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Effective production: measuring of the sales effect using data envelopment analysis

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Abstract Sales fluctuations lead to variations in the output levels affecting technical efficiency measures of operations when units sold are used at an output measure. The present study uses the concept of "effective production" and "effectiveness" to account for the effect of sales on operational performance measurements in a production system. The effectiveness measure complements the efficiency measure which does not account for the sales effect. The Malmquist productivity index is used to measure the sales effects characterized as the difference between the production function associated with efficiency and the sales-truncated production function associated with effectiveness. The proposed profit effectiveness is distinct from profit efficiency in that it accounts for sales. An empirical study of US airlines demonstrates the proposed method which describes the strategic position of a firm and a productivity-change analysis. These results demonstrate the concept of effectiveness and quantifies the effect of using sales as output.

Keywords Data envelopment analysis · Effectiveness measure · Sales effect · Effective production · Strategic position

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1 Introduction

In productivity and efficiency analysis, given the same input resources, a firm is called efficient if its output levels are higher than other firms. A typical efficiency study does not distinguish between poor performance in terms of production and sales (the performance of the sales group) when the outputs are units sold or sales (Lee and Johnson 2014). Thus, this research continues the development of an "effectiveness" measure to quantify a sales effect distinct from productive efficiency, in particular, for the Malmquist productivity index in panel data analysis (Caves et al. 1982).

In the literature there are two common ways to assess effectiveness. First way is to assess organizational effectiveness with respect to given goals and objectives. Several research efforts have used data envelopment analysis (DEA)[1] explicitly to address the issue of effectiveness analysis. Golany (1988) and Golany et al. (1993) propose that effectiveness measures characterize how well an organization's performs when attempting to achieve a goal(s) or an objective(s) and argues that inefficiency is associated with waste, and, therefore, cannot be associated with effective operations. Golany and Tamir (1995) describe trade-offs among efficiency, effectiveness, and equality. These authors define an efficiency criterion that seeks to achieve "more-for-less," i.e., achieving resource savings while maintaining output levels or expanding outputs generated while maintaining input levels. The effectiveness criterion is determined by the distance between observed outputs and a set of desired goals. Finally, the equality criterion measures the degree of fairness in the allocation of resources or the distribution of outputs among the units that are evaluated. Asmild et al. (2007) state when measuring effectiveness or other behavioral objectives, multipliers in DEA must reflect realistic values or prices. Overall effectiveness measures the degree to which a single behavioral or organizational goal such as cost minimization has been attained for a given set of market prices.

The second way to assess the effectiveness is to use a network analysis to illustrate the decomposition of a production process (Vaz et al. 2010). Fielding et al. (1985) develop performance evaluation approaches for transportation systems. They distinguish between the production process and the consumption process, arguing that output consumption is substantially different from output production since transportation services cannot be stored. These authors propose various performance indicators, specifically, service effectiveness, which is the ratio of passenger trip miles over vehicle operating miles. However, single factor productivity indicators do not represent all factors in the production system (Chen and McGinnis 2007). Byrnes and Freeman (1999) measure the efficiency and effectiveness in health service. They describe the behavioral health service provision as a two-stage production process. In the first stage, providers assess client functioning and structure a service plan within the budget limits. Then, the service plan activities yield changes in client functioning in the second stage. High performance in the first stage is termed cost-efficiency, whereas high performance in the second stage is term cost-effectiveness. Thus, effectiveness refers to achieving a level of outcome for the least cost. Yu and Lin (2008) use network DEA models to characterize a consumption process and assess the service effectiveness and technical effectiveness.

The literature regarding the demand (or sales) effect in productivity and efficiency analysis is limited. Recently, Lee and Johnson (2011, 2012) use network DEA to decompose a production process into capacity design, demand generation, operations components and demand consumption, and measure the productivity change of each component. They distin-

[1] Charnes et al. (1978), Banker et al. (1984) and Talluri et al. (2006).

guish the production process from the demand generation/consumption process. The results indicate technical regress can be caused by sales fluctuations rather than production capabilities. Further the capacity design component generally has a significant effect on long-term productivity. Lee and Johnson (2014) propose a demand-truncated production function for effectiveness measure and use stochastic programming technique to handle demand fluctuation. However, the focus of their research is on a cross-sectional production function and therefore only addresses the relationship between efficiency and effectiveness. This paper considers the role of an effectiveness measure when price information and panel data are available. Thus, we consider profit effectiveness compared to the more classical profit efficiency and we investigate the implications and interpretations possible when a Malmquist productivity decomposition of effective production is performed.

The paper is organized as follows. Section 2 defines a sales-truncated production function and illustrates the relationship between efficiency and effectiveness. Section 3 proposes a measure of sales effect by characterizing the gap between the original production function and the sales-truncated production function. Section 4 proposes that when evaluating operational performance, the measure of profits should be estimated while accounting for the effect of sales, thus effectiveness rather than efficiency is a useful concept. In Sect. 5 productivity change and industry growth are quantified using the Malmquist productivity index (MPI). In Sect. 6 the US airline industry is investigated to demonstrate the effectiveness measure. Finally, Sect. 7 concludes the paper.

2 Effective production

2.1 Truncated production function

A production function (PF) defines the maximum outputs that an organization or production system can produce given input resources. Let $\boldsymbol{x}$ be a vector of input variable quantifying the input resources, y be the single-output variable generated from production system, and y^{PF} represent maximal output level given inputs. A standard production function with a single output is shown in Eq. (1) and satisfies the properties of nonnegativity, weak essentiality, monotonicity, and concavity (Coelli et al. 2005).

$$y^{PF} = f(\boldsymbol{x}) \tag{1}$$

Based on Lee and Johnson (2014), *effective output* is defined as the output product or service generated by the production system that is consumed. Furthermore, they define the *sales-truncated production function* as the maximum sales for a product or service that can be fulfilled given the quantities of the input resources consumed. A firm is achieving *effective production* if the effective output level identified by the sales-truncated production function (STPF) is generated.

A STPF is defined based on the sales level. To maintain generality, sales are firm-specific, each firm can have a different sales level, and the STPF is defined as the production function truncated by the sales of the specific firm. Let s be the realized sales. The effective production, y^E, is the smaller of the two variables: the frontier production output level y^{PF} and realized sales s. The STPF with output level y^E is formulated as Eq. (2), where y^{STPF} is the output level of STPF.

$$y^{STPF} = \min(y^{PF}, s) = \min\left(f\left(\boldsymbol{x}\right), s\right) \tag{2}$$

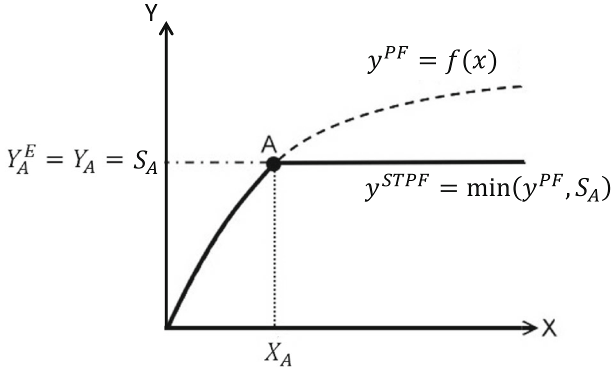


Fig. 1 Sales-truncated production function

Figure 1 illustrates the STPF and its properties for a single-input and a single-output case. For an observation, firm A, the production level is equal to the sales level, $S_A = Y_A^E = Y_A = f(X_A)$. That is, a firm can produce the optimal output level without unfulfilled sales or excessive inventory. In addition, it is straight-forward to validate the properties-nonnegativity, weak essentiality, monotonicity, and concavity of STPF since the minimum function of a production function and constant, sales, is a convex polyhedral.

Now consider a multiple-input and multiple-output production process. Let $\boldsymbol{x} \in \mathbb{R}_+^I$ denote a vector of input variables and $\boldsymbol{y} \in \mathbb{R}_+^J$ denote a vector of output variables for a production system. The production possibility set (PPS) T is defined as $T = \{(\boldsymbol{x}, \boldsymbol{y}) : \boldsymbol{x} \text{ can produce } \boldsymbol{y}\}$ and is estimated by a piece-wise linear convex function enveloping all observations shown in model (3). Let $i = \{1, 2, \ldots, I\}$ be the set of input index, $j = \{1, 2, \ldots, J\}$ be the set of output index, and $k = \{1, 2, \ldots, K\}$ be the set of firm index. X_{ik} is the data of the ith input resource, Y_{jk} is the amount of the jth production output, and λ_k is the multiplier for the kth firm (observation). Model (3) defines the feasible region of the estimated production possibility set $\tilde{T}$. Then, efficiency, θ, can be measured using the variable-returns-to-scale (VRS) DEA estimator which generalizes constant-returns-to-scale (CRS) and captures the effect of the law of diminishing marginal returns. Output-oriented technical efficiency (TE) is defined as the distance function $D_y(\boldsymbol{x}, \boldsymbol{y}) = \inf\{\theta \,|\, (\boldsymbol{x}, \boldsymbol{y}/\theta) \in \tilde{T}\}$.[2] If $\theta = 1$, then the firm is efficient; otherwise it is inefficient when $\theta < 1$.

$$\tilde{T} = \left\{(\boldsymbol{x}, \boldsymbol{y}) \middle| \sum\nolimits_k \lambda_k Y_{jk} \geq y_j, \forall j; \sum\nolimits_k \lambda_k X_{ik} \leq x_i, \forall i; \sum\nolimits_k \lambda_k = 1; \lambda_k \geq 0, \forall k\right\} \tag{3}$$

Similarly, let $\boldsymbol{y}^E \in \mathbb{R}_+^J$ denote an effective output vector produced and consumed. The sales-truncated production possibility set (PPS$^{\mathrm{E}}$) $T^E = \{(\boldsymbol{x}, \boldsymbol{y}^E) : x \text{ can produce } \boldsymbol{y}^E$ that will be consumed in current period$\}$ can be estimated by a piece-wise linear convex function truncated by the sales level as shown in (4). Y_{jk}^E is the observation of the amount of the jth output produced by the kth firm and consumed given the firm specific sales S_j. That is, $Y_{jk}^E = \min\left(Y_{jk}, S_j\right)$. The model (4) illustrates the feasible region of the effective production possibility set $\tilde{T}^E$, where $\tilde{T}^E$ is a PPS$^{\mathrm{E}}$ estimated by observations with outputs Y_{jk}^E.

