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The Rise and Fall of Exceptional Australian Income Since 1800

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Keywords: Australia, productivity, natural resources, knowledge, education

JEL codes: N10, N5, O30, O40

THE RISE AND FALL OF EXCEPTIONAL AUSTRALIAN INCOMES SINCE 1800

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Abstract. We gauge how productivity and factor endowments shaped the rise and fall of Australia's exceptional incomes. New measures of TFP, which include natural resource inputs, are utilized in an accounting of income growth. Further, the drivers of TFP growth are explored. Pastoralism and mining had negative TFP externalities, and we incorporate these finding into a unified accounting of incomes which distinguishes the roles of endowments and productivity. Nevertheless, TFP growth played an important role in promoting exceptional incomes between 1842-1890. Our findings favour a more balanced interpretation of Australian growth that has roles for natural resources, labour participation and productivity.

JEL Classification: N1, N5, O30, O40

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1. Introduction

Australia's early settler economy had internationally high levels of income per capita. The leading paradigms are that settler Australia's prosperity was created by natural resource abundance relative to population (Abramovitz, 1986, Broadberry and Irwin, 2007) and by high labour participation that had origins in the convict economy (McLean, 2007). Here we add to the debates by considering if total factor productivity (TFP) was also an important driver of incomes. The new measure of TFP incorporates land inputs, to help clarify the roles of accumulation and productivity in Australian economic development. Further, the underpinning of TFP growth are explored by gauging the possible externalities associated with scale, the form of land use, and the contributions of investment in education, research and development. To the extent that TFP was a driver of incomes, gauging the forces shaping TFP will provide a finer grained analysis of the rise and fall of Australia's exceptional incomes.

Australia was a poor country in the period before European settlement and a spectacularly rich one by the 1850s. In 1820 Australia's GDP per capita was, according to Maddison (2003), close to subsistence level, reflecting the balance of the aboriginal and the much smaller European settler population. Australia's GDP per capita growth after 1820 reflects the decline of the aboriginal population, and the surge in the settlers' average incomes. The focus here centres on what happened to the settler economy. Settler Australia in the 1850s was the richest country in the world with a GDP per capita averaging around 50% and 80% above those of the UK and USA respectively. These relatives are well above those of Maddison, whose Australian estimates include the aboriginals. Settler Australia's internationally high incomes add wider interest to the question of whether natural and labour resources chiefly shaped the contours of its prosperity or if TFP also played a substantive role. Australia's exceptional position was short-lived, with, from the 1890s, Australia's GDP per capita mirroring that of the UK and trailing behind the USA.

Pastoral land and minerals were colonial Australia's principal natural resources. Interior New South Wales, NSW, with its native grasses, mild winters and adequate rainfall was well suited to grazing sheep. By 1838 the sheep flock numbered over 3 million, and fine merino wool dominated exports. The gold finds of the 1850s added lustre to Australia's resource endowments. Extracting the natural resource rents was facilitated by the convict economy and by British subsidies (Butlin, 1994). Landscape and the British Crown moulded the new colonies institutions. The capturing of pastoral land rents by elite squatters were tempered by the countervailing force of the Crown, during the transition to representative governments (McLean, 2013). Gold rents in the 1850s spread widely, partly reflecting Victoria's system of licensing small claims.

Natural resource rents augmented Australia's national income, but the wider productivity effects are complex and harder to gauge. For example, sparsely populated pastoral landscapes may deter networks conducive to the development and use of new technology (Greasley and Madsen, 2010). In contrast, some types of mining have strong inter-industry linkages and foster wider enterprise; coal and iron ore mining, for example, have different developmental consequences to extracting and exporting alluvial gold (Ville and Wickens, 2013). Greasley and Oxley (1997) argue that the gold rushes starting in 1851 had powerful demographic effects but did not disturb the trajectory of GDP per capita. Maddock and McLean (1984) show that gold-induced immigration supported the growth in manufacturing and services. The new index of TFP directly includes land use inputs, but the analysis here goes further by investigating the possible drivers of measured TFP.

Although natural resources and high labour participation take centre stage in the discussions of settler Australia's early prosperity, alternative underpinnings, including productivity drivers, have been investigated. Banerjee (2012) tests for the influence of patent intensity (patent-employment ratio) on productivity growth over the period 1870-2008 and finds it to have been a significantly positive determinant of growth, while population growth was a drag. The central objectives are firstly to provide a new measure of TFP, which incorporates land inputs. Then, the relative contributions of labour, land, produced capital, and the TFP residual, to settler Australia's GDP per capita are gauged. Finally, the drivers of the TFP residual (and labour productivity) are explored, to show the underlying forces shaping productivity.

Australia's exceptional per capita incomes were eroded after 1890. The possible culprits are also investigated within the factor-usage versus TFP framework. Thus a diminishing or degradation of mineral or land resources may have had direct impact on factor inputs and consequentially on GDP per capita (Broadberry and Irwin, 2007). Alternatively, Australia may have been caught in a staples trap by a 'curse' of natural resources that impinged on residual productivity (Schedvin, 1990). Although Australia's GDP per capita growth accelerates again, from the 1940s, its average incomes only matched those of the UK and trailed the USA (Greasley and Oxley, 1998). The contours of factor-use and TFP provide a simple decomposition of what shaped Australia's unexceptional 20th century growth. Additionally, alternative conjectures of what drove Australia's post-1890 productivity are considered, including the possibility that natural resource usage had productivity externalities, which in turn influenced GDP per capita.

This paper makes three principal contributions. Firstly, it reports the construction of a new TFP index that includes land inputs and spans the near entire history of settler Australia. Trend TFP growth, according to this index, surged to the 1880s, but fell by around 50% during the 20th century. Secondly, a growth accounting exercise shows the contributions of factor use and residual TFP to GDP per capita growth. Thirdly, the drivers of TFP (and labour productivity) are investigated by estimating cointegrating relationships with possible productivity augmenting externalities associated with scale, the form of land use, and with investment in education, research and development. A central issue is whether resource abundance shaped Australia's incomes simply by usage and rent extraction or, additionally, through productivity externalities.

2. Measuring TFP in Australia since 1800

All TFP indexes gauge the relationship between production and measured inputs, usually produced capital and labour, to show the roles of any unmeasured inputs in economic growth. Natural resources are typically unmeasured and, if so, residual TFP indexes may be misleading, most especially in natural resource abundant economies (Topp and Kuyls, 2013). Augmenting indexes of TFP with farmland attracts little or no dissent beyond the challenges of data construction (Matthews et al, 1982, Young, 1994). The inclusion or otherwise of mineral inputs in TFP raises more complex issues, and a variety of approaches to measuring reserves and their quality have been proposed (Syed et al, 2013). Contemporary analyses, for example of the falls in Australian productivity growth since the 1990s, generally highlight the deterioration of natural capital and report higher TFP growth after adjusting for the diminished resource. The debates of British coal mining's productivity decline provide one historical illustration of how natural resource depletion may influence economy-wide productivity (Feinstein et al 1981, Greasley, 1990). In contrast, Australia's history provides multiple illustrations of discoveries improving the quality of mineral reserves, to potentially reveal a misleading productivity gain if TFP indexes are not adjusted.

Pastoral farms have dominated Australian land use. The TFP index constructed here includes the utilization of pastoral land, approximated by the stock of sheep and cattle. Arable land inputs are also included and they are measured directly as the cultivated area. Agricultural land rents are a tiny fraction of Australia's national income, which renders arable land near invisible in the economy-wide TFP measure. Minerals as raw materials should not be included as inputs in indexes of TFP if the numerator, GDP, adopts net output measures (Matthews et al, 1982). Our measure of GDP includes net mining product (Butlin, 1962). Thus, an allowance for minerals in the TFP index is only needed if the availability or the quality of the reserve changes. Our initial construction of TFP excludes minerals:

$$A = Y/K^{\alpha}T^{\beta}L^{1-\alpha-\beta}, \qquad (1)$$

where A is TFP, Y is real GDP, K is produced capital, T is pastoral and cultivated land, L is labour hours, and the exponents are the relevant output elasticity, measured by income shares.

