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Putting the Australian Economy on the Scales

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Abstract

Based on the increasing size of the service sector, some believe that growth in advanced countries has come without much change in the physical weight of output. To investigate the question, I generate rough estimates of the physical weight of Australian output from 1831 to 2018, using data on the weight of traded goods. These ballpark estimates imply that the weight of annual output increased from around 50,000 tonnes to around 800 million tonnes. Over the long term, a 10 per cent increase in real GDP was associated with a 12 per cent increase in the physical weight of output.

JEL CLASSIFICATION

N17; N57; Q56

1. Weightless Work, Weightless Economy?

The year 2019 marked the first time in human history that a majority of the world's workers were engaged in the services sector.[1] From architects to zoologists, most employees' output now takes the form of human interactions, intellectual endeavour or combining existing products. Although service sector jobs consume physical inputs such as electricity and paper, the production process is largely concerned with ideas rather than physical items.

In general, a country's development tends to be associated with a larger services sector. At any given point in time, richer countries tend to have a greater share of the economy in services than poorer countries. Similarly, if one tracks a single nation over time, most nations' economies tend to become more services-intensive as incomes rise.

Parallel to this shift has been a fall in the physical weight of many items and activities. Houses and vehicles are built from lighter materials than in the past. Domestic appliances are more compact. Transport networks are more energy-efficient. Software makes it possible to upgrade devices—from games to vehicles—that might previously have required new physical parts or total replacement.

Together, these shifts led Alan Greenspan to claim: ‘The considerable increase in the economic well-being of most advanced nations in recent decades has come about without much change in the bulk or weight of their gross domestic product.’ (Greenspan 2014, p. 172). The economy, he argues, ‘has gotten lighter without question’. He then goes on to calculate the physical weight of US Gross Domestic

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Product (GDP) since 1955 and concludes that it has experienced considerable 'weight loss'. Similarly, Quah (2019, p. 464) contends that advanced countries are experiencing the 'ongoing dematerialization in economic activity', and argues that weightless sectors comprise a growing share of exports and new jobs.

Meanwhile, estimates of the resource use of nations have arrived at a different conclusion. Drawing on material flows associated with global production and consumption networks, Wiedmann et al. (2015, p. 6271) estimate nations' material footprints, which they define as 'the global allocation of used raw material extraction to the final demand of an economy'. Each country's material footprint is calculated by aggregating data on 35 separate kinds of material. The 35 materials fall into four major categories: biomass (for example, fruits and timber), metal ores (for example, copper and gold), construction materials (for example, stone and chalk) and fossil fuels (for example, coal and natural gas). The two key data sources used in this work are the global multiregion input–output database Eora and a Global Material Flow Database.

Over the period 1990–2008, most countries increased their material footprint. Even though the relative size of the services sector grew in many countries, the absolute output of sectors such as food production, housing construction and energy generation had the effect of increasing most countries' material footprint.

Tracking the relationship between material footprint and GDP, Wiedmann et al. (2015) estimate that, on average, a 10 per cent increase in real per capita GDP is associated with a 6 per cent increase in a nation's material footprint. The material footprint measure is collected on a regular basis by the United Nations Environment Programme and used as the basis for Sustainable Development Goal 8.4.1, which tracks countries' material footprint, material footprint per capita and material footprint per dollar of output.

Other indicators used in industrial ecology studies point in a similar direction. Domestic material consumption is the combined physical weight of materials extracted domestically, plus imports, minus exports. In this sense, domestic material consumption takes a production perspective, while material footprint takes a consumption perspective. Historical analyses for Britain, Japan, the United States and the Soviet Union suggest that domestic material consumption per capita was higher at the start of the 21st century than it had been at the start of the 20th century (and therefore massively larger in aggregate) (Schandl and Schulz 2002; Krausmann, Gingrich and Nourbakhch-Sabet 2011; Gierlinger and Krausmann 2012; Krausmann et al. 2016, 2017).

This study adds a historical perspective, by estimating the physical weight of Australian output over nearly two centuries. Owing to data limitations, I do not take a material flow approach. Instead, I estimate the physical weight of GDP by multiplying the dollar output in the goods sector by the weight-per-dollar of traded goods. This makes it possible to estimate the figure back to 1831. The results are longer run, but less precise, than estimates of Australia's material footprint or domestic material consumption. Accordingly, they should be regarded as indicative of the order of magnitude rather than the exact weight of the economy.

To preview the findings, I observe a massive increase in the physical weight of the Australian economy. In raw tonnage, the weight of annual output was around 15,000 times larger in 2018 than it had been in 1831. Over this period, each 10 per cent increase in real GDP is associated with a 12 per cent increase in the physical weight of output. This suggests that the weightless economy may be further off than is sometimes imagined.

2. Approaches to Measuring the Physical Weight of Australian Output

In their analysis of the material footprint of nations, Wiedmann et al. (2015) build on earlier work that estimates nations' total raw materials usage (see for example, Muñoz, Giljum and Roca 2009; Schoer et al. 2012) (what is now termed 'material footprint' was previously described as 'raw material consumption'). This analysis is based on estimates of final demand across disaggregated

Table 1 Differing Approaches to Estimating the Weight of Output

Measure	*Using the physical weight of traded goods*	*Material footprint (consumption concept)*	*Domestic material consumption (production concept)*
Definition	Estimate the weight per dollar of traded goods (imports and exports). Multiply this by the dollar value of the goods component of GDP.	Estimate the physical weight of four kinds of raw materials (biomass, metal, construction materials and fossil fuels) required to satisfy a country's own final demand. Add the raw material equivalent weight of imports and subtract the raw material equivalent weight of exports.	Same methodology as material footprint, but raw materials are counted if they physically enter the economic system for further processing or direct consumption (does not distinguish between intermediate demand and final demand).
Dates available	1831–2018	1990–2017	1970–2017
Value in 2017 (tonnes)	830,666,864	1,059,911,000	927,442,768

industrial sectors, multiplied by the upstream material requirements associated with a dollar of output in each sector.