[2] To avoid the fractional linear programming, the *TE* is calculated by $D_y(\boldsymbol{x}, \boldsymbol{y}) = \theta = 1/\delta$, where $\delta = \sup\{\delta \,|\, (\boldsymbol{x}, \delta\boldsymbol{y}) \in \tilde{T}\}$.

$$\tilde{T}^E = \left\{ (\boldsymbol{x}, \boldsymbol{y}^E) \middle| \sum\nolimits_k \lambda_k Y_{jk} \geq y_j^E, \forall j; S_j \geq y_j^E, \forall j; \sum\nolimits_k \lambda_k X_{ik} \right.$$
$$\left. \leq x_i, \forall i; \sum\nolimits_k \lambda_k = 1; \lambda_k \geq 0, \forall k \right\} \quad (4)$$

To complete the discussion we restate a previous result by Lee and Johnson (2014) to characterize the STPF.

Proposition 1 *The sales-truncated production function (STPF) defined as* $y^{STPF} = \min(f(\boldsymbol{x}), s)$ *satisfies the underlying properties of nonnegativity, weak essentiality, monotonicity, and concavity.*

Proof Recognizing $\mathrm{PPS^E} \subseteq \mathrm{PPS}$, the underlying properties can be proven directly by using the definition $y^{STPF} = \min(f(\boldsymbol{x}), s)$ and the definition of the properties in Coelli et al. (2005).

2.2 Effectiveness measure

Lee and Johnson (2014) introduced an effectiveness measure with respect to the STPF as follows. The output-oriented technical effectiveness (TE^E), θ^E, is defined as distance function $D_y^E(\boldsymbol{x}, \boldsymbol{y}^P) = \inf\left\{\theta^E | (\boldsymbol{x}, \boldsymbol{y}^P/\theta^E) \in \tilde{T}^E\right\}$ where $\boldsymbol{y}^P$ is penalized output and defined below. Assuming producing less than the sales level will lead to lost sales and producing more output than the sales level will lead to inventory holding cost, a generalized effectiveness measure is developed. First, a penalized output Y_{kj}^P is calculated. If $Y_{kj} < S_{kj}$, then the opportunity to sell $S_{kj} - Y_{kj}$ units is lost and we set $Y_{kj}^P = Y_{kj} - \alpha_{kj}(S_{kj} - Y_{kj}) \geq 0$, where $\alpha_{kj}(S_{kj} - Y_{kj})$ is the penalty associated with the opportunity cost; otherwise $Y_{kj} > S_{kj}$ and $Y_{kj} - S_{kj}$ units of inventory are generated and we set $Y_{kj}^P = S_{kj} - \beta_{kj}(Y_{kj} - S_{kj}) \geq 0$, where $\beta_{kj}(Y_{kj} - S_{kj})$ is the penalty associated with carrying this inventory. In calculating Y_{kj}^P the penalty parameters $\alpha_{kj} \geq 0$ and $\beta_{kj} \geq 0$ are used to quantify the effect of lost sales and inventories, respectively, on effectiveness. Note this definition of Y_{kj}^P allows for the same normalization of the efficiency measure for the case of lost sales or inventories.[3] Given $\alpha_A = 0$ and $\beta_A = 1$ (i.e. only consider penalty for holding inventory), Fig. 2 illustrates two cases of firm A by single-input single-output production function.

We formalize the definitions of capacity shortage and surplus with definitions 1 and 2.

Definition 1 (*Capacity shortage*) For a firm k with J output products, the penalized output Y_{kj}^P represents the output product Y_{kj} generated and consumed by customer sales S_{kj} with a penalty $\alpha_{kj}(S_{kj} - Y_{kj})$ for output j if $Y_{kj} \leq S_{kj}$. That is, $Y_{kj}^P = Y_{kj} - \alpha_{kj}(S_{kj} - Y_{kj}) \geq 0$.

Definition 2 (*Capacity surplus*) For a firm k with J output products, the penalized output Y_{kj}^P represents the output product Y_{kj} generated and consumed by customer sales S_{kj} with a penalty $\beta_{kj}(Y_{kj} - S_{kj})$ for output j if $Y_{kj} > S_{kj}$. That is, $Y_{kj}^P = S_{kj} - \beta_{kj}(Y_{kj} - S_{kj}) \geq 0$.

Note that the STPF and T^E is firm-specific because the sales level is firm-specific. In addition, if sales is low, a significant gap between efficiency and effectiveness exists; however,

[3] The description of Y_A^P in Fig. 2b implies when there is inventory, firm A is flipped to the other side of the demand level and the dummy point A' is created to calculate Y_A^P making θ^E comparable between the capacity shortage and surplus cases. When demand levels are low, the dummy point A' maybe located outside of T^E (outside of the positive orthant). However, in this case the penalty is truncated by the x-axis (or $\boldsymbol{Y} = 0$). Alternatively, a super efficiency measure could be used as in Lovell and Rouse (2003).

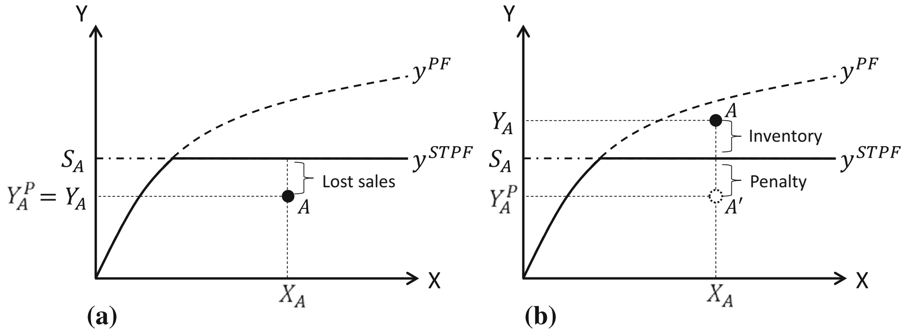


Fig. 2 Effectiveness measured by **a** penalty for capacity shortage, or **b** penalty for capacity surplus

if sales is high and $\alpha_{kj} = 0$, efficiency and effectiveness are identical measures. This indicates effectiveness is particularly important during economic down-turns. Thus, a firm is efficient if $\theta = 1$; otherwise it's inefficient. Similarly, a firm is effective if $\theta^E = 1$ or it's ineffective.

Proposition 2 (revised from *Lee and Johnson 2014:) When sales is large enough, the sales-truncated production possibility set converges to the production possibility set and the effectiveness converges to efficiency when* $\alpha_{kj} = 0$.

Proof Based on the definition of effectiveness and model (4), for all output j, given $\alpha_{kj} = 0$, we have $Y_j^P = Y_j$ and if $S_j \to \infty$, then the constraint $S_j \geq Y_j^P$ in model (4) is redundant. Thus, $\lim_{S_j \to \infty} \theta^E = \theta$.

In summary, the definition of sales-truncated production function implies some notable issues. Given this definition, if actual output exceeds sales, then inventories are built and the inventory is ineffective production due to the holding costs and risk of obsolesce of the product; vice versa, if sales exceeds production, a shortage is created leading to loses in goodwill or market share. Thus, the effectiveness analysis proposed is suitable for characterizing production system with perishable goods, make-to-order production systems, or service systems.

There are two additional considerations in an effectiveness analysis. First, the parameters α_{kj} and β_{kj} characterize the relationship between the opportunity costs and the inventory costs. In general, we can define α_{kj} as a function of β_{kj} to capture the relationship between these two types of cost.[4] Second, the proposed model assumes that output is high enough that Y_{kj}^P is not truncated by the x-axis (or $\boldsymbol{Y}_j = 0$) when A' is constructed.[5]

2.3 Efficiency v.s. effectiveness

Efficiency and effectiveness complement each other and are not mutually independent, but have different strategic interpretations (Lee and Johnson 2014). Efficiency measures the relative return on inputs used while effectiveness indicates the ability to match sales given an existing production technology. High effectiveness generates revenues by providing products

[4] For example, let C_{kj}^l be the cost of lost sales and C_{kj}^h be the inventory holding cost of the output j of the firm k, we can derive the function as $\alpha_{kj} = \frac{C_{kj}^l}{C_{kj}^h}\beta_{kj}, \forall k, j$. Thus, if $\beta_{kj} = 1$, then $\alpha_{kj} = \frac{C_{kj}^l}{C_{kj}^h}$.

[5] In this case truncation will bias the effectiveness measure and alternative methods based on the super efficiency model alternative would be preferred.

Fig. 3 Strategic position

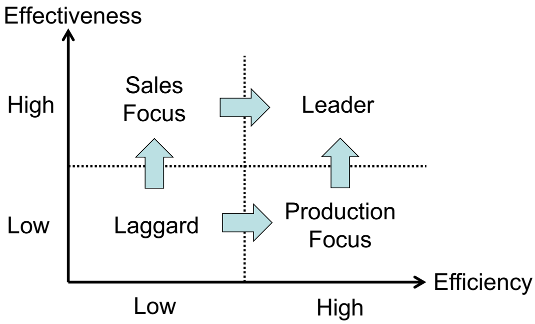
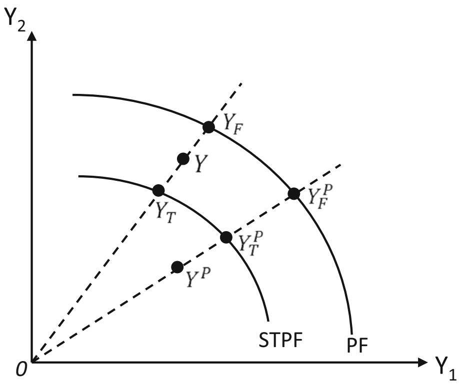


Fig. 4 Sales effect measured by *MPI*



and services to customers; low effectiveness implies high inventories or unmet sales. Figure 3 illustrates a two-dimensional strategic position between efficiency and effectiveness. The mean of efficiency or effectiveness is used to separate a low and high category. If both efficiency and effectiveness are low, the firm is labeled a "Laggard" who adopts others' superior strategy and attempts to catch-up before they are driven out of the industry. If a firm performs well in terms of efficiency and bad in terms of effectiveness, the firm is labeled "Production Focus", indicating that the firm is leading the industry in terms of making the best use of their input resources and technology. In the case of manufacturing industry, it also refers to inventory builder. If a firm is performing poorly in terms of efficiency and well in terms of effectiveness, the firm is labeled "Sales Focus" indicating a market-oriented strategy focuses on matching production levels to sales and maintaining or expanding market share. The production team is good at matching the sales level but is using an inefficient production process. Finally, if the firm is performing well in terms of both efficiency and effectiveness, the firm is labeled a "Leader" indicating it is developing new markets while also innovating to keep a competitive advantage.