In the longer term the extraction of minerals will diminish the reserve, to the likely detriment of conventionally measured TFP. An adjusted measure, denoted here TFPm, which allows for variations in mineral reserves, is additionally reported. New discoveries, most often of gold before 1914, but of a wider range of minerals from the 1960s, including iron ore and bauxite interrupt the degradation, possibly augmented Australia's TFP over shorter periods. The gap between TFP and TFPm will reflect the net effects of depletion and new mineral finds on conventionally measured TFP, which excludes mineral reserves. The measure TFPm reported in section 4, adjusts TFP for shifts in economy-wide factor proportions related to minerals extraction and discovery, approximated by mineral rents per labour hour.

Extending Equation (1) to include mineral reserves, M, gives the adjusted index, TFPm,

$$\text{TFPm} = Y/K^{\alpha}T^{\beta}M^{c}L^{1-\alpha-\beta-c}, \qquad (2)$$

Thus the gap between TFPm and TFP equates to M/L^{c} . (3)

In the absence of direct historical data for mineral reserves, M, the ratio of TFP and TFPm is extracted from an estimated relationship between conventional TFP and annual mining rents per labour hour ($\frac{Y^R}{Lab}$), defined as Equation (5) in section 3, controlling for a range of TFP drivers. The World Bank methodology values natural capital as the sum of discounted income streams (mining rents in this context) looking forward over 25 years (McLaughlin, 2014). Their approach assumes a 'lifetime' of a reserve and projects future rents for years which do not have 25 years of forward-looking data. By extracting the measure TFPm from an estimated model of the drivers of TFP, these two assumptions of the World Bank approach are avoided. Estimation of Equation 5 allows the adjusted measure TFPm to be extracted from TFP, without imposing prior restrictions on the relationship between mining rents, ($\frac{Y^R}{Lab}$), and the value of mineral reserves. This approach allows for a comparison between conventionally measured TFP and an adjusted measure TFPm to show how variations in mineral reserves, approximated by mining rents, influenced productivity.

2.1 GDP per capita.

There are several estimates of Australia's GDP (Hutchinson, 2013). The pioneering work of Butlin (1962, 1994) provides the foundation of all the historical estimates. An important issue for the earlier years is whether or not to include estimates of aboriginal production. If aboriginals are included, Australia was among the poorest countries in 1800, but then shows spectacular gains to achieve the world's highest GDP per capita by the 1850s (Maddison, 2003). In contrast, the NSW convict-settler economy had average incomes (but not labour productivity, given the high labour participation rates) on a par with the UK in the early decades of the 19th century, and then surged ahead by the 1850s, see Figure 1. The focus here centres on settler economy. For Australia more generally Maddison's GDP estimates rest on conjectures, both of the aboriginal population and their subsistence incomes. These are important issues, for example Australia's population may have been lower in 1850 than at the onset of British settlement in 1788, but they are outside the scope of this analysis. The aboriginal population and its productivity strongly influences Maddison's estimates of Australia's early 19th century GDP per capita, hence they are not used here. Instead two estimates of GDP reported in Ville and Withers (2015) are adopted.

The preferred GDP index, Butlin, Dixon and Lloyd (2015) labelled Australia-BDL in Figure 1, utilizes Butlin's estimates for years to 1959/60, except for 1800-28 and 1911/12-1938/39 where the estimates of Snooks (1994) and Haig (2001) are deployed. Official Australian statistics are used from 1959. In the settler economy Australia's GDP per capita generally exceeded that of the UK from the 1830s, partly because of high labour participation. Despite a downturn around 1842, Australia's settlers' average incomes were around 60% higher than British incomes by the peak of the gold rush in the 1853. On any accounting Australia lost its exceptional GDP per capita by the 1890s, and thereafter its average incomes mirror closely those of the UK, and they were surpassed by the USA.

The contours of settler Australia's GDP per capita during the half-century after Victoria's gold rush are contested. The more widely accepted estimates of Butlin (1962) show continuing growth to 1890, followed by a sharp decline in the 1890s depression. In contrast, Haig's (2001) estimates point to stagnant GDP per capita 1861-1900. Analysts generally prefer Butlin's estimates for years to 1911 (Broadberry and Irwin, 2007, Hutchinson, 2013, BDL, 2015). Haig's estimates rest on relatively few production series for the years to 1911, but they include more series thereafter. Thus Maddison adopted Haig's estimates from 1911. However, Madsen (2015) argues in favour of using Haig's estimates from 1861 on the basis of statistical reliability tests where the measurement error in each series is gauged by regressing one series against the other. Moreover, although Butlin's estimates of nominal GDP utilize substantial data, his estimated deflators have not been fully endorsed. Accordingly, results are also reported here using Madsen's GDP estimates (labelled Australia-Haig1861 in Figure 1), and thus for two measures of TFP (Figure 3).

2.2 Measuring inputs and factor shares.

In the case of labour, one important, likely long-run depressing influence on Australia's GDP per capita is declining labour force participation from the exceptionally high levels of the convict economy. The labour input also reflects participation shifts from the changing age and gender distribution of the population, as well as the decreases in weekly working hours. The workforce estimates draw upon the participation rates reported by Withers *et al*. (1985) and Butlin (1994), but they are further adjusted for shifts in participation rates during the gold boom of the 1850s. Participation rates in excess of 90% were associated with the early convict economy to contribute to Australia's internationally high GDP per capita (McLean, 2013). Participation rates lessened as the gender balance shifted and local births increased. The participation decline did not prevent rapid labour-force expansion in the settler economy, from around 5000 workers in 1800 to over 0.5 million in 1859. The labour-force growth rate declined through the 19th century, but there was a brief reversal during the gold rush of the 1850s.

Gauging workforce participation rates during the gold rush raises complex issues, since the census enumerations only estimate the workforce in 1851, 1854 and 1856, and these show rates of 44.9%, 46.4% and 45.3% respectively (Withers *et al.*, 1985, p. 89). However, the highest annual rates of population growth during the gold rush, of around 17%, were in 1852 and 1853 (Maddock and McLean, 1983) and participation rates were almost certainly higher during these years. The gold boom arrested the long decline in participation rates, and the estimates used here for 1852-3 and 1855, of 47.1%, 46.7% and 46.1% reflect the rise in immigration from around 22.5 thousand each year in 1850-51 to around 74.5 thousand each year 1852-56. The long decline in participation rates was re-established after 1860 to rates of around 40% in the later 19th century. It is not until the 1970s that participation rates again show sustained increases, to rates of around 50% in 2010.

The average annual workforce is adjusted for variations in hours. Estimates of the average annual hours of those in employment have been constructed by Huberman (2004) for 1870, 1880, 1890, 1900, and 1913. They are used here, with annual estimates geometrically interpolated between these benchmarks. The high annual hours of 1870 (around 56 hours per week for a 50-week year) are adopted for earlier years. Post-1950 hours' estimates are taken from Groningen's Development Centre database. Clark's (1957) annual data are used to bridge the data between 1913 and 1950. The estimates show that average hours were 2792 in 1870 and declined to 2023 hours in 1950, and to 1900 hours in 2011. The working hours' estimates are not adjusted for annual variations in unemployment. Colonial and subsequently Commonwealth census estimates of unemployment are extant from 1890, and these data, along with pre-1890 estimates of capacity utilization are incorporated in the regression analysis of section 3, as possible influences on TFP.

Colonial Australia's most important natural resource was pastoral land; its' most important non-human resource were sheep. Nomadic sheep farming spread over the native grasslands of interior NSW from the 1820s. The first pastoral boom peaked by 1850 when around 55 million acres were occupied by squatters, with their holdings averaging around 30,000 acres (Roberts, 1935, p. 448). Land occupation can only be measured imprecisely for earlier years, and the shifting location of nomadic grazing further complicates identifying land in use. Estimates of sheep and cattle provide the alternative route followed here to gauging the resource inputs associated with the pastoral expansion. The settler population grew rapidly, but the ratio of sheep to settlers rose by at least three-fold 1820-50 see Figure 2. Care needs to be taken with the interpretation of Figure 2. Falling pastoral inputs per capita in the 1850s occurred despite the animal stock increasing in every year, and rising by around 50% over the decade. It was the spike in population associated with the gold boom that diminished the ratio of animals per capita in the 1850s. The pastoral animal stock did fall by around 12% 1837-40, when export markets were depressed, but it was a doubling of the settler population 1836-43, that was chiefly responsible for reducing animals per capita during these years.