For example, the material footprint of beef takes into account the quantity of grazed biomass required to produce each unit of output, with one study estimating that the material footprint of 1 kilogram of beef is 46 kilograms (World Business Council for Sustainable Development 2016). This example reflects the fact that measures of material footprint include aspects of the production process that are not traded or included in national accounting statistics. This is a key difference in the way that I will estimate the physical weight of output, which does not derive from an analysis of the inputs in the production process. Among the key data sources used to calculate the material footprint are the weight of metals, minerals and fossil fuels extracted, tonnage of agricultural production, fodder volume, and roundwood harvest. Unlike GDP, material footprint includes imports and excludes exports.

As noted above, a closely related concept to the material footprint is domestic material consumption. While material footprint refers to the global allocation of used raw material extracted to meet the final demand of an economy, domestic material consumption refers to the amount of materials directly used in an economy. In this sense, material footprint looks at the consumption side of the economy, while domestic material consumption (somewhat confusingly) looks at the production side. At a global level, the material footprint and domestic material consumption measures are equal, but high-income countries tend to have a higher material footprint than domestic material consumption, reflecting the fact that consumption in those countries relies on materials from other countries through international supply chains. Material footprint and domestic material consumption data are published by the United Nations Environment Programme International Resource Panel (see Appendix 1 for more details). Table 1 summarises the three approaches. In 2017, Australia's domestic material consumption was around one-eighth less than Australia's material footprint. The physical weight of output (calculated using the weight of traded goods) was around one-fifth less than Australia's material footprint.

In the absence of detailed sectoral output data back to the early 1800s, I exploit the fact that we instead have estimates of the physical weight of the tradeable sector. These figures come from the total tonnage of shipping and (in more recent times) air freight. Using these numbers, it is possible to calculate the weight-per-dollar of merchandise exports and imports. Multiplying this weight-per-dollar estimate by the value of total goods output produces an estimate of the physical weight of total GDP.

This approach to approximating the long-run physical weight of Australian output is conceptually similar to the exercise carried out by Greenspan (2014). As noted, using the physical weight of traded goods has a number of key differences from the techniques used to calculate a nation's material footprint (or domestic material consumption). The material footprint attempts to measure all the material used to produce final goods in an economy. For example, in the case of wool, the material footprint would include all the biomass consumed by sheep. By contrast, the approach of using the physical weight of trade would capture the weight of the wool, but would not include fodder inputs, unless these were themselves final goods.

Additionally, while the material footprint approach attempts to capture the physical weight of inputs used in the services sector, the approach of using the physical weight of tradeable goods assumes that the services sector is weightless. As it turns out, material footprint analysis suggests that the physical weight of services output is indeed low, though not zero. For example, Giljum et al. (2016, Additional File 5) estimate that the weight-per-euro of output in the educational services sector is almost 10 times smaller than in the copper products or beverage production sectors, and almost 100 times smaller than in the stone or chemical production sectors.

Calculating the physical weight of merchandise trade requires splicing together several series. For the 1800s, import and export volumes are combined, and include ballast volumes. I therefore adjust these series using actual estimates of import and export weight for 1904–1906. Shipping volumes were published intermittently in Australian Year Books throughout the 20th century. From 1972 onwards, air cargo volumes have also been published, and these are added to the total (in that year, air cargo amounted to 0.08 per cent of total exports, so its omission in earlier years is unlikely to make much difference). A consistent series of the physical weight of trade only becomes available from 1992 onwards.

Other series are more straightforward. Import values, export values and industry shares of GDP are drawn from Butlin, Dixon and Lloyd (2015) for earlier years, and from Australian Bureau of Statistics (ABS) sources for recent years. GDP and population figures are drawn from Hutchinson and Ploeckl (2021). Appendix 1 provides further details on the derivation of all series.

In principle, one could use either imports or exports to estimate the weight-per-dollar of GDP. To see this, take the case of an export-oriented agricultural sector. Here, using the physical weight of exports might provide an indication of whether production is focused on crops with a high value per tonne (for example, berries) or a low value per tonne (for example, potatoes). Conversely, take the case of a domestically oriented manufacturing sector. In this instance, using the physical weight of imports might indicate whether production is focused on heavy manufacturing (for example, ship-building) or light manufacturing (for example, medical equipment).

I opt to use both import weights and export weights, since this provides the broadest possible measure of the economy, spanning the widest range of goods. So that the measure is not affected by the trade balance, I estimate the physical weight of imports and the physical weight of exports separately, and then average them.

For recent years, it is possible to compare this approach for measuring the physical weight of GDP with the material footprint and domestic material consumption approaches. As noted, the traded goods approach produces a smaller total than either of the two metrics. However, the three indicators track quite closely over time. The correlation between the trade-derived measure of the physical weight of GDP and the material footprint is 0.94, and the correlation between the trade-derived measure of the physical weight of GDP and domestic material consumption is 0.80.[2]

The relatively large differences between the series also serve as a reminder that the exercise of estimating the physical weight of GDP using the physical weight of trade is inherently imprecise. Results should therefore be interpreted cautiously, as an indication of the general order of magnitude, rather than precise point estimates.