3 Measure of sales effect

From the economics perspective, sales effect describes the gap between production function and sales-truncated production function. To measure the sales effect, this study employs the Malmquist Productivity Index (*MPI*) developed by Caves et al. (1982) and Färe et al. (1992, 1994). The *MPI* is typically used to measure the productivity change over time. Here, we define a sales effect and illustrate this effect in Fig. 4. In this example a firm produces a vector of output $\boldsymbol{Y}$ made up of two types of output, Y_1 and Y_2. Efficiency is measured relative to a production function, *PF*, and effectiveness is measured relative to a *STPF*. Output level $\boldsymbol{Y}$ projected to *PF* is $\boldsymbol{Y}_F$, and projected to *STPF* is $\boldsymbol{Y}_T$ (subscript F means "frontier" and T means "truncated frontier"). Similarly the (penalized) effective output vector $\boldsymbol{Y}^P$ is projected to *PF* and labeled point $\boldsymbol{Y}_F^P$ and projected to *STPF* and labeled point $\boldsymbol{Y}_T^P$. The sales effect is defined using a decomposition of the *MPI* consisting of the inverse of the effectiveness-efficiency ratio $\frac{TE^E}{TE}$ and the frontier gap (FG).

$$\begin{aligned}\textit{Sales effect} &= \left[\frac{D_y(\boldsymbol{x},\boldsymbol{y})}{D_y\left(\boldsymbol{x},\boldsymbol{y}^P\right)}\times\frac{D_y^E(\boldsymbol{x},\boldsymbol{y})}{D_y^E\left(\boldsymbol{x},\boldsymbol{y}^P\right)}\right]^{\frac{1}{2}} = \frac{D_y(\boldsymbol{x},\boldsymbol{y})}{D_y^E\left(\boldsymbol{x},\boldsymbol{y}^P\right)}\left[\frac{D_y^E\left(\boldsymbol{x},\boldsymbol{y}^P\right)}{D_y(\boldsymbol{x},\boldsymbol{y})}\times\frac{D_y^E(\boldsymbol{x},\boldsymbol{y})}{D_y\left(\boldsymbol{x},\boldsymbol{y}^P\right)}\right]^{\frac{1}{2}}\\ &= \left(\frac{TE^E}{TE}\right)^{-1}\times FG\end{aligned}$$

where

$$\begin{aligned}D_y(\boldsymbol{x},\boldsymbol{y}) &= \inf\left\{\theta\middle|\,(\boldsymbol{x},\boldsymbol{y}/\theta)\in\tilde{T}\right\} = \overline{OY}/\overline{OY_F} = TE\\ D_y^E(\boldsymbol{x},\boldsymbol{y}) &= \inf\left\{\theta^E\middle|\left(\boldsymbol{x},\boldsymbol{y}/\theta^E\right)\in\tilde{T}^E\right\} = \overline{OY}/\overline{OY_T}\\ D_y\left(\boldsymbol{x},\boldsymbol{y}^P\right) &= \inf\left\{\theta\middle|\left(\boldsymbol{x},\boldsymbol{y}^P/\theta\right)\in\tilde{T}\right\} = \overline{OY^P}/\overline{OY_F^P}\\ D_y^E\left(\boldsymbol{x},\boldsymbol{y}^P\right) &= \inf\left\{\theta^E\middle|\left(\boldsymbol{x},\boldsymbol{y}^P/\theta^E\right)\in\tilde{T}^E\right\} = \overline{OY^P}/\overline{OY_T^P} = TE^E.\end{aligned}$$

Typically MPI is decomposed into the Change in Efficiency (CIE) and Change in (Production) Technology (CIT). CIE describes the change in technical efficiency while CIT characterizes the technical change, that is, the shift of the production frontier. The *MPI*, *CIE* and *CIT* are each interpreted as achieving progress, no change, and regress when the values for their estimates are greater than 1, equal to 1, and less than 1, respectively. Here a parallel structure for decomposition is used, but the interpretation is adjusted for the current setting. Sales effect is decomposed into the inverse of the $\frac{TE^E}{TE}$ and *FG*. The effectiveness-efficiency ratio $\frac{TE^E}{TE}$ illustrates the gap between effectiveness and efficiency. If $\frac{TE^E}{TE} < 1$, then the firm should strive to increase sales and focus on market development. If $\frac{TE^E}{TE} > 1$, then the firm should focus on productivity to catch up with the cutting-edge production technology. In addition, the frontier gap (*FG*) characterizes the sales change, that is, the shift between *STPF* and *PF*. *STPF* is always closer to the origin than *PF*, thus *FG* must be greater-than-or-equal-to 1.

Proposition 3 *Based on the decomposition of sales effect, FG is always greater-than-or-equal-to 1. Thus, if* $\left(\frac{TE^E}{TE}\right)^{-1} > 1$*, then sales effect must be greater than 1.*

Proof Based on footnote 3, output is high enough and $\boldsymbol{Y}^P$ should not be less than zero. The *FG* can be calculated as follows.

$$\begin{aligned}FG &= \left[\frac{D_y^E\left(\boldsymbol{x},\boldsymbol{y}^P\right)}{D_y(\boldsymbol{x},\boldsymbol{y})}\times\frac{D_y^E(\boldsymbol{x},\boldsymbol{y})}{D_y\left(\boldsymbol{x},\boldsymbol{y}^P\right)}\right]^{\frac{1}{2}} = \left[\frac{\overline{\boldsymbol{OY}^P}/\overline{\boldsymbol{OY}_T^P}}{\overline{\boldsymbol{OY}}/\overline{\boldsymbol{OY}_F}}\times\frac{\overline{\boldsymbol{OY}}/\overline{\boldsymbol{OY}_T}}{\overline{\boldsymbol{OY}^P}/\overline{\boldsymbol{OY}_F^P}}\right]^{\frac{1}{2}}\\ &= \left[\frac{\overline{\boldsymbol{OY}_F^P}}{\overline{\boldsymbol{OY}_T^P}}\times\frac{\overline{\boldsymbol{OY}_F}}{\overline{\boldsymbol{OY}_T}}\right]^{\frac{1}{2}} \geq 1\end{aligned}$$

In particular, *STPF* cannot move beyond the *PF*. Thus, sales effect $>$ 1 when $\left(\frac{TE^E}{TE}\right)^{-1}$ > 1.

Sales effect characterizes the frontier gap between *STPF* and *PF*. From an economic perspective, sales effect is a measure to account for sales on operational performance. While efficiency attributes the entire difference between the production frontier and the observation to operations, the sales effects identifies the part of inefficiency that is attributable to the lack of sales. In particular, given the output price, the revenue efficiency (Nerlove 1965) assumes that all the output generated from production system can be consumed and may overestimate the revenue; however, in fact, only sold products generate revenues. In such a case, given price information the revenue difference between efficiency and effectiveness results in the sales effect. That is, sales effect characterizes the gap between production revenue (without considering the sales level) and sales revenue (with considering the sales level) if output prices are given. We describe economic efficiency in Sect. 4.

4 Economic efficiency and economic effectiveness

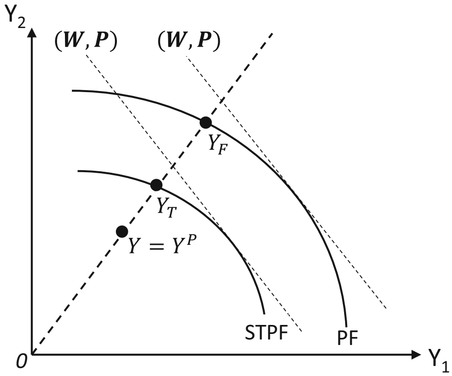
Economic efficiency is a measure characterizing the use of resources so as to maximize the value of production goods (Coelli et al. 2005). Here we discuss profit efficiency for economic efficiency. The profit maximization function $PF^*(\boldsymbol{W},\boldsymbol{P}) = \max\left\{\left\{\boldsymbol{Py} - \boldsymbol{Wx}\middle|\, (\boldsymbol{x},\boldsymbol{y}) \in \tilde{T}\right\}\right\}$ presents the maximal profit achievable with the given input and output price, where $\boldsymbol{W}$ is a price vector of inputs and $\boldsymbol{P}$ is a price vector of outputs. We define profit efficiency (*PE*) (Nerlove 1965) as the ratio of the profit of an observation r and the maximum profit given the specific input and output price $PE\left(\boldsymbol{W},\boldsymbol{P}; \boldsymbol{x}_r, \boldsymbol{y}_r\right) = \frac{\boldsymbol{Py_r} - \boldsymbol{Wx_r}}{PF^*(\boldsymbol{W},\boldsymbol{P})} = \frac{PF}{PF^*}$. Based on the traditional definition of economic efficiency (Farrell 1957), the profit efficiency can be decomposed into allocative efficiency (*AE*) and technical efficiency (*TE*). Specifically, $PE = AE \times TE$, where *TE* can be measured by general productivity technique.

As mentioned, only sold products generate revenues. Here a parallel structure similar to economic efficiency is used to define economic effectiveness. Economic effectiveness is a measure characterizing the use of resources so as to maximize the value of sold products generated from a production system. Thus, the profit-maximization function and profit effectiveness is firm-specific and defined as $PF_r^{E*}(\boldsymbol{W},\boldsymbol{P}) = \max\left\{\left\{\boldsymbol{Py}^P - \boldsymbol{Wx}\middle|\, \left(\boldsymbol{x},\boldsymbol{y}^P\right) \in \tilde{T}_r^E\right\}\right\}$ and $PE_r^E\left(\boldsymbol{W},\boldsymbol{P}; \boldsymbol{x}_r, \boldsymbol{y}_r^P\right) = \frac{\boldsymbol{Py}_r^P - \boldsymbol{Wx_r}}{PF_r^{E*}(\boldsymbol{W},\boldsymbol{P})} = \frac{PF_r^E}{PF_r^{E*}}$ of firm r, where $\boldsymbol{y}^P$ is penalized output related to *STPF* described in Sect. 2. Similarly, profit effectiveness can be decomposed into allocative effectiveness (AE^E) and technical effectiveness (TE^E). That is, $PE^E = AE^E \times TE^E$. Note that *PE* is calculated under the assumption all output can be consumed no matter the sales level; however, PE^E considers the effective product with respect to the sales level. Thus, when sales is limited, the traditional measure of *PE* is biased. The ratio $\frac{PE^E}{PE}$ measures the gap between economic efficiency and economic effectiveness, and $\frac{PE^E}{PE} = \frac{AE^E}{AE} \times \frac{TE^E}{TE}$.

In a special case in which all firms under produce, $Y_j \le S_j$ for all j, and the cost associated with missed sales are negligible, then $\frac{PE^E}{PE} = \frac{PF^E/PF^{E*}}{PF/PF^*} = \frac{PF^*}{PF^{E*}} \ge 1$ because $PF^E = PF$ and $T^E \subseteq T$. This result shows the traditional measure of *PE* is a lower bound for the true profit efficiency (i.e. profit effectiveness) when sales is sufficient.