A second pastoral boom dates from the 1870s (Butlin, 1964) with an upturn in animals per capita lasting until the depression of the 1890s. In 1890 grazing land in NSW had extended to around 170 million acres (Vamplew, 1987, 73). Much of the expansion took place in the more arid areas of mid and western NSW. The pastoral frontier also spread quickly through Queensland, where recorded land use, chiefly for cattle and sheep stations reached 285 million acres by 1890. The animal stock fell sharply in the 1890s and, although land was returned to use in the 20th century and the frontier expanded, pastoralism use did not keep pace with population expansion. Indeed, the ratio of pastoral animals to population was remarkably similar in 1810 and 2010.

Only a small proportion of Australia's land resources have been cultivated since 1800, with pasture dominating occupied farmland. Around 400,000 acres of Australian land was cultivated in 1850, which rose to 1.4 and 5.7 million acres respectively in 1865 and 1890. To provide context, pastoral land use increased by around 400 million acres 1862-90. Agriculture played a supporting role to the pastoral sector in Australia's development. Cultivation initially, during the convict era, facilitated pastoral export specialization, but latterly wheat was exported from SA and NSW (Dunsdorf, 1956). The swings in cultivated land per capita are less extreme than for pasture (Figure 3). The low point in cultivated hectares per capita in the 1850s was associated with the population surge of the gold rush and the attraction of farmers to the gold fields. Alternatively, in the half-century to 1920 wheat became an important Australian export and largely underpinned the rise in cultivated land to the higher levels of the 20th century.

Estimates of Australia's capital formation are extant from 1861 (Butlin, 1962). The produced capital stock is estimated as the sum of capital stock for non-residential buildings and structures, and for machinery and equipment using the perpetual inventory method. The initial capital stock is defined equal to the average investment for 1861-66 divided by the sum of the depreciation rate and the average annual investment growth rate over the period 1861-2011. The data are disaggregated to buildings and machinery because their relative size changes quite strongly over the long-run, with depreciation rates substantially higher for machinery than for buildings. For the years to 1860 the preferred estimates of the capital stock are back-cast assuming that the capital-output ratio (*K-Y)* before 1860 is equal to its average in the period 1861-65. The assumption of a constant *(K-Y)* before 1860 gains credence from the experience of the USA which had a near constant (*K-Y)* before 1840 (Gallman, 2000). Over the long 19th century the USA (*K-Y)* rose around 10%, partly because of high investment during the industrial expansion of the 1880s. It appears unlikely that Australia's (*K-Y)* rose 10% before 1860, in the absence substantial industrialization. However, additionally, an Australian capital stock series is constructed by postulating a 10% (*K-Y)* rise to 1860, and used in sensitivity tests of the estimates for the TFP drivers.

The inputs in the TFP index are weighted by estimates of their factor incomes shares. These are constructed as averages for three periods: 1800-90, 1890-1960 and 1960-2010, and used to construct the segments of the spliced TFP index in Section 2.3. The shares of wages and the rental values land are estimated directly, and thus produced capital's share is defined as residual income. The pastoral land weights are 0.13, 0.08 and 0.02 for the periods to 1890, 1960 and 2010 respectively, and are based on land values de-capitalized using an interest rate of 8%. Pre-1890 land prices are from Taylor (1992), using the average price of Crown land sales in pastoral colonies for 1862-90. Occasional estimates of pastoral land use, and for cultivation used to estimate values are from Vamplew (1987). The initial 0.13 pastoral land weight used for years to 1890 is projected to the later periods using commodity prices and estimates of occupied pastoral land. Agricultural land is included in the TFP index but its' small rental value relative to national income renders it near invisible. Even allowing for the higher rental values in agricultural areas (average SA Crown land sale prices of £1.28 per acre 1862-90 were two-thirds above the NSW and Queensland average, Taylor, 1992), cultivated land's share of Australia's natural income was modest. One estimate for 1850-90 suggests that agricultural land rent expansion was equal to around 2% of the increased value of pastoral rents during these years (Greasley, 2015). Using that relative, cultivated land is assigned a 0.003 weight for 1800-90, and the values are closer to zero in later years.

Wage income is estimated as the economy-wide compensation to employees plus imputed labour income of self-employed, which is estimated as the average earning per employee multiplied by the number of self-employed. The wage income shares are 0.43, 0.49 and 0.54 for the periods to 1800-1890, 1890-1960 and 1960-2010 respectively. The residual income shares ascribed to produced capital are (to two decimal places) therefore 0.44, 0.43 and 0.44 for the three periods.

2.3 Total Factor Productivity: a first assessment

Australia's level of TFP as specified by Equation 1 rose by around five-times 1803-2009, on average by around 0.78% p.a., see Figure 4. There was substantial TFP growth in the 19th century, principally from around 1840-80 when the preferred Butlin GDP series is used to 1911 (TFP-BDL). In contrast, a post- 1850s TFP stagnation emerges if Haig's GDP series is used from 1861 (TFP–Haig1861). Both TFP series show only modest growth during the early decades of the 20th century. There was renewed upward trajectory of Australia's TFP from the 1930s and through the Second World War, which lessened in the 1970s and again in the first decade of the present century. If the pre-1861capital stock is constructing by postulating a 10% rise in (*K-Y)*, then (TFP-BDL) rises by 31% to 1860, compared to 41% with the preferred capital data.

The initial estimates of TFP suggest that the evolving long-run prosperity of resource-rich Australia rested a good deal on productivity, even when land is included as an input. (The implications of the availability and quality of mineral reserves for TFPm and GDP per capita are gauged in a later section.) A simple decomposition of Australia's growth shows real GDP per capita rose by around ten-times and TFP by around five-times since 1800. The temptation to associate around one-half of Australia's rising prosperity with higher TFP, however, needs to be avoided. Australia's population grew at twice the rate as the labour force 1803-2010, given the falls in the participation rate, and average hours worked per year fell. Thus, over the long run, less than one-quarter of labour productivity growth can be attributed to TFP growth.

The relative contributions of TFP and measured endowments to GDP per capita and per worker hour have varied over time, see Table 1. TFP depressed labour productivity to 1841, partly reflecting the inclusion of land inputs in TFP. Thus GDP/L growth rested upon the growth of endowments (chiefly pastoral land) per worker, and the slower growth of GDP per capita reflects falling labour participation. In contrast, a surge in TFP growth 1842-90 largely underpinned the faster growth of GDP/L to ameliorate the continuing falls in labour participation. TFP growth slowed after 1890 and accounts for around two-thirds of the GDP/L retardation 1891-2009, although the effects on GDP per capita were tempered by a lesser decline in working hours.

Trend productivity growth (with Butlin's GDP estimates to 1911) shown as Figure 5 reinforces a possibly central role for TFP (but not necessarily TFPm) during the period of exceptional incomes of the 1840s-1880s. There was a down-step in trend TFP growth in the 20th century, to an average rate of around 1.1% p.a. In the 19th century trend TFP growth surged from negative rates early in the century to a high plateau, with average rates for the years 1848-90 of 2.39% p.a. Between 1804-48 TFP trend growth rates were negative at -0.27% p.a. highlighting the importance of increased sheep and land resources per capita in the early settler economy. On these initial estimates a TFP upturn in the 1840s-1880s underpinned Australia's exceptional GDP per capita in the middle decades of the 19th century, given labour participation rates were falling. The burden of lower participation rates came to an end in the 1890s. Concomitantly, GDP per capita and labour productivity growth align more closely in the 20th century Australia, and the ratio of TFP growth to GDP per capita growth diminishes after the 1890s. In a wider context, Australia's actual TFP growth 1842-90 was double that of the USA during the same period (Gallman, 2000, p. 23), and somewhat above British TFP growth between 1856-73 (Matthews et al, 1982, p. 208), to further highlight the role of TFP in promoting exceptional Australian incomes during these years.

The estimates of TFP do not adjust for variations in capital or labour utilization, beyond for average working hours. Thus the productivity dips around 1842, 1896 and 1932, and the spike in 1944, partly reflect factor utilization. Nevertheless, the broad contours of Australia's trend TFP growth are clear enough. There was a shift to positive growth rates around 1830, followed by a long phase of exceptionally high TFP growth to the 1880s. A noticeable down-step in trend productivity growth from the high plateau of the 1840s-1880s occurred during the 20th century. The lower TFP growth trend in the 20th century was remarkably stable. Australia's historical trend TFP contrasts sharply with other OECD countries, which typically show 20th TFP spurts. Thus British trend TFP peaks in the 1960s (Greasley et al, 2014) and the USA in the 1930s (Hanley et al, 2015). Next we explore the drivers of Australia's distinctive TFP.

