Productivity and Financial Performance

Emili Grifell-Tatjé and C.A. Knox Lovell

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Edited by Emili Grifell-Tatjé, C. A. Knox Lovell, and Robin C. Sickles

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Abstract and Keywords

This chapter explores the relationship between productivity and financial performance, primarily at the level of an individual business. It begins by decomposing profit change into price and quantity drivers, under alternative accounting treatments of operating surplus. The chapter considers a range of related issues, including the drivers of productivity change, the distribution of the value productivity that change creates, problems associated with missing or distorted prices, complications caused by fluctuating exchange rates, and the use of price change to measure productivity change. In addition to profit, it considers alternative measures of financial performance, such as return on assets and unit cost. The chapter concludes by pointing to some topics deserving of further research.

Keywords: profit, return on assets, unit cost, value creation, productivity, price recovery

9.1. Introduction

IN this chapter we explore the complex relationship between business productivity and financial performance, and we use BHP Billiton, an Anglo-Australian global resources company headquartered in Melbourne, Australia, to illustrate key concepts.[1] The *BHP Billiton 2016 Annual Report* provides a good introduction to the material we cover in this chapter. The *Report* contains three key performance indicators that are used “to assess the financial performance of the Company . . . and to make decisions on the allocation of resources,” one being underlying EBIT (earnings before interest and taxes and excluding exceptional items).[2]Figures 9.1 and 9.2 track recent trends in profit (underlying EBIT, expressed in USD) and return on assets (underlying EBIT/total assets).

Segments of the *Report* are devoted to a discussion of the sources of profit variation, both through time and across businesses. The three primary sources are volume changes, price changes, and change in external factors such as exchange rate movements and climate change. Volume changes are attributed toproductivity change and growth. Price changes are attributed to changing market conditions in countries where commodities are consumed and produced. Importantly, the financial contribution of productivity improvements is attributed to both “sustainable productivity-led volume improvements” and “sustainable productivity-led cost efficiencies.” These productivity gains are valued at more than USD 10 billion over 2013–2016, values we refer to as a *productivity bonus* throughout the chapter.

The concepts of productivity and financial performance are linked throughout the *Report*. It is apparent that BHP Billiton management understands that change in financial performance is driven by quantity changes, price changes, and change in external factors, and that productivity change creates value through its impact on both quantity (p. 330) changes and unit cost changes. In this chapter we analyze the separate impacts of quantity change and price change on three measures of financial performance.

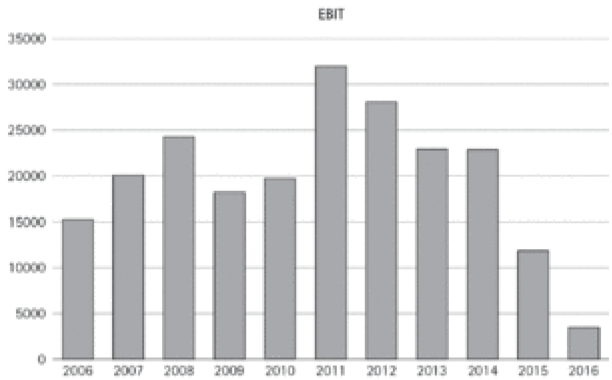

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Figure 9.1. Profit at BHP Billiton.

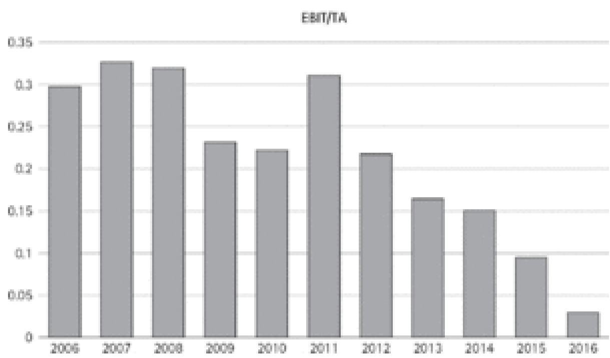

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Figure 9.2. Return on assets at BHP Billiton.

In section 9.2 we measure financial performance with profit, whatever its precise definition, although we use EBIT. We develop an analytical framework that allows us to attribute profit change to quantity changes, a driver of which is productivity change, and price changes, a driver of which is price-recovery change. We measure productivity change with the ratio of an output quantity index to an input quantity index, and we (p. 331) measure price-recovery change with the ratio of an output price index to an input price index.[3]

The analytical framework has a rich history, the primary contributors being Davis (1955); Kendrick (1961, Chapter 5; 1984); Kendrick and Creamer (1961); Kendrick and Sato (1963); Vincent (1968); Courbis and Templé (1975); Houéry (1977); writers associated with the French state agency Centre d'Étude des Revenus et des Coûts (CERC, 1969); Eldor and Sudit (1981); and Miller (1984). We utilize two accounting conventions within this framework. In subsection 9.2.1 we treat profit as the difference between revenue and cost, which can be positive, zero, or negative. In subsection 9.2.2 we treat profit as a return to those who bear the risk of providing capital to the business; in the business accounts this return augments the cost of capital, and so revenue minus augmented cost is zero by construction.[4] The latter treatment also is consistent with national accounts, in which receipts and expenditures balance; this accounting identity is exploited by Jorgenson and Griliches (1967).

In section 9.3 we explore selected topics relevant to both accounting conventions, including the identification of potential drivers of productivity change, and the appropriation (or distribution) of the financial benefits of productivity change among those agents involved in its creation, among others.

In section 9.4 we measure financial performance with return on assets (ROA), and we embed the ROA analysis within a duPont triangle framework, in which change in ROA is decomposed into the product of change in profit margin and change in asset turnover. ROA is a widely acknowledged key financial performance indicator, and Kline and Hessler (1952) describe the pioneering use of ROA and its two components at duPont. In his study of management accounting at duPont, Johnson (1975, 185) describes the triangle as the use of accounting data "for management control" and to support "the allocation of new investment among competing economic activities." This assessment of ROA is strikingly similar to the assessment of EBIT at BHP Billiton. The literature linking ROA as a financial performance indicator with potential drivers of ROA is extremely diverse, although apart from the recent work of Bloom and his colleagues (e.g., Bloom and Van Reenen 2007, 2010; Bloom, Lemos, Sadun, Scur, and Van Reenen 2014), the list of potential drivers of ROA seems to have managed to exclude productivity! Our analytical framework incorporates productivity change as a driver of ROA change.

Inspired by the significance that BHP Billiton attaches to productivity-led cost reductions, in section 9.5 we measure financial performance with unit cost if we can aggregate multiple outputs into a single value, or with unit costs of individual outputs if we cannot. BHP Billiton identifies five business segments, one for each commodity it extracts and markets. The largest segment is iron ore, for which "[o]ur focus remains on producing at the lowest possible cost. . . ."[5] Nearly a century ago, Bliss (1923, 104) recommended the use of unit cost, particularly "[i]n businesses having satisfactory measures of physical volume." Gold (1971) believed information on unit cost to be essential to all areas of managerial decision-making, including the allocation of resources among product lines and pricing policies. More recently, Borenstein and Farrell (2000) have explored alternative cost-cutting strategies. Each of these scenarios fits BHP Billiton.

(p. 332) Section 9.6 provides a summary of the chapter and suggests some avenues for future research.[6]

We conclude this section with an introduction to our notation, which we augment in the following as necessary. A firm uses input vector $x=(x_1, \ldots, x_N)\in R_+^N$ to produce output vector $y=(y_1, \ldots, y_M)\in R_+^M$. The set of feasible (x, y) combinations is the production set $T = \{(x, y)$: x can produce $y\}$, whose outer boundary is a production frontier. The set of feasible x is the input set $L(y)=\{x:(x, y)\in T\}\forall y$, and the set of feasible y is the output set $P(x)=\{y:(x, y)\in T\}\forall x$. Input prices and output prices are given by the vectors $w=(w_1, \ldots, w_N)\in R_{++}^N$ and $p=(p_1, \ldots, p_M)\in R_{++}^M$. Cost is $C=w^Tx=\Sigma_{n=1}^N w_n x_n\geq 0$, revenue is $R=p^Ty=\Sigma_{m=1}^M p_m y_m\geq 0$, profit is $\pi=R-C\gtreqless 0$, and profitability (or cost recovery) is $\Pi=R/C\gtreqless 1$. Return on assets is π/A, where A is the firm's assets, and the duPont triangle decomposes ROA as $\pi/A=\pi/R\times R/A$, the product of the profit margin and asset turnover. A cost frontier is defined as $c(y, w)=\min_x\{w^Tx:D_i(y, x)\geq 1\}\leq w^Tx$, in which the input distance function $D_i(y, x)$ is defined as $D_i(y, x)=\max\{\phi:x/\phi\in L(y)\}\geq 1$. A revenue frontier is defined as $r(x, p)=\max_y\{p^Ty:D_o(x, y)\leq 1\}\geq p^Ty$, with output distance function $D_o(x, y)$ defined as $D_o(x, y)=\min\{\theta:y/\theta\in P(x)\}\leq 1$.[7]

We consider two time periods, indicated by superscripts "0" and "1." Thus profit change from base period to comparison period is $\pi^1 - \pi^0$.The superscripts also can refer to producing units, for example a benchmarking organization and a target organization, in which case "change" becomes "variance" or "deviation." Miller (1984) developed a framework similar to ours to analyze yet another difference, that between actual and anticipated comparison-period profit, and Grifell-Tatjé and Lovell (2013) apply this framework to cost variance analysis.

9.2. Decomposing Profit Change

Decomposing profit change requires a definition of profit, which varies across accounting conventions. We consider two conventions.