3. Long-Run Trends in the Physical Weight of Output

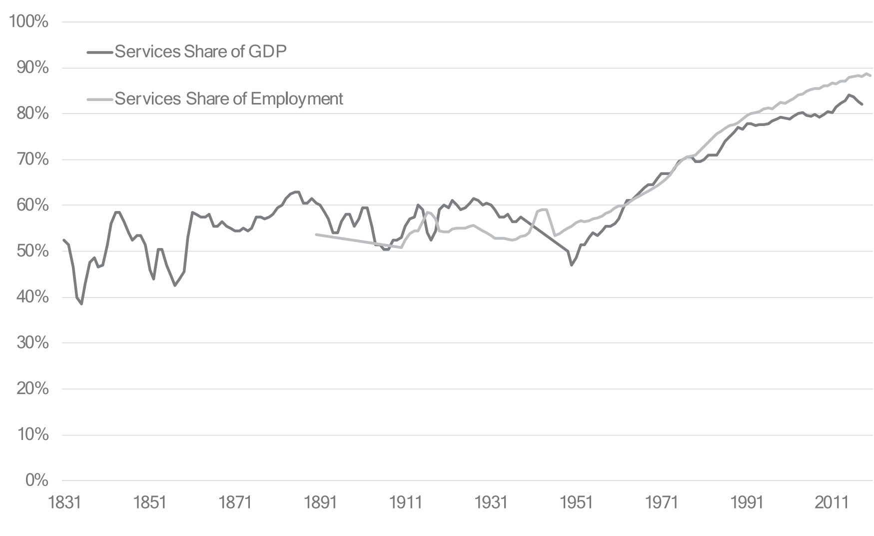
To set the scene, Figure 1 shows the share of services in the overall economy, and as a share of employment. For these purposes, I define the goods sector as agriculture, mining and manufacturing, and the services sector as the remainder of the economy. Classifying construction as a services sector rather than a goods sector follows Greenspan (2014) for the United States, and also reflects the fact that estimates of the size of the Australian construction sector simply do not exist for much of the period in question.

The services share of output rose slightly from the 1830s to the 1860s, and then fluctuated around 55 per cent of the economy before falling during the 1940s. After World War II, the services share rose steadily, to 82 per cent in 2018. Services employment has only been available from 1890 onwards, but shows a similar pattern, staying stable through the first half of the 20th century, and then rising from 56 per cent in 1950 to 89 per cent in 2020. With the services sector now accounting for 82 per cent of output and 89 per cent of employment, it is little surprise to hear talk of a 'dematerialised' or 'weightless' economy. However, Kander (2005) and Fix (2019) caution against assuming that a larger services sector will inevitably reduce an economy's environmental footprint, noting empirically that a larger services sector tends to be associated with higher fossil fuel usage and more carbon emissions.

I turn now to estimate the weight of economic output. Dividing trade tonnage by the real value of trade, I estimate the weight in kilograms of a dollar of exports and a dollar of imports (for the purposes of this analysis, a dollar is adjusted into 2018 terms using the GDP deflator). For most of Australian history, exports have been heavier per dollar than imports. Put another way, a kilogram of exports has typically been worth less than a kilogram of imports. This held true in the 1830s, when a dollar of exports weighed 0.29 kilograms, while a dollar of imports weighed 0.19 kilograms. By the time of Federation, a dollar of exports weighed 0.45 kilograms, while a dollar of imports weighed 0.31 kilograms.

From 1942 to 1966, this pattern temporarily reversed. During this period, a dollar of exports weighed 0.48 kilograms, while a

Figure 1 Services Share of Output and Employment, 1831–2018



dollar of imports weighed 0.69 kilograms. But since the late 1960s, rising mining exports have seen a marked increase in the weight-per-dollar of exports. In the 2010s, a dollar of exports weighed 4.32 kilograms, while a dollar of imports weighed 0.37 kilograms. This is consistent with a country whose top exports include iron ore, coal and beef, and top imports include motor vehicles, computers and telecommunications equipment. As noted, my estimate of the long-run physical weight of output is based on a simple average of the weight-per-dollar of exports and imports. Figure 2 charts the average weight of an inflation-adjusted dollar of traded goods from 1831 to 2018.

The trade share of the Australian economy fluctuated considerably over the period 1831–2018. According to Butlin, Dixon and Lloyd (2015), the openness ratio (merchandise exports and imports divided by GDP) was above 50 per cent for much of the period from 1831 to 1860, then fell to around one-third in the latter part of the 19th century. By the 1920s, the openness ratio was down to one-quarter, and bottomed out at one-tenth in 1943. Openness increased after World War II, and from the 1950s to the 1970s, the openness ratio was around one-fifth. In the 1980s and 1990s, openness increased slightly. Since the start of the 21st century, Australia's openness ratio has been about one-third.

