs due to shifting resources to locations with relatively low unit labour costs outweigh the higher costs associated with the greater service link activities. For a graphical exposition of the model and more detailed analysis, see Jones *et al* (2005).

From this simple model we can derive three testable hypotheses:[19]

1. Fragmentation rises as an industry (or economy) grows
2. Fragmentation rises as trade (or service link) costs fall
3. Offshoring (or the share of production that occurs in other countries) rises as international trade costs fall.

Clearly, information on international and domestic trade costs is required to test these hypotheses. Before turning to the regression framework, we therefore need to briefly discuss how we measure international and domestic trade costs.

5.2 International Trade Costs

Trade costs can be inferred from an economic model linking trade flows to observable variables and unobserved trade costs. The standard model in the international macroeconomic literature is the 'gravity model'. This model assumes that the level of bilateral trade between an importing country and an exporting country is a function of the level of economic activity in each of the two countries, as well as bilateral trade barriers. We follow the recent literature by estimating international trade using the inverse gravity model, which essentially 'flips' the

19 In essence, there are three key assumptions in the model that generate increasing returns to scale in production and, in turn, deliver the three stated hypotheses. First, there is constant returns to scale (and hence constant marginal costs) within each production fragment. Second, the fragments vary in terms of factor endowments and productivities, such that marginal costs are lower in some fragments than in others. Third, the costs of services to link different stages of production mainly comprise fixed costs, so that service link costs do not rise in proportion to output.

gravity model on its head (Novy 2013). International trade costs can be derived from a micro-founded gravity equation (Anderson and van Wincoop 2003):

$$x^s_{ijt} = (\frac{y^s_{it} \times y^s_{jt}}{y^{sw}_t}) \times (\frac{\tau^s_{ijt}}{P^s_{it} \times P^s_{jt}})^{(1-\sigma^s)} \tag{1}$$

where, for each industry s in year t, x^s_{ijt} denotes nominal exports from country i to country j, y^s_{it} and y^s_{jt} denote the levels of output produced in country i and country j respectively, y^{sw}_t denotes world output, P^s_{it} and P^s_{jt} are the aggregate price indices of country i and country j respectively, τ^s_{ijt} is the bilateral trade cost, $\sigma^s > 1$ is the elasticity of substitution across goods within the industry.

Algebraic manipulation of Equation (1) (provided in Appendix D) gives an expression for international trade costs (θ^s_{ijt}) as a function of bilateral international trade, domestic (or intra-national) trade and the elasticity of substitution in consumption between goods:

$$\theta^s_{ijt} = (\frac{\tau^s_{ijt} \times \tau^s_{jit}}{\tau^s_{iit} \times \tau^s_{jjt}})^{\frac{1}{2}} = (\frac{x^s_{iit} \times x^s_{jjt}}{x^s_{ijt} \times x^s_{jit}})^{\frac{1}{2(\sigma^s-1)}}. \tag{2}$$

The definition of international trade costs combines the ratio of domestic to bilateral trade with an exponent that involves the industry-specific elasticity of substitution. In an industry with highly elastic goods, consumers are very sensitive to variations in price and so a small price rise induced by bilateral trade costs can lead to a high ratio of domestic to bilateral trade. Therefore, the ratio reflects not only bilateral trade frictions but also the extent of product differentiation.

The implied estimates of international trade costs include all the costs involved in moving goods between two countries relative to the cost of selling the goods domestically. These trade costs include factors such as transportation costs, policy barriers, information costs, contract enforcement costs, and local distribution costs. The more two countries trade with each other, the lower is the measure of relative trade costs, all other things being equal.

To compute trade costs across industries, countries and time, we need data on the bilateral export flows between countries i and j as well as the domestic trade within each country. For each industry and year, the domestic trade of each country is assumed to be given by the level of gross output minus total exports to the rest of the world. These data are readily available in the WIOD.

As Equation (2) suggests, the trade cost measures also require an estimate of the elasticity of substitution between goods within each industry. We follow Anderson and van Wincoop (2004) and Novy (2013) in setting the elasticity of substitution equal to eight across all industries and countries. The estimated level of trade costs is very sensitive to this choice of elasticity. However, because the elasticity does not vary with time, it has little effect on estimates of the change over time in trade costs. And, because our econometric analysis depends on the variation over time in trade costs, it is not affected by the choice of parameter value for the elasticity of substitution.

Our estimates imply that, since the mid 1990s, world international trade costs have averaged about 169 per cent of what it would cost for the same trade to occur domestically. Furthermore, we find international trade costs are around 132 per cent of the value of domestic production for manufactured goods and 234 per cent for services. This estimate may seem large at first glance. The difference in costs reflects not only shipping costs, but tariff and non-tariff barriers, as well as other less observable costs, such as those associated with using different currencies or any language barriers. Furthermore, the estimate is an *average* for all goods and services produced around the world, some of which may not be traded due to prohibitively high trade costs.

To understand the intuition behind these estimates, consider the following hypothetical example. Suppose the domestic cost of producing a traded good in country A is $10. Further, suppose that the '*ad valorem*' cost for international shipping from country A to B is equal to 2.5. This cost captures factors including transportation costs, tariffs and costs associated with converting currencies. The implied landed import price of the traded good in country B would be $25 (i.e. landed import price = domestic production cost × international shipping cost). Further, suppose that the cost of domestic shipping in country B is 1.4. This captures local distribution costs associated with the domestic transport, wholesale and retail trade sectors. This would imply that the final sale price in country B is $35 (i.e. final sale price = landed import price × local shipping cost). Moreover, note that the *ad valorem* cost of bilateral trade from country A to B equals 3.5 (i.e. international shipping cost from A to B × domestic shipping cost in B).

Now consider the opposite direction of trade. For simplicity, let the domestic cost of producing the good in country B again be equal to \$10. Further, let the *ad valorem* international shipping cost from country B to A be a bit lower at 1.5. The landed import price in country A would be \$15. Let the local shipping (*ad valorem*) cost in country A be a bit higher at 1.6. This would imply that the final sale price in country A is \$24. Again, the total bilateral (*ad valorem*) trade cost from country B to A would be equal to 2.4 (i.e. international shipping cost from B to A $\times$ domestic shipping cost in A).

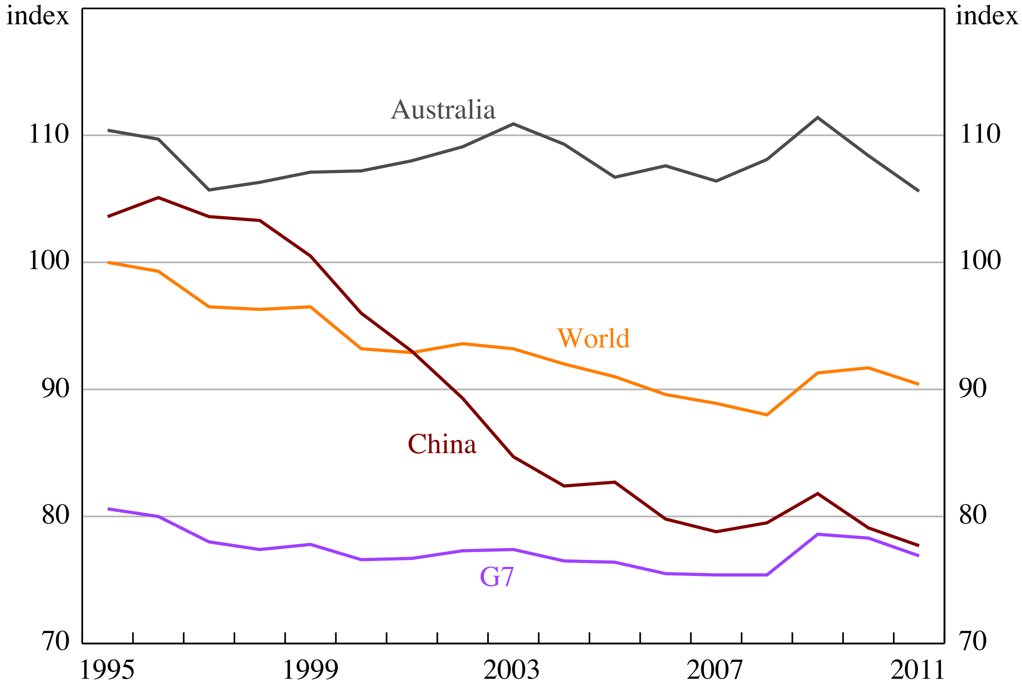
In this example, the *ad valorem* international trade cost equals 93.6 per cent. There are two ways to think about this estimate. First, it measures the ratio of total bilateral trade costs to domestic trade costs (i.e. $(3.5 \times 2.4)/(1.4 \times 1.6) - 1$). Second, it measures the international component of trade costs net of local distribution trade costs in each destination country (i.e. $2.5 \times 1.5 - 1$).