One accounting convention defines $\pi = R - C$, without imposing equality between the value of output and the value of input, and without associating profit with any specific input. This convention is consistent with defining the cost of capital narrowly as depreciation expense and interpreting $R - C$ as profit (EBIT), and also with defining the cost of capital more broadly as depreciation expense plus interest expense, and interpreting $R - C$ as "pure" profit (EBT). The choice between reporting interest as an expense or as a component of profit can be important empirically, but it is irrelevant analytically. Under this accounting convention, we analyze variation in $\pi = R - C$.

(p. 333) Another accounting convention places special emphasis on the capital input. We write $w_N x_N = w_N K$, K being the capital input and w_N being the unit cost of capital. Davis (1955) associates $w_N K$ with depreciation expense, which is consistent with BHP Billiton's use of EBIT as a measure of profit. We distinguish the cost of capital $w_N K$ from the (endogenous) return to capital, which we define as $rK=\pi$, r being the (endogenous) rate of return to capital. The return to capital must be sufficient to cover interest payments and taxes (hence EBIT), and also dividends and retained earnings to provide for future growth. Consistent with national income accounting conventions, this convention imposes equality between the value of output and the value of input by treating the return to capital as an expense, yielding augmented cost $\widetilde{C} = w_1 x_1 + \cdots + w_{N-1} x_{N-1} + (w_N + r)K = \tilde{w}^T x$. Under this accounting convention, we analyze variation in $R - \widetilde{C} \equiv 0$.[8]

The two conventions use the same data to analyze variation in financial performance, but they organize the data in different ways, and they yield complementary insights. We analyze variation in $R - C$ in subsection 9.2.1, and we analyze variation in $R - \widetilde{C}$ in subsection 9.2.2.

9.2.1. Change in *R – C*

Under the first accounting convention, we examine change in $R - C$, one expression for which is

$$\pi^1 - \pi^0 = \left[p^{0T}(y^1 - y^0) - w^{0T}(x^1 - x^0)\right] + \left[y^{1T}(p^1 - p^0) - x^{1T}(w^1 - w^0)\right],$$

(9.1)

in which we use base-period prices to weight quantity changes in what we call the quantity effect, and comparison-period quantities to weight price changes in what we call the price effect.

The quantity effect decomposes in two different ways:

$$\begin{aligned} p^{0T}(y^1 - y^0) - w^{0T}(x^1 - x^0) &= w^{0T}x^1\left[(Y_L / X_L) - 1\right] + \pi^0(Y_L - 1) \\ &= p^{0T}y^1\left[1 - (Y_L / X_L)^{-1}\right] + \pi^0(X_L - 1), \end{aligned}$$

(9.2)

in which $Y_L = p^{0T}y^1/p^{0T}y^0$ is a Laspeyres output-quantity index, $X_L = w^{0T}x^1/w^{0T}x^0$ is a Laspeyres input-quantity index, and $Y_L/X_L \gtreqless 1$ is a Laspeyres productivity index. The first term on the right side of each equality is a productivity effect, and the second is a growth (or contraction) effect. In the first equality the productivity effect scales the rate of productivity change $[(Y_L/X_L) - 1]$ by deflated comparison-period cost $w^{0T}x^1$ to generate a productivity bonus, which measures the contribution, positive or negative, of productivity change to profit change, and which amounted to USD 0.4 billion for BHP Billiton in 2016. The growth effect scales the output growth rate $(Y_L - 1)$ by base period profit π^0 to generate what we call a *growth bonus*, which measures the contribution, again positive or negative, of output change to profit change. The growth effect evaluates the business strategy of replication, often referred to as the "McDonalds approach" (p. 334) (Winter and Szulanski 2001). It is worth noting that the productivity effect can create (or destroy) value in the absence of output growth, and the growth effect can create (or destroy) value in the absence of productivity growth. Garcia-Castro, Ricart, Lieberman, and Balasubramanian emphasize this dual source of value creation in Chapter 10. The second equality is interpreted similarly, although the two effects in the second equality are not generally equal to their counterparts in the first equality.

The price effect also decomposes in two different ways:

$$y^{1T}(p^1 - p^0) - x^{1T}(w^1 - w^0) = p^{0T}y^1\left[\left(P_P / W_P\right) - 1\right] + \pi^1\left[1 - W_P^{-1}\right]$$
$$= w^{0T}x^1\left[1 - \left(P_P / W_P\right)^{-1}\right] + \pi^1\left[1 - P_P^{-1}\right],$$

(9.3)

in which $P_P = y^{1T}p^1 / y^{1T}p^0$ is a Paasche output-price index, $W_P = x^{1T}w^1 / x^{1T}w^0$ is a Paasche input-price index, and $P_P / W_P \gtreqless 1$ is a Paasche price-recovery index, which measures the extent to which a producer's output price changes compensate for its input price changes.[9] The first term on the right side of each equality is a price-recovery effect, and the second is an inflation (or deflation) effect. In the first equality, the price-recovery effect scales the rate of price-recovery change $[(P_P / W_P) - 1]$ by deflated comparison-period revenue $p^{0T}y^1$ to generate a price-recovery bonus, which measures the contribution, positive or negative, of price-recovery change to profit change. The price-recovery effect can be interpreted as a financial reflection of a firm's market power. A notable application of the price-recovery effect occurs under incentive regulation, in which the regulator can constrain the ability of regulated firms to recover cost increases through price or revenue caps. Agrell and Bogetoft analyze incentive regulation in Chapter 16 of this *Handbook*. The inflation effect scales the input-price growth rate $\left[1 - W_P^{-1}\right]$ by comparison-period profit π^1 to generate an inflation bonus, which measures the contribution of input-price change to profit change. The second equality is interpreted similarly, and again the two effects in the second equality are not generally equal to their counterparts in the first equality. An empirically relevant interpretation of both inflation effects is that, assuming $\pi^1 > 0$, "a little inflation is good for business." Conversely, the inflation effects also suggest that a little deflation, such as that recently threatening the European Union, is bad for business and has induced the European Central Bank to adopt policies designed to stimulate moderate inflation.[10]

Expressions (9.2) and (9.3) provide four distinct decompositions of profit change. Each identifies productivity change and price-recovery change as potential drivers of profit change, and the choice among them depends on the objective of the analysis. Identifying the drivers of productivity change, and those of price-recovery change, requires tools from economic theory. We provide an input-oriented identification of the drivers of productivity change in section 9.3.

As a concluding observation, it is noteworthy that in its *Annual Report* BHP Billiton, although it does not explicitly follow our methodology, does decompose annual change in underlying EBIT into volume and price effects. It also decomposes the volume effect into a productivity effect and a growth effect, and it decomposes the price effect into change in sales prices and change in price-linked costs. It also reports a third component (p. 335) of profit change, which includes exogenous factors such as exchange rate movements, exploration and business development, and asset sales.

9.2.2. Change in $R - \tilde{C}$

Under the second accounting convention, we examine change in $R - \tilde{C}$. This change is zero by construction, but the zero change nonetheless decomposes into offsetting quantity and price effects as

$$\begin{aligned}\left(R^1 - R^0\right) - \left(\tilde{C}^1 - \tilde{C}^0\right) &= \left[p^{0T}\left(y^1 - y^0\right) - w^{0T}\left(x^1 - x^0\right) \quad - r^0\left(K_0^1 - K^0\right)\right] \\ &+ \left[y^{1T}\left(p^1 - p^0\right) - x^{1T}\left(w^1 - w^0\right) \; - K_0^1\left(r^1 - r^0\right)\right] \\ &= \left[p^{0T}\left(y^1 - y^0\right) - \tilde{w}^{0T}\left(x^1 - x^0\right)\right] \\ &+ \left[y^{1T}\left(p^1 - p^0\right) - x^{1T}\left(\tilde{w}^1 - \tilde{w}^0\right)\right],\end{aligned}$$

(9.4)

in which K_0^1 is comparison-period capital, valued at base-period prices. Capital is the only quantity variable measured in monetary units, and so the nominal change in capital from one period to the next combines the effects of price change with those of quantity change. We eliminate the effect of price change by using capital's real comparison period value K_0^1.[11]

Expensing the return to capital in the base period makes $p^{0T}y^0 = \tilde{w}^{0T}x^0$, which simplifies the quantity effect in expression (9.4) to

$$\begin{aligned}p^{0T}\left(y^1 - y^0\right) - \tilde{w}^{0T}\left(x^1 - x^0\right) &= p^{0T}y^1 - \tilde{w}^{0T}x^1 \\ &= \tilde{w}^{0T}x^1\left[\left(Y_L / \tilde{X}_L\right) - 1\right] \\ &= p^{0T}y^1\left[1 - \left(Y_L / \tilde{X}_L\right)^{-1}\right],\end{aligned}$$

(9.5)

and so the quantity effect is a productivity effect in which $\tilde{X}_L = \tilde{w}^{0T}x^1 / \tilde{w}^{0T}x^0$ is a Laspeyres input-quantity index with price weights $\tilde{w}^0$. Under this accounting convention, there is no growth effect, even if $Y_L \neq 1$ or $\tilde{X}_L \neq 1$, because the associated value weight analogous to π^0 in expression (9.2) is $p^{0T}y^0 - \tilde{w}^{0T}x^0$, which is zero by construction. The two expressions for the productivity effect are equal, even if $Y_L / \tilde{X}_L \neq 1$, because they both equal $p^{0T}y^1 - \tilde{w}^{0T}x^1$ in the first row of expression (9.5).