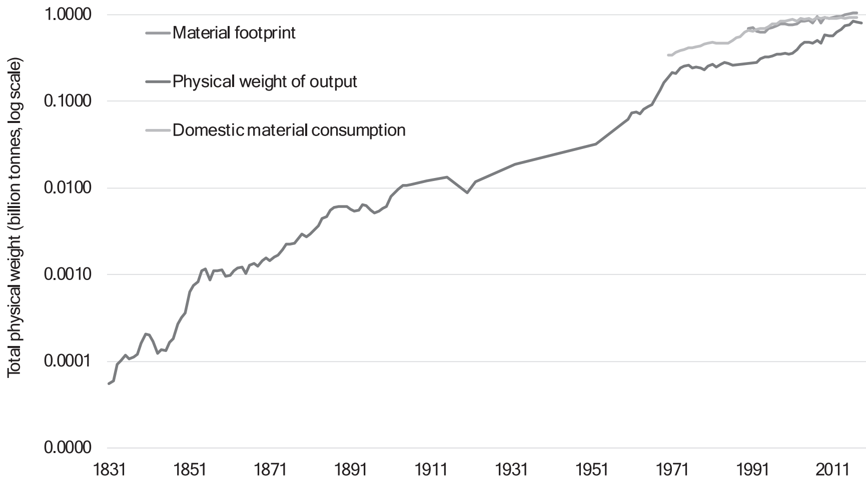
Figure 3 shows the physical weight of Australian output (the full data series are provided in Tables A1 and A2). Since the increase is so considerable, the estimates are plotted on a logarithmic scale. The physical weight of Australia's GDP was 55,000 tonnes in 1831, 6 million tonnes in 1900, 62 million tonnes in 1960, 355 million tonnes in 2000 and 811 million tonnes in 2018. For comparison, Figure 3 also charts estimates of Australia's material footprint and domestic material consumption.

The long-run trends suggest that the physical weight of Australian output grew by a factor of 15,000 over the period 1831–2018. The physical weight of GDP grew by a factor of 112 in the 19th century (1831–1900), by a factor of 58 in the 20th century (1900–2000) and by a factor of slightly over 2 in the 21st century (2000–2018).

Figure 4 shows these estimates on a per-capita basis. Here, the increase is smaller, but still substantial. The weight of Australian output was less than 1 tonne per person in 1831, 2 tonnes in 1900, 6 tonnes in 1960, 18 tonnes in 2000 and 32 tonnes in 2018. In proportionate terms, the physical weight of output per capita grew 47-fold

Figure 2 Average Weight of a Dollar of Traded Goods, 1831–2018

Figure 3 Total Physical Weight of Output, 1831–2018

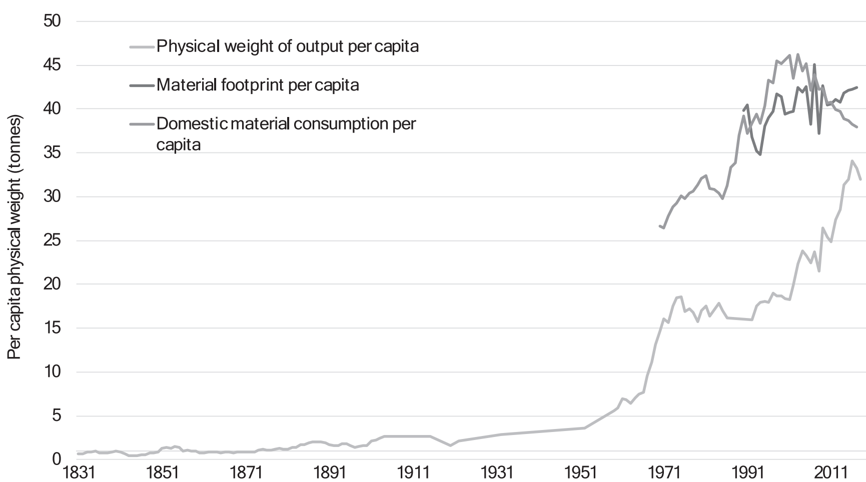


from 1831 to 2018. The physical weight of Australia's output doubled in the 19th century (1831–1900), grew by a factor of 11 in the 20th century (1900–2000) and increased by a factor of slightly under 2 in the 21st century (2000–2018).

Finally, I estimate the elasticity of the physical weight of GDP with respect to the value of GDP. The first column in Table 2 shows the results of a regression of the logarithm of the physical weight of GDP on the logarithm of real GDP, producing a coefficient of 1.2, which suggests that a 10 per cent increase in real GDP is associated with a 12 per cent increase in the physical weight of Australian output.

The same exercise can be performed for material footprint and domestic material consumption. The elasticity of the material footprint with respect to real GDP is 0.55, which is close to the average elasticity of 0.60 across 137 countries over the period 1990–2008 (Wiedmann et al. 2015). The elasticity for domestic material consumption is 0.74.

Figure 4 Per Capita Physical Weight of Output, 1831–2018



Note that this is not merely an artefact of the timespan. The elasticity of the physical weight of GDP with respect to real GDP is higher than corresponding elasticities for the other two measures when measured over the period since 1970 or 1990. However, it is possible that the result is partly due to the fact that the physical weight of GDP is more directly derived from the value of GDP than the other two measures.

4. Conclusion: What Explains the Supersized Economy?

Drawing on historical statistics, I compile rough but long-run estimates of the physical weight of Australian GDP, covering almost two centuries. These data debunk the contention that the economy has grown lighter. On an aggregate basis or a per-capita basis, the weight of the Australian economy has grown considerably, outpacing the value of output. This supports the conclusions of Wiedmann et al. (2015), and casts doubt on the suggestions by Greenspan (2014) and Quah (2019) that the increase in economic wellbeing across advanced countries over the past two centuries has occurred without much change in the physical weight of GDP.

Weightless production is an exciting development, but proponents should not get carried away. Over the course of the 19th, 20th and 21st centuries, the Australian economy has become considerably heftier as it has grown more affluent. This has taken place despite a substantial economic shift in employment towards services, with services jobs growing from half the workforce in 1900 to nine-tenths of the workforce in 2020. Goods-producing sectors such as agriculture and mining may employ a smaller share of workers, but large-scale harvesters and mechanised mining have allowed them to engage in heavyweight production. One reason why the physical weight of Australian output has risen significantly in the past three decades is that Australian iron ore production rose ninefold between 1990 and 2020.