3. The Drivers of Total Factor Productivity

Standard endogenous growth theories including the pioneering models of Lucas (1988), Romer (1990) and the more recent expositions of Aghion and Howitt (2009) demonstrate that innovation and human capital formation are important income drivers. In an early model of endogenous growth Romer (1987) also shows how factor endowments may interact with the knowledge stock and productivity. His purpose was to articulate the possible implications of land abundance for the 1970s productivity slowdown in the USA. Romer's model was extended by Greasley and Madsen (2010) to consider how externalities associated with mining and farm land influenced post-1870 TFP growth in presently rich countries. The model used here builds on these knowledge-innovation models and postulates that TFP growth is partly driven by the externalities associated with factor endowments, including pastoral land and minerals, as well as by human capital formation and research investment.

The following model provides the starting point for the empirical analysis:

$$\begin{aligned}\text{Ln}\, TFP_t &= a_0 + a_1 ln\left(\frac{Y^R}{Y^N}\right)_t + a_2 h_t + a_3 lnR\&D_{\text{t}} \\ &\quad + a_4 ln\left(\frac{T^{Cul}}{Lab}\right)_t + a_5 ln\left(\frac{T^{Pas}}{Lab}\right)_t + \varepsilon_{1,t}, \qquad (4)\end{aligned}$$

where Y^R is nominal mining rents, Y^N is nominal GDP, h is educational attainment, $R\&D$ is real R&D expenditure, Lab is labour hours, T^{Cul} is land area under cultivation, T^{Pas} is pastoral land measured by the animal stock, and ε is a stochastic error term. The model postulates that externalities associated with minerals and land use, and investment in education and research are the drivers of TFP.

Since mineral reserves are not included in the initial TFP index, the estimated effects of Y^R in Equation 2 will reflect both productivity externalities and shifts in endowments. To show the two effects, the ratio of mining rents to labour $\frac{Y^R}{Lab}$ is added to Equation 4 to control for shifts in factor proportions associated both with the extraction and discoveries of minerals. A further extension is made to reflect that the inputs of the TFP index do not fully reflect the utilization of capital and labour. A measure of utilization U is added, and based on estimates of unemployment.

Accordingly, the drivers of TFP are investigated using the following model:

$$\begin{aligned}\text{Ln}\, TFP_t &= b_0 + b_1 ln\left(\frac{Y^R}{Y^N}\right)_t + b_2 h_t + b_3 lnR\&D_{\text{t}} \\ &\quad + b_4 ln\left(\frac{T^{Cul}}{Lab}\right)_t + b_5 ln\left(\frac{T^{Pas}}{Lab}\right)_t + b_6 ln\left(\frac{Y^R}{Lab}\right) + b_7 U + \varepsilon_{1,t}. \qquad (5)\end{aligned}$$

To explore the sensitivity of the postulated productivity drivers to the formulation of the TFP index, a labour productivity analogue of Equation 5 is estimated as:

$$\text{Ln } (Y/Lab)_t = c_0 + c_1 ln\left(\frac{Y^R}{Y^N}\right)_t + c_2 h_t + c_3 lnR\&D_t + c_4 ln\left(\frac{K}{Y}\right)_t + c_5 ln\left(\frac{T^{Cul}}{Lab}\right)_t + c_6 ln\left(\frac{T^{Pas}}{Lab}\right)_t + c_7 U + \varepsilon_{1,t}. \quad (6)$$

In Equation 6, the variables $\left(\frac{T^{Cul}}{Lab}\right)$, $\left(\frac{T^{Pas}}{Lab}\right)$, and $\left(\frac{Y^R}{Y^N}\right)$ will reflect both factor usage and productivity externalities. The model includes the *K*/*Y* ratio instead of the *K/L* ratio to filter out technology-induced capital deepening (Madsen, 2010). The *K*/*L* ratio in steady state is driven entirely by technological progress and, therefore, its contribution to productivity growth cannot be attributed savings-induced capital deepening. The change in the *K*/*Y* ratio, however, will account for changes in the savings rate on labour productivity.

3.1 Measuring the TFP Drivers

A widening of natural resource exploitation in Australia dates from the 1840s with the mining of copper in SA and the finding of gold specimens in NSW and Victoria. SA experienced Australia’s first minerals’ boom. Copper production began in 1844 and reached around 5000 tons annually by 1850 (Vamplew, 1987, p. 89). A succession of minerals discoveries augmented Australia’s natural capital in the period to 1890 and beyond. Most dramatic were Victoria’s gold finds of 1851. Later discoveries included further copper deposits in SA 1861, gold in Queensland 1867 and 1871, silver and lead at Broken Hill, NSW 1882, and gold in Western Australia (WA) in 1887-8. The major gold finds at Coolgardie-Kalgoorlie, WA date from 1892. Some coal was mined in NSW but the quantities were small reaching 3 million tons by 1890, and iron ore was mined intermittently, including several thousand tons in the 1870s (Vamplew, 1987, pp. 90-2). Mining value added and rents provided around 37% and 25% of GDP respectively in 1852, see Figure 6. Mining rents, Y^R are defined as the value of production less marginal extraction costs, measured here as wage costs. They declined to a post-gold rush low of around 1.2% of GDP in 1886.

WA and gold led the minerals’ recovery around the turn of the 20^{th} century. Silver, copper, zinc, iron ore and coal also contributed to the new mining boom, with mining rents exceeding 5% of GDP 1899-1908. Thereafter, there was a long hiatus in mining expansion until the

1960s. For Wright and Czelusta (2002, pp. 12-4) the interregnum arose from a paucity of mining expertise within Australia, and from regulations that hindered discoveries. McLean (2013, pp. 170-3), alternatively, highlights the limited demand for minerals within Australia, and links the mining resurgence of the 1960s to new overseas demands, notably for iron ore in Japan, and bulk shipping innovations. Wider Asian industrialization added impetus to minerals extraction in Australia, including of bauxite and coal, for export to China, South Korea and India. Additionally, nickel, uranium, zinc, diamonds and copper figured in the export manifests. For the third time in Australia's economic history mining rents rose to above 5% of GDP and that ratio persisted 1988-2011. Mining investment also reached 4% of GDP in 2009, around twice the ratio of the early 20th century minerals' boom. The substantial demands placed by mining on the supplying industries may have encouraged knowledge creation and spillovers (Ville and Wicken, 2013).

Educational attainment, *h* is defined as the product of the average years of schooling among the population of working age and the returns to schooling, which is set at 0.064 following the estimates of Bils and Klenow (2000) for Australia. The Mincerian approach is adopted under the assumption that the returns to one additional year of schooling are independent of the level of schooling. Educational attainment is estimated from 1870 using cohort schooling enrolment dating back to 1812, since the oldest workers in the labour force in 1870 started their primary schooling in 1812 (Madsen, 2014). Earlier estimates of educational attainment are based on the UK literacy rates since British immigrants dominated the settler inflows. Estimates of Australia's real R&D spending are extant from 1940. For 1870-1940, the estimates are the average R&D/GDP of the United States, Japan and Germany and converted with Australian nominal GDP and deflators.

The measure of utilization *U* adopts direct Commonwealth census estimates of unemployment from 1890, and a constructed estimate of unemployment for earlier years. Unemployment before 1890 is the predicted value from a regression in which the unemployment rate is regressed on a constant and the business cycle in the overlapping period 1890-2011, where the business cycle is computed as the residual from regressing the log of GDP per capita on a constant and a time-trend in the period 1800-2011.

4. Estimating the Productivity Relationships

4.1 The drivers of TFP

This section reports estimates of the coefficients in Equations 5 and 6, using annual data for the period 1803-2009, and for the sub-period 1803-1900. Table 2 shows the estimates for the two measures of TFP with the results using the preferred BDL GDP series detailed in columns 1-3, 5. Estimates for the TFP series adopting the Haig1861 GDP series are only reported, in column 4, for the 1803-1900 period, given the commonality of the data for later years. The long-run drivers of TFP are most clearly shown by the estimated coefficients using the 1803-2009 sample period, with the preferred estimates shown in column 1. They show negative TFP externalities associated with both minerals' extraction and pastoralism, whereas cultivation of the land has no TFP effects. The ratio of mining rents to labour hours positively influences TFP and the estimated coefficient provides a basis for refining the measure of TFP for shifts in the availability and quality of minerals' reserves, to construct TFPm. Educational attainment and investment in R&D are shown to positively influence TFP over the long sample period. Column 2 reports a sensitivity test using the alternative measure of the pre-1861 capital stock. The estimated coefficients are not materially affected by the choice of capital stock data.