Expensing the return to capital in the comparison period makes $p^{1T}y^1 = \tilde{w}^{1T}x^1$, which simplifies the price effect in expression (9.4) to

$$\begin{aligned}y^{1T}\left(p^1 - p^0\right) - x^{1T}\left(\tilde{w}^1 - \tilde{w}^0\right) &= -\, y^{1T}p^0 + x^{1T}\tilde{w}^0 \\ &= p^{0T}y^1\left[\left(P_P / \tilde{W}_P\right) - 1\right] \\ &= \tilde{w}^{0T}x^1\left[1 - \left(P_P / \tilde{W}_P\right)^{-1}\right],\end{aligned}$$

(9.6)

(p. 336) and so the price effect is a price-recovery effect in which $\tilde{W}_P = x^{1T}\tilde{w}^1 / x^{1T}\tilde{w}^0$ is a Paasche input price index. Under this accounting convention, there is no inflation effect, even if $P_P \neq 1$ or $\tilde{W}_P \neq 1$, because the associated value weight analogous to π^1 in expression (9.3) is $p^{1T}y^1 - \tilde{w}^{1T}x^1$, which is zero by construction. The two expressions for the price-recovery effect are equal, even if $P_P / \tilde{W}_P \neq 1$, because they both equal $-y^{1T}p^0 + x^{1T}\tilde{w}^0$ in the first row of expression (9.6).

Under this accounting convention, special interest attaches to the return to those who provide capital to the business; Davis (1955) called them "investors." However, the return to capital is profit under a different name, since in the comparison period $p^{1T}y^1 - w^{1T}x^1 - r^1K_0^1 = 0, \quad p^{1T}y^1 - w^{1T}x^1 = r^1K_0^1 = \pi^1$, and in the base period $p^{0T}y^0 - w^{0T}x^0 - r^0K^0 = 0, \quad p^{0T}y^0 - w^{0T}x^0 = r^0K^0 = \pi^0$. Consequently, $r^1K_0^1 - r^0K^0 = \pi^1 - \pi^0$. Thus the following expression for change in the return to capital also provides a new expression for profit change

$$\begin{aligned} r^1K_0^1 - r^0K^0 = {} & \left[p^{0T}\left(y^1 - y^0\right) - w^{0T}\left(x^1 - x^0\right) - r^0\left(K_0^1 - K^0\right)\right] \\ & + r^0\left(K_0^1 - K^0\right) + \left[y^{1T}\left(p^1 - p^0\right) - x^{1T}\left(w^1 - w^0\right)\right], \end{aligned}$$

(9.7)

and adding and subtracting $r^0\left(K_0^1 - K^0\right)$ to the right side yields

$$\begin{aligned} r^1K_0^1 - r^0K^0 = {} & \left[p^{0T}\left(y^1 - y^0\right) - \tilde{w}^{0T}\left(x^1 - x^0\right)\right] \\ & + r^0\left(K_0^1 - K^0\right) + \left[y^{1T}\left(p^1 - p^0\right) - x^{1T}\left(w^1 - w^0\right)\right]. \end{aligned}$$

(9.8)

Thus, under this accounting convention, change in the return to those who provide capital to the business has three components: that portion of profit change attributable solely to productivity change (from expression (9.5)), a return to capital expansion effect $r^0\left(K_0^1 - K^0\right)$, and a price effect based on *(p, w)* rather than $(p, \tilde{w})$, which appears in expression (9.3). The return to capital expansion effect was introduced by Eldor and Sudit (1981), and is analogous to the growth effects $\pi^0\left(Y_L - 1\right)$ and $\pi^0\left(X_L - 1\right)$ in expression (9.2), although it collects the impact of growth in a single input, that of capital expansion.

We conclude by returning to Davis (1955), who showed that comparison-period profitability valued at base-period prices

$$\begin{aligned} \tilde{\Pi}_0^1 &= y^{1T}p^0 \big/ x^{1T}\tilde{w}^0 \\ &= Y_L / \tilde{X}_L \end{aligned}$$

(9.9)

is the Laspeyres productivity index appearing in expression (9.5), and that comparison-period profit valued at base-period prices

$$\begin{aligned} \tilde{\pi}_0^1 &= p^{0T}y^1 - \tilde{w}^{0T}x^1 \\ &= \tilde{w}^{0T}x^1\left(\tilde{\Pi}_0^1 - 1\right) \end{aligned}$$

(9.10)

(p. 337) converts the Laspeyres productivity index in expression (9.9) to a Laspeyres productivity bonus. Since expression (9.10) is another way of expressing the second equality in expression (9.5), it confirms that, when profit is expensed, the quantity effect is a productivity effect (which we also call a *productivity bonus*). The significance of these two results is that the two financial performance indicators $\tilde{\Pi}_0^1$ and $\tilde{\pi}_0^1$, both of which can be obtained from a company's accounts, provide measures of productivity change and the productivity bonus, respectively. These two results do not hold unless profit is expensed.

9.3. Selected Topics

We briefly consider some topics relevant to both accounting conventions, and we show how the treatment of each differs between the two conventions.

9.3.1. Drivers of Productivity Change

We have attributed a portion of profit change to productivity change, but we have not explored the sources of productivity change. Doing so requires specification of an orientation, either input-conserving or output-expanding, which in turn depends on management strategy. We adopt an input-conserving orientation, in keeping with our observation in section 9.1 on the emphasis that BHP Billiton places on the cost savings arising from productivity growth. We develop two approaches.

In the first approach we begin with the first productivity effect in expression (9.2), which we rewrite, exploiting the fact that $\Pi^0 = p^{0T}y^0 / w^{0T}x^0$, as

$$\begin{aligned} w^{0T}x^1\left[\left(Y_L / X_L\right) - 1\right] &= \left(p^0 / \Pi^0\right)^T\left(y^1 - y^0\right) - w^{0T}\left(x^1 - x^0\right) \\ &= \left(p^0 / \Pi^0\right)^T y^1 - w^{0T}x^1. \end{aligned}$$

(9.11)

With the assistance of Figure 9.3, which depicts production sets in base and comparison periods, we decompose the productivity effect in expression (9.11) as

$$\begin{aligned} &\left(p^0 / \Pi^0\right)^T y^1 - w^{0T}x^1 \\ &= w^{0T}\left(x^0 - x^A\right) - w^{0T}\left(x^1 - x^C\right) && \text{technical efficiency effect} \\ &+ w^{0T}\left(x^A - x^B\right) && \text{technical change effect} \\ &+ \left(p^0/\Pi^0\right)^T\left(y^1 - y^0\right) - w^{0T}\left(x^C - x^B\right), && \text{size effect} \end{aligned}$$

(9.12)

in which $x^A = x^0 / D_i^0\left(y^0, x^0\right)$ is a technically efficient radial contraction of observed base-period input vector x^0, $x^B = x^0 / D_i^1\left(y^0, x^0\right)$ incorporates a further radial contraction of (p. 338) x^0 made possible by input-saving technical progress, and $x^C = x^1 / D_i^1\left(y^1, x^1\right)$ is a technically efficient radial contraction of observed comparison-period input vector x^1. If production is more technically efficient in the comparison period than in the base period, the technical efficiency effect contributes positively to productivity change. If technical change is input-saving technical progress, the technical change effect also contributes positively to productivity change. Size change can contribute to productivity change in either direction, depending on the magnitudes of $(y^1 - y^0)$ and $(x^C - x^B)$, and since y^1 and x^C are not necessarily radial expansions or contractions of y^0 and x^B, size change includes both scale and mix changes.

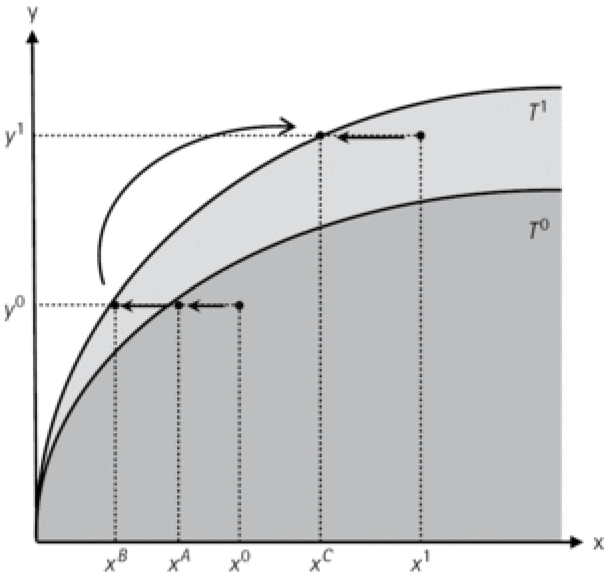

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Figure 9.3. Identifying the drivers of productivity change.

Decomposition (9.12) has an input-saving, cost-reducing orientation, in the sense that both technical efficiency change and technical change are measured, and valued, in an input-saving direction. It is analytically possible, and equally plausible from a managerial perspective, to adopt an output- and revenue-enhancing orientation when decomposing the productivity effect, so that both technical efficiency change and technical change are measured and valued in an output-enhancing direction.

In the second approach, originally developed by Grifell-Tatjé and Lovell (1999), we also begin with the first quantity effect in expression (9.2), but we use the entire quantity effect instead of just its productivity effect component. Continuing to use Figure 9.3, we have

$$
\begin{aligned}
&p^{0T}(y^1 - y^0) - w^{0T}(x^1 - x^0) \\
&\quad = w^{0T}(x^0 - x^A) - w^{0T}(x^1 - x^C) && \text{technical efficiency effect} \\
&\quad + w^{0T}(x^A - x^B) && \text{technical change effect} \\
&\quad + p^{0T}(y^1 - y^0) - w^{0T}(x^C - x^B), && \text{activity effect}
\end{aligned}
$$

(9.13)

(p. 339) in which the technical efficiency effect and the technical change effect are unchanged from expression (9.12). The activity effect collects the margin effect from the first quantity effect in expression (9.2) and the size effect in expression (9.12), and quantifies the aggregate impact on profit of efficient firm growth along the surface of T^1

in Figure 9.3. In this approach, the technical efficiency effect and the technology effect are the only drivers of productivity change, which is defined as $w^{0T}(x^0 - x^B) - w^{0T}(x^1 - x^C)$.