On the consumption side, efficiency has been offset by higher consumption. Airliners may be more fuel-efficient, but people are significantly more likely to travel by air. Designers may have created lighter clothes, but households have more items in their wardrobes. Food packaging may be thinner, but consumption of takeaway food has risen.

An extensive literature considers policies that could reduce the physical weight of economic production (see, for example, Cleveland and Ruth 1998; Ausubel and Waggoner 2008; Schandl and Turner 2009; Hatfield-Dodds et al. 2015; Schandl et al. 2016, 2020). Energy policies can reduce greenhouse gas emissions by shifting generation away from fossil fuels and towards renewables. Product quality standards can encourage the manufacture of longer-lasting durable goods. More medium-density housing in inner urban areas will reduce commuting distances. Better public transport, more cycle paths and greater uptake of electric cars will cut transport emissions. Reducing food wastage and shifting towards more plant-based diets would lower the physical weight of food consumption.

This should be a particular issue for Australia. Using the material footprint measure, Australia comprises 1.1 per cent of the global material footprint, considerably larger than our share of

Table 2 Relationship between the Physical Weight of GDP and the Value of GDP

Dependent variable	*[1]* *Log physical weight of GDP (1831–2018)*	*[2]* *Log material footprint (1990–2017)*	*[3]* *Log domestic material consumption (1970–2017)*
Log real GDP	1.246***	0.551***	0.740***
	(0.013)	(0.035)	(0.030)
R squared	0.99	0.91	0.93
Observations	137	28	48

Notes: GDP = gross domestic product.
***denotes statistical significance at the 1 percent level.

world population or world output. On a per-capita basis, Australia's material footprint is among the highest in the world, weighing in at 43 tonnes per person (my estimates of the physical weight of output are only a little smaller).

Those who tout the gains in lightweight production should be careful not to extrapolate from simple trends in the services share of the economy. To the extent that there is a turning point beyond which higher levels of economic output are associated with a reduction in the physical weight of output, Australia does not appear to have reached it. Indeed, it may be that there is no such thing as a Kuznets Curve for the tonnage of an economy. Like the paperless office, the weightless economy remains surprisingly elusive.

Endnotes

1. According to the International Labour Organization, 50.1 per cent of the world's workforce were engaged in services employment in 2019 (data ID SL.SRV.EMPL.ZS). The ILO defines employment as persons of working age who were engaged in any activity to produce goods or provide services for pay or profit, whether at work during the reference period or not at work due to temporary absence from a job, or to working-time arrangement. The services sector consists of wholesale and retail trade and restaurants and hotels; transport, storage and communications; financing, insurance, real estate and business services; and community, social and personal services. The series dates back to 1991, at which time 34.5 per cent of global workers were in the services sector.

2. One might reasonably wonder whether the correlation between the physical weight of GDP and the material footprint (0.94) is higher than the correlation between the physical weight of GDP and domestic material consumption (0.80) because domestic material consumption data are available from 1970, while material footprint data are only available from 1990. This is not the case. In fact, the correlation between the physical weight of GDP and domestic material consumption is even smaller (0.71) when estimated using data from 1990 onwards.

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Appendix 1: Data Sources

Material Footprint and Domestic Material Consumption

Material footprint and domestic material consumption data are drawn from the United Nations Environment Programme International Resource Panel. This database is a joint project of the Commonwealth Scientific and Industrial Research Organisation in Australia, the Vienna University of Economics and Business in Austria, the Institute of Social Ecology Vienna in Austria, the University of Nagoya, Japan, and the University of Sydney's Integrated Sustainability Analysis. The data, as well as a detailed description of sources and methods, may be found at www.resourcepanel.org/global-material-flows-database.

Gross Domestic Product and Population

GDP and population figures are from Hutchinson and Ploeckl (2021). These are presented on a fiscal-year basis, and are converted to calendar years by averaging across adjacent pairs of years.

Goods and Services Shares of Gross Domestic Product

The services share of GDP is calculated from Butlin, Dixon and Lloyd (2015, Table A1). These figures are provided for 1800–01 to 2009–10 on a fiscal-year basis (with the exception of 1940–41 to 1947–48). They are converted to a calendar-year basis by averaging adjacent years. Services are defined as the share of GDP produced in sectors other than agriculture, mining and manufacturing. Butlin, Dixon and Lloyd's figures are used to 1989. As noted, classifying the construction sector as part of services production rather than goods production follows Greenspan (2014) for the United States. Moreover, because construction is not separately identified in the tabulation of Butlin, Dixon and Lloyd (2015), it would not be possible to include it in the goods sector for most of the period in question.

From 1990 onwards, I use ABS estimates for the percentage of gross value added (at basic prices, current prices) comprised of sectors other than agriculture, forestry and fishing, mining, and manufacturing, as set out in ABS [2020a, Table 5: Gross Value Added (GVA) by Industry]. They are converted to calendar year basis by averaging adjacent years.

Goods and Services Shares of Employment

Data on the services share of employment for 1890–1979 are drawn from Withers, Endres and Perry (1985, pp. 100–101). Services are defined as all employees except those in the rural, mining and manufacturing sectors. Figures from 1960–61 onwards are expressed by Withers, Endres and Perry on a fiscal-year basis, and I convert them to a calendar-year basis by averaging adjacent years.

Export and Import Weights

1831–1903: The Australian Year Book No. 15 (1922, p. 507) provides total net tonnage of both imports and exports from 1822–1921. This is not separated into imports and exports, nor is ballast excluded. To make these adjustments, I use data from 1904–06, for which ballast is excluded and imports separated from exports. In these overlap years, the ratio of total exports (excluding ballast) to total net tonnage of imports and exports (including ballast) is 48.5 per cent, while the ratio of total imports (excluding ballast) to total net tonnage of imports and exports (including ballast) is 35.7 per cent. These figures are then multiplied by 1.016 to convert from imperial tons to metric tonnes.