Some caution is warranted for the estimated R&D coefficient since the variable has zero pre-1870 values and direct Australian data are extant only from 1940. However, the estimated coefficients with the pre-1900 data, which exclude R&D, show only modest differences to the longer sample estimates. For example, both TFP measures using 1803-1900 data yield estimates in favour of negative externalities arising from pastoral land use and minerals' exploitation, although the absolute sizes of the coefficients are lower than with the longer sample. Similarly, educational attainment has a positive relationship with TFP in the pre-1900 samples. Column 5 reports results with additional population and urbanization variables to investigate the possible effects of scale of productivity, but the estimates coefficients are not statistically significant.

The estimated coefficients in Table 2 are used in conjunction with the average growth of the respective variable to gauge the force of the TFP drivers. The predictions are shown in Table 3 for three periods using the preferred TFP ($_{BDLgdp}$) index and estimated coefficients for 1803-2009 and 1803-1900. The choice of the growth phases reflects the contours of TFP trend growth illustrated above as Figure 5, which distinguish a high growth plateau of 1842-90 from an earlier segment of negative TFP growth and a subsequent TFP growth slowdown lasting through the 20^{th} century. The actual (as opposed to trend) TFP growth rates for the respective periods average -0.24%, 1.57%, and 0.79% per annum.

During the high TFP growth phase 1842-90 natural resources exploitation had negative productivity externalities and these were chiefly associated with pastoralism. With the 1803-2009 estimated coefficients, the second pastoral boom over the decades to 1890 reduced economy-wide TFP growth by 0.32% p.a. The negative TFP externality of the first pastoral boom to 1841 was stronger and it substantially explains the falls in Australia's TFP levels during the early decades of the 19^{th} century. The adverse TFP effects of mining externalities were much smaller than for pastoralism. In the period 1842-90, which includes Victoria's gold rush, the mining externality reduced TFP growth by 0.07% p.a. on the basis of the longer run coefficients, or by 0.03% p.a. with the pre-1900 estimates. TFP growth during the high growth phase 1842-90 is substantially explained by increased educational attainment and by increases in minerals' rents per labour hour.

The educational attainment of the work force rose strongly after 1870 and had its strongest effects of productivity growth during 1842-90. The attainments measure reflects school enrolments from 1812, the start date of the schooling of the eldest workers in 1870. The educational attainment of the labour force rose by more than three times 1870-90, while attainment only doubled over the following century, which explains the more modest contribution of education to TFP growth between 1890-2009. The pre-1870 estimates of educational attainment are less robust, but the predictions of Table 3 show a relatively modest 0.17% p.a. contribution of education to TFP growth between 1804-41.

The interpretation of mining rents per labour hour's contribution to TFP growth warrants close attention, given its use in an extracting a value for TFPm. If, as we postulate, the ratio of mining rents per worker hours reflects changes in the availability and quality of minerals' reserves, then the predictions of Table 3 show how the minerals endowment directly contributed to the conventional measure of TFP growth. New minerals discoveries, including of gold in the 1850s, shifted factor proportions in Australia by augmenting mineral's reserves compared to the economy-wide workforce. In contrast, extraction diminished the availability and quality of minerals' reserves relative to other endowments. With the 1803-2009 estimated coefficients, the net effects of shifts in the minerals endowment increased TFP growth by 0.9% and 0.14% p.a. between 1842-90 and 1890-2009 respectively. These estimates indicate the gap between TFP and TFPm growth, and show TFPm growth of 0.67% p.a. and 0.65% p.a. between 1842-90 and 1890-2009 respectively.

4.2 The drivers of labour productivity

Turning attention to the drivers of labour productivity, the estimates reported in Table 4 (column 1) confirm that the net effect of extracting minerals augmented GDP per worker, given the positive effect on endowments offset the negative productivity externality. Pastoralism also benefitted labour productivity, most clearly in the period to 1900 according to the estimates in Table 4 (columns 2 and 3). While the spread of the pastoral frontier had negative externalities for economy-wide TFP, these were more than offset by the value of the natural resource value of the grasslands. In contrast, the increased cultivation of land was detrimental for labour productivity, a result that may reflect agriculture's lower levels of labour productivity than mining or pastoralism (Broadberry and Irwin, 2007). If so, shifting employment towards agriculture as mineral or pastoral resources were depleted or degraded, diminished GDP per worker. Educational attainment and R&D spending are shown to have positively influenced GDP per worker. Capital deepening as measured by *K*/*Y* is also shown to have a positive effect on labour productivity, most especially in the decades before 1900. Excluding *K*/*Y* from the model (Table 4, column 4) has almost no effect on the other, long run estimated coefficients. The alternative measures of GDP make only modest difference to the pre-1900 estimates, with the preferred BDL series yielding higher positive coefficients for educational attainment and capital deepening.

In the long run the growth of labour productivity exhibits swings similar to the movements of TFP (Table 5). During the low growth phase 1804-41 GDP per worker hour grew by 1.29% p.a., then rose to 2.54% p.a. 1842-90 and slowed to 1.39% p.a. 1891-2009. Combining the estimated coefficients of Table 4 (columns 1 and 2) with the average growth of the respective variables shows the force of each labour productivity driver (Table 5). Since TFP growth was negative 1804-41, it is shifts in endowments per worker that explain the rise in labour productivity in the early settler economy. Increased pastoral land per worker augmented economy-wide labour productivity before 1890 despite the negative TFP externalities, irrespective of whether the predictions are based on the coefficients of the pre-1900 of full sample regression. During the first pastoral boom to the 1840s cultivated land per worker fell, which augmented economy wide labour productivity. The predictions show that around one-half of labour productivity growth 1804-41 was associated with the relative decline of cultivation. The rise of the pastoral economy to the 1840s principally drove labour productivity in the early settler economy, but it was supported by human capital formation. The gains from increased educational attainment before 1841 were modest if the pre-1900 coefficients are preferred, but higher according to the full sample estimates.

The sources of labour productivity growth are more varied 1842-90 and include positive contributions from minerals extraction and capital deepening. The higher GDP per labour hour growth 1842-90 can be substantially attributed to the drivers of TFP, most especially educational attainment. Additionally, capital deepening contributed to labour productivity growth in the second half of the 19th century. The estimated relative force of human and physical capital formation, measured by educational attainment and the rise in the capital-output ratio, on labour productivity growth 1842-90 depends on the choice of the regression estimates. With the full sample estimated coefficients, educational attainment is the dominant driver, but with the pre-1900 estimates capital deepening plays the bigger role. Minerals extraction and an expanding pastoral frontier benefitted labour productivity, but the gains were partially offset by increased land cultivation. The growth of wheat farming 1842-90 damaged economy-wide productivity, irrespective of whether the full sample or pre-1900 estimated coefficients are adopted.

Nor was natural capital a substantial force driving post-1891 labour productivity. Mining continued to have a positive effect, but its benefits were offset by the relative decline of pastoralism. The results highlight the contribution of R&D, supported by some increase in educational attainment, as the chief influences on GDP per worker hour growth in the 20th century. The lower labour productivity growth of 1891-2009 is explained by a marked slowdown in capital deepening and a tapering of the rise in educational attainment. The relative decline of pastoralism and the lower rates of minerals extraction per worker also retarded 20th century labour productivity growth. On balance, the upturn in in R&D spending was insufficient to offset the negative forces and labour productivity growth 1890-2009 was not much different to the rates of 1804-41.

5. Discussion and Concluding Remarks

Australia's settler economy attained exceptional GDP per capita by the middle decades of the 19th century. After 1890 Australian incomes are less exceptional, matching those of the UK but trailing the USA. The analysis here utilizes new indexes of TFP and TFPm which include natural resource inputs as part of a unified interpretation of the rise and fall of Australia's exceptional incomes. The TFP index includes pastoral and arable land inputs, while TFPm additionally adjusts for mineral reserves. TFPm growth has been remarkably stable since the 1840s and averaged 0.66% p.a. A simple decomposition of GDP per capita growth is shown in Table 6. Gauging the relative contributions of endowments and productivity to the rise and fall of Australia's exceptional incomes rests partly on the choice of the productivity index. Three elements underpin the wider analysis of average incomes. They are the ratios of labour hours and population, natural resources per capita, and TFP/TFPm.