To address this issue, profit effectiveness is proposed to capture the sales effect. $\frac{TE^E}{TE}$ directly measures the gap between *STPF* and *PF*, a measure of the sales effect on the shift

Fig. 5 Economic efficiency and effectiveness in output space while $Y_j \le S_j$



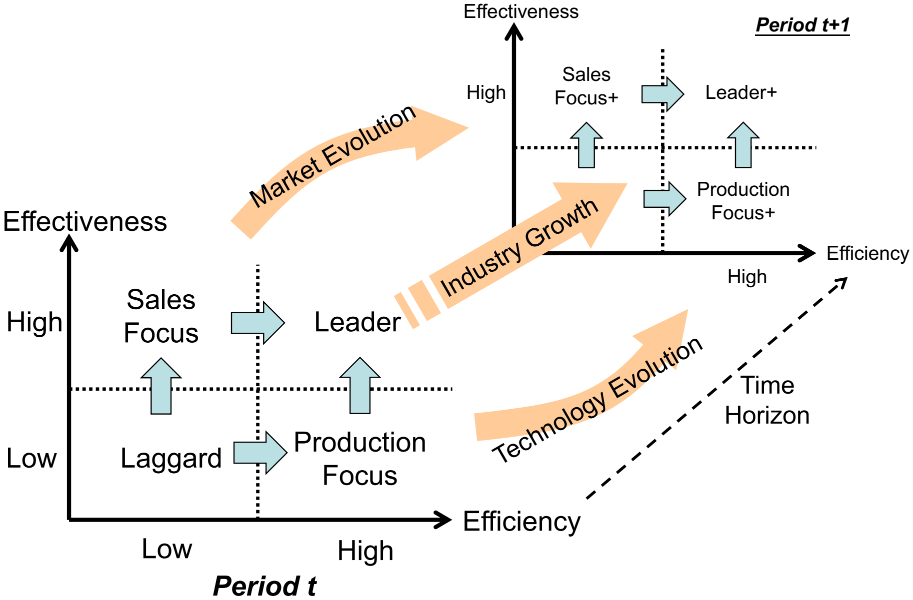


Fig. 6 Industry growth

of frontier $FG = \frac{TE^E}{TE}$. Figure 5 illustrates efficiency and effectiveness given price vector $(\boldsymbol{W}, \boldsymbol{P})$ when $Y_j \le S_j$.

5 Strategic evolution and industry growth

As technologies and markets evolve over time, new paradigms of competition can emerge. Product design, machinery development and sales diversity can shock an industry and push firms to enhance core competence. "Industry Growth" is a term to describe a firm that both leads in terms of implementing and maximizing the productivity of new technology and improves sales to match production as shown in Fig. 6. Here a Malmquist decomposition (Althin et al. 1996; Grifell-Tatjé and Lovell 1997; Ouellette and Vierstraete 2010) is used on both efficiency and the new effectiveness measure to measure market evolution, technology evolution, or identify industry growths using the measure of productivity change with respect to efficiency and effectiveness (all of which are defined rigorously below).

Färe et al. (1992, 1994) describes the output-oriented *MPI* at period $t+1$ relative to period t, quantifying productivity changes from period t to $t+1$, by defining the components CIE and *CIT*.

$$MPI_y^{t\to t+1}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1},\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)=\left[\frac{D_y^{t+1}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}\right)}{D_y^{t+1}\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)}\times\frac{D_y^{t}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}\right)}{D_y^{t}\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)}\right]^{\frac{1}{2}}$$
$$=\frac{D_y^{t+1}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}\right)}{D_y^{t}\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)}\left[\frac{D_y^{t}\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)}{D_y^{t+1}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}\right)}\times\frac{D_y^{t}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}\right)}{D_y^{t+1}\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)}\right]^{\frac{1}{2}}=CIE\times CIT$$

where

$$D_y^{t}\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)=\inf\left\{\theta\middle|\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}/\theta\right)\in\tilde{T}^{t}\right\}$$
$$D_y^{t+1}\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)=\inf\left\{\theta\middle|\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}/\theta\right)\in\tilde{T}^{t+1}\right\}$$
$$D_y^{t}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}\right)=\inf\left\{\theta\middle|\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}/\theta\right)\in\tilde{T}^{t}\right\}$$
$$D_y^{t+1}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}\right)=\inf\left\{\theta\middle|\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}/\theta\right)\in\tilde{T}^{t+1}\right\}$$

$D_y^{t}\left(\boldsymbol{x}^{t+1},\boldsymbol{y}^{t+1}\right)$ is the cross-period distance function of an observation in period $t+1$ relative to the reference technology in period t. Conversely $D_y^{t+1}\left(\boldsymbol{x}^{t},\boldsymbol{y}^{t}\right)$ is defined.

The *MPI* is used to measure the productivity change with respect to efficiency. Similarly, the definition of *MPI* can be used to measure the productivity change with respect to effectiveness. That is,

$$MPI^E=CIE^E\times CIT^E$$

where CIE^E is Change in Effectiveness and CIT^E is Change in sales truncated technology. In measuring productivity change, if $MPI>1$ this indicates productivity improvement; $MPI<1$ this indicates productivity reduction; and $MPI=1$ indicates no change in productivity. Similar to *CIE* and *CIT*.

Furthermore, the change in economic efficiency and effectiveness can be defined as follows. $CPE=\frac{PE^{t+1}}{PE^t}=\frac{AE^{t+1}}{AE^t}\times\frac{TE^{t+1}}{TE^t}=CAE\times CIE$, where *CPE* is the change in profit efficiency and *CAE* is the change in allocative efficiency. Similarly the change in effectiveness is defined as $CPE^E=CAE^E\times CIE^E$ where CPE^E is change in profit effectiveness and CAE^E is change in allocative effectiveness.

Based on these productivity-change measures, strategic evolution is defined. Let FP^t, SP^t, PP^t and LP^t denote the sets of firms classified as Laggards, Sales-focus Firms, Production-focus Firms and Leaders in period t. Then market evolution, technology evolution, and industry growth are defined.

Definition 3 (*Market Evolution*) For a firm k that satisfies both condition (1) and (2): (1) $k\in SP^t$ and $k\in SP^{t+1}\cup LP^{t+1}$, or if $k\in LP^t$ and $k\in SP^{t+1}$, and (2) productivity change $MPI^E>1$ increases from period t to $t+1$; then firm k is an example of Market Evolution.

Definition 4 (*Technology Evolution*) For a firm k that satisfies both condition (1) and (2): (1) $k \in PP^t$ and $k \in PP^{t+1} \cup LP^{t+1}$, or if $k \in LP^t$ and $k \in PP^{t+1}$, and (2) the productivity change $MPI > 1$ progresses from period t to $t+1$; then firm k is an example of Technology Evolution.

Definition 5 (*Industry Growth*) For a firm k that satisfies both condition (1) and (2): (1) $k \in LP^t$ and $k \in LP^{t+1}$, and (2) the productivity change $MPI > 1$ or $MPI^E > 1$ progresses from period t to $t+1$; then firm k is an example of Industry Growth.

We assume the production possibility set expands as improved methods for production become available, thus Diewert's sequential model (1980, 1992) is used. The reference set to evaluate a production process in a given period is constructed by including observations of the production processes from that same period and all previous periods. However, applying Diewert's sequential model to the estimation of the STPF does not necessarily result in the sales truncated production possibility set expanding because when sales levels fall the sales truncated production possibility set will contract.

6 US airline industry

6.1 Data description

A panel data set of 13 US civil airline firms observed between 2006 and 2010 is used to investigate the effects of sales fluctuations on airline performance (Barros and Peypoch 2009; Graf and Kimms 2013). The data was primarily gathered from Bureau of Transportation Statistics (2011) and a brief description is given below; see Lee and Johnson (2012) for a detailed description of the data construction and sources.

The dataset is described as follows. The two input variables are fuel and employees. Fuel (FU) is the number of gallons consumed annually, estimated by fuel expenses over the average jet fuel cost per gallon. Employee (EP) is defined as the number of employees during the year, which includes flight shipping staff, pilots, flight attendants, and managers but not ground shipping drivers or sales. Average prices are calculated by salaries and benefits expenses over number of employees. A single output, Available Passenger Output (APO), is the actual output of available seat-miles during the year. Available seat-miles is calculated as the number of seats including first class and economy on an airplane multiplied by the distance traveled measured in miles. Finally, Realized Passenger Sales (RPS) is the sum of scheduled and nonscheduled revenue passenger-miles during the year.

Because airline markets are imperfectly competitive (Lee and Johnson 2015), the marginal price and the average price for APO and RPS are likely to be different.[6] Using total cost equal to fuel expenses plus salaries and benefits expenses available from the Bureau of Transportation Statistics, we estimate a cost function using sign-constrained convex nonparametric least squares (CNLS) (Kuosmanen and Johnson 2010). In these estimates we impose the axioms of monotonicity and convexity on the cost function and then calculate marginal revenue by assuming a fixed percentage mark-up which is operating margin of the industry

[6] Farrell (1957) makes the perfect competition assumption. Under perfect competition or constant returns to scale the marginal cost is equal to the average cost, and thus the marginal price is equal to the average price under a fix markup. For an alternative analysis where average price is used see "Appendix 4".

average 0.0348, see “Appendix 1”.[7] Table 1 summarizes the dataset. A further description of the data is available in the “Appendix 2”.

In the panel data, mergers and acquisitions are observed in 2009 and 2010. As reported in the financial statements, Delta Airlines and Northwest Airlines merged in 2009. Similarly, Continental Airlines and United Airlines, and the ExpressJet Airlines and SkyWest Airlines merged in 2010. The effects of merges and acquisitions will be investigated in Sect. 6.3.

6.2 Productivity level analysis: strategic position

Efficiency, effectiveness, sales effect, and strategic position are estimated.[8] In this data set the actual output is greater than or equal to the sales, i.e., we discuss only the case of capacity surplus with the penalty parameter $\beta_{kj} = 0.5$ since we assume that the cost of two empty seats can be covered by the payment of one passenger. Table 2 and Fig. 7 show the performance of 13 US airline firms in 2008 and the industrial weighted[9] average performance. The strategic position of each airline is categorized as either laggard (Lag), sales focus (S), production focus (P), or leader in Fig. 7.