Our estimates of world international trade costs are similar, albeit somewhat higher, than comparable estimates from the literature. For example, using a different trade database, Miroudot, Sauvage and Shepherd (2013) estimate international trade costs of 95 per cent for manufactured goods and 169 per cent for services. Chen and Novy (2011) estimate international trade costs for manufactured goods to be around 110 per cent. Furthermore, using US data, Anderson and van Wincoop (2004) estimate international trade costs for manufactured goods to be about 74 per cent, on average.[20]

To aid comparability in the estimates of international trade costs across sectors, countries and over time, and given the caveat that the estimates are sensitive to the chosen elasticity of substitution, we index the levels of the trade cost estimates in the subsequent graphical analysis. More specifically, in Figure 12, the level of global international trade costs in 1995 is set equal to 100. In Figure 13, the level of global manufactured goods trade costs in 1995 is set equal to 100.

20 Moreover, they find that total trade costs are, on average, around 170 per cent, with 55 per cent due to local (retail and wholesale) distribution costs and 74 per cent due to international trade costs (i.e. $1.7 = 1.55 \times 1.74 - 1$). The estimate of international trade costs can be further broken down into 21 per cent due to shipping costs and 44 per cent due to border-related trade barriers (i.e. $1.7 = 1.55 \times 1.21 \times 1.44 - 1$).

Figure 12: International Trade Costs
Relative to value of domestic production



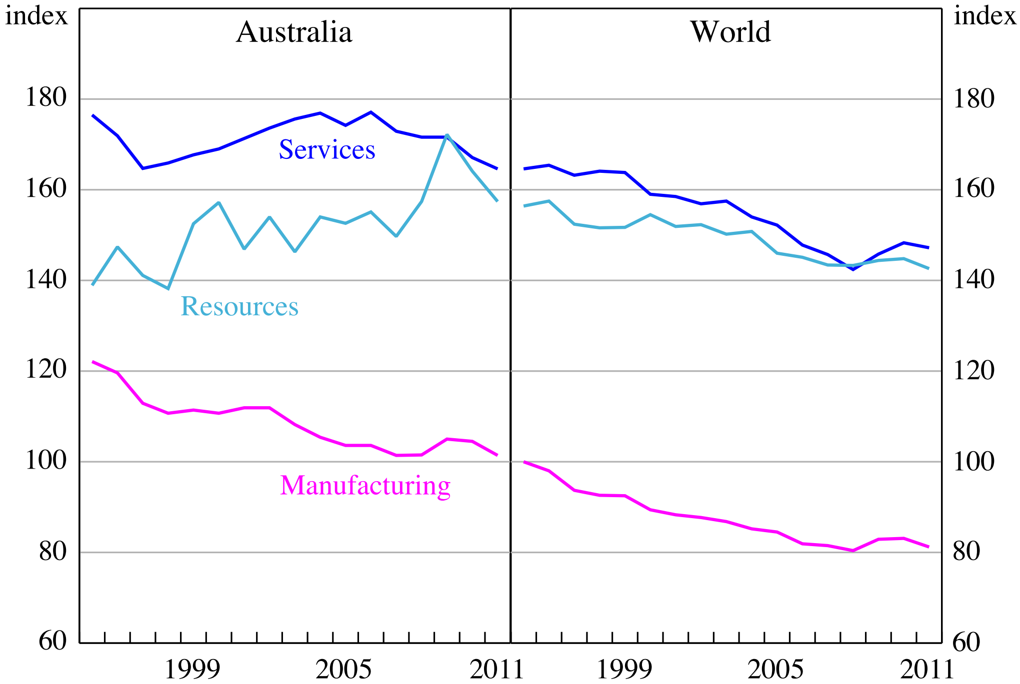
Notes: Goods and services, unweighted mean; world international trade costs in 1995 = 100
Sources: Authors' calculations; World Input-Output Database

By international standards, Australia has a relatively high level of trade costs, particularly in relation to the G7 economies. Australia's trade costs are estimated to be around 17 per cent higher than the world average in 2011. This reflects both Australia's geographic isolation, as goods and services are traded over greater distances on average, and its composition of trade, because resources are estimated to be more costly to trade than manufactured goods (Figure 13).

Our estimates also imply that world international trade costs have fallen by about 10 per cent over the past two decades, with a faster pace of decline for developing economies and manufactured goods. For most advanced economies, much of the reduction in international trade costs occurred during the 1970s and

1980s (Jacks, Meissner and Novy 2008). Since the mid 1990s, the average level of trade costs is estimated to have fallen by almost 5 per cent for Australia and the G7 economies.[21]

Figure 13: International Trade Costs
Relative to value of domestic production



Notes: Goods and services, unweighted mean; world international manufacturing trade costs in 1995 = 100
Sources: Authors' calculations; World Input-Output Database

5.3 Domestic Trade Costs and Sectoral Regulation

We proxy the level of domestic trade (or service link) costs using the OECD sectoral regulation index. This provides an internationally comparable measure of the degree to which government policies inhibit the use of intermediate inputs in a particular industry and country. The indicators effectively measure the 'knock-on' effects of regulation in non-manufacturing sectors on all sectors of the economy.

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21 It also appears that the global financial crisis caused an upward spike in world international trade costs, which may be related to disruptions to supply-chain financing at the time (Chor and Manova 2012). Alternatively, there may have been a decline in demand for goods and services that involve relatively low trade costs and this change in the composition of trade may have affected the aggregate estimates.

The indices are constructed as averages of the indicators of regulation for non-manufacturing industries weighted by the share these industries represent in supplying intermediate inputs to each sector. The 'knock-on' effect of regulation on the aggregate economy is a function of two factors: i) the extent of anti-competitive regulation in a particular sector; and ii) the importance of that sector as a supplier of intermediate inputs to other sectors in the economy.