Settler Australia experienced modest growth of GDP per capita in the period 1804-41, but a much faster growth of labour productivity of 1.29% p.a. Labour participation in the convict economy was remarkably high, exceeding 90% in the first decade of the 19th century, around twice the UK rate at that time (Tranter, 1981). Thus, while settler Australia's average incomes were internationally high its GDP per labour hour was around one-half that of the UK early in the 19th century. Fast labour productivity growth was a characteristic of settler Australia 1804-41, but the rising dependency ratio, as the high participation rates diminished, held back income per capita growth.

The new TFP estimates show negative growth 1804-41 (TFP and TFPm are identical before the mining booms). Higher endowments per worker thus explain the growth of labour productivity, which offset the effects of falling labour participation to allow modest income growth. The expansion to the native grasslands of interior NSW from the 1820s transformed factor proportions against a backcloth of rapid population growth. The effect was to diminish the ratio of cultivated land and population, but to increase pastoral land per capita, and in turn, income per capita. The extent of the gain was tempered by the negative TFP growth 1804-41. Nomadic grazing over distant, sparsely settled landscapes had negative TFP externalities, but they were offset by the higher ratio of sheep and pastoral land to the population. On balance, the increased importance of pastoralism largely explains the growth of incomes in the early settler economy to 1841, although human capital formation played a supporting role.

Then, in the period 1842-90 the average labour productivity growth nearly doubled, and Australia's GDP per capita rose to internationally exceptional levels. Falling labour participation, accentuated by diminished average hours, remained a drag on incomes growth to 1890, but did not prevent Australia attaining exceptional GDP per capita. The increased growth of labour productivity can be fully explained by the increased growth of TFP to 1.57% p.a. between 1842-90, but not by the growth of TFPm. Improved TFP growth offset the detrimental effects on labour productivity of increased land cultivation, associated with the expanding wheat frontier, to 1890 (Table 4). The higher rate of TFP growth resulted from a combination of forces, two of which were negative. Pastoral expansion was the chief negative TFP externality, but the higher share of minerals in GDP also diminished TFP. These negative effects were more than offset by additions to the availability and quality of minerals relative to the economy wide workforce, and by human capital formation (Table 3).

The adjusted measure TFPm shows growth of 0.67% p.a. in the period 1842-90, and tempers the role of productivity in accounting for Australia's exceptional incomes during these years (Table 5). Even so, the upturn in TFPm can account for around 73% of the increased growth of labour productivity between the 1804-41 and 1842-90 periods. However, only 26% of GDP per worker hour growth is accounted for by TFPm growth during the period 1842-90, while the comparative figure for TFP growth is 62%. The gap, of 36%, provides an estimate of how higher mineral endowments augmented labour productivity growth during the era of exceptional incomes. There were negative externalities associated with mining which reduced TFP growth by around 5% between 1842-90, hence the net contribution of the minerals sector to labour productivity growth was around 31% during these years.

To sum, a combination of forces generated Australia's exceptional incomes between 1842 and 1890. Mining and pastoralism played important positive roles, as did TFPm. Stated boldly, higher endowments per worker, including of physical capital, contributed around 74% of the labour productivity growth, compared to the 26% associated with TFPm. The findings for TFPm add to traditional paradigms that Australia's exceptional incomes were chiefly shaped by natural resources and labour participation, especially given the sharp TFPm turnaround in the 1840s. Of course TFPm is a measure of residual productivity, which had drivers. The analysis here shows a combination of negative and positive forces. Natural resource usage had negative TFP externalities, chiefly related to pastoralism, while human capital formation was the chief positive driver in the period 1842-90 (Table 3).

Australia's GDP per capita is less exceptional after 1890, despite the drag of falling labour hours per capita largely disappearing. Labour productivity growth rates were around 1% p.a. lower 1891-2009 than during the era of exceptional incomes. TFPm growth shows little change after 1891, and accounts for around 47% of labour productivity growth through

2009. Investment in education and in R&D largely explain the continuing growth of TFPm (Table 3). A lower growth of endowments per worker hour underpinned the retardation of labour productivity. The consequences for GDP per capita growth were ameliorated by the eventual rise in participation rates. In the case of the natural endowments, the reduced gains from minerals per capita were reinforced by the pastoral decline. Reduced pastoral land per capita diminished economy wide labour productivity growth after 1890. Natural resources aside, the chief negative forces on labour productivity growth were the ending of capital deepening and a slower growth of human capital. The barriers to capital deepening and to augmenting human and natural capital per capita, rather than a lessening of TFPm growth, lessened labour productivity growth. On balance, Australia achieved respectable GDP per capita growth 1891-2009, but the rates were no longer exceptional.

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Tables and Figures

Table 1: Decomposing Australia's GDP per capita growth (% p.a.)

	GDP per capita	*GDP/L* hours	TFP
1804-41	0.30	1.29	-0.24
1842-90	1.57	2.54	1.57
1891-2009	1.30	1.39	0.79

Note: These estimates are based on the preferred BDL GDP series.

Sources, see text.

Table 2: Estimated coefficients of Equation 3 (Dependent variable = Ln TFP)					
	1. TFP (BDLgdp) (preferred)	2. TFP (BDLgdp) (adjusted)	3. TFP (BDLgdp)	4. TFP (Haig1861gdp)	5. TFP (BDLgdp)
	1803-2009	1803-2009	1803-1900	1803-1900	1803-2009
Ln Y^R/ Y^N	-0.048(3.04)	-0.048(3.23)	-0.023(1.68)	-0.016(2.05)	-0.016(0.98)
Ln Y^R/ Lab	0.068(5.59)	0.066(5.70)	0.051(5.13)	0.057(9.87)	0.033(2.39)
Ln T^{Cul}/ Lab	0.020(0.53)	0.011(0.28)	-0.021(0.61)	-0.024(0.91)	0.105(2.69)
Ln T^{Pas}/ Lab	-0.126(5.77)	-0.148(6.31)	-0.095(5.12)	-0.086(7.18)	-0.168(4.90)
h	0.365(11.73)	0.351(11.67)	0.176(4.78)	0.149(5.52)	0.136(1.98)
Ln R&D	0.084(16.00)	0.082(15.59)			0.071(9.52)
U	-0.009(5.18)	-0.009(5.61)	-0.009(3.12)	-0.014(5.43)	-0.009(5.08)
Ln Pop					0.051(0.88)
Ln Urb					0.145(1.34)
DF	-14.1	-14.2	-14.5	-22.1	-7.01

Note. DF = Dickey-Fuller test for cointegration. *Pop* = population size, *Urb* = urbanization rate. Column 1 shows the preferred estimates, column 2 shows the results of a sensitivity test, where pre-1861 capital stock is measured by assuming a 10% rise in the capital output ratio. Sources, see text.

Table 3: Predictions of TFP (% per annum)					
	1803-2009 regression (TFP (BDLgdp))			1803-1900 regression (TFP (BDLgdp))	
	1804-1841	1842-1890	1891-2009	1804-1841	1842-1890
TFP (actual)	-0.24	1.57	0.79	-0.24	1.57
Ln Y^R/ Y^N	0.00	-0.07	-0.04	0.00	-0.03
Ln Y^R/ Lab	0.00	0.90	0.14	0.00	0.66
Ln T^{Pas}/ Lab	-0.71	-0.32	0.12	-0.56	-0.25
h	0.17	1.05	0.23	0.06	0.39
Ln R&D			0.51		
TFP (predicted)	-0.51	1.56	0.96	-0.50	0.77

Sources: as for Table 2.