This strategy of decoupling the impacts of productivity change and size change on profit change can be particularly appropriate in certain situations, such as

- when one of the main components of the business model and strategy of the firm is growth. In this case, it is appropriate to distinguish the contribution of growth from that of productivity change to change in financial performance. The activity effect plays a leading role in the Brea-Solís, Casadesus-Masanell, and Grifell-Tatjé (2015) study of Walmart's sources of competitive advantage.
- when a regulator is willing to pay for improvements in productivity associated with technical efficiency change and technical change, but not for size change linked with mergers and acquisitions. De Witte and Saal (2010) distinguished the activity effect from the productivity effect in their study of regulatory impacts on the Dutch drinking water sector.

The decomposition strategy is very similar under the second accounting convention, in which $R - \widetilde{C} = 0$. The productivity effect in expression (9.5) can be rewritten as

$$\tilde{w}^{0}{}_{T}x^1\left[\left(Y_L / \tilde{X}_L\right) - 1\right] = p^{0T}\left(y^1 - y^0\right) - \tilde{w}^{0}{}_{T}\left(x^1 - x^0\right),$$

(9.14)

and we apply the same decomposition as in expression (9.12), substituting $\tilde{w}^0$ for w^0. The size effect in expression (9.12) coincides with the activity effect in expression (9.13) since $\left(p^0 / \Pi^0\right) = p^0 / \left[p^{0T}y^0 / \tilde{w}^{0}{}_{T}x^0\right] = p^0$. Consequently, under the second accounting convention, decompositions (9.12) and (9.13) coincide apart from their different input price vectors. This decomposition identifies the same input vectors x^A, x^B and x^C, but it weights output-quantity changes with p^0 rather than (p^0/Π^0) and weights input-quantity changes with $\tilde{w}^0$ rather than w^0. Implementing either procedure requires estimation of the unobserved input vectors x^A, x^B, and x^C.

9.3.2. Value Creation and Its Appropriation (or Distribution)

We consider how the productivity bonus, the value created by the production unit, is appropriated by (or distributed among) those who participate in its creation. But what value is to be distributed? The productivity effect? The quantity effect? An augmented quantity effect? The answer depends on how one views the firm as creating value.

Davis (1955) and Kendrick (1984) at the level of the individual business, and Kendrick (1961) and Kendrick and Sato (1963) at the level of the aggregate economy, viewed (p. 340) productivity change as the source of value creation. Kendrick (1961, 111) explained the distribution process succinctly: "If productivity advances, wage rates and capital return necessarily rise in relation to the general product price level, since this is the means whereby the fruits of productivity gains are distributed to workers and investors by the market mechanism."

Substituting the first equality in expression (9.2) into expression (9.1) and solving for the productivity effect yields an expression for the functional distribution of created value

$$w^{0T}x^1\left[\left(Y_L/X_L\right)-1\right]=-y^{1T}\left(p^1-p^0\right)+x^{1T}\left(w^1-w^0\right)+\left(\pi^1-Y_L\pi^0\right),$$

(9.15)

which shows how the productivity bonus is distributed to consumers through product price changes, to input suppliers through input price changes, and to investors who receive an income greater than, equal to, or less than profit change, depending on the value of the Laspeyres output-quantity index Y_L. Of course, some product prices can fall, consumer electronics providing a prominent example, while others rise; some input prices can rise, iron ore until 2011, while others fall; and profit can increase or decline.[12]

Expression (9.15) can provide evidence on the source(s) of increasing income inequality observed in most advanced nations (International Monetary Fund, n.d.). For example, a movement of the bonus away from input suppliers toward suppliers of capital is likely to increase inequality (OECD, 2014). In addition, disaggregating $-y^{1T}(p^1-p^0)$ can identify consumer groups who gain or lose from product group price changes, and disaggregating $x^{1T}(w^1-w^0)$ can identify input supplier groups who gain or lose from input-group price changes. For example, new technology generates a shift in demand away from less educated labor groups toward highly educated labor groups, which also is likely to increase inequality.

Some writers associated with CERC distribute the entire quantity effect, rather than just the productivity effect. The argument underlying this enlarged view of value creation is that growth, perhaps obtained through a strategy of replication, can also contribute to profit change. To see this, rewrite the growth effect in the first quantity effect in expression (9.2) as $\pi^0\left(Y_L-1\right)=\left(\pi^0/R^0\right)\left[p^{0T}\left(y^1-y^0\right)\right]$, which shows that the producing unit can create value through growth $p^{0T}(y^1-y^0)>0$, even in the absence of productivity gains, provided it has a positive base-period profit margin $(\pi^0/R^0)>0$ to build on. Under this view, the first quantity effect in expression (9.2), which includes the financial benefits of growth as well as those of productivity change, generates the following expression for the functional distribution of created value:

$$w^{0T}x^1\left[\left(Y_L/X_L\right)-1\right]+\pi^0\left(Y_L-1\right)=-y^{1T}\left(p^1-p^0\right)+x^{1T}\left(w^1-w^0\right)+\left(\pi^1-\pi^0\right),$$

(9.16)

and so the quantity effect is distributed among the same claimants as the productivity effect is, but in a larger or smaller amount and in a different composition, depending on $\pi^0 \gtreqless 0$ and $Y_L \gtreqless 1$. In this scenario, a profitable growth strategy enables firms to (p. 341) distribute more than just the productivity effect. Again, some product prices can fall while others rise, some input prices can rise while others fall, and profit can increase or decrease.

Other writers associated with CERC go still further, augmenting the quantity effect to be distributed with what they call "héritages," the sum of the values of any product price increases and any input price decreases, leading to yet another expression for the functional distribution of created value:

$$
\begin{aligned}
w^{0T}x^1\left[\left(Y_L/X_L\right)-1\right]+\pi^0\left(Y_L-1\right)&+\underset{p^1>p^0}{y^{1T}\left(p^1-p^0\right)}-\underset{w^1<w^0}{x^{1T}\left(w^1-w^0\right)}-\underset{\pi^1<\pi^0}{\left(\pi^1-\pi^0\right)}\\
&=-\underset{p^1>p^0}{y^{1T}\left(p^1-p^0\right)}+\underset{w^1>w^0}{x^{1T}\left(w^1-w^0\right)}+\underset{\pi^1>\pi^0}{\left(\pi^1-\pi^0\right)}.
\end{aligned}
$$

(9.17)

In this scenario, the productivity bonus and the growth effect are enhanced by additional revenue generated by price increases in some product markets, by cost reductions resulting from price decreases in some input markets, and by declines in any components of profit, such as taxes, dividends, or retained earnings. The number of claimants to the augmented quantity effect declines, but the amount to be distributed grows by the amount of héritages. Providers of capital continue to gain or lose. Among the applications of this approach are Grifell-Tatjé and Lovell (2008), who examined the distribution of the fruits of profit (and loss) change at the United States Postal Service over a 30-year period subsequent to its reorganization from a government department to an independent agency in 1971; Arocena, Blázquez, and Grifell-Tatjé (2011), who examined the sources of value creation and its distribution by utilities in the Spanish electric power sector prior to and subsequent to its restructuring in the late 1990s; and Estache and Grifell-Tatjé (2013), who identified distributional winners and losers among key stakeholders in a brief failed water privatization experience in Mali, one of the poorest countries in the world.

In section 9.2.2 there is no growth effect, and the productivity bonus also is distributed to consumers, suppliers, and investors [via the $(r^1 - r^0)$ component of $\left(\tilde w_N^1 - \tilde w_N^0\right)$]. In expression (9.5) the productivity bonus $p^{0T}y^1 - \tilde w^{0T}x^1 = p^{0T}y^1\left[1-\left(Y_L/\tilde X_L\right)^{-1}\right]$ is distributed by means of

$$
p^{0T}y^1\left[1-\left(Y_L/\tilde X_L\right)^{-1}\right]=-y^{1T}\left(p^1-p^0\right)+x^{1T}\left(w^1-w^0\right)+K_0^1\left(r^1-r^0\right),
$$

(9.18)

since the price-recovery effect is the negative of the productivity effect in expression (9.4). Just as other claimants receive their portion of the bonus through changes in the prices they receive or pay, investors receive their portion of the bonus as a change in the rate of return to the capital they provide. Among the applications of this approach are Boussemart, Butault, and Ojo (2012), who analyze the generation and distribution of productivity gains in French agriculture over a half century, and **(p. 342)** Garcia-Castro and Aguilera (2015), who build a value creation and appropriation model similar to ours, but expressed in ratio form inspired by the Solow growth model. The latter approach is summarized and extended, with emphasis on replication gains, and applied to US airlines by Garcia-Castro et al. in Chapter 10 of this *Handbook*.

Eldor and Sudit (1981) augment the productivity bonus with the return on capital expansion effect in expression (9.8), and so under this convention the value to be distributed is

$$p^{0T}y^1\left[1-\left(Y_L/\tilde{X}_L\right)^{-1}\right]+r^0\left(K_0^1-K^0\right)=-y^{1T}\left(p^1-p^0\right)$$
$$+x^{1T}\left(w^1-w^0\right)+\left(r^1K_0^1-r^0K^0\right).$$

(9.19)

The qualitative difference between expressions (9.18) and (9.19) is the return to investors. In expression (9.18) investor income derives from a change in the rate of return to capital, whereas in expression (9.19) investor income derives from both a change in the rate of return to capital and a change in the real quantity of capital to which the rates are applied. The two sources of investor income constitute profit change, since $r^1K_0^1-r^0K^0=\pi^1-\pi^0$.