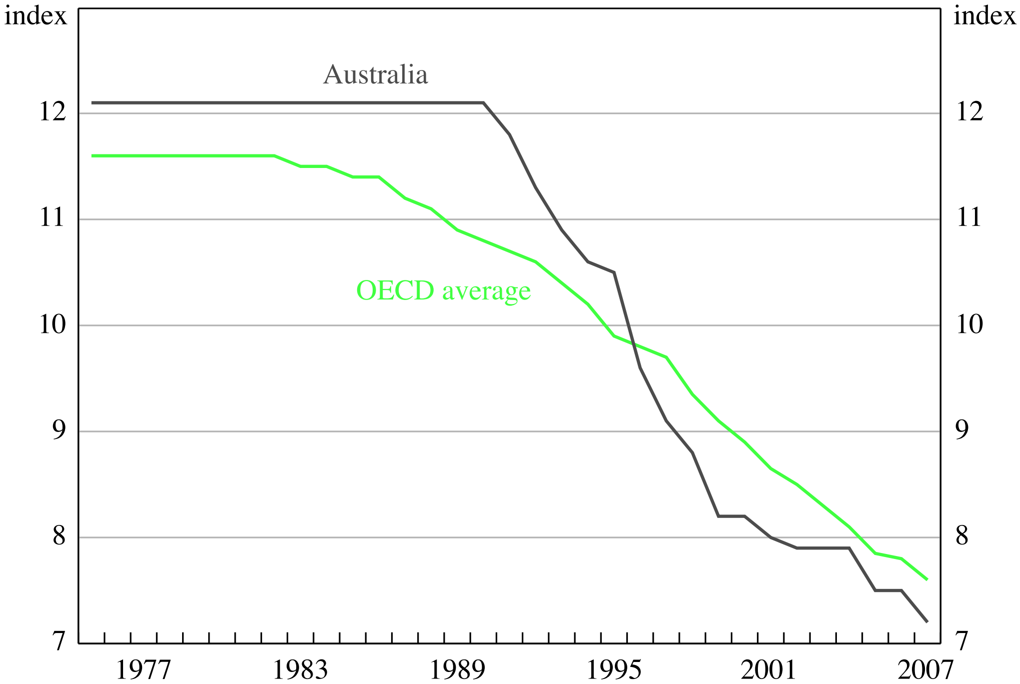
The sectoral regulation index does not capture all sources of domestic trade frictions, only those that are affected by government policy. But, given that much of the increase in fragmentation in the advanced economies (including Australia) coincided with a period of extensive microeconomic reform in the 1990s (e.g. product market deregulation), regulations are likely to be an important component of domestic trade frictions. Moreover, to our knowledge, the link between government regulation and vertical fragmentation has not been studied before.

There are a few channels through which sectoral regulation and the degree of fragmentation might be linked: regulation can affect i) the costs of entry for new firms that rely on the regulated intermediated inputs; ii) the extent to which firms outsource their inputs; iii) the organisation of work within each firm; and iv) the allocation of resources between firms. Previous research has used these regulation indices to study the effect of anti-competitive regulation on productivity growth (Bourlès *et al* 2013) and export performance (Amable and Ledezma 2013), but not to measure the effect of government regulation on fragmentation. For more details on the construction of the indices, see Appendix E.

On average, the level of sectoral regulation has been gradually declining across all OECD countries and industries since the mid 1970s (Figure 14). Sectoral regulation in Australia has followed a similar trend, although deregulation started a little later (in the early 1990s) and has occurred at a faster pace than the OECD average.[22]

22 The OECD estimates suggest that, across countries, the level of sectoral regulation is highest in Belgium, Poland and the Slovak Republic and lowest in Denmark, Sweden and the United States. Across industries, regulation is highest in industries such as utilities, transport and storage, and post and telecommunications, and lowest in education, real estate, and health and social work.

Figure 14: OECD Sectoral Regulation Index
Average across industries



Note: Index can vary between 0 and 100, where lower values indicate less regulation
Sources: Authors' calculations; OECD

5.4 Modelling Framework

To test our hypotheses about the extent of vertical fragmentation and offshoring, we estimate panel regressions of the following form:

$$\begin{aligned} Y_{ict} = \alpha_0 + OUTPUT'_{ict}\alpha_1 \ & + TRCOSTS'_{ict}\alpha_2 + REG'_{ict}\alpha_3 \\ & + X'_{ict}\alpha_4 + \underbrace{\theta_{ic} + \eta_t + \varepsilon_{ict}}_{v_{ict}} \end{aligned} \tag{3}$$

where the dependent variable (Y_{ict}) is either the fragmentation index, measured as the (log level) of the number of production stages in industry i in country c in year t ($FRAG_{ict}$), or the offshoring index, measured as the ratio of foreign production stages to total production stages ($OFFSHORE_{ict}$).[23]

23 The output from estimating the same specification for other supply chain indicators – namely, the level of upstreamness and the VAX ratio – is shown in Appendix F.

Based on our hypotheses, the key explanatory variables include, for each industry, country and year, the (nominal) level of domestic output ($OUTPUT_{ict}$), international trade costs (as a share of the value of domestic production) ($TRCOSTS_{ict}$) and the OECD regulation index (REG_{ict}).

To reiterate the hypotheses outlined earlier, we expect there to be a positive correlation between the scale of production in an industry or economy and the level of fragmentation. Furthermore, there should be a negative correlation between the domestic regulation index and the overall level of fragmentation. Similarly, the level of offshoring and international trade costs should be inversely related. If foreign outsourcing is an imperfect substitute for domestic outsourcing, then lower trade costs may also increase the overall level of fragmentation.

In each regression specification, we also include a set of control variables (X_{ict}) that the literature has identified as being important in explaining vertical fragmentation. These control variables (and their associated measurement) include:

- **Trade to GDP ratio**: the ratio of exports and imports to gross value-added
- **Productivity**: the level of labour productivity, measured as gross value-added divided by the total number of hours worked
- **Physical capital intensity**: the level of capital stock divided by gross output
- **Human capital intensity**: the share of total hours worked by high-skilled workers.

International trade can have two opposite effects on the level of vertical fragmentation. International trade provides new opportunities to reduce costs by shifting production processes abroad, in which case we might expect a positive effect of trade on the fragmentation of production. However, much of this effect is likely to be already captured by the inclusion of international trade costs in the set of explanatory variables. An increase in trade can also reduce the measure of fragmentation if it reduces the relative price of intermediate goods and the total amount of expenditure on these goods, thereby reducing the share of value-added associated with upstream stages.[24]

Industries with low levels of productivity may have greater potential for fragmentation and offshoring of production stages. This would suggest that there should be an inverse relationship between both the level of productivity and fragmentation, and productivity and offshoring, across industries and countries.

The extent of vertical fragmentation can also depend on physical capital intensity. Capital-intensive industries rely more on centralised investment decisions and are thus more likely to be integrated, whereas decisions taken by suppliers are relatively more important in labour-intensive industries, leading to more offshoring in these industries (Antràs 2003). We therefore predict that higher physical capital use will be associated with less fragmentation.

Human capital intensity – measured through skill intensity and the complexity of tasks – can also affect the level of fragmentation. In general, more complex tasks are more likely to be performed within the firm (Costinot, Oldenski and Rauch 2011). Consequently, industries and countries with lower levels of human capital intensity should be more fragmented.

Finally, the regression specification also includes a composite error term (ν_{ict}), which consists of a country-industry specific effect (θ_{ic}), a year fixed effect (η_t) and an idiosyncratic term (ε_{ict}). Country-industry fixed effects are included to control for unobserved factors that vary by country and industry but not by time. This would include factors such as geographic location and the nature of the industry's product. The year fixed effects capture factors that affect all countries and industries at a given point in time, such as the global financial crisis.

Our final sample consists of 28 industries in each of 24 countries covering the period from 1995 to 2007. While the WIOD covers 35 industries in 40 countries and spans the period from 1995 to 2011, some of our explanatory variables are obtained from alternative data sources that restrict our sample both in terms of the

24 However, this negative price effect will only occur if there is low substitution between outsourced intermediate goods and intermediate goods produced within the firm. Otherwise, the lower relative price of outsourced goods should stimulate demand, leading to a positive volume effect of trade on the share of outsourced intermediate goods. In any case, we estimated regression models that included the ratio of intermediate input prices to gross output prices in the set of control variables and the results barely changed.

time series and the cross-section. Most importantly, the OECD sectoral regulation index is only available up to 2007 and covers only OECD countries. Finally, for each of the key variables – namely, the fragmentation index, the OECD regulation index and international trade costs, the top and bottom 1 per cent of observations have been removed to minimise the impact of outliers. Table 5 summarises the key data used in the regression analysis.