In general all airlines have similarly good levels of technical effectiveness. This indicates all airlines are effectively matching sales levels to output levels generated. Second, even good performance in technical effectiveness, this does not mean firms are generating large profits because most firms have poor profit effectiveness. Take for example Southwest Airlines, it has an excellent profit efficiency but poor profit effectiveness. In the airline industry, half of airlines perform poorly in terms of allocative effectiveness, thus given the current sales level the airline is not using the cost efficient mix of labor and capital (i.e., fuel in this case). Third, Southwest has a larger sales effect, that is the gap between *PF* and *STPF* is large. Generally, larger sales effects imply the lower sales levels, and thus indicate a lower technical effectiveness than industrial average. Southwest should focus on better matching their seats available to the seats customers are demanding. Fourth, at the industry level, the average profit efficiency is almost 2.06 times as large as the profit effectiveness, $PE = 0.73$ and $PE^E = 0.35$. This indicates the severity of the bias in estimating profit using the original production function. Finally, a high allocative efficiency does not guarantee a high allocative effectiveness, and vice versa. For instance, the American Airlines allocative efficiency is 0.80, higher than average, but its allocative effectiveness is 0.27. American Airlines should select their labor to capital ratio based on their actual sales levels rather than their available seat levels. Similar conclusions hold for profit efficiency and profit effectiveness. Note that lower AE^E measures the resources wasted due to differences between sales and production levels. In the case of airlines, sales is lower than production output in 2006–2010 because inventorying seats is not possible. Large fixed capital investments limit the airline’s flexibility to adjust to fluctuating sales, in particular, downturns.

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[7] Sign-constrained CNLS is a deterministic estimator that for a cost function gives the same estimated cost levels as DEA for observed output levels, but typically has different estimates of marginal cost. Under certain conditions the equivalence between the two estimators is shown in Kuosmanen and Johnson (2010). The specific estimator of the cost function used is shown in “Appendix 1”.

[8] Negative profits can occur. To maintain positive profits for the analysis, a constant dollar value is added to each airline’s profits. This transformation maintains an ordinal ranking in PE and PE^E, however the cardinal range is condensed. This issue may lead to AE and AE^E larger than 1, but does not affect our result and conclusion.

[9] Passenger-miles is used as weights.

Table 1 Descriptive statistics in the U.S. airlines

Year	Variable	Fuel		Employee		APO		RPS	
	Statistics	Gallons (10^6)	Price (US$)	Units	Price (US$)	Passenger-miles (10^6)	Price (US$)	Passenger-miles (10^6)	Price (US$)
2006	Mean	1157	2.00	27757	76511	66816	0.066	53319	0.066
	SD	918	0.00	21473	14141	55792	0.018	45174	0.018
	Max.	2892	2.00	72757	94880	173940	0.096	139451	0.096
	Min.	114	2.00	6800	52650	11298	0.048	8420	0.048
2007	Mean	1137	2.17	28282	76196	69292	0.065	55577	0.065
	SD	877	0.00	21228	12265	54993	0.017	45083	0.017
	Max.	2770	2.17	71818	95398	169856	0.096	138448	0.096
	Min.	149	2.17	7500	54408	11211	0.049	8340	0.049
2008	Mean	1163	3.05	27757	78753	69352	0.064	55684	0.064
	SD	902	0.00	20773	14123	53253	0.016	43307	0.016
	Max.	2673	3.05	70923	101265	163483	0.096	131755	0.096
	Min.	75	3.05	7115	55874	10370	0.049	7383	0.049
2009	Mean	1221	1.80	28773	80911	70637	0.065	57213	0.065
	SD	1212	0.00	24517	13907	62380	0.017	51491	0.017
	Max.	3969	1.80	76200	99444	196502	0.095	163688	0.095
	Min.	7	1.80	5600	58791	9810	0.034	7146	0.034
2010	Mean	1433	2.28	34892	82810	85010	0.079	70245	0.079
	SD	1440	0.00	29748	19006	78633	0.036	66092	0.036
	Max.	4192	2.28	84049	105560	216694	0.166	182261	0.166
	Min.	149	2.28	8229	41622	10803	0.056	7986	0.056

Table 2 Efficiency, effectiveness, and strategic position in 2008

Firm		Efficiency			Effectiveness			Sales effect			Strategic position
Name	No.	PE	AE	TE	PE^E	AE^E	TE^E	Sales effect	$\left(\frac{TE^E}{TE}\right)^{-1}$	FG	
AirTran	A	0.91	0.91	1.00	0.83	0.96	0.87	1.46	1.15	1.27	P
Alaska	B	0.89	1.07	0.83	0.80	0.94	0.85	1.38	0.97	1.42	Lag
American	C	0.79	0.80	0.99	0.24	0.27	0.88	1.40	1.12	1.25	Leader
Amer. Eagle	D	0.80	1.93	0.42	0.80	1.00	0.80	1.14	0.52	2.18	Lag
Continental	E	0.68	0.80	0.85	0.38	0.43	0.88	1.28	0.96	1.33	S
Delta	F	0.72	0.72	1.00	0.27	0.30	0.89	1.36	1.12	1.22	Leader
ExpressJet	G	1.00	1.00	1.00	0.99	1.17	0.85	1.55	1.18	1.31	P
JetBlue	H	0.92	0.95	0.97	0.85	0.97	0.88	1.40	1.11	1.26	Leader
Northwest	I	0.47	0.50	0.93	0.23	0.25	0.91	1.24	1.02	1.21	Leader
SkyWest	J	0.79	1.50	0.52	0.74	0.88	0.84	1.12	0.62	1.81	Lag
Southwest	K	0.95	0.97	0.98	0.40	0.49	0.81	1.68	1.20	1.39	P
United	L	0.61	0.61	0.99	0.16	0.18	0.88	1.39	1.12	1.23	Leader
US Airways	M	0.64	0.86	0.74	0.41	0.46	0.89	1.18	0.83	1.42	S
Industry		0.73	0.80	0.93	0.35	0.41	0.88	1.37	1.06	1.30	

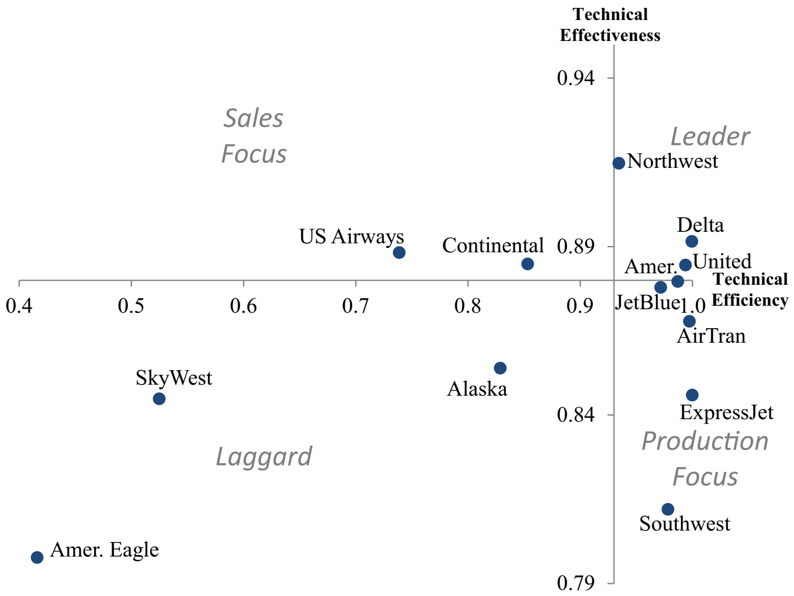

Fig. 7 Strategic position of airline firms in 2008

6.3 Productivity change analysis: strategic evolution

This section describes the use of panel data for a productivity change. Change in efficiency, change in effectiveness, change in sales effect, and strategic evolution are evaluated. Table 3 shows the productivity change of 13 US airlines between 2007 and 2008. The strategic evolution is categorized as either market evolution (M), technology evolution (T), or industry growth (I). A table describing the complete analysis of data from 2006 to 2010 appears in the "Appendix 3".

Table 3 illustrates the productivity change in efficiency and effectiveness. The performance of Delta Airlines, Jet Blue, and Northwest indicates an industry growth. Note that airlines with efficiency and effectiveness levels initial (i.e., leaders) tend to have small productivity changes in the future. In general, this phenomenon is the result of the public good nature of technology that leads to spillover effects from leaders to followers as the laggards learn from the innovators and catch-up (Semenick Alam and Sickles 2000). In addition, *CIT* is always greater-than-or-equal-to 1 because a sequential model is used. Thus, there is no productivity regress; however CIT^E may have regress due to the fluctuating sales levels.

Table 4 summarizes the productivity change in industry between 2006 and 2010. Airline's CPE^{E} is 0.59 between 2007 and 2008, indicating a regress in profits and a sales effect of 1.01 indicates the gap between *PF* and *DTPF* is increasing. These metrics are consistent with sales drop observed in 2008 due to the economic crisis (IATA 2010). However, the change in profit efficiency $CPE = 0.85$ is larger than the change in profit effectiveness $CPE^E = 0.59$, and the $MPI = 1.12$ representing significantly productivity progress is larger than $MPI^E = 1.02$. Thus we conclude that the effectiveness measure is capturing sales fluctuations that efficiency does not. Note that the change in profit effectiveness is 1.91 between 2008 and 2009 which is quite large. This is due to the decrease the number of flights between 2007–2008 in order to match a lower sales and avoid an excess output.

Table 3 Productivity change and strategic evolution from 2007 to 2008

Firm no.	Change in efficiency					Change in effectiveness					Change in sales effect			Strategic evolution
	CPE	CAE	CIE	MPI	CIT	CPE^E	CAE^E	CIE^E	MPI^E	CIT^E	Sales effect	$\left(\frac{TE^E}{TE}\right)^{-1}$	FG	
AirTran	1.03	0.98	1.05	1.18	1.12	0.95	0.92	1.03	1.12	1.09	0.96	1.02	0.94	T
Alaska	0.92	0.98	0.94	1.40	1.49	0.92	0.91	1.01	1.03	1.01	0.95	0.93	1.02	
American	0.80	0.81	0.99	0.99	1.00	0.47	0.48	0.99	0.94	0.95	1.01	0.99	1.02	
Amer. Eagle	0.95	1.00	0.95	1.00	1.06	0.94	0.98	0.96	0.85	0.89	1.06	0.98	1.07	
Continental	0.87	0.87	1.00	1.00	1.00	0.68	0.69	0.99	0.98	0.99	1.02	1.01	1.01	
Delta	0.84	0.84	1.01	1.01	1.00	0.57	0.57	1.01	1.03	1.02	0.99	1.00	0.98	I
ExpressJet	1.10	0.95	1.15	1.15	1.00	1.03	1.01	1.02	0.92	0.90	1.02	1.13	0.91	
JetBlue	1.11	1.14	0.97	1.55	1.59	0.95	0.94	1.00	1.02	1.02	0.98	0.97	1.01	I
Northwest	0.61	0.62	0.99	1.65	1.67	0.40	0.40	1.00	1.00	1.00	0.98	0.98	1.00	I
SkyWest	0.99	0.84	1.19	1.20	1.01	0.97	0.98	0.99	0.95	0.96	1.12	1.20	0.93	
Southwest	0.95	0.97	0.98	0.98	1.00	0.69	0.68	1.02	1.01	0.99	0.95	0.96	0.99	
United	0.67	0.67	1.00	1.00	1.00	0.29	0.29	0.99	0.93	0.94	1.03	1.01	1.02	
US Airways	1.11	0.87	1.28	1.28	1.00	0.85	0.84	1.01	1.41	1.39	1.09	1.26	0.86	M
Industry	0.85	0.83	1.02	1.12	1.10	0.59	0.59	1.00	1.02	1.01	1.01	1.02	0.99	