1904–06: The Australian Year Book No. 1 (1908, pp. 530, 535) provides data on export volumes (cleared tonnage) and import volumes (entered tonnage), and the share of that tonnage comprised from ballast. From these, I estimate the net tonnage of exports and imports (excluding ballast). These figures are then multiplied by 1.016 to convert from imperial tons to metric tonnes.

1910–20: Vamplew (1987, Table TC211–218, p. 182) provides data on net tonnage of exports and imports. In principle, one could adjust these figures downwards, using the ballast percentages from 1904–06. However, data in the 1985 Year Book show both the number of revenue tonnes and the net tonnage for 1922 and 1932 (the closest years). In these years, the number of revenue tonnes *exceeds* the net tonnage for exports, but is smaller than the net tonnage for imports. I therefore use data from 1922 and 1932 to estimate that the Vamplew export tonnage should be multiplied by 1.24, while the Vamplew import tonnage should be multiplied by 0.53. Note that both these calculations also adjust for the conversion from imperial tons to metric tonnes.

1921–81: The Australian Year Book No. 69 (1985, p. 671) provides the weight in revenue tonnes of exports and imports from 1922–80. Revenue tonnes are a composite measure, constructed for the purposes of calculating

Table A1 Physical Weight of Output and Service Sector Shares

Calendar year	*Weight of output (tonnes)*	*Weight of output per capita (tonnes)*	*Services share of GDP*	*Services share of employment*
1831	54,955	0.69	52.5%	
1832	59,238	0.65	51.5%	
1833	92,318	0.91	46.5%	
1834	101,866	0.93	40.0%	
1835	116,532	0.98	38.5%	
1836	106,951	0.82	43.0%	
1837	112,386	0.78	47.5%	
1838	120,442	0.75	48.5%	
1839	162,807	0.90	46.5%	
1840	206,514	1.00	47.0%	
1841	200,519	0.87	51.5%	
1842	169,604	0.69	56.0%	
1843	123,230	0.48	58.5%	
1844	135,404	0.50	58.5%	
1845	132,464	0.46	56.5%	
1846	166,889	0.55	54.0%	
1847	183,770	0.57	52.5%	
1848	271,997	0.77	53.5%	
1849	316,849	0.81	53.5%	
1850	360,407	0.86	51.5%	
1851	631,317	1.33	46.0%	
1852	758,651	1.36	44.0%	
1853	835,968	1.29	50.5%	
1854	1,119,146	1.50	50.5%	
1855	1,164,484	1.39	47.0%	
1856	868,585	0.94	44.5%	
1857	1,112,910	1.10	42.5%	
1858	1,112,396	1.04	44.0%	
1859	1,134,120	1.01	45.5%	
1860	950,283	0.82	53.0%	
1861	981,012	0.83	58.5%	
1862	1,097,987	0.89	58.0%	
1863	1,184,350	0.92	57.5%	
1864	1,211,876	0.89	57.5%	
1865	1,037,371	0.73	58.0%	
1866	1,298,955	0.89	55.5%	
1867	1,354,500	0.90	55.5%	
1868	1,239,902	0.79	56.5%	
1869	1,439,571	0.89	55.5%	
1870	1,558,619	0.93	55.0%	
1871	1,441,521	0.84	54.5%	
1872	1,595,593	0.90	54.5%	
1873	1,677,570	0.92	55.0%	
1874	1,965,341	1.05	54.5%	
1875	2,258,548	1.17	55.0%	
1876	2,231,391	1.12	57.5%	
1877	2,314,820	1.12	57.5%	
1878	2,605,266	1.22	57.0%	
1879	2,966,085	1.35	57.5%	
1880	2,739,929	1.21	58.0%	
1881	2,921,248	1.24	59.5%	
1882	3,359,575	1.37	60.0%	
1883	3,706,251	1.45	61.5%	

(Continues)

Table A1 (Continued)

Calendar year	*Weight of output (tonnes)*	*Weight of output per capita (tonnes)*	*Services share of GDP*	*Services share of employment*
1884	4,481,443	1.69	62.5%	
1885	4,685,885	1.71	63.0%	
1886	5,495,128	1.94	63.0%	
1887	6,039,435	2.06	60.5%	
1888	6,156,977	2.04	60.5%	
1889	6,151,261	1.98	61.5%	
1890	6,073,876	1.90	60.5%	53.6%
1891	5,702,176	1.74	60.0%	
1892	5,465,133	1.64	58.5%	
1893	5,586,569	1.65	57.0%	
1894	6,476,260	1.87	54.0%	
1895	6,255,118	1.78	54.0%	
1896	5,602,974	1.56	56.5%	
1897	5,180,955	1.42	58.0%	
1898	5,372,151	1.46	58.0%	
1899	5,858,622	1.57	55.5%	
1900	6,154,364	1.62	57.0%	52.3%
1901	8,089,637	2.10	59.5%	
1902	8,922,191	2.29	59.5%	
1903	9,689,685	2.46	55.5%	
1904	10,615,837	2.65	51.5%	
1905	10,628,191	2.62	51.5%	
1906	11,098,577	2.69	50.5%	
1907			50.5%	
1908			52.5%	
1909			52.5%	
1910	11,985,934	2.66	53.0%	50.7%
1911			55.5%	52.4%
1912			57.0%	53.8%
1913			57.5%	54.4%
1914			60.0%	54.4%
1915	13,383,362	2.71	59.0%	56.5%
1916			54.0%	58.5%
1917			52.5%	58.2%
1918			54.5%	57.1%
1919			59.0%	54.5%
1920	8,866,712	1.62	60.0%	54.2%
1921			59.5%	54.3%
1922	11,937,964	2.10	61.0%	54.8%
1923			60.0%	55.0%
1924			59.0%	55.0%
1925			59.5%	55.0%
1926			60.5%	55.4%
1927			61.5%	55.6%
1928			61.0%	55.1%
1929			60.0%	54.5%
1930			60.5%	54.1%
1931			60.0%	53.4%
1932	18,840,573	2.84	59.0%	52.9%
1933			57.5%	52.8%
1934			57.5%	52.8%
1935			58.0%	52.6%
1936			56.5%	52.5%