9.3.3. Weights

In both subsections 9.2.1 and 9.2.2 we use base-period prices to weight quantity changes, and comparison-period quantities to weight price changes, which leads to Laspeyres quantity and productivity indices and Paasche price and price-recovery indices. It is also possible to use comparison-period prices to weight quantity changes, and base-period quantities to weight price changes, which leads to Paasche quantity and productivity indices and Laspeyres price and price-recovery indices. A third approach, inspired by Bennet (1920), uses arithmetic mean prices to weight quantity changes and arithmetic mean quantities to weight price changes, which leads to Edgeworth-Marshall quantity, productivity, price, and price-recovery indices.

Whenever base and comparison periods are far apart, or in turbulent times of rapid price and quantity change, the use of arithmetic mean prices and quantities is appealing. Adopting the accounting convention in subsection 9.2.1, profit change becomes

$$\pi^1-\pi^0=\left[\bar{p}^T\left(y^1-y^0\right)-\bar{w}^T\left(x^1-x^0\right)\right]+\left[\bar{y}^T\left(p^1-p^0\right)-\bar{x}^T\left(w^1-w^0\right)\right],$$

in which $\bar{p}=½\left(p^0+p^1\right)$ and $\bar{w}=½\left(w^0+w^1\right)$, and similarly for $\bar{y}$ and $\bar{x}$.

Grifell-Tatjé and Lovell (2015, 219) have shown that one of four decompositions of the quantity effect is

$$\bar{p}^T\left(y^1-y^0\right)-\bar{w}^T\left(x^1-x^0\right)=\bar{p}^Ty^1\left[1-\left(Y_{EM}/X_{EM}\right)^{-1}\right]+\left(\bar{p}^Ty^0-\bar{w}^Tx^0\right)\left[X_{EM}-1\right],$$

(9.20)

(p. 343) in which $Y_{EM} = \bar{p}^T y^1 / \bar{p}^T y^0$; $X_{EM} = \bar{w}^T x^1 / \bar{w}^T x^0$ and Y_{EM}/X_{EM} are Edgeworth-Marshall output quantity, input quantity, and productivity indices. This quantity-effect decomposition into productivity and growth components is structurally similar to the second decomposition in (9.2), but it uses Bennet arithmetic mean prices to generate Edgeworth-Marshall quantity and productivity indices.

Similarly, one of four decompositions of the price effect is

$$\bar{y}^T(p^1 - p^0) - \bar{x}^T(w^1 - w^0) = \bar{y}^T p^0[(P_{EM}/W_{EM}) - 1] + (\bar{y}^T p^1 - \bar{x}^T w^1)[1 - W_{EM}^{-1}],$$

(9.21)

in which $P_{EM} = \bar{y}^T p^1 / \bar{y}^T p^0$; $W_{EM} = \bar{x}^T w^1 / \bar{x}^T w^0$, and P_{EM}/W_{EM} are Edgeworth-Marshall output-price, input-price, and price-recovery indices. This decomposition is structurally similar to the first decomposition in expression (9.3), but it uses Bennet arithmetic mean quantities to generate Edgeworth-Marshall price and price-recovery indices.

An alternative way of implementing the arithmetic mean concept is to calculate the arithmetic mean of either Laspeyres quantity effect in expression (9.2) and the corresponding Paasche quantity effect to generate a Bennet type of quantity effect

$$\begin{aligned}\bar{p}^T(y^1 - y^0) - \bar{w}^T(x^1 - x^0) &= ½\{p^{0T} y^1[1 - (Y_L/X_L)^{-1}] + p^{1T} y^0[(Y_P/X_P) - 1]\} \\ &+ ½[\pi^0(X_L - 1) + \pi^1(1 - X_P^{-1})],\end{aligned}$$

(9.22)

in which the first term on the right-hand side is a productivity effect and the second is a growth effect. Similarly, the arithmetic mean of either Paasche price effect in expression (9.3) and the corresponding Laspeyres price effect generates a Bennet type of price effect

$$\begin{aligned}\bar{y}^T(p^1 - p^0) - \bar{x}^T(w^1 - w^0) &= ½\{p^{0T} y^1[(P_P/W_P) - 1] + p^{1T} y^0[1 - (P_L/W_L)^{-1}]\} \\ &+ ½[\pi^1(1 - W_P^{-1}) + \pi^0(W_L - 1)],\end{aligned}$$

(9.23)

which consists of a price-recovery effect and an inflation effect.

Application of the arithmetic mean concept to the accounting convention used in subsection 9.2.2 follows similar procedures, noting that neither growth effects nor inflation effects appear in the decompositions, and replacing w with $\tilde{w}$, which in turn replaces X_L and X_P with $\tilde{X}_L$ and $\tilde{X}_P$, and W_P and W_L with $\tilde{W}_P$ and $\tilde{W}_L$. The analysis is based on the arithmetic mean of expression (9.8) and the corresponding expression having quantity effect with comparison-period price weights and price effect with base-period quantity weights, in which the productivity effect is the arithmetic mean of the Laspeyres productivity effect in expression (9.5) and the corresponding Paasche productivity effect, and the price-recovery effect is the arithmetic mean of the Paasche price-recovery effect in expression (9.6) and the corresponding Laspeyres price-recovery effect. Under this accounting convention, we lose the linkage between Bennet indicators and EM indices.

(p. 344) 9.3.4. Missing, Subsidized, or Distorted Prices

The productivity effect is a function of prices as well as quantities. However, prices can be missing or subsidized in the non-market sector, and distorted, by discrimination or cross-subsidy, for example, in the market sector. If, for example, output prices are distorted, then it may be desirable to weight output quantities with their unit costs of production $c = (c_1, \ldots, c_M)$, c_m = (expenditure on output y_m)/y_m, $c^T y = C = w^T x$, in the quantity effect.

In subsection 9.2.1 this procedure converts the quantity effect in expression (9.1) to

$$\begin{aligned} p^{0T}(y^1 - y^0) - w^{0T}(x^1 - x^0) &= c^{0T}(y^1 - y^0) - w^{0T}(x^1 - x^0) + \left[(p^0 - c^0)^T (y^1 - y^0)\right] \\ &= w^{0T} x^1 \left[(Y_L^c / X_L) - 1\right] + \left[(p^0 - c^0)^T (y^1 - y^0)\right] \\ &= c^{0T} y^1 \left[1 - (Y_L^c / X_L)^{-1}\right] + \left[(p^0 - c^0)^T (y^1 - y^0)\right], \end{aligned}$$

(9.24)

in which $Y_L^C = c^{0T} y^1 / c^{0T} y^0$ is a Laspeyres output-quantity index with base-period unit cost weights in place of base-period output prices. The quantity effect decomposes into an adjusted productivity effect and an adjusted growth effect. The adjusted productivity effect $c^{0T} y^1 [1 - (Y_L^c / X_L)^{-1}]$ is a productivity bonus, free of output price distortion. The adjusted growth effect $(p^0 - c^0)^T (y^1 - y^0)$ incorporates both distorted output prices p^0 and output unit costs c^0. Products for which $p_m^0 \gtreqless c_m^0$ make positive, zero, or negative contributions to the quantity effect, and hence to profit change, provided $y_m^1 > y_m^0$. The expressions for the adjusted productivity effect in the final two equalities are equal.

In subsection 9.2.2 the quantity effect is the productivity effect, and so use of unit cost output weights converts the productivity effect in (9.5) to

$$\begin{aligned} p^{0T}(y^1 - y^0) - \tilde{w}^{0T}(x^1 - x^0) &= \tilde{w}^{0T} x^1 \left[(Y_L / \tilde{X}_L) - 1\right] \\ &= c^{0T} y^1 \left[1 - (Y_L^c / \tilde{X}_L)^{-1}\right]. \end{aligned}$$

(9.25)

The first equality is unaffected. In the second equality, unit costs replace product prices in the productivity index and in the value used to scale the productivity growth rate to create an adjusted productivity bonus.[13]

9.3.5. Exchange Rates

BHP Billiton publishes its consolidated financial statements in US dollars because the majority of its revenues are earned in US dollars, although its operating costs are incurred in the currencies of those countries where its operations are located. To ensure comparability of revenue and cost data, BHP Billiton converts its operating costs (p. 345)

to US dollars, and this introduces a new element into the price effect: exchange rate variation.

Suppose, contrary to fact but to simplify the exposition, that all operating costs are incurred and denominated in Australian dollars. Then its input price vector expressed in *USD* is $w^{USD} = w^{AUD} \times E$, where $E = AUD / USD$ is the exchange rate that converts *AUD* to *USD*. Expressions (9.1) and (9.3) show that price change influences profit change, and that price change has two components. Expressing the price effect in *USD* converts expression (9.3) to

$$\begin{aligned} y^{1T}(p^1 - p^0) - x^{1T}(w^{USD1} - w^{USD0}) &= p^{0T} y^1 \left[(P_P / W_P^{USD}) - 1 \right] + \pi^{USD1} \left[1 - (W_P^{USD})^{-1} \right] \\ &= w^{USD0T} x^1 \left[1 - (P_P / W_P^{USD})^{-1} \right] + \pi^{USD1} \left[1 - P_P^{-1} \right], \end{aligned}$$

(9.26)
in which

$$W_P^{USD} = \frac{x^{1T}(w^{AUD1} \times E^1)}{x^{1T}(w^{AUD0} \times E^0)},$$

and

$$\pi^{USD1} = p^{1T} y^1 - w^{USD1T} x^1 = p^{1T} y^1 - (w^{AUD1} \times E^1)^T x^1.$$

Exchange rate movements influence both components of the price effect. They influence the price-recovery effect in both equalities in expression (9.26) through their impact on W_P^{USD}. They influence the inflation effect through their impact on π^{USD1} and, in the first expression only, through their impact on W_P^{USD}. Each influence on W_P^{USD} is of the form ($w^{AUD} \times E$), and so exchange rate movements can reinforce or counter domestic input price changes.