Table 4 Productivity change of US airline industry

Year	Change in efficiency					Change in effectiveness					Change in sales effect		
	CPE	CAE	CIE	MPI	CIT	CPE^E	CAE^E	CIE^E	MPI^E	CIT^E	Sales effect	$\left(\frac{TE^E}{TE}\right)^{-1}$	FG
06->07	1.00	0.99	1.00	1.03	1.02	0.98	0.97	1.00	1.05	1.05	0.99	1.00	0.99
07->08	0.85	0.83	1.02	1.12	1.10	0.59	0.59	1.00	1.02	1.01	1.01	1.02	0.99
08->09	1.23	1.25	0.99	1.15	1.16	1.91	1.89	1.01	0.96	0.96	0.98	0.98	1.00
09->10	1.05	1.01	1.04	1.08	1.03	1.07	1.06	1.01	1.04	1.03	0.98	1.02	0.96
Avg.	1.02	1.01	1.01	1.09	1.08	1.04	1.04	1.01	1.02	1.01	0.99	1.01	0.99

Table 5 Productivity change of the mergers from 2008 to 2010

Year	Firm no.	Change in efficiency					Change in effectiveness					Change in sales effect			Strategic evolution
		CPE	CAE	CIE	MPI	CIT	CPE^E	CAE^E	CIE^E	MPI^E	CIT^E	Sales effect	$\left(\frac{TE^E}{TE}\right)^{-1}$	FG	
08->09	F->N	1.38	1.38	1.00	1.55	1.55	1.90	1.89	1.01	0.94	0.93	0.98	0.99	0.99	I
	I->N	2.12	1.99	1.07	1.64	1.53	2.23	2.26	0.98	0.92	0.93	1.08	1.09	0.99	I
	Industry	1.23	1.25	0.99	1.15	1.16	1.91	1.89	1.01	0.96	0.96	0.98	0.98	1.00	
09->10	N	1.01	1.01	1.00	1.05	1.05	1.21	1.20	1.01	1.03	1.03	0.98	0.99	0.99	I
	E->O	1.27	1.05	1.21	1.27	1.05	1.14	1.12	1.01	1.04	1.02	1.06	1.19	0.89	M
	L->O	1.14	1.09	1.05	1.12	1.07	1.22	1.20	1.02	1.04	1.02	0.98	1.03	0.95	I
	G->P	0.73	0.93	0.79	0.79	1.00	0.85	0.84	1.01	0.68	0.67	0.86	0.78	1.11	
	J->P	0.91	0.75	1.22	1.22	1.00	0.97	0.96	1.01	0.68	0.67	1.08	1.20	0.89	
	Industry	1.05	1.01	1.04	1.08	1.03	1.07	1.06	1.01	1.04	1.03	0.98	1.02	0.96	

The notation F->N means the firm F is merged to the firm N

Table 5 illustrates changes in performance due to mergers.[10] Let "N" represent the merged airline consisting of Delta Airlines and Northwest Airlines, "O" represent the merged airline consisting of Continental Airlines and United Airlines, and "P" represent the merged airline consisting of ExpressJet and SkyWest Airlines. Mergers benefit the merging airlines by improving efficiency through increased economies of scale; whereas a merger may not improve effectiveness immediately (see all MPI^E are lower than the industry average). Even worse the merger may lead to trouble in maintaining customer relationships and lead to profit loses in the short-term. So while mergers allow a larger scale of operations leading to more output, sales may not be similarly affected, thus the profit effectiveness could drop as in the case of the Sky West/ExpressJet merger. In particular, the Delta merger significantly improved the change in profit effectiveness because of the economic downturn in 2008 and gradual recovery in 2010.[11]

7 Conclusion

This study uses an effectiveness measure to capture the sales effect in productivity analysis, in particular, a panel data analysis. It complements efficiency measures. The concepts of strategic position and strategic evolution are developed for identifying the competitive advantage using the metrics of efficiency and effectiveness. An empirical study of US airlines is conducted to demonstrate the proposed framework. The results show that effectiveness captures sales fluctuations, in particular, the economic crisis in 2008. Furthermore, mergers and acquisitions in the airline industry are evaluated; we conclude that mergers benefit efficiency by increasing the scale of operations but not necessarily improve effectiveness in the short run.

The effectiveness measure can be applied to the different domains, in particular, service industry whose non-storable commodities once generated need to be consumed immediately. Effectiveness also represents the "real" profit we earn from the consumption. In Sect. 4 we demonstrated the traditional measure of profit efficiency is a lower bound for the true profit efficiency when sales is sufficient. Thus, effectiveness can capture the sales effect and connect to profits. To extend the study, capacity planning based on an effectiveness measure is suggested rather than efficiency measure which captures only the production capability. The purpose of capacity planning is to adjust the input resource to control required output. Thus, an objective of maximizing effectiveness is more appropriate than maximizing efficiency in helping a firm reallocate resource to maximize profits. In addition, this study focuses on sales fluctuation and develops effectiveness measure. To develop a generalized model for effectiveness with respect to some variable fluctuation, e.g. interest rate fluctuation, may provide new insights to different applications.

[10] To assess the cross-period effectiveness of the merger in period $t+1$, for two firms in period t relative to the frontier in period $t+1$, the sales of merger in period $t+1$ is separated into two parts according to the sales proportions in period t. Vice versa, the sum of sales in period t is used for the merger in period $t+1$ relative to the frontier in period t.

[11] The progress indicated by $CPE^E > 1$ does not necessarily mean an increase in sales goes up rather this indicates the airlines is controlling the input resource to match sales levels. The MPI^E is mainly an index to show the sales growth or drop since it characterizes the STPF.

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Appendix 1: Cost function estimation

The sign-constrained convex nonparametric least squares (CNLS) technique is used to estimate the cost function and marginal cost. CNLS can be traced to the seminal work of Hildreth (1954) and was popularized by Kuosmanen (2008) as a powerful tool for describing the average behavior of observations. CNLS avoids strong prior assumptions regarding function form while maintaining the standard regularity conditions from microeconomic theory for production functions, namely continuity, monotonicity, and concavity. Kuosmanen and Johnson (2010) demonstrated that inefficiency estimated by the sign-constrained CNLS is equivalent to that estimated by DEA. This study imposes the axioms of monotonicity and convexity on cost function and estimates it by sing-constrained CNLS to obtain marginal cost estimates (Kuosmanen 2012).

Let C_k be the total cost equal to fuel expenses plus salaries and benefits expenses of firm k. ε_k be the inefficiency term of firm k. Let index h be an alias of index k, α_k be the intercept coefficient, and β_{kj} be the slope coefficient of the jth output of kth firm. In particular, β_{kj} is the coefficients of the tangent hyperplanes to the piece-wise linear cost frontier which can be interpreted as the marginal cost of outputs. We obtain the marginal cost estimate β_{kj} of firm k by solving the following sign-constrained CNLS.

$$\begin{aligned} &\min \textstyle\sum_k \varepsilon_k^2 \\ &\text{s.t. } \ln C_k = \ln\left(\alpha_k + \textstyle\sum_j \beta_{kj} Y_{kj}\right) + \varepsilon_k, \forall k \\ &\quad \alpha_k + \textstyle\sum_j \beta_{kj} Y_{kj} \geq \alpha_h + \textstyle\sum_j \beta_{hj} Y_{kj}, \forall k, \forall h \\ &\quad \beta_{kj} \geq 0, \forall j, k \\ &\quad \varepsilon_k \geq 0, \forall k \end{aligned} \tag{5}$$

Next, the marginal price for passenger-miles is a fixed mark-up of marginal cost by operating margin of all firms (i.e., the industry average). Operating margin data is available from Airlinefinancials.com (2014).

Appendix 2: Dataset

See Table 6.

Table 6 Dataset in the U.S. airlines

Company	No.	Year	Input				Available passenger output		Realized passenger sales	
			Fuel		Employee		Passenger		Passenger	
			Gallons (10^6)	Price (US$)	Units	Wages (US$)	Passenger-miles (10^6)	Price (US$)	Passenger-miles (10^6)	Price (US$)
AirTran Airways	A	2006	337.7	2	7415	52650.0	18984	0.04878	13814	0.04878
Alaska Airlines	B	2006	378.5	2	9307	82840.9	23263	0.04878	17826	0.04878
American Airlines	C	2006	2892.0	2	72757	85242.7	173940	0.09621	139451	0.09621
American Eagle Airlines	D	2006	309.0	2	9184	85242.7	11298	0.04878	8420	0.04878
Continental	E	2006	1517.0	2	39363	85242.7	93512	0.08050	76319	0.08050
Delta Air Lines	F	2006	2159.5	2	45562	90601.8	125100	0.08050	98909	0.08050
ExpressJet airlines	G	2006	113.6	2	6800	56864.4	13199	0.04812	10298	0.04812
JetBlue Airways	H	2006	393.0	2	9272	59641.9	28581	0.06219	23310	0.06219
Northwest Airlines	I	2006	1693.0	2	30729	86628.3	85582	0.06219	72690	0.06219
SkyWest Airlines	J	2006	505.4	2	8792	76656.2	11954	0.04878	9497	0.04878
Southwest Airline	K	2006	1069.0	2	32167	94879.8	92662	0.08050	67782	0.08050
United Airlines	L	2006	2412.0	2	55027	77507.4	142780	0.09621	117471	0.09621
US Airways	M	2006	1259.0	2	34462	60646.5	47754	0.06219	37366	0.06219
AirTran Airways	A	2007	370.3	2.17	8304	54407.5	22680	0.04878	17252	0.04878
Alaska Airlines	B	2007	339.9	2.17	9680	79276.9	24197	0.04878	18456	0.04878
American Airlines	C	2007	2770.0	2.17	71818	85382.5	169856	0.09621	138448	0.09621
American Eagle Airlines	D	2007	303.7	2.17	9453	85382.5	11211	0.04878	8340	0.04878
Continental	E	2007	1545.6	2.17	40948	75046.4	99061	0.06953	81428	0.06953
Delta Air Lines	F	2007	2158.5	2.17	47286	88588.6	127323	0.08345	103450	0.08345
ExpressJet airlines	G	2007	148.9	2.17	7500	58342.4	13729	0.04878	10206	0.04878
JetBlue Airways	H	2007	446.1	2.17	9713	66714.7	32148	0.06219	25722	0.06219
Northwest Airlines	I	2007	1556.7	2.17	29619	86701.1	86123	0.06219	73023	0.06219