Table 5: Variable Summary Statistics

Variable	Mean	Median	25th pct	75th pct	Std dev
Fragmentation (no of stages)	2.1	2.2	1.8	2.4	0.4
International fragmentation (%)	25.1	21.5	13.7	33.0	15.3
Upstreamness (no of stages)	2.2	2.2	1.7	2.6	0.6
International trade costs (%)	231.0	198.3	138.3	297.4	121.9
Sectoral regulation (index)	15.1	10.6	6.6	20.3	11.7
Output (US$m, log level)	9.1	9.3	7.7	10.6	2.2
Trade to GDP ratio (%)	94.0	42.7	6.8	135.4	127.5
Productivity (US$m per hour worked, log level)	3.1	3.2	2.6	3.7	0.9
High-skilled labour share (%)	17.8	13.9	8.4	24.2	12.6
Capital stock ratio (%)	23.5	18.5	12.1	29.9	16.9

Sources: OECD; World Input-Output Database

5.5 Regression Results

The regression output from estimating Equation (3) is shown in Table 6.

First, considering the determinants of the overall level of fragmentation (columns (1) and (2)), we find, as predicted, that output is positively correlated with fragmentation across countries and industries. The fixed effects estimates imply that a 1 per cent higher level of output is associated with an increase of about 7.2 per cent in the number of production stages, on average. This is equivalent to an increase of about 0.15 of a production stage, on average.

The OLS estimates also indicate that lower international trade costs are associated with significantly higher levels of vertical fragmentation, on average (column (1)). But the effect is not statistically significant and of the opposite sign when country-industry fixed effects are included (column (2)).

The level of anti-competitive regulation is negatively associated with the level of fragmentation across countries and industries (columns (1) and (2)). In other words, when a particular country lowers regulations on intermediate inputs within a given industry, this increases the use of intermediate inputs and hence the number of production stages in that industry. This suggests that fragmentation can be affected by the extent of domestic trade frictions. The fixed-effects estimates indicate that a 1 per cent decrease in sectoral regulation is associated with a 0.2 per cent increase in the number of production stages per annum, on average. Given that the degree of regulation has fallen by 0.4 per cent and the number of production stages has risen by 0.3 per cent each year, on average, since the mid 1990s, this implies that government deregulation may have contributed about 25 per cent ($= 0.4 \times 0.2/0.3$) to the increase in fragmentation around the world.

Table 6: Determinants of the Supply Chain

	Fragmentation		Offshoring	
	OLS	Fixed effects	OLS	Fixed effects
	(1)	(2)	(3)	(4)
Output	0.002	0.072***	–0.034***	0.005
	(0.32)	(5.85)	(–5.00)	(0.41)
International trade costs	–0.075***	0.005	–0.023**	–0.028**
	(–7.70)	(1.41)	(–2.51)	(–2.43)
Sectoral regulation	–0.135	–0.198***	–0.154*	–0.024
	(–1.57)	(–2.83)	(–1.73)	(–0.48)
Trade-to-GDP ratio	0.014***	0.000	0.028***	0.006***
	(3.59)	(0.03)	(3.40)	(3.38)
Productivity	–0.030**	–0.116***	0.033**	0.024**
	(–2.17)	(–5.74)	(2.09)	(2.21)
High-skill labour share	–0.346***	0.056	–0.077	–0.089
	(–3.62)	(0.98)	(–1.17)	(–1.07)
Capital stock ratio	0.039	–0.003	–0.084***	–0.010
	(1.12)	(–0.76)	(–2.96)	(–1.36)
Time fixed effects	Y	Y	Y	Y
Country-industry fixed effects	N	Y	N	Y
Within R^2		0.374		0.219
R^2	0.536	0.974	0.440	0.950
Observations	9 671	9 671	9 671	9 671

Notes: Standard errors are two-way clustered by industry and country; *t* statistics are in parentheses; *, ** and *** denote statistical significance at the 10, 5 and 1 per cent levels, respectively

Considering the determinants of offshoring (columns (3) and (4)), we find little evidence that the level of output is a significant determinant. If anything, the OLS estimates point to a negative correlation between the level of output and the foreign share of production stages (column (3)), although the effect is positive and not statistically significant when country-industry fixed effects are included (column (4)).

More notably, lower trade costs are associated with higher offshoring (columns (3) and (4)). The fixed-effects estimates suggest that a 1 percentage point decline in international trade costs (measured on an *ad valorem* basis) is associated with a 0.028 percentage point increase in the share of production stages that are outsourced overseas, on average. Given that trade costs have fallen by 1.3 percentage points per annum since the mid 1990s and the share of production stages located overseas has risen by 0.2 percentage points over the same period, this suggests that the trend decline in global trade costs has contributed about 16 per cent ($= 1.3 \times 0.028/0.2$) to the rise in offshoring.[25]

We also find that, within countries and industries, fragmentation is positively correlated with the trade to GDP ratio. In contrast, countries and industries with high levels of labour productivity are, overall, less fragmented (columns (1) and (2)) but have a greater share of production stages sourced overseas (columns (3) and (4)). The relationship between human capital intensity and fragmentation is ambiguous. The OLS estimates indicate that across countries and industries, skill intensity is negatively associated with fragmentation (column (1)) while the fixed-effects estimates point to a positive correlation (column (2)).

25 We find very similar results for the effect of economic activity and trade costs on vertical fragmentation when we drop the regulation indices and, as a result, broaden the sample to include non-OECD countries and the period since 2007. We also get similar results when we estimate the model based on a lower frequency time series. In particular, we collapse the data to two time periods – pre- and post-2001 – and examine the effect of changes in output, trade costs, and regulation on vertical fragmentation over these two periods. This alleviates any potential stationarity problems and is a useful cross-check given that some of the underlying WIOD data are estimated rather than actual input-output data.

6. Conclusion

The growing prevalence of global supply chains has been associated with important structural changes in Australian trade that are not fully reflected in conventional measures of gross trade flows. The World Input-Output Database allows the construction of value-added measures of trade that can identify Australia's underlying trade linkages. The estimates suggest that the United States and Europe comprise a larger share of Australia's value-added exports than implied by gross exports. In contrast, the estimates indicate that China comprises a smaller share of value-added exports than gross exports. The service sector also constitutes a higher share of Australia's value-added exports than implied by gross exports because of its indirect exposure to trade, as services are extensively used as inputs to produce goods exports.

The value-added content of Australian trade is high by international standards, mainly due to Australia's large endowment of natural resources and its geographic isolation. These factors contribute to Australia exporting a relatively high share of resource commodities and a low share of manufactured goods. Manufactured exports typically embody little value-added as their production involves the extensive use of intermediate inputs, which are increasingly sourced from imports. These compositional differences also explain why the value-added content of Australian trade has been relatively stable while it has fallen for most countries over the past two decades, as they increasingly source intermediate inputs from other countries.

Australia has increasingly become a net exporter of intermediate products and a net importer of final products over the past two decades. This reflects the growing fragmentation of production across borders, as the emerging economies in Asia become major importers of Australian resource commodities that are used as intermediate goods for processing and export.

We also apply new measurement techniques to historical input-output data to examine how the domestic supply chain has evolved over recent decades. By international standards, Australian production is highly fragmented and relatively upstream, partly because of the importance of resource exports. We find evidence of an increase in the average number of stages involved in production (fragmentation), and the average distance to final demand (upstreamness), mainly during the 1990s. These changes coincided with a period of significant structural change in Australia, and result from both the changing composition of Australian industry as well as adaptation within industries.