9.3.6. Indirect (or Dual) Productivity Measurement

Under some circumstances, productivity can be measured indirectly, by tracking price changes rather than quantity changes. Siegel (1952) first proposed the idea, and Fourastié (1957, 196_, 196_) made extensive use of indirect productivity indices, noting that price trends reflect productivity trends, and since rates of productivity change vary across sectors of the economy, sectoral price trends also vary. Fourastié's idea continues to gain adherents (Aiyar and Dalgaard 2005; Jorgenson and Griliches 1967). A strong argument in support of indirect productivity measurement is that price changes can be measured more accurately than quantity changes, especially with reference to physical capital. Fernald and Neiman (2011) provide an analytical comparison of direct and indirect productivity measurement, with an empirical application that calls into question the conventional wisdom that the primary source of the East Asian growth miracle was factor accumulation rather than productivity growth.

(p. 346) In subsection 9.2.1, suppose that $\pi^1 = \pi^0 = 0$. In this case, $\pi^1 - \pi^0 = 0$ and the price effect is the negative of the quantity effect. In addition, the growth effect in (9.2) and the inflation effect in (9.3) are both zero, and so the price-recovery effect is the negative of the productivity effect. Thus

$$p^{0T}y^1\left[1-\left(P_P/W_P\right)\right] = w^{0T}x^1\left[\left(W_P/P_P\right)-1\right] = w^{0T}x^1\left[\left(Y_L/X_L\right)-1\right] = p^{0T}y^1\left[1-\left(Y_L/X_L\right)^{-1}\right]$$

provide equivalent measures of the productivity bonus. It follows from the second and third measures, or from the first and fourth, that $W_P/P_P = Y_L/X_L$. Thus if profit is zero in both periods, the reciprocal of the rate of price recovery equals the rate of productivity change. The argument generalizes beyond Laspeyres and Paasche indices to Fisher indices. The $\pi^1 = \pi^0 = 0$ assumption is sufficient for existence, but not necessary. A weak necessary condition is $\Pi^1 = \Pi^0 \gtreqless 1$.

In subsection 9.2.2, the price effect is the negative of the quantity effect, and since there is no growth effect and no inflation effect, the price-recovery effect is a dual productivity effect, based on $\widetilde{w}$ rather than w, so that $\tilde{W}_P / P_P = Y_L / \tilde{X}_L$. The same duality holds in subsection 9.2.1 if $\pi^1 = \pi^0 = 0$, which is easily seen in expressions (9.2) and (9.3). In both cases, this duality result also extends to Fisher indices.

9.4. Decomposing Return on Assets Change

In section 9.1 we noted the possibility of analyzing return on assets (ROA) within a duPont triangle framework, and we wrote $\mathrm{ROA} = \pi / A = \pi / R \times R / A$. While the analysis of profit change involves quantities and prices, the analysis of ROA change involves an additional variable, the producing unit's assets. It is clear that reducing A raises asset turnover R/A and thus ROA, and financial institutions around the world have done just this in the wake of the global financial crisis. BHP Billiton reports having divested assets "that no longer fit our strategy" worth several billion US dollars since 2013. Although asset shedding raises ROA, it does so directly, rather than through quantities or prices, and so we do not incorporate the rather obvious impact on ROA of changes in assets in our analysis.[14] Our analytical framework shows how productivity change and price-recovery change influence the profit margin π/R, and hence ROA π/A.

It is useful to express change in ROA as the product of change in profit margin and change in asset turnover as

$$\frac{\pi^1/A^1}{\pi^0/A^0} = \frac{\pi^1/R^1}{\pi^0/R^0} \times \frac{R^1/A^1}{R^0/A^0}.$$

(9.27)

(p. 347) Change in profit margin occurs because quantities change and because prices change, and it is useful to separate the two sources in two ways as

$$\frac{\pi^1/R^1}{\pi^0/R^0} = \frac{\pi^1/R^1}{\pi_0^1/R_0^1} \times \frac{\pi_0^1/R_0^1}{\pi^0/R^0}$$
$$= \frac{\pi_1^0/R_1^0}{\pi^0/R^0} \times \frac{\pi^1/R^1}{\pi_1^0/R_1^0},$$

(9.28)

in which $R_0^1 = p^{0T}y^1$ and $\pi_0^1 = p^{0T}y^1 - w^{0T}x^1$ are comparison-period revenue and profit evaluated at base-period prices, and $R_1^0 = p^{1T}y^0$ and $\pi_1^0 = p^{1T}y^0 - w^{1T}x^0$ are base-period revenue and profit evaluated at comparison-period prices.

In the first term in the first equality comparison period, quantities appear in numerator and denominator, but comparison-period prices appear in the numerator and base-period prices appear in the denominator. This term therefore captures the contribution of price change to profit-margin change, and it can be rewritten as

$$\frac{\pi^1/R^1}{\pi_0^1/R_0^1} = \frac{\pi^1}{R^1 - \left(\frac{P_P}{W_P}\right)w^{1T}x^1}.$$

(9.29)

Expression (9.29), which shows the contribution of (P_P/W_P) to profit-margin change, and hence to ROA change, can be compared with expression (9.3), which shows the contribution of (P_P/W_P) to the price-recovery effect, and hence to profit change, and to expression (9.6), which shows the contribution of $(P_P/\tilde{W}_P)$ to the modified price-recovery effect.

In the second term in the first equality, the opposite is true; prices are fixed at base-period values and quantities change. This term therefore captures the contribution of quantity change to profit-margin change, and it can be rewritten as

$$\frac{\pi_0^1/R_0^1}{\pi^0/R^0} = \frac{\pi_0^1}{R_0^1 - \left(\frac{Y_L}{X_L}\right)w^{0T}x^1}.$$

(9.30)

Expression (9.30), which shows the contribution of (Y_L/X_L) to profit margin change, and hence to ROA change, can be compared with expression (9.2), which shows the contribution of (Y_L/X_L) to the productivity effect, and hence to profit change, and to expression (9.5), which shows the contribution of $(Y_L/\tilde{X}_L)$ to the modified productivity effect.

Substituting expressions (9.29) and (9.30) into the first equality in expression (9.28) and substituting again into expression (9.27) generates

$$\frac{\pi^1/A^1}{\pi^0/A^0} = \frac{\pi^1}{R^1 - \left(\frac{P_P}{W_P}\right)w^{1T}x^1} \times \frac{\pi_0^1}{R_0^1 - \left(\frac{Y_L}{X_L}\right)w^{0T}x^1} \times \frac{R^1/A^1}{R^0/A^0},$$

(9.31)

(p. 348) which attributes change in ROA to a Paasche measure of the contribution of price-recovery change to profit-margin change, a Laspeyres measure of the contribution of productivity change to profit-margin change, and change in asset turnover.

Repeating the analysis using the second equality in expression (9.28) generates a similar decomposition of ROA change, and taking the geometric mean of the two yields

$$\frac{\pi^1/A^1}{\pi^0/A^0} = \left[\frac{\pi^1}{R^1 - \left(\frac{P_P}{W_P}\right) w^{1T} x^1} \times \frac{\pi_1^0}{R_1^0 - \left(\frac{P_L}{W_L}\right) w^{1T} x^0}\right]^{1/2} \times \left[\frac{\pi_0^1}{R_0^1 - \left(\frac{Y_L}{X_L}\right) w^{0T} x^1} \times \frac{\pi^1}{R^1 - \left(\frac{Y_P}{X_P}\right) w^{1T} x^1}\right]^{1/2} \times \frac{R^1/A^1}{R^0/A^0},$$

(9.32)

which attributes change in ROA to a geometric mean of Paasche and Laspeyres measures of the contribution of price-recovery change to profit-margin change, a geometric mean of Laspeyres and Paasche measures of the contribution of productivity change to profit-margin change, and change in asset turnover. Improvements in price recovery and productivity, and asset shedding, all raise ROA.

Grifell-Tatjé and Lovell (2014) apply the productivity change decomposition in section 9.3 to the geometric mean productivity effect in expression (9.32). They also introduce change in the rate of capacity utilization as an additional driver of change in ROA. Both the economic drivers of productivity change and change in the rate of capacity utilization influence ROA change through their impact on profit-margin change.

9.5. Decomposing Unit Cost Change

We consider unit cost as a measure of financial performance, which we motivate by noting that BHP Billiton, already one of the lowest-cost producers of iron ore, expects to reduce its unit cost by a quarter from 2015 to 2018. It claims it can reach this target through productivity gains achieved by eliminating supply chain bottlenecks, and by expanding output by nearly 30 percent. We develop an analytical framework within which these claims can be tested.