(Continues)

Table A1 (Continued)

Calendar year	*Weight of output (tonnes)*	*Weight of output per capita (tonnes)*	*Services share of GDP*	*Services share of employment*
1937			56.5%	52.6%
1938			57.5%	53.3%
1939				53.5%
1940				54.0%
1941				56.2%
1942				58.7%
1943				59.0%
1944				59.0%
1945				56.7%
1946				53.5%
1947				53.8%
1948				54.4%
1949			50.0%	55.0%
1950			47.0%	55.5%
1951			48.5%	56.2%
1952	31,858,497	3.61	51.5%	56.7%
1953			51.5%	56.4%
1954			53.0%	56.6%
1955			54.0%	57.1%
1956			53.5%	57.4%
1957			54.5%	57.6%
1958			55.5%	58.2%
1959	57,800,303	5.62	55.5%	58.7%
1960	61,957,132	5.89	56.0%	59.5%
1961	74,218,590	6.91	57.0%	59.9%
1962	75,528,081	6.90	59.5%	60.0%
1963	71,666,272	6.42	61.0%	60.3%
1964	80,734,146	7.09	61.0%	61.0%
1965	86,346,205	7.44	62.0%	61.6%
1966	91,015,061	7.71	63.0%	62.2%
1967	115,576,137	9.61	64.0%	62.7%
1968	136,138,659	11.09	64.5%	63.1%
1969	165,063,000	13.17	64.5%	63.7%
1970	190,634,321	14.74	66.0%	64.3%
1971	213,653,978	16.06	67.0%	65.0%
1972	210,937,036	15.61	67.0%	65.7%
1973	240,855,117	17.55	67.0%	66.8%
1974	256,636,274	18.46	68.0%	68.2%
1975	261,424,032	18.62	69.5%	69.2%
1976	240,396,309	16.93	70.0%	70.0%
1977	246,879,302	17.20	70.5%	70.6%
1978	244,244,422	16.83	70.5%	70.8%
1979	232,137,765	15.79	69.5%	70.9%
1980	254,644,236	17.06	69.5%	0.0%
1981	265,776,616	17.52	70.0%	0.0%
1982	252,212,066	16.39	71.0%	0.0%
1983	266,491,265	17.10	71.0%	0.0%
1984	281,495,535	17.83	71.0%	75.6%
1985	272,479,924	17.01	72.5%	76.3%
1986	263,174,417	16.18	74.0%	76.9%
1987			75.0%	77.4%
1988			76.0%	77.6%
1989			77.0%	78.1%

(Continues)

Table A1 (Continued)

Calendar year	Weight of output (tonnes)	Weight of output per capita (tonnes)	Services share of GDP	Services share of employment
1990			76.6%	78.8%
1991			77.8%	79.7%
1992	281,388,397	15.95	77.8%	80.0%
1993	311,616,540	17.50	77.5%	80.2%
1994	323,888,491	17.99	77.6%	80.5%
1995	329,347,623	18.07	77.6%	81.1%
1996	330,621,001	17.95	77.9%	81.2%
1997	352,614,829	18.95	78.4%	81.1%
1998	352,253,406	18.72	78.8%	81.8%
1999	355,550,900	18.68	79.3%	82.4%
2000	354,664,884	18.41	79.1%	82.2%
2001	355,917,920	18.26	78.8%	82.8%
2002	392,410,784	19.90	79.4%	83.2%
2003	444,504,787	22.30	80.1%	84.1%
2004	479,879,188	23.78	80.2%	84.3%
2005	476,658,818	23.29	79.6%	84.8%
2006	467,713,420	22.46	79.5%	85.3%
2007	504,261,672	23.73	79.9%	85.5%
2008	466,249,234	21.52	79.3%	85.5%
2009	582,528,150	26.46	79.9%	86.0%
2010	568,014,901	25.42	80.5%	86.2%
2011	564,245,529	24.83	80.2%	86.7%
2012	631,813,201	27.34	81.5%	86.5%
2013	669,437,016	28.52	82.2%	87.0%
2014	746,538,651	31.35	82.8%	87.1%
2015	772,857,048	31.95	84.2%	87.9%
2016	836,721,963	34.04	83.7%	88.0%
2017	830,666,864	33.26	82.6%	88.4%
2018	811,387,624	32.00	82.0%	88.1%

port levies. They equal the weight in metric tonnes or volume in cubic metres, whichever is higher (consequently, items that have less density than water are charged as though they had the density of water). Year Book No. 73 shows both revenue tonnes and gross weight over a 6-year span. In every year, the two measures are within 1 per cent of one another.

1982–86: The Australian Year Book No. 73 (1990, p. 624) provides gross weight of shipping exports and imports. These are presented on a fiscal-year basis, and converted to calendar years by averaging across adjacent pairs of years.