Our analysis suggests that the rise in vertical fragmentation in Australia is, at least in part, a global phenomenon. In particular, our econometric analysis indicates that, since the mid 1990s, the global rise in vertical fragmentation and offshoring has reflected a combination of lower international trade costs, extensive deregulation of markets that produce intermediate goods and services, and rapid economic growth in emerging economies, particularly in China.

Appendix A: Construction of Value-added Trade Estimates

This appendix outlines the input-output tables available in the WIOD and describes the construction of the key indicator of value-added trade – the VAX ratio. A multiregional input-output table (Figure A1) extends the traditional concept of an input-output table by concatenating matrices of inter-industry input use and vectors of final demand to record internal and cross-border flows of final and intermediate goods and services. The flows represent values rather than volumes. This implies a common set of prices and ensures the market clearing condition that overall revenue equals expenditure.

The columns of the table represent the inputs used by each industry in each country, with the total value of production equal to the sum of domestic inputs, imported inputs, taxes, margins, and value-added (the contribution of labour and capital). The rows of the table represent the output of each industry in each country, with total output equal to the sum of domestic intermediate use, domestic final use and exports.

Formally, the table entry $m_{ij}(s,s')$ denotes intermediate use of the output of sector s of country i by sector s' in country j, while the entry $f_{ij}(s)$ denotes final use of the output of sector s of country i by country j. Total output of sector s in country i is denoted $y_i(s) = \sum_j f_{ij}(s) + \sum_j \sum_{s'} m_{ij}(s,s')$, with $\mathbf{y}_i$ denoting the $S \times 1$ vector of output for country i's S sectors and $\mathbf{f}_{ij}$ denoting the $S \times 1$ vector of country j's final demand for the output of country i's S sectors.

Total exports of sector s in country i can be denoted $x_i(s) = \sum_{j \neq i} f_{ij}(s) + \sum_{j \neq i} \sum_{s'} m_{ij}(s,s')$.

The world input-output table contains information on the approximate technical requirements of production, which means that the value of intermediate inputs used in the k-th step of the production process can be derived from the values of final demand, i.e. those inputs that are used as direct inputs into final demand (first step), those that are used as inputs into those inputs (second step), and so on.

Figure A1: Structure of a Multi-country Input-Output Table

From \ To	Country 1, Sector 1	Country 1, Sector 2	$\cdots$	Country 1, Sector S	Country 2, Sector 1	$\cdots$	Country 2, Sector S	$\cdots$	$\cdots$	Country K, Sector S	Final demand, Country 1	Final demand, Country 2	$\cdots$	Final demand, Country K	Σ = gross output
Country 1, Sector 1	$m_{11}(1,1)$	$m_{11}(1,2)$	$\cdots$	$m_{11}(1,S)$	$m_{12}(1,1)$	$\cdots$	$m_{12}(1,S)$	$\cdots$	$\cdots$	$m_{1K}(1,S)$	$f_{11}(1)$	$f_{12}(1)$	$\cdots$	$f_{1K}(1)$	$y_1(1)$
Country 1, Sector 2	$m_{11}(1,2)$	$m_{11}(2,2)$	$\cdots$	$m_{11}(2,S)$	$m_{12}(1,2)$	$\cdots$	$m_{12}(2,S)$	$\cdots$	$\cdots$	$m_{1,K}(2,S)$	$f_{11}(2)$	$f_{12}(2)$	$\cdots$	$f_{1K}(2)$	$y_1(2)$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
Country 1, Sector S	$m_{11}(S,1)$	$m_{11}(S,2)$	$\cdots$	$m_{11}(S,S)$	$m_{12}(S,1)$	$\cdots$	$m_{12}(S,S)$	$\cdots$	$\cdots$	$m_{1K}(S,S)$	$f_{11}(S)$	$f_{12}(S)$	$\cdots$	$f_{1K}(S)$	$y_1(S)$
Country 2, Sector 1	$m_{21}(1,1)$	$m_{21}(1,2)$	$\cdots$	$m_{21}(1,S)$	$m_{22}(1,1)$	$\cdots$	$m_{22}(1,S)$	$\cdots$	$\cdots$	$m_{2K}(1,S)$	$f_{21}(1)$	$f_{22}(1)$	$\cdots$	$f_{2K}(1)$	$y_2(1)$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
Country 2, Sector S	$m_{21}(S,1)$	$m_{21}(S,2)$	$\cdots$	$m_{21}(S,S)$	$m_{22}(S,1)$	$\cdots$	$m_{22}(S,S)$	$\cdots$	$\cdots$	$m_{2K}(S,S)$	$f_{21}(S)$	$f_{22}(S)$	$\cdots$	$f_{2K}(S)$	$y_2(S)$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
Country K, Sector S	$m_{K1}(S,1)$	$m_{K1}(S,2)$	$\cdots$	$m_{K1}(S,S)$	$m_{K2}(S,1)$	$\cdots$	$m_{K2}(S,S)$	$\cdots$	$\cdots$	$m_{KK}(S,S)$	$f_{K1}(S)$	$f_{K2}(S)$	$\cdots$	$f_{KK}(S)$	$y_K(S)$
Taxes less subsidies	$t_1(1)$	$t_1(2)$	$\cdots$	$t_1(S)$	$t_2(1)$	$\cdots$	$t_2(S)$	$\cdots$	$\cdots$	$t_K(S)$					
Value added	$va_1(1)$	$va_1(2)$	$\cdots$	$va_1(S)$	$va_2(1)$	$\cdots$	$va_2(S)$	$\cdots$	$\cdots$	$va_K(S)$					
Σ = gross output	$y_1(1)$	$y_1(2)$	$\cdots$	$y_1(S)$	$y_2(1)$	$\cdots$	$y_2(S)$	$\cdots$	$\cdots$	$y_K(S)$					

For a table of S sectors in N countries, taking $\mathbf{y} = (\mathbf{y}_1, \mathbf{y}_2, \ldots, \mathbf{y}_N)'$ to be the $SN \times 1$ vector of total world production, we can write $\mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{f}$, where $\mathbf{f} = (\sum_j \mathbf{f}_{1j}, \sum_j \mathbf{f}_{2j}, \ldots, \sum_j \mathbf{f}_{Nj})'$ is the $SN \times 1$ vector of total world final demand, and $\mathbf{A}$ is the *technical requirements matrix*, an $SN \times SN$ matrix with $\mathbf{A}_{ij}(s,s') = m_{ij}(s,s')/y_j(s')$. Then $\mathbf{A}^k\mathbf{f}$ gives the value of intermediate inputs used in the k-th step of the production process.

The succession of production stages continues indefinitely due to the 'circular flow' of the production process, with the sum of final and intermediate goods and services production converging to the full value of total gross output as the number of stages increases.

A circular production process involving an effectively infinite number of stages, with identical input requirements and output uses at each stage, is a basic assumption of input-output analysis. The infinite sum of successive powers of the technical requirements matrix $\mathbf{A}$ converges to $\sum_{k=0}^{\infty} \mathbf{A}^k = (\mathbf{I} - \mathbf{A})^{-1}$. The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is the 'Leontief inverse', which transforms the final demand vector into the gross output vector, i.e. $\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$, which is simply a rearrangement of $\mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{f}$.

By decomposing the final demand vector by region, we can estimate the total value of domestic production that is attributable to final demand in various parts of the world.

Similarly the $S \times 1$ vector of output from country i used to produce goods in country j (denoted $\mathbf{y}_{ij}$) is derived as $(\mathbf{y}_{1j}, \mathbf{y}_{2j}, \ldots, \mathbf{y}_{Nj})' = (\mathbf{I} - \mathbf{A})^{-1}(\mathbf{f}_{1j}, \mathbf{f}_{2j}, \ldots, \mathbf{f}_{Nj})'$.