Table 6 continued

Company	No.	Year	Input				Available passenger output		Realized passenger sales	
			Fuel		Employee		Passenger		Passenger	
			Gallons (10^6)	Price (US$)	Units	Wages (US$)	Passenger-miles (10^6)	Price (US$)	Passenger-miles (10^6)	Price (US$)
SkyWest Airlines	J	2007	489.4	2.17	10249	70928.6	14923	0.04878	11564	0.04878
Southwest Airline	K	2007	1239.6	2.17	33680	95397.9	103274	0.08345	73640	0.08345
United Airlines	L	2007	2305.5	2.17	55160	77175.5	141838	0.08345	117399	0.08345
US Airways	M	2007	1099.1	2.17	34256	67199.9	54427	0.06219	43567	0.06219
AirTran Airways	A	2008	391.8	3.05	8259	57500.9	23756	0.04878	18789	0.04878
Alaska Airlines	B	2008	381.1	3.05	9628	78780.6	24183	0.04878	18715	0.04878
American Airlines	C	2008	2673.4	3.05	70923	85219.2	163483	0.09621	131755	0.09621
American Eagle Airlines	D	2008	282.0	3.05	9683	85219.2	10370	0.04878	7383	0.04878
Continental	E	2008	1608.2	3.05	40630	70145.2	99047	0.06953	80495	0.06953
Delta Air Lines	F	2008	2074.4	3.05	47420	101265.3	128635	0.08345	105698	0.08345
ExpressJet airlines	G	2008	74.8	3.05	7115	55874.1	11962	0.04878	9144	0.04878
JetBlue Airways	H	2008	458.0	3.05	10177	68193.0	32436	0.06219	26069	0.06219
Northwest Airlines	I	2008	1721.6	3.05	29124	92775.7	83862	0.06219	71646	0.06219
SkyWest Airlines	J	2008	400.2	3.05	8987	80571.3	14618	0.04878	11156	0.04878
Southwest Airline	K	2008	1217.4	3.05	34680	96309.1	99636	0.06953	72410	0.06953
United Airlines	L	2008	2531.8	3.05	51536	83669.7	135480	0.08345	110062	0.08345
US Airways	M	2008	1303.0	3.05	32683	68261.8	74106	0.06219	60567	0.06219
AirTran Airways	A	2009	377.1	1.8	8220	59416.1	23258	0.05640	18512	0.05640
Alaska Airlines	B	2009	305.0	1.8	8912	95848.3	23075	0.05640	18366	0.05640
American Airlines	C	2009	2786.1	1.8	66519	93477.1	151708	0.09515	122418	0.09515
American Eagle Airlines	D	2009	298.9	1.8	9070	93477.1	9810	0.05640	7146	0.05640

Table 6 continued

Company	No.	Year	Input				Available passenger output		Realized passenger sales	
			Fuel		Employee		Passenger		Passenger	
			Gallons (10^6)	Price (US$)	Units	Wages (US$)	Passenger-miles (10^6)	Price (US$)	Passenger-miles (10^6)	Price (US$)
Continental	E	2009	1530.6	1.8	38720	76652.9	94255	0.06896	77785	0.06896
ExpressJet airlines	G	2009	7.4	1.8	5600	58790.5	10299	0.03442	8029	0.03442
JetBlue Airways	H	2009	525.0	1.8	10583	73325.1	32551	0.06219	25959	0.06219
SkyWest Airlines	J	2009	230.0	1.8	8654	80694.0	15002	0.05640	11720	0.05640
Southwest Airline	K	2009	1691.1	1.8	34874	99443.7	98004	0.06896	74572	0.06896
United Airlines	L	2009	1891.7	1.8	46587	80988.3	122493	0.06896	100476	0.06896
US Airways	M	2009	1038.9	1.8	31340	69081.0	70683	0.06219	57885	0.06219
Delta and Northwest	N	2009	3969.4	1.8	76200	89737.5	196502	0.09515	163688	0.09515
AirTran Airways	A	2010	380.7	2.28	8229	64224.1	23775	0.05640	19564	0.05640
Alaska Airlines	B	2010	346.9	2.28	8649	97352.3	24370	0.05640	20354	0.05640
American Airlines	C	2010	2513.6	2.28	65506	95060.0	153178	0.09515	125485	0.09515
American Eagle Airlines	D	2010	293.4	2.28	10195	95060.0	10803	0.05640	7986	0.05640
JetBlue Airways	H	2010	489.0	2.28	11211	79475.5	34739	0.06219	28290	0.06219
Southwest Airline	K	2010	1587.7	2.28	35089	105560.1	98440	0.06896	78135	0.06896
US Airways	M	2010	1053.9	2.28	30876	72677.8	71551	0.06219	58972	0.06219
Delta and Northwest	N	2010	3325.9	2.28	76742	87970.1	199805	0.10997	168139	0.10997
Continental and United Airlines	O	2010	4192.1	2.28	84049	89102.8	216694	0.16622	182261	0.16622
SkyWest and ExpressJet	P	2010	149.2	2.28	18378	41622.2	16741	0.05640	13260	0.05640

Appendix 3: Productivity analysis with marginal price

See Tables 7 and 8.

Table 7 Productivity-level analysis of US airlines firms

Year	Firm no.	Efficiency			Effectiveness			Sales effect			Strategic position
		PE	AE	TE	PE^E	AE^E	TE^E	Sales	$\left(TE^E/TE\right)^{-1}$	FS	
2006	A	0.85	0.85	1.00	0.89	1.09	0.81	1.69	1.23	1.37	P
	B	0.95	1.14	0.83	0.87	1.02	0.85	1.40	0.98	1.43	Lag
	C	1.00	1.00	1.00	0.51	0.58	0.88	1.42	1.14	1.25	Leader
	D	0.86	1.90	0.45	0.86	1.03	0.83	1.09	0.55	2.00	Lag
	E	0.81	0.94	0.86	0.57	0.64	0.89	1.28	0.97	1.32	S
	F	0.89	0.89	1.00	0.47	0.54	0.87	1.46	1.15	1.26	P
	G	0.91	0.91	1.00	0.99	1.15	0.86	1.49	1.16	1.28	P
	H	0.81	0.81	1.00	0.92	1.04	0.89	1.38	1.13	1.23	Leader
	I	0.73	0.76	0.97	0.55	0.60	0.91	1.27	1.06	1.20	Leader
	J	0.79	1.73	0.46	0.79	0.91	0.87	0.98	0.53	1.86	Lag
	K	1.00	1.00	1.00	0.64	0.79	0.82	1.67	1.22	1.37	P
	L	0.94	0.94	1.00	0.62	0.70	0.89	1.36	1.12	1.22	Leader
	M	0.50	1.04	0.49	0.42	0.49	0.86	1.03	0.56	1.83	Lag
	Indu.	0.88	0.96	0.93	0.59	0.68	0.87	1.39	1.07	1.32	
2007	A	0.88	0.93	0.95	0.88	1.05	0.84	1.52	1.12	1.35	P
	B	0.96	1.09	0.88	0.88	1.04	0.84	1.46	1.04	1.40	Lag
	C	0.98	0.98	1.00	0.50	0.56	0.89	1.38	1.13	1.23	Leader
	D	0.85	1.93	0.44	0.85	1.02	0.83	1.08	0.53	2.03	Lag
	E	0.78	0.92	0.85	0.55	0.62	0.89	1.26	0.95	1.32	S
	F	0.85	0.86	0.99	0.47	0.54	0.88	1.39	1.12	1.24	Leader
	G	0.91	1.05	0.87	0.96	1.16	0.83	1.52	1.05	1.44	Lag
	H	0.83	0.83	1.00	0.90	1.03	0.88	1.43	1.14	1.25	Leader
	I	0.76	0.80	0.94	0.57	0.63	0.91	1.26	1.04	1.21	Leader
	J	0.79	1.80	0.44	0.76	0.89	0.85	1.00	0.52	1.94	Lag
	K	1.00	1.00	1.00	0.58	0.73	0.80	1.76	1.25	1.40	P
	L	0.91	0.91	0.99	0.54	0.61	0.90	1.34	1.11	1.21	Leader
	M	0.57	0.99	0.58	0.48	0.55	0.88	1.08	0.66	1.65	S
	Indu.	0.87	0.96	0.93	0.57	0.66	0.88	1.38	1.06	1.31	
2008	A	0.91	0.91	1.00	0.83	0.96	0.87	1.46	1.15	1.27	P
	B	0.89	1.07	0.83	0.80	0.94	0.85	1.38	0.97	1.42	Lag
	C	0.79	0.80	0.99	0.24	0.27	0.88	1.40	1.12	1.25	Leader
	D	0.80	1.93	0.42	0.80	1.00	0.80	1.14	0.52	2.18	Lag
	E	0.68	0.80	0.85	0.38	0.43	0.88	1.28	0.96	1.33	S
	F	0.72	0.72	1.00	0.27	0.30	0.89	1.36	1.12	1.22	Leader
	G	1.00	1.00	1.00	0.99	1.17	0.85	1.55	1.18	1.31	P