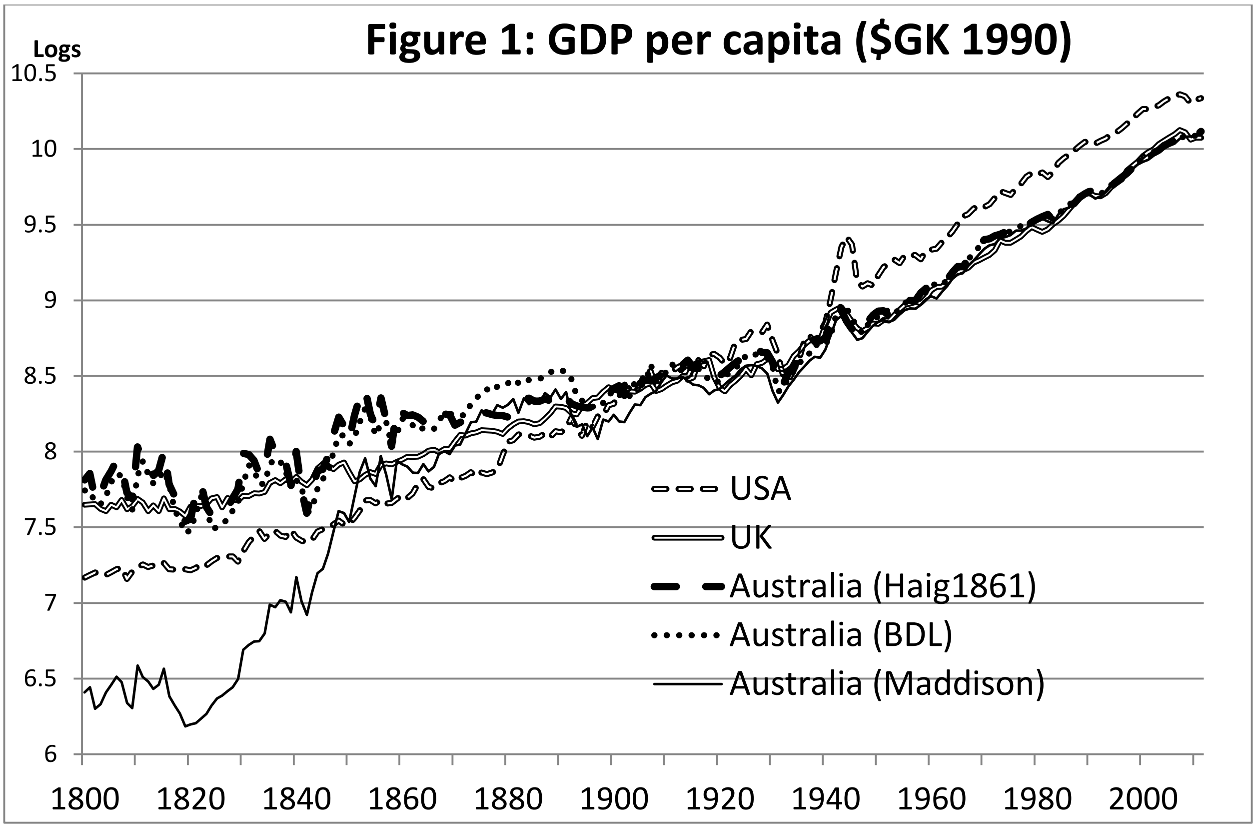
Table 4: Estimated coefficients of Equation 4 (Dependent variable = Ln GDP per labour hour)				
	1. Y/Lab (BDLgdp)	2. Y/Lab (BDLgdp)	3. Y/Lab (Haig1861gdp)	4. Y/Lab (BDLgdp)
	1803-2009	1803-1900	1803-1900	1803-2009
Ln Y^R/ Y^N	0.105 (4.29)	0.094 (4.48)	0.102(4.82)	0.113 (4.61)
Ln Y^R/ Lab				
Ln T^{Cul}/ Lab	-0.231 (3.61)	-0.336 (6.53)	-0.336(7.35)	-0.218 (3.30)
Ln T^{Pas}/ Lab	0.066 (1.52)	0.099 (2.37)	0.095(2.69)	0.068 (1.58)
h	0.914 (15.6)	0.218 (1.81)	0.075(1.63)	0.986 (20.8)
Ln R&D	0.189 (20.9)			0.188 (21.1)
Ln K/Y	0.409(1.88)	1.78 (2.96)	1.52(2.81)	
U	-0.010 (2.46)	-0.030 (5.70)	-0.034(5.82)	-0.004 (1.25)
DF	-8.28	-8.07	-8.81	-8.51

Sources: as for Table 2.

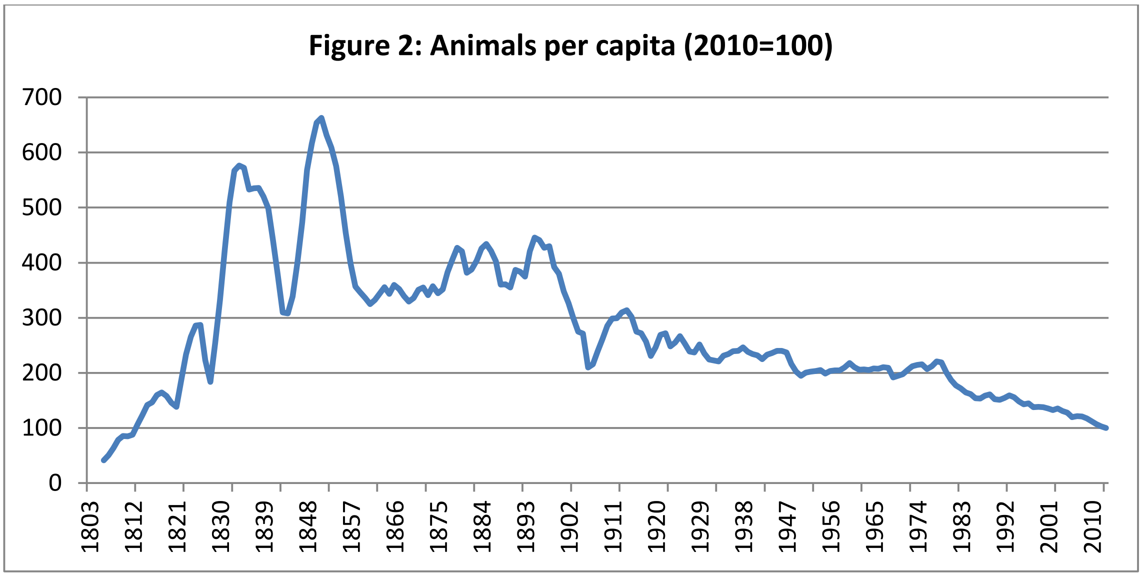
Table 5: Predictions of Y/L (% per annum)					
	1803-2009 regression (Y/Lab (BDLgdp))			1803-1900 regression (Y/Lab (BDLgdp))	
	1804-1841	1842-1890	1891-2009	1804-1841	1842-1890
Y/Lab (actual)	1.29	2.54	1.39	1.29	2.54
Ln Y^R/Y^N	0.00	0.14	0.09	0.00	0.12
Ln K/ Y	0.00	0.42	0.01	0.00	1.36
Ln T^{Cul}/Lab	0.71	-0.39	-0.09	0.55	-0.56
Ln T^{Pas}/Lab	0.29	0.13	-0.07	0.39	0.17
h	0.38	2.39	0.59	0.09	0.56
Ln R&D	0.00	0.00	1.14	0.00	0.00
Y/Lab (predicted)	1.38	2.69	1.67	1.05	1.65

Sources: as for Table 2.

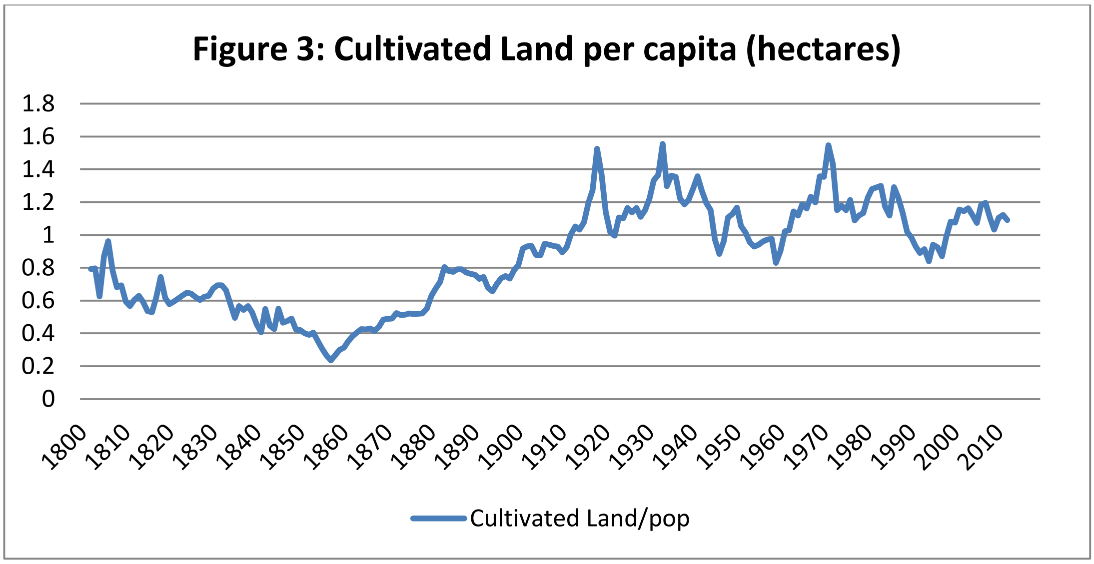
Table 6: Decomposing Australia's GDP per capita growth (% p.a.)				
	GDP per capita	*Y/L* hours	TFP	TFPm
1804-41	0.30	1.29	-0.24	-0.24
1842-90	1.57	2.54	1.57	0.67
1891-2009	1.30	1.39	0.79	0.65
Note; These estimates use the preferred BDL GDP series. The TFP estimates are from Table 1 and TFPm adjusts TFP for the ratio of minerals rents to labour hours using the estimates of Table 3.				