The difficulty with unit cost is defining a “unit” of output. This is not a problem in a single-product firm, for which $UC = \sum_{n=1}^{N} w_n x_n / y = w^T x / y$ in which y is a scalar, but it presents a challenge otherwise. BHP Billiton defines unit cost for each commodity it extracts, and so $UC_m = \sum_{n=1}^{N} w_n x_{nm} / y_m$, $m = 1, \ldots, M$. This requires cost allocation, which is difficult. The alternative is to define unit cost for a multiproduct producer as (p. 349) $UC = \sum_{n=1}^{N} w_n x_n / Y = w^T x / Y$, in which Y is a measure of aggregate output level such as real gross output or real value added. We follow the latter approach and define unit cost as $UC = w^T x / Y = w^T z$, with $z = x / Y$ a quantity vector of input–output ratios.[15]

9.5.1. Decomposing Unit-Cost Change by Economic Driver

We begin by decomposing unit-cost change into its economic drivers, with the help of a unit-cost frontier, which we define as $uc(y,w)=c(y,w)/Y$, where $c(y,w)$ is a cost frontier and Y is aggregate output. Since $uc(y,w)$ is the minimum unit cost required to produce output vector y at input prices w, $w^Tz \geq uc(y,w)$. Use of a unit cost frontier leads to the decomposition

$$\begin{aligned} w^{1T}z^1 - w^{0T}z^0 = {} & uc^1(y^1, \quad w^1) - uc^1(y^1, \quad w^0) && \text{input price effect} \\ & + [w^{1T}z^1 - uc^1(y^1, \quad w^1)] - [w^{0T}z^0 - uc^1(y^1, \quad w^0)] && \text{productivity effect.} \end{aligned}$$

(9.33)

The input price effect and the productivity effect are illustrated in Figure 9.4, which depicts three unit cost frontiers, a base-period frontier $uc^0(y,w^0)$, a comparison-period frontier $uc^1(y,w^1)$ and a mixed-period frontier $uc^1(y,w^0)$. All are U-shaped, reflecting the existence of increasing and decreasing returns to scale; $uc^1(y,w^0)$ lies beneath $uc^0(y,w^0)$ on the assumption that technical progress has occurred from base period to comparison period; $uc^1(y,w^1)$ lies between the two on the assumption that the cost-reducing impact of technical progress outweighs the cost-increasing impact of input price growth. Unit cost in the two periods is $w^{1T}z^1 \geq uc^1(y,w^1)$ and $w^{0T}z^0 \geq uc^0(y,w^0)$.

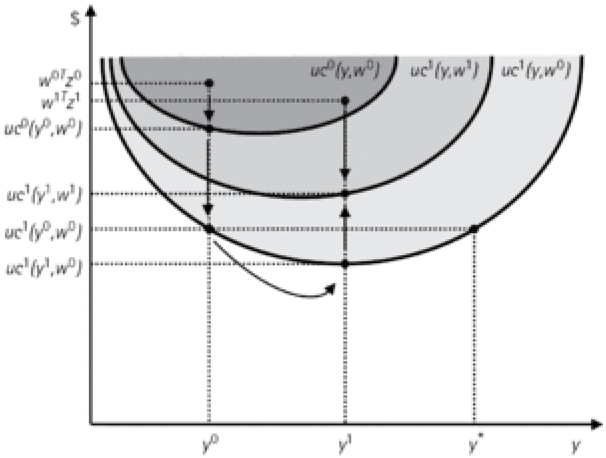
In expression (9.33) and in Figure 9.4, the input price effect captures the increase in $uc^1(y^1,w)$ when w increases from w^0 to w^1, and the productivity effect measures the change in w^Tz not attributable to the input price increase. The productivity effect decomposes as

$$\begin{aligned} & [w^{1T}z^1 - uc^1(y^1, \quad w^1)] - [w^{0T}z^0 - uc^1(y^1, w^0)] \\ & = [w^{1T}z^1 - uc^1(y^1, \quad w^1)] - [w^{0T}z^0 - uc^0(y^0, \quad w^0)] && \text{cost efficiency effect} \\ & \quad + [uc^1(y^0, \quad w^0) - uc^0(y^0, \quad w^0)] && \text{technical change effect} \\ & \quad + [uc^1(y^1, \quad w^0) - uc^1(y^0, \quad w^0)] && \text{size effect.} \end{aligned}$$

(9.34)

Expression (9.34) attributes the cost-reducing impact of productivity growth to three drivers: change in cost efficiency, technical change, and size change. Change in cost efficiency compares the extent to which actual unit cost exceeds minimum feasible unit cost (for the output produced and input prices paid) in comparison and base periods. The technical change effect measures by how much the minimum unit-cost frontier shifts, downward in this case, holding outputs and input prices constant at their base (p. 350) period values. The size effect compares minimum unit cost at comparison-period and base-period outputs, holding technology fixed at comparison period level and holding input prices fixed at base-period values. In Figure 9.4, cost efficiency has deteriorated, technical progress has shifted the minimum unit-cost frontier downward, and the exploitation of economies of size through output growth has reduced minimum unit cost along $uc^1(y, w^0)$. It is clear from expressions (9.33) and (9.34) and Figure 9.4 that these three drivers fully account for actual unit cost change.

It is instructive to compare expression (9.34), Figure 9.4, and surrounding discussion with expression (9.12), Figure 9.3, and surrounding discussion. Both are input oriented. Both attribute productivity change to technical change and size change, although they do so differently. Both also attribute productivity change to efficiency change, although one measures the impact on cost of change in technical efficiency, while the other measures the impact on unit cost of change in cost efficiency, of which technical efficiency is one component. It is also worth reiterating that BHP Billiton aims for a 25 percent reduction in the unit cost of producing iron ore through a combination of productivity improvements, which shift $uc\,(y, w)$ down, and expansion, which is a movement down the declining portion of $uc\,(y, w)$, both of which appear as drivers of unit-cost change in expression (9.34).



Click to view larger

Figure 9.4. Decomposing productivity change using unit cost.

9.5.2. Decomposing Unit-Cost Change by Partial Productivities

The second unit-cost change decomposition we develop is structurally similar to the cost side of the profit-change decomposition in section 9.2, with two exceptions. We replace cost change with unit-cost change, which is achieved by replacing x with z, and (p. 351) we disaggregate quantity and price effects into quantity and price effects for each input. This approach enables management to identify individual quantity and price changes most responsible for increases and decreases in unit cost.

Unit cost change can be written and decomposed as

$$\begin{aligned} w^{1T}z^1 - w^{0T}z^0 &= w^{0T}\left(z^1 - z^0\right) + z^{1T}\left(w^1 - w^0\right) \\ &= w^{0T}z^1\left(1 - Z_L^{-1}\right) + z^{1T}w^0\left(W_P - 1\right) \\ &= w^{0T}z^1\left(W_P - Z_L^{-1}\right). \end{aligned}$$

(9.35)

The first equality states that unit-cost change has quantity-change and price-change components. The second and third equalities show that the quantity-change component is a Laspeyres input–output quantity effect, and the price-change component is a Paasche input-price effect. The input–output quantity index is $Z_L = w^{0T}z^1 / w^{0T}z^0 = (w^{0T}x^1 / w^{0T}x^0)/(Y^1/Y^0) = X_L / Y_L$, and so $Z_L^{-1} = (Y^1/Y^0)/X_L = Y_L/X_L$ is a productivity index.[16] An increase in productivity $(Z_L^{-1} > 1)$ reduces unit cost, and an increase in input prices ($W_P > 1$) raises unit cost.

Expressions (9.35) and (9.33) both decompose unit-cost change into *aggregate* productivity and price effects. Both aggregate effects in expression (9.35) decompose by variable, since the aggregate productivity effect

$$w^{0T}(z^1 - z^0) = \sum w_n^0 [(x_n^1/Y^1) - (x_n^0/Y^0)] = \sum w_n^0 z_n^1 [(1 - (z_n^0/z_n^1))],$$

(9.36)

with N partial productivity change terms $z_n^0/z_n^1 = (Y^1/Y^0)/(x_n^1/x_n^0) = (Y^1/x_n^1)/(Y^0/x_n^0)$, $n = 1, \ldots, N$, with weights $w_n^0 z_n^1 = w_n^0 x_n^1 / Y^1$ that measure comparison-period unit input costs valued at base-period input prices, and the aggregate price effect

$$z^{1T}(w^1 - w^0) = \sum (x_n^1/Y^1)[w^1 - w^0] = \sum w_n^0 z_n^1 [(w_n^1/w_n^0) - 1],$$

(9.37)

with N *partial* input price effects w_n^1/w_n^0, $n = 1, \ldots, N$, with the same weights.

Interest naturally centers on the labor input, for three reasons. In most if not all economies, and in most sectors, labor has a larger cost share than any other input, frequently larger than all other inputs combined. This makes unit labor cost an important determinant of unit cost and hence economic competitiveness, both among firms and among nations. And the labor input is easier to measure than most other inputs.[17] Labor's partial productivity change is, in reciprocal form,

$$\begin{aligned} w_l^0[(l^1/Y^1) - (l^0/Y^0)] &= (S_{l0}^1 \times UC_0^1) \times \{1 - [(Y^1/l^1)/(Y^0/l^0)]\} \\ &= UlC_0^1 \times \{1 - [(Y^1/l^1)/(Y^0/l^0)]\}, \end{aligned}$$

(9.38)

in which ℓ indicates labor, $S_{l0}^1 = w_l^0 l^1 / w^{0T}x^1$ is labor's comparison-period cost share valued at base-period input prices, $UC_0^1 = w^{0T}x^1/Y^1$ is comparison-period unit cost valued at base-period input prices, and $UlC_0^1 = w_l^0 l^1 / Y^1$ is comparison-period unit (p. 352) labor cost valued at labor's base-period unit price. Thus the cost impact of a change in labor's partial productivity depends on the extent of the change and on comparison-period unit labor cost valued at labor's base-period unit price.

Labor's partial price change is

$$\left(l^1/Y^1\right)\left[w_l^1 - w_l^0\right] = \left(S_{l0}^1 \times UC_0^1\right) \times \left[\left(w_l^1/w_l^0\right) - 1\right]$$
$$= UlC_0^1 \times \left[\left(w_l^1/w_l^0\right) - 1\right],$$

(9.39)

and so the cost impact of a change in labor's unit price depends on the extent of the change and on the comparison-period unit labor cost valued at labor's base-period unit price.