The ratio $r_i(s)$ of value-added to gross output in sector s of country i is defined as one minus the intermediate consumption share of output; $r_i(s) = 1 - \sum_j \sum_{s'} \mathbf{A}_{ji}(s', s)$.[26] Total value-added exports from country i are then given by $va_i = \sum_{j \neq i} \sum_s va_{ij}(s)$ where $va_{ij}(s) = r_i(s) y_{ij}(s)$. This implicitly assumes that the share of value-added to gross output is the same for all products of an industry, regardless of whether the products are exported or not.

The ratio of bilateral value-added to gross exports from sector s of country i to country j is then $VAX_{ij}(s) = va_{ij}(s)/x_{ij}(s)$.

26 More precisely, value-added also excludes the value of taxes less subsidies.

Appendix B: Construction of Supply Chain Statistics

The measures for 'fragmentation' and 'upstreamness' outlined by Fally (2012) and Antràs, Chor, Fally and Hillberry (2012) are based on input-output methodology. The product of any sector can be used either for final consumption or as an input into further production (intermediate consumption). For a total of n sectors,[27] the value of the gross output Y_i for sector $i \in \{1, 2, , n\}$ can be expressed as the sum $Y_i = F_i + \sum_{j=1}^{n} a_{ij} Y_j$, where F_i denotes its use as a final good and a_{ij} denotes the number of units of sector i inputs required to produce one unit of sector j's output.

The intermediate and final uses of all sectors can be represented in matrix notation as $\mathbf{Y} = \mathbf{F} + \mathbf{AY}$ where $\mathbf{Y}$ and $\mathbf{F}$ are $n \times 1$ column vectors with Y_i and F_i as their respective row i entries, and $\mathbf{A}$ an $n \times n$ matrix with a_{ij} as its (i, j)-th element (the technical requirements matrix). The 'Leontief inverse' relates total production to final use (or final demand): $\mathbf{Y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{F}$.

The difference between the total value of sector j's intermediate inputs and the total value of sector j's output is equivalent to the 'value-added' of that sector (the value contributed by factors of production). That is, $Y_j = V_j + \sum_{i=1}^{n} a_{ij} Y_i$, where V_j is the value-added of sector j. This can be represented in matrix notation as $\mathbf{Y} = \mathbf{V} + \mathbf{BY}$, where $\mathbf{V}$ is an $n \times 1$ column vector with V_i as its row i entries and $\mathbf{B}$ an $n \times n$ matrix with $b_{ij} = a_{ij} Y_j / Y_i$ as its (i, j)-th element (the *allocations* matrix). The 'Ghosh inverse' relates total production to value-added: $\mathbf{Y} = (\mathbf{I} - \mathbf{B})^{-1}\mathbf{V}$.

The 'fragmentation' and 'upstreamness' measures use the relationships between final demand, intermediate production and value-added to measure the 'length' of upstream and downstream supply chains as a weighted average number of production stages. They provide a specific interpretation for the traditional measures of total forward and backward linkages in traditional input-output theory (Miller and Blair 2009).

The 'fragmentation' of sector i, denoted N_i, measures the 'average' number of stages of production involved for sector i's output, or the length of the *upstream* supply chain. Production with no inputs involves one stage; production requiring intermediate inputs involves one stage plus the number of stages involved in each

27 In the case of a multi-country input-output table, the same sector in different countries are simply treated as different sectors; we do not require separate notation to specify the country.

input's production, with each input's number of stages weighted according to the share of overall value-added contributed by that input. This describes a system of equations where

$$N_i = 1 + \sum_{j=1}^{n} a_{ji} N_j$$

or in matrix notation, $\mathbf{N} = (\mathbf{I} - \mathbf{A}^T)^{-1}\mathbf{1}$, for an $n \times 1$ column vector of fragmentation measures $\mathbf{N}$ and an $n \times 1$ column vector of ones $\mathbf{1}$. This measure will be at least one (where there are no intermediate inputs) and rises according to the proportion of a product's value that is added by intermediate inputs, and by the length of these inputs' own supply chains.

As a summary of the nature of a production chain, this fragmentation measure has several shortcomings; it can only capture vertical fragmentation, not horizontal fragmentation, and therefore does not measure the number of suppliers involved at each stage, only the number of stages. It does not take firm ownership into account and will be unaffected if a single firm is responsible for multiple production stages.

Another issue is the treatment of imports. While the WIOD accounts for imported inputs using a multi-country input-output table, single-country input-output tables can treat imported inputs in one of two ways; direct allocation, which excludes imports from the values of inter-industry transactions; and indirect allocation, which includes them. The fragmentation index is best applied to national input-output tables that use indirect allocation of imports, as these tables better reflect the technological input requirements of the industry. The resulting index is accurate on the assumption that the supply-chain characteristics of foreign producers are comparable to those of domestic producers. While this assumption may not be correct, any bias in the index values is likely to be smaller than the difference with the index values found when using direct-allocation tables, which in Australian data is generally insignificant.

The 'upstreamness' of sector i, denoted U_i, measures the 'average' number of stages of production between the production in sector i and final use, or the length of the *downstream* supply chain. Production that goes entirely to final use involves one stage; production that goes in part to intermediate use involves one stage plus the number of stages involved in the intermediate uses, with each intermediate use's number of stages weighted according to that use's share of sector i's total output. This describes a system of equations where

$$U_i = 1 + \sum_{j=1}^{n} b_{ij} U_j$$

or in matrix notation, $\mathbf{U} = (\mathbf{I} - \mathbf{B})^{-1}\mathbf{1}$, for an $n \times 1$ column vector of upstreamness measures $\mathbf{U}$ and an $n \times 1$ column vector of ones $\mathbf{1}$. This measure will be at least one (where none of the output goes toward intermediate use) and rises according to the proportion of the sector's output that goes toward intermediate use, and by the length of these intermediate uses' own supply chains.

The elements of the allocations matrix $\mathbf{B}$, $b_{ij} = a_{ij}Y_j/Y_i$, give the total share of sector i's output that goes toward intermediate use by sector j. In an open economy, intermediate and final uses for sector i include the uses of imports belonging to that sector, meaning that it may be more appropriate to consider shares of the sum of domestically produced and imported output. Similarly, in an open economy, 'final use', as opposed to 'intermediate use', includes exports, which may actually be used for intermediate use in another country, and the treatment of exports as final use may distort the measure. For this reason it may be more appropriate to consider the intermediate-use and final-use shares of *domestically absorbed* output (in this way, we are implicitly assuming that the downstream supply chains for exports have the same characteristics as the downstream supply chain for domestic output, similar to how assumptions are made for intermediate inputs in the fragmentation measure). Another consideration is the part of output that goes to changes to inventories, which is a component of 'final demand' despite representing an absence of effective demand. For our upstreamness measures we use a modified allocations matrix with $b_{ij} = a_{ij}Y_j/(Y_i + M_i - X_i - T_i)$, where M_i, X_i and T_i represent sector i's imports, exports and inventory changes respectively.

The lengths of upstream and downstream supply chains as represented by the fragmentation and upstreamness measures can be divided into components. Where the input-output table includes the sectors of multiple countries, these components may be the domestic and international sections of the supply chain. For example, for n_D domestic sectors $j \in D$ and n_I international sectors $j \in I$, the international and domestic components of sector i's fragmentation measure (that is, their upstream supply chain), denoted N_i^D and N_i^I, can be given as

$$N_i^D = \frac{N_i \times \sum_{j \in D} a_{ji} N_j}{\sum_{j \in D} a_{ji} N_j + \sum_{j \in I} a_{ji} N_j}$$

$$N_i^I = \frac{N_i \times \sum_{j \in I} a_{ji} N_j}{\sum_{j \in D} a_{ji} N_j + \sum_{j \in I} a_{ji} N_j}.$$

The upstreamness measure can be similarly decomposed, giving the domestic and international components of the downstream supply chain.