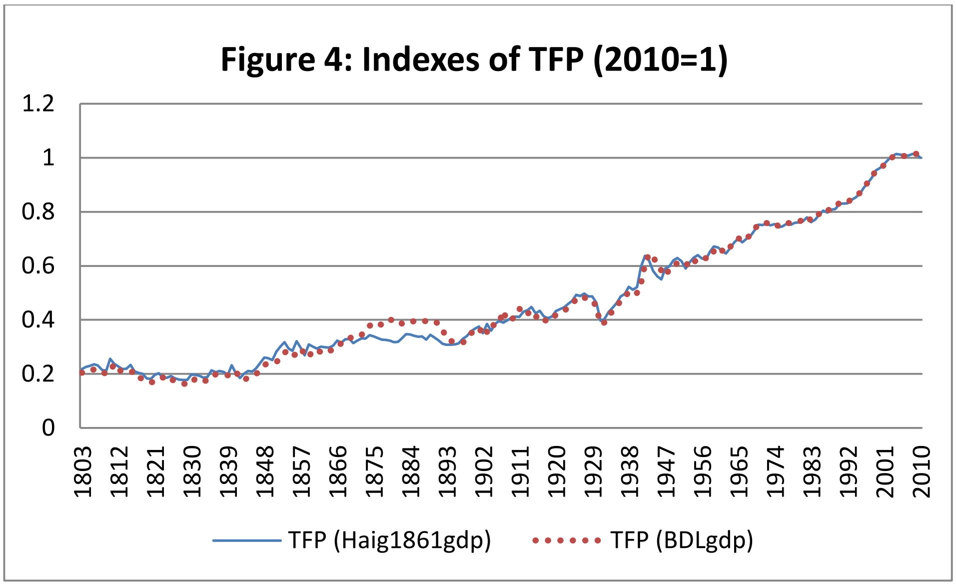
Note: The relative level of these estimates is based $GK in 1990 estimated by Maddison (2003). Sources: Maddison (2003) and Ville and Withers (2015).



Note: Pastoral animals are approximated with sheep and cattle, weighting 1 cattle as 8 sheep (Davidson, 1972). In the years to 1890 a 5-year moving average of animal stocks is used. Source: Vamplew (1987).

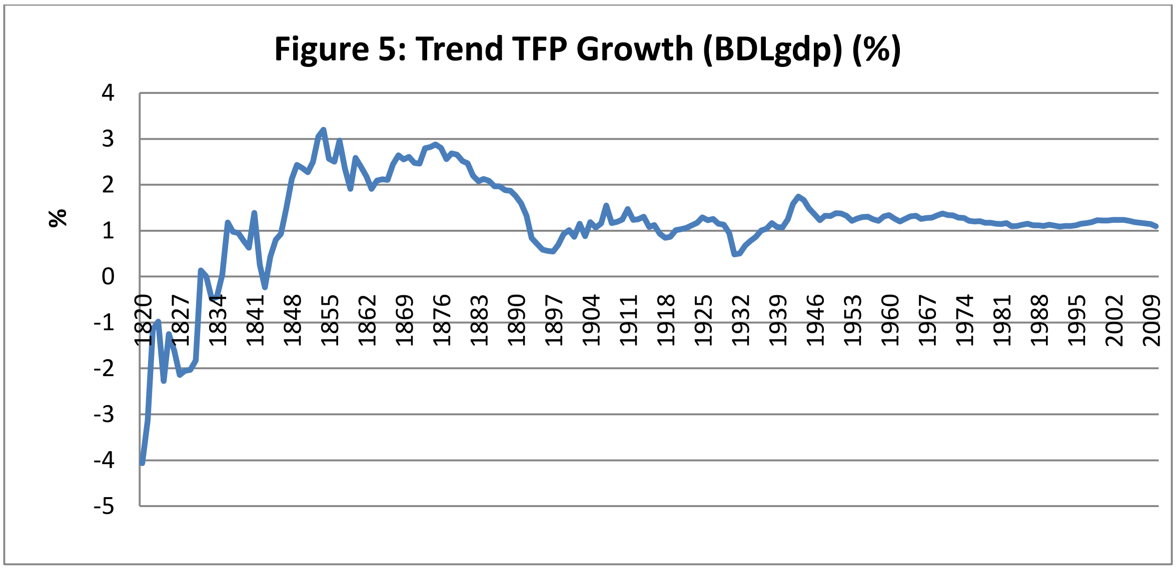


Sources: Mitchell (2008) and Vamplew (1987).

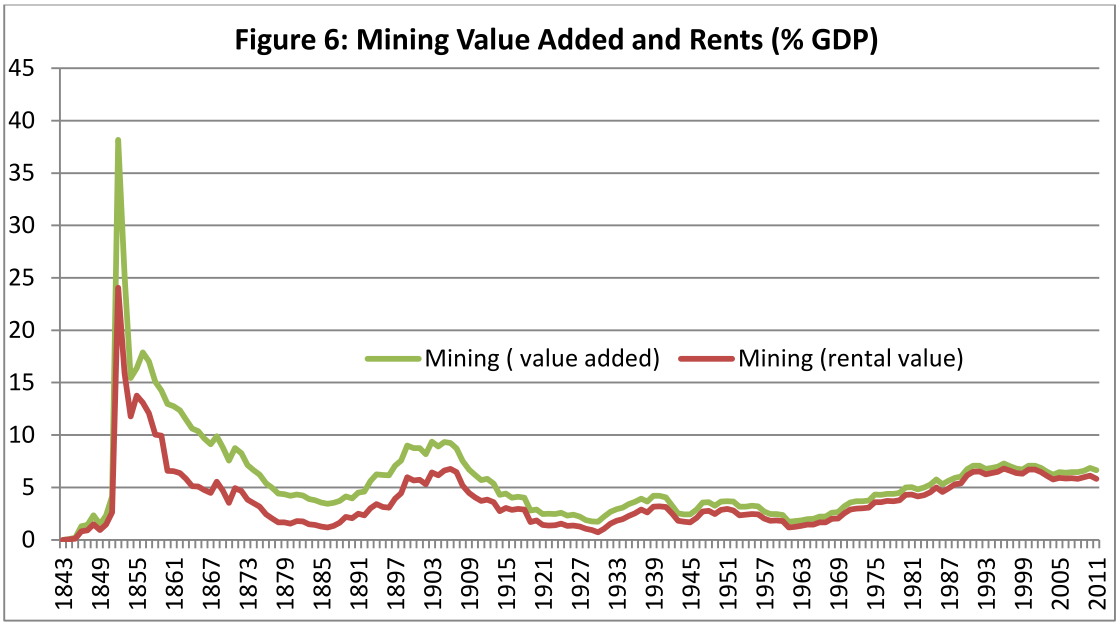


Note: TFP indexes are constructed for 1800-90, 1890-1960 and 1960-2010, with inputs and output measured relative to the final year values of each segment. The sub-period indexes are spliced to produce the index for 1803-2010.

Sources: see text.



Note: Trend growth is extracted using the Kalman filter. The treatment of outliers by the filter means average trend growth does not equate to average actual growth.



Sources: Butlin's nominal GDP spliced with ABS estimates, as reported in Hutchinson (2013), are used as the denominator. Mining value added and rents are from Greasley (2015).