Combining expressions (9.38) and (9.39) gives labor's net contribution to unit cost change

$$w_l^0\left[\left(l^1/Y^1\right) - \left(l^0/Y^0\right)\right] + \left(l^1/Y^1\right)\left(w_l^1 - w_l^0\right)$$
$$= \left(S_{l0}^1 \times UC_0^1\right) \times \left\{\left(w_l^1/w_l^0\right) - \left[\left(Y^1/l^1\right)/\left(Y^0/l^0\right)\right]\right\}$$
$$= UlC_0^1 \times \left\{\left(w_l^1/w_l^0\right) - \left[\left(Y^1/l^1\right)/\left(Y^0/l^0\right)\right]\right\}.$$

(9.40)

Thus unit labor cost acts as a multiplier, scaling the difference between labor's wage change and its partial productivity change. Labor's net impact on unit cost change is positive, zero, or negative, according as $\left(w_l^1/w_l^0\right) \gtreqless \left(Y^1/l^1\right)/\left(Y^0/l^0\right)$.

9.6. Summary and New Directions

At the outset we noted that BHP Billiton management understands that changes in its financial performance, however measured, are driven by quantity changes, price changes, and changes in external factors such as exchange rates. It also understands that it has no control over commodity prices or exchange rates, both of which have been extremely volatile since 2006.[18] In such an operating environment it explicitly recognizes that "controlling our operating costs is a key driver of our results," and its management strategy has therefore focused on improving financial performance through cost-reducing productivity growth.

We have examined the relationship between productivity change and three popular financial performance indicators—profit, return on assets, and unit cost—each of which plays a prominent role in BHP Billiton *Annual Reports*. In order to focus on productivity change, in each case we have had to separate the financial impacts of quantity change from those of price change, and then identify the financial impact of productivity change as a component of the financial impact of quantity change.

(p. 353) With two exceptions, the approach we have taken has been entirely empirical, based on price-dependent quantity indices and quantity-dependent price indices. These indices can be calculated from price and quantity information readily available from company reports (as we have demonstrated with BHP Billiton), trade associations, regulatory bodies, and government statistical agencies. The two exceptions involve identifying, and ultimately quantifying, the economic drivers of productivity change, an exercise that requires the assistance of economic theory. Thus productivity change decomposition (9.13) is based on production frontiers, and these frontiers are not contained in any database and must be estimated. Productivity change decomposition (9.34) is based on unit-cost frontiers, which also must be estimated. With these two exceptions, the analysis in this chapter is based exclusively on quantity and price data, and so requires no estimation.

There is an alternative approach, grounded in economic theory and based on best-practice frontiers, production, cost, revenue, profit, and profitability. The choice between production and value frontiers typically depends on the availability of relevant price information. The choice among value frontiers is usually governed by the perceived objective of the production units. In some cases, the business strategy is clear ("Every Day Low Prices" at Walmart, for example). In other cases, the business orientation is constrained by the nature of the operating environment or by a regulatory body; when product prices are exogenous, attention naturally focuses on cost control.

This alternative approach exploits theoretical quantity and productivity indices inspired by and named after Malmquist (1953), and theoretical price and price-recovery indices inspired by and named after Konüs (1939). The cost change decomposition in expressions (9.33) and (9.34) is based on Konüs indices. Diewert (2014b) and Grifell-Tatjé and Lovell

(2015, 2016) combine theoretical Konüs indices with empirical Fisher indices to decompose profitability change, a size-independent alternative to profit change as a financial performance indicator.

Both approaches provide valuable information to management concerning how well the firm's business strategy is working, and on the sources of the strengths and weaknesses of the business strategy. As we noted in the introduction to this chapter, BHP Billiton has used EBIT to assess its performance and to allocate resources. The decompositions developed in this chapter can identify the sources of variation in EBIT or other financial performance indicators, both through time and across segments of the business.[19]

Much work remains to be done. As the title of this chapter suggests, our objective has been to develop analytical frameworks within which the contribution of productivity change to change in financial performance can be identified. A logical sequel is to decompose the contribution of productivity change into those of its economic drivers. We achieved this objective in expressions (9.13) and (9.34). The value of these decompositions is that they shed light on the sources of productivity change. We have paid somewhat less attention to the contribution of price-recovery change to change in financial performance, and no attention to the possible sources of price-recovery (p. 354) change. This is a glaring omission in the case of BHP Billiton, whose product prices and exchange rates have been so volatile. Businesses, governments, competition commissions, and regulatory agencies are keenly interested in what is also known as cost recovery, the ratio of (or the difference between) product prices and input prices, and this interest may motivate another logical sequel, a decomposition of the contribution of price-recovery change into those of its drivers.

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Notes:

(1.) Grifell-Tatjé thanks the Spanish Ministry of Science and Technology (ECO2013-46954-C3-2-R) for financial support, and Lovell thanks the University of Queensland School of Economics for financial support.

(2.) The 2016 Annual Report and supporting documents are available at http://www.bhpbilliton.com/investor-centre/annual-reporting-2016. Accessed March 6, 2017.

(3.) Kendrick (1984) has productivity and price recovery as the two ingredients of a business performance measurement system that he attributes to van Loggerenberg and Cucchiaro (1981–1982).

(4.) Davis (1955, 68) interprets profit as “. . . the input of risk-taking combined with the foregoing of alternative uses of the funds invested in the company’s operations.”

(5.) BHP Billiton’s CEO Andrew MacKenzie, referring to unit cost, cost per tonne of iron ore, at http://www.abc.net.au/news/2015-04-22/bhp-billiton-continues-to-lift-output-cut-costs/6411594. Accessed March 7, 2017.

(6.) Grifell-Tatjé and Lovell (2015) provide a comprehensive survey and extension of the literature on productivity and financial performance.

(7.) Färe and Primont (1995) provide details on distance functions and value (cost and revenue) functions.

(8.) The return to capital goes by a number of names, including “investor input” (Davis 1955), “operating surplus” (OECD, http://stats.oecd.org/glossary/detail.asp?ID=1912), and “EBIT.” Whatever its name, it is a return, positive or negative, to those who provide capital to the business. The rate of return is endogenous because it emerges from an accounting convention that requires $rK = \pi$, which equates the value of output with the value of input. Schreyer (2010) and Diewert (2014a) have examined productivity measurement with alternative exogenous rates of return that do not force equality; see also Balk’s Chapter 2 in this volume.

(9.) An improvement in a firm’s price recovery raises its profit. In an international trade context, the analogous concept is called the terms of trade, the ratio of an export-price index to an import-price index, and an improvement in a country’s terms of trade raises its real income. Diewert and Morrison (1986) provide analytical details.

(10.) The inflation effect is a microeconomic counterpart to the rate of inflation in an economy, and “a little inflation is good for business” is a microeconomic counterpart to the belief in an optimal rate of inflation in an economy. Schmitt-Grohé and Uribe (2010) provide a good introduction to the huge literature on the optimal rate of inflation.

(11.) Ideally K_0^1 would measure a flow of capital services, but frequently it is a measure of book value. OECD (2001) has a good discussion of the measurement of capital services.

(12.) In principle the *functional* distribution of created value in (9.15) can be related to the *size* distribution of income, which exhibits increasing inequality in most developed countries. In practice this would seem to require disaggregation of the price vectors p and w and the scalar π, and the development of an analytical framework. Glyn (2011) asserts a linkage between the two types of distribution, but without an analytical framework or empirical evidence.

(13.) The System of National Accounts (Eurostat, 1993) recommends the use of unit cost output valuations in the public sector when prices are missing. Diewert (2012) discusses productivity measurement when output prices are missing, and notes that our output-quantity index Y_L^C is used in the United Kingdom. Diewert extends his (2012) work in Chapter 7 of this volume. A prominent example of missing prices concerns productivity measurement in the presence of undesirable outputs such as pollutants. Førsund analyzes this situation in Chapter 8 of this volume.

(14.) This assumes independence of A from x. BHP Billiton’s assets include just one component, plant and equipment, that incurs depreciation and amortization expense, and so might be considered an input.

(15.) The term “level” is due to Eichhorn and Voeller (1976), who define a price level as a strictly increasing linearly homogeneous function ρ (p) of a price vector p, and a price index as a function $P(p, p^0) = \rho(p) / \rho(p^0)$.

(16.) $(Y^1 / Y^0) = Y_L$ assumes, following Eichhorn and Voeller (1976), that $Y^1 = p^{0T} y^1$ and $Y^0 = p^{0T} y^0$.

(17.) The OECD (https://stats.oecd.org/glossary/detail.asp?ID=2809) treats unit labor cost as “a reflection of cost competitiveness,” and tracks unit labor cost in a variety of sectors across its member countries (http://stats.oecd.org/Index.aspx?DataSetCode=PDBI_I4#).

(18.) The nominal price per dry metric ton of iron ore has fluctuated widely, from USD 33 in late 2006 to a peak of USD 187 in early 2011 and a trough of USD 41 in late 2015 before recovering to USD 81 in early 2017. http://www.indexmundi.com/commodities/?commodity=iron-ore&months=120. Accessed March 3, 2017. The prices of BHP Billiton’s other export products have behaved similarly. The exchange rate (AUD/USD) has exhibited similar volatility, ranging from 0.75 in 2006 to a high of 1.10 in 2011 and back down to 0.76 in early 2017.

(19.) After many years of using EBIT as its preferred financial performance indicator, in its 2016 *Annual Report* it prefers EBITDA (EBIT plus depreciation and amortization) because it is “. . . more relevant to capital-intensive industries with long-life assets.”

Emili Grifell-Tatjé

Emili Grifell-Tatjé, Universitat Autònoma de Barcelona

C.A. Knox Lovell

C. A. Knox Lovell, University of Queensland