The fragmentation and upstreamness measures are sensitive to the level of aggregation, that is, the number of sectors used. Where fragmentation or upstreamness measures are available at a disaggregated level, measures can be made for more aggregated sectors by taking a weighted average of the measures of the component industries, weighting the fragmentation measure of each industry by its share of the aggregate sector's total final demand and weighting the upstreamness measure of each industry by its share of the aggregate sector's total value-added. Aggregation of industries into sectors introduces bias for the fragmentation measure where the component industries of a sector differ systematically in the allocation of their output, and introduces bias for the upstreamness measure where the component industries of a sector differ systematically in their input requirements. For a closed economy at the highest level of aggregation (one sector for the whole economy), both measures will converge to the ratio of gross output to value-added (or final demand). For an open economy, the gross output to value-added ratio will overstate the aggregate economy-wide measures of fragmentation and upstreamness if net exports are positively correlated with either measure and will understate these measures if there is a negative correlation (see Fally (2012)).

Appendix C: Shift-Share Analysis

To examine the factors that might explain the changes over time in the domestic supply chain, we conduct a shift-share analysis. This analysis allows us to decompose the aggregate changes in the supply chain indices into changes in the relative sizes of sectors with differing supply chain characteristics ('between effects') and changes in the supply chain characteristics of individual sectors ('within effects').

Denote aggregate fragmentation and upstreamness for the economy as a whole by $\bar{N} = \sum_i F_i N_i / \sum_i F_i$ and $\bar{U} = \sum_i V_i U_i / \sum_i V_i$ respectively. The changes in aggregate fragmentation and upstreamness between times $t-1$ and t, $\Delta\bar{N}_t$ and $\Delta\bar{U}_t$, are approximated as the sum of 'between' and 'within' effects, i.e. $\Delta\bar{N}_t = \Delta\bar{N}_t^B + \Delta\bar{N}_t^W$ and $\Delta\bar{U}_t = \Delta\bar{U}_t^B + \Delta\bar{U}_t^W$, where

$$\Delta\bar{N}_t^B = \sum_i \frac{(N_{i,t} + N_{i,t-1})}{2} \cdot \Delta f_{i,t} \qquad \Delta\bar{U}_t^B = \sum_i \frac{(U_{i,t} + U_{i,t-1})}{2} \cdot \Delta v_{i,t}$$

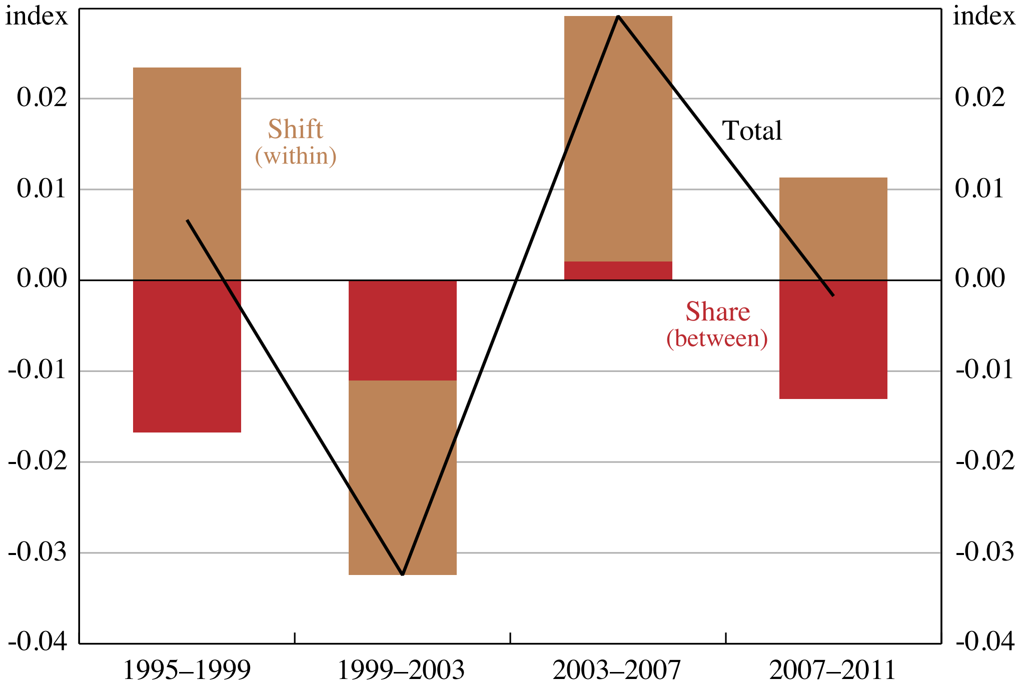
$$\Delta\bar{N}_t^W = \sum_i \frac{(f_{i,t} + f_{i,t-1})}{2} \cdot \Delta N_{i,t} \qquad \Delta\bar{U}_t^W = \sum_i \frac{(v_{i,t} + v_{i,t-1})}{2} \cdot \Delta U_{i,t}$$

$$f_{i,t} = \frac{F_{i,t}}{\sum_j F_{j,t}} \qquad v_{i,t} = \frac{V_{i,t}}{\sum_j V_{j,t}}.$$

In aggregate, the Australian economy has become slightly more vertically fragmented since the mid 1990s, with most of the increase in fragmentation due to changes within industries (Figure C1). However, there has been an offsetting 'between effect' over the most recent few years, as the level of economic activity has shifted towards the resource and service sectors that are typically less fragmented than other sectors.

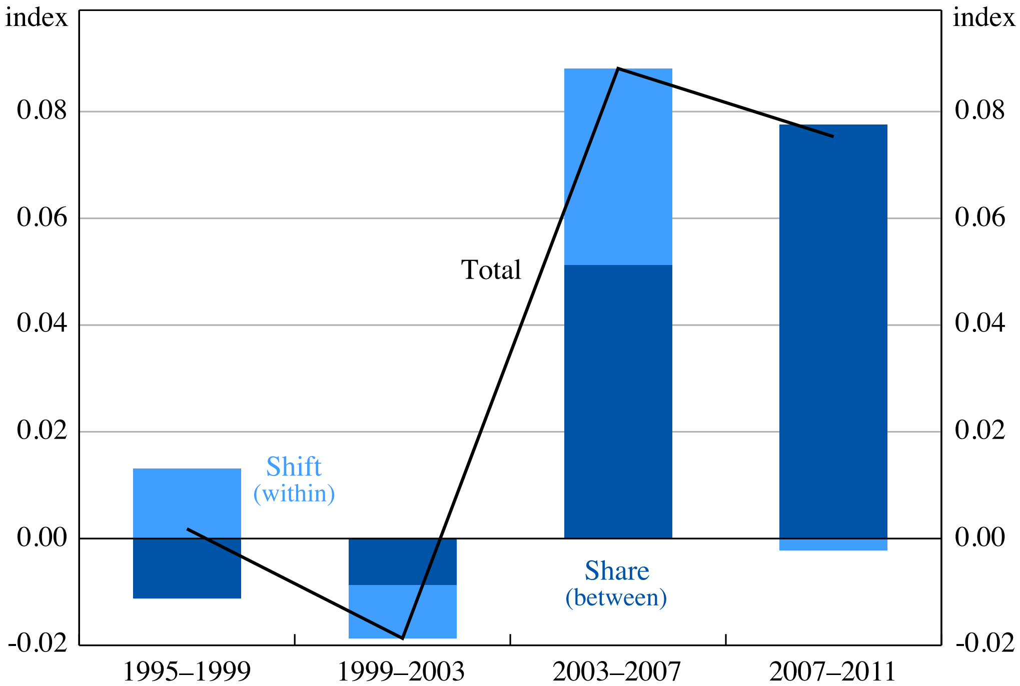
Also, there has been an increase in upstreamness in the aggregate economy since the mid 1990s. This has been mainly driven by an increase in the relative size of the resource sector which, in turn, is due to the terms of trade boom (Figure C2). However, over the mid 2000s the resource sector also became more upstream itself, which is likely to be a response to the commodity price boom.