Air freight statistics for 1972–86 are drawn from Australian Year Book No. 62 (1977–78, p. 522), Australian Year Book No. 69 (1985, p. 455) and Australian Year Book No 73 (1990, p. 645). Figures are presented on a fiscal-year basis, and converted to calendar years by averaging across adjacent pairs of years. Estimates are linearly interpolated for 1977 and 1978. Air import volumes are not available for all years. Where missing, they are assumed to be 127 per cent of air export volumes, being the ratio of the two in 1983–4. Note that adjustments to the air freight statistics make almost no difference, since air freight volumes never exceed 0.05 per cent of total export volumes, and never exceed 0.5 per cent of total import volumes.

For recent years, the ABS supplied me with unpublished annual estimates of the total weight of exports (from 1988 onwards) and imports (from 1992 onwards). This includes both shipping and air freight.

Table A2 Material Footprint and Domestic Material Consumption Estimates from United Nations Environment Programme

Calendar year	*Material footprint (tonnes)*	*Material footprint per capita (tonnes)*	*Domestic material consumption (tonnes)*	*Domestic material consumption per capita (tonnes)*
1970			341,878,312	26.62
1971			345,991,170	26.44
1972			368,889,359	27.74
1973			388,842,869	28.83
1974			399,058,231	29.21
1975			416,456,061	30.11
1976			416,780,053	29.78
1977			429,611,558	30.36
1978			437,930,012	30.6
1979			454,403,471	31.4
1980			469,663,810	32.06
1981			480,590,799	32.39
1982			465,358,565	30.94
1983			470,683,525	30.85
1984			471,296,318	30.43
1985			468,578,727	29.79
1986			499,891,627	31.27
1987			542,283,584	33.36
1988			560,138,758	33.89
1989			622,040,211	37.04
1990	688,618,500	39.86	668,191,328	39.21
1991	706,753,500	40.46	642,303,161	37.19
1992	648,585,000	36.77	670,187,186	38.33
1993	627,853,600	35.26	697,135,190	39.41
1994	626,536,300	34.79	685,727,890	38.35
1995	693,829,900	38.07	729,923,637	40.38
1996	718,423,000	39.00	791,719,930	43.33
1997	739,419,600	39.74	792,893,448	42.93
1998	785,531,700	41.76	849,769,852	45.53
1999	787,917,600	41.40	852,966,606	45.22
2000	759,645,500	39.43	868,438,870	45.55
2001	772,547,600	39.63	888,066,826	46.09
2002	783,900,400	39.76	847,282,074	43.51
2003	847,159,300	42.49	910,689,710	46.24
2004	845,966,300	41.92	884,993,667	44.36
2005	871,770,700	42.59	914,379,169	45.18
2006	797,558,100	38.30	866,920,584	42.14
2007	956,837,100	45.04	920,911,521	43.96
2008	805,827,600	37.19	901,189,505	42.23
2009	939,081,400	42.65	921,077,518	42.37
2010	903,879,500	40.45	899,550,662	40.67
2011	922,832,900	40.61	917,662,637	40.82
2012	950,519,900	41.13	910,434,102	39.89
2013	957,918,300	40.82	920,297,941	39.75
2014	995,395,500	41.80	912,075,161	38.85
2015	1,018,331,700	42.10	919,954,906	38.65
2016	1,039,107,000	42.27	924,037,428	38.3
2017	1,059,911,000	42.44	927,442,768	37.93

Tonnages of exports and imports are not available on a sectoral level over any substantial period.

Export and Import Values

Export and import values are drawn from Butlin, Dixon and Lloyd (2015, Table A3, pp. 570–7). These figures are provided from 1822–1913 on a calendar-year basis, and from 1914–15 to 2009–10 on a fiscal-year basis. Years from 1914–15 onwards are converted to calendar-year basis by averaging adjacent years. These figures are used up to 2005.

From 2006 onwards, trade values are from Department of Foreign Affairs and Trade (2020), which is constructed using ABS Cat No. 5368.0, adjusted 'to produce the most accurate dataset possible on Australia's merchandise trade data on a calendar year and financial year basis'. Adjustments include using ABS trade data that are released after a time lag, and using ABS unpublished data.

From 1984 onwards, estimates are drawn from ABS [2020b, Table 4: Employed persons by Industry division of main job (ANZSIC)]. I use the original series (as distinct from the trend and seasonally adjusted figures), and average shares across each calendar year. As with the output data, services employment is total employment less those in the agriculture, forestry and fishing, mining, and manufacturing sectors.

Data Range

Although all data are available for 1822 onwards, I opt to start the series in 1831. This is because Butlin, Dixon and Lloyd's estimates of the value of exports and imports from 1822–30 are extremely volatile. For example, the value of imports is estimated to have risen from \$0.12 million in 1824 to \$0.78 million in 1825, while the value of exports is estimated to have risen from \$0.29 million in 1830 to \$0.93 million in 1831. Yet the shipping weights across this period show much less year-to-year volatility. As a consequence, using data from the period 1822–30 to estimate the weight-per-dollar of economic output produces extremely volatile estimates, and makes estimates of the weight of total output highly sensitive to whether exports, imports or an average of both are used to estimate the weight-per-dollar of economic output.

Investigating the primary sources from which Butlin, Dixon and Lloyd's import and export data are compiled, the source of this volatility in import and export values appears to arise from figures from New South Wales rather than those from Van Diemen's Land, Western Australia or South Australia, since the New South Wales numbers are both larger and more volatile (compare Vamplew 1987, Table EC80–88, p. 109 with Table EC209–217, p. 118, Table EC283–299, p. 122 and Table EC331–343, p. 124).