Figure C1: Australia – Decomposition of Changes in Fragmentation



Sources: Authors' calculations; World Input-Output Database

Figure C2: Australia – Decomposition of Changes in Upstreamness



Sources: Authors' calculations; World Input-Output Database

Appendix D: Measures of International Trade Costs

International trade costs are estimated using the following gravity equation:

$$x^s_{ijt} = (\frac{y^s_{it} \times y^s_{jt}}{y^{sw}_t}) \times (\frac{\tau^s_{ijt}}{P^s_{it} \times P^s_{jt}})^{(1-\sigma^s)} \tag{D1}$$

where, for each industry s in year t, x^s_{ijt} denotes exports from country i to country j, y^s_{it} and y^s_{jt} denote the levels of output produced in country i and country j respectively, y^{sw}_t denotes world output, P^s_{it} and P^s_{jt} are the aggregate price indices (or 'multilateral resistance' terms) of country i and country j respectively, τ^s_{ijt} is the bilateral trade cost, $\sigma^s > 1$ is the elasticity of substitution across goods within the industry.

The aggregate price indices measure the average trade barriers imposed by country i and country j. All else being equal, bilateral trade between country i and country j increases if either country i or country j raise their average trade barriers. This is because, for a given bilateral trade barrier between country i and country j, higher barriers between the importing country j and its other trading partners reduce the relative price of exports from country i to country j. But if the exporting country i also lifts its barriers with all trading partners, this lowers aggregate demand for its exports and therefore reduces its supply price in equilibrium. For a given bilateral trade barrier between country i and country j, this raises the level of trade between the two countries (Anderson and van Wincoop 2003).

We cannot directly solve Equation (D1) for the trade cost term (τ^s_{ijt}) because the aggregate price indices are not observed. However, they can be eliminated by multiplying the gravity equation by its counterpart for trade flows in the opposite direction (x^s_{jit}) and then dividing it by the product of the gravity equations for domestic trade flows in each country ($x^s_{iit} \times x^s_{jjt}$):

$$\frac{x^s_{ijt} \times x^s_{jit}}{x^s_{iit} \times x^s_{jjt}} = (\frac{\tau^s_{ijt} \times \tau^s_{jit}}{\tau^s_{iit} \times \tau^s_{jjt}})^{1-\sigma^s}.$$

The geometric average of trade costs between the two countries is then given by:

$$\theta^s_{ijt} = (\frac{\tau^s_{ijt} \times \tau^s_{jit}}{\tau^s_{iit} \times \tau^s_{jjt}})^{1/2} = (\frac{x^s_{iit} \times x^s_{jjt}}{x^s_{ijt} \times x^s_{jit}})^{\frac{1}{2(\sigma^s-1)}}.$$

To obtain aggregate international trade costs for each industry and year we take a simple (unweighted) mean of trade costs across all trading partners:

$$\theta^s_{it} = (1/J) * \sum_{j=1}^{J} (\frac{x^s_{iit} \times x^s_{jjt}}{x^s_{ijt} \times x^s_{jit}})^{\frac{1}{2(\sigma^s-1)}}.$$

The *ad valorem* equivalent of international trade costs is calculated by subtracting the value of one from this expression.

Appendix E: Measures of Sectoral Regulation

The OECD sectoral regulation indices are constructed based on regulations across two broad groups of sectors. The first group consists of network sectors, including energy, transport and communications. These indicators are computed for a time series spanning from 1975 to 2007. The second group consists of regulations in retail trade and professional services. These indicators are computed for three years: 1998, 2003 and 2007.

The indicators have been developed to measure how changes in regulations in one sector affect other sectors of the economy that use the output of that sector in production. These flow-on effects depend on i) the extent of anti-competitive regulation in a given sector and ii) the importance of the sector as a supplier of intermediate inputs to other sectors.

The regulation indices are calculated as:

$$REG_{ict} = \sum_{j} R_{jct} \times w_{ijc}$$

where the variable R_{jct} is an indicator of anti-competitive regulation in industry j for country c at time t and the weight w_{ijc} is the total input requirement of sector i for intermediate inputs of sector j in country c. Essentially, this weight measures the importance of sector j in supplying intermediate inputs to sector i. Total input coefficients are produced for 38 sectors in 29 OECD countries. The regulation indices are scaled to be between 0 and 100, with higher values representing greater regulation.

The regulation indices are constructed for each country using the input-output structure of the economy in the year 2000. Holding the input-output structure of the economy constant over time ensures that changes in the indices reflect policy changes and not changes in the weights. It also helps to minimise any endogeneity between regulation and the input-output structure of the economy. The methodology behind the indicators is described in more detail in Conway and Nicoletti (2006).

Appendix F: Other Supply Chain Indicators

In this appendix we estimate the econometric model described in Section 5.4 for two other supply chain indicators – the level of upstreamness and the VAX ratio. The regression results are shown in Table F1.

Table F1: Determinants of the Supply Chain

	Upstreamness		VAX ratio	
	OLS	Fixed effects	OLS	Fixed effects
	(1)	(2)	(3)	(4)
Output	–0.014	0.026**	0.562	1.013
	(–0.95)	(2.74)	(1.24)	(0.62)
International trade costs	–0.118***	–0.008	10.209***	19.576***
	(–5.87)	(–1.50)	(3.55)	(4.00)
Sectoral regulation	0.731***	–0.057*	25.826	–5.520
	(3.82)	(–1.94)	(1.64)	(–0.25)
Trade-to-GDP ratio	–0.023*	–0.002	2.457**	1.502**
	(–1.79)	(–1.67)	(2.02)	(2.19)
Productivity	0.050***	–0.044**	2.619***	1.940
	(2.59)	(–2.53)	(3.24)	(0.81)
High-skill labour share	–0.207	0.052	–8.327	–4.933
	(–1.15)	(0.64)	(–1.51)	(–0.32)
Capital stock ratio	0.167***	–0.006	–5.387	–1.511
	(2.84)	(–0.56)	(–0.69)	(–0.39)
Time fixed effects	Y	Y	Y	Y
Within R^2		0.056		0.095
R^2	0.395	0.979	0.168	0.807
Observations	9 642	9 642	9 549	9 549

Notes: Standard errors are two-way clustered by industry and country; *t* statistics are in parentheses; *, ** and *** denote statistical significance at the 10, 5 and 1 per cent levels, respectively

Broadly speaking, the results from the upstreamness regressions are very similar to those found for fragmentation (columns (1) and (2)). Based on the fixed-effects estimates (column (2)), a higher level of output and weaker regulation are both associated with more upstreamness. There is also some evidence that lower international trade costs are associated with more upstreamness, but the estimates are not statistically significant when fixed effects are included in the specification. In contrast, the VAX ratio regression estimates provide strong evidence that lower international trade costs are associated with lower VAX ratios, on average. This is consistent with the notion that lower international trade costs stimulate demand for imported intermediate inputs and encourage more production sharing across international borders. In terms of economic significance, the estimates imply that the trend decline in international trade costs explains about 6 per cent of the average decline in the VAX ratio over the sample period. Compared to the fragmentation and offshoring models, these regressions appear less able to explain variation in upstreamness and the VAX ratio, as shown by the relatively low within *R*-squared for each of the fixed effects regressions.

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