Table 7 continued

Year	Firm no.	Efficiency			Effectiveness			Sales effect			Strategic position
		PE	AE	TE	PE^E	AE^E	TE^E	Sales	$\left(TE^E/TE\right)^{-1}$	FS	
	H	0.92	0.95	0.97	0.85	0.97	0.88	1.40	1.11	1.26	Leader
	I	0.47	0.50	0.93	0.23	0.25	0.91	1.24	1.02	1.21	Leader
	J	0.79	1.50	0.52	0.74	0.88	0.84	1.12	0.62	1.81	Lag
	K	0.95	0.97	0.98	0.40	0.49	0.81	1.68	1.20	1.39	P
	L	0.61	0.61	0.99	0.16	0.18	0.88	1.39	1.12	1.23	Leader
	M	0.64	0.86	0.74	0.41	0.46	0.89	1.18	0.83	1.42	S
	Indu.	0.73	0.80	0.93	0.35	0.41	0.88	1.37	1.06	1.30	
2009	A	0.78	0.81	0.96	0.89	1.02	0.87	1.41	1.10	1.28	P
	B	0.91	1.03	0.88	0.89	1.02	0.87	1.35	1.01	1.34	Lag
	C	0.86	0.94	0.92	0.42	0.48	0.88	1.35	1.04	1.29	P
	D	0.77	2.05	0.37	0.81	1.00	0.81	1.03	0.46	2.24	Lag
	E	0.79	0.95	0.83	0.60	0.67	0.89	1.23	0.93	1.33	S
	G	1.00	1.00	1.00	0.99	1.16	0.86	1.49	1.16	1.28	P
	H	0.79	0.84	0.94	0.86	0.98	0.87	1.39	1.07	1.30	P
	J	0.81	1.25	0.65	0.87	1.01	0.86	1.20	0.75	1.59	Lag
	K	0.80	0.87	0.93	0.46	0.55	0.84	1.50	1.10	1.37	P
	L	0.88	0.92	0.95	0.56	0.63	0.89	1.34	1.07	1.25	Leader
	M	0.78	1.00	0.78	0.69	0.77	0.89	1.21	0.88	1.38	S
	N	0.99	0.99	1.00	0.51	0.57	0.90	1.33	1.11	1.20	Leader
	Indu.	0.87	0.96	0.91	0.57	0.65	0.88	1.34	1.03	1.30	
2010	A	0.85	0.86	0.98	0.87	0.98	0.89	1.35	1.10	1.23	P
	B	0.94	1.03	0.92	0.88	0.97	0.90	1.27	1.02	1.25	S
	C	0.83	0.88	0.94	0.41	0.46	0.89	1.33	1.06	1.26	Lag
	D	0.79	2.06	0.38	0.76	0.92	0.82	1.02	0.47	2.19	Lag
	H	0.87	0.91	0.95	0.86	0.97	0.89	1.35	1.08	1.26	P
	L	0.78	0.84	0.92	0.42	0.49	0.87	1.39	1.06	1.31	Lag
	M	0.78	0.99	0.79	0.64	0.71	0.89	1.21	0.88	1.37	Lag
	N	1.00	1.00	1.00	0.62	0.68	0.91	1.31	1.10	1.19	Leader
	O	1.00	1.00	1.00	0.69	0.76	0.91	1.31	1.10	1.19	Leader
	P	0.73	0.93	0.79	0.85	0.97	0.87	1.29	0.90	1.42	Lag
	Indu.	0.91	0.97	0.95	0.61	0.68	0.89	1.31	1.06	1.25	

Table 8 Productivity-change analysis of US airlines firms

Year	Firm no.	Change in efficiency					Change in effectiveness					Change in sales effect			Strategic evolution
		CPE	CAE	CIE	MPI	CIT	CPE^E	CAE^E	CIE^E	MPI^E	CIT^E	Sales effect	$\left(\frac{TE^E}{TE}\right)^{-1}$	FS	
06->07	A	1.03	1.09	0.95	0.95	1.01	1.00	0.96	1.04	1.29	1.25	0.90	0.91	0.98	
	B	1.01	0.95	1.06	1.08	1.02	1.01	1.01	1.00	1.03	1.04	1.04	1.07	0.97	
	C	0.98	0.98	1.00	1.00	1.00	0.99	0.97	1.01	1.00	0.99	0.97	0.99	0.98	I
	D	0.99	1.02	0.97	0.98	1.01	0.99	0.99	1.00	0.99	0.99	0.99	0.97	1.02	
	E	0.97	0.98	0.99	1.03	1.05	0.97	0.97	1.00	1.07	1.07	0.98	0.98	1.00	M
	F	0.95	0.96	0.99	0.99	1.00	1.01	0.99	1.02	1.07	1.05	0.95	0.97	0.98	
	G	1.00	1.15	0.87	0.87	1.00	0.97	1.01	0.96	0.95	0.99	1.02	0.90	1.13	
	H	1.02	1.02	1.00	1.05	1.05	0.98	0.99	0.99	1.09	1.10	1.03	1.01	1.02	I
	I	1.04	1.06	0.98	1.04	1.07	1.05	1.06	1.00	1.00	1.00	0.99	0.98	1.01	I
	J	1.00	1.04	0.97	1.02	1.05	0.97	0.99	0.98	1.20	1.22	1.03	0.98	1.04	
	K	1.00	1.00	1.00	1.04	1.04	0.90	0.92	0.98	1.06	1.09	1.05	1.02	1.03	T
	L	0.97	0.98	0.99	1.00	1.00	0.87	0.86	1.00	1.00	1.00	0.99	0.99	1.00	I
	M	1.14	0.96	1.18	1.22	1.03	1.13	1.12	1.02	1.19	1.17	1.05	1.16	0.90	
	Indu.	1.00	0.99	1.00	1.03	1.02	0.98	0.97	1.00	1.05	1.05	0.99	1.00	0.99	
07->08	A	1.03	0.98	1.05	1.18	1.12	0.95	0.92	1.03	1.12	1.09	0.96	1.02	0.94	T
	B	0.92	0.98	0.94	1.40	1.49	0.92	0.91	1.01	1.03	1.01	0.95	0.93	1.02	
	C	0.80	0.81	0.99	0.99	1.00	0.47	0.48	0.99	0.94	0.95	1.01	0.99	1.02	
	D	0.95	1.00	0.95	1.00	1.06	0.94	0.98	0.96	0.85	0.89	1.06	0.98	1.07	
	E	0.87	0.87	1.00	1.00	1.00	0.68	0.69	0.99	0.98	0.99	1.02	1.01	1.01	
	F	0.84	0.84	1.01	1.01	1.00	0.57	0.57	1.01	1.03	1.02	0.99	1.00	0.98	I
	G	1.10	0.95	1.15	1.15	1.00	1.03	1.01	1.02	0.92	0.90	1.02	1.13	0.91	

Table 8 continued

Year	Firm no.	Change in efficiency					Change in effectiveness					Change in sales effect			Strategic evolution
		CPE	CAE	CIE	MPI	CIT	CPE^E	CAE^E	CIE^E	MPI^E	CIT^E	Sales effect	$\left(\frac{TE^E}{TE}\right)^{-1}$	FS	
	H	1.11	1.14	0.97	1.55	1.59	0.95	0.94	1.00	1.02	1.02	0.98	0.97	1.01	I
	I	0.61	0.62	0.99	1.65	1.67	0.40	0.40	1.00	1.00	1.00	0.98	0.98	1.00	I
	J	0.99	0.84	1.19	1.20	1.01	0.97	0.98	0.99	0.95	0.96	1.12	1.20	0.93	
	K	0.95	0.97	0.98	0.98	1.00	0.69	0.68	1.02	1.01	0.99	0.95	0.96	0.99	
	L	0.67	0.67	1.00	1.00	1.00	0.29	0.29	0.99	0.93	0.94	1.03	1.01	1.02	
	M	1.11	0.87	1.28	1.28	1.00	0.85	0.84	1.01	1.41	1.39	1.09	1.26	0.86	M
	Indu.	0.85	0.83	1.02	1.12	1.10	0.59	0.59	1.00	1.02	1.01	1.01	1.02	0.99	
08->09	A	0.86	0.89	0.96	1.01	1.05	1.06	1.06	1.00	0.99	0.99	0.97	0.96	1.01	T
	B	1.03	0.96	1.07	1.27	1.19	1.10	1.08	1.02	1.02	1.00	0.98	1.04	0.94	
	C	1.09	1.17	0.93	0.94	1.01	1.80	1.80	1.00	0.93	0.93	0.96	0.93	1.04	
	D	0.95	1.06	0.90	1.32	1.46	1.02	1.00	1.02	0.99	0.97	0.91	0.88	1.03	
	E	1.15	1.19	0.97	0.98	1.01	1.59	1.58	1.01	0.98	0.97	0.96	0.96	1.00	
	G	1.00	1.00	1.00	1.05	1.05	1.01	0.99	1.02	0.89	0.88	0.97	0.99	0.98	T
	H	0.86	0.89	0.96	1.16	1.20	1.00	1.01	0.99	1.03	1.04	1.00	0.97	1.03	T
	J	1.02	0.83	1.23	1.45	1.18	1.17	1.15	1.02	1.07	1.05	1.06	1.21	0.88	
	K	0.85	0.90	0.95	0.95	1.00	1.15	1.11	1.04	1.07	1.03	0.89	0.91	0.98	
	L	1.44	1.50	0.96	0.99	1.04	3.62	3.60	1.01	0.92	0.91	0.96	0.95	1.01	
	M	1.23	1.16	1.06	1.06	1.00	1.67	1.66	1.00	0.96	0.96	1.03	1.06	0.97	
	F->N	1.38	1.38	1.00	1.55	1.55	1.90	1.89	1.01	0.94	0.93	0.98	0.99	0.99	I
	I->N	2.12	1.99	1.07	1.64	1.53	2.23	2.26	0.98	0.92	0.93	1.08	1.09	0.99	I
	Indu.	1.23	1.25	0.99	1.15	1.16	1.91	1.89	1.01	0.96	0.96	0.98	0.98	1.00	

Table 8 continued

Year	Firm no.	Change in efficiency					Change in effectiveness					Change in sales effect			Strategic evolution
		CPE	CAE	CIE	MPI	CIT	CPE^E	CAE^E	CIE^E	MPI^E	CIT^E	Sales effect	$\left(\frac{TE^E}{TE}\right)^{-1}$	FS	
09->10	A	1.09	1.06	1.02	1.02	1.00	0.98	0.96	1.02	1.08	1.06	0.95	1.00	0.96	T
	B	1.03	0.99	1.04	1.04	1.00	0.99	0.95	1.03	1.15	1.11	0.94	1.01	0.93	
	C	0.97	0.94	1.03	1.07	1.04	0.97	0.96	1.01	1.04	1.02	0.99	1.02	0.97	
	D	1.03	1.01	1.02	1.02	1.00	0.94	0.93	1.01	1.13	1.12	0.99	1.01	0.97	
	H	1.10	1.08	1.02	1.02	1.00	1.00	0.98	1.01	1.11	1.09	0.97	1.00	0.97	T
	K	0.97	0.97	1.00	1.00	1.00	0.92	0.89	1.03	1.08	1.05	0.93	0.97	0.96	
	M	1.00	0.99	1.01	1.01	1.00	0.93	0.92	1.00	1.02	1.02	0.99	1.00	0.99	
	N	1.01	1.01	1.00	1.05	1.05	1.21	1.20	1.01	1.03	1.03	0.98	0.99	0.99	I
	E->O	1.27	1.05	1.21	1.27	1.05	1.14	1.12	1.01	1.04	1.02	1.06	1.19	0.89	M
	L->O	1.14	1.09	1.05	1.12	1.07	1.22	1.20	1.02	1.04	1.02	0.98	1.03	0.95	I
	G->P	0.73	0.93	0.79	0.79	1.00	0.85	0.84	1.01	0.68	0.67	0.86	0.78	1.11	
	J->P	0.91	0.75	1.22	1.22	1.00	0.97	0.96	1.01	0.68	0.67	1.08	1.20	0.89	
	Indu.	1.05	1.01	1.04	1.08	1.03	1.07	1.06	1.01	1.04	1.03	0.98	1.02	0.96	

Appendix 4: Productivity analysis with average price/perfect competition assumption

The average price for APO and RPS is calculated by total passenger revenue over scheduled and nonscheduled passenger-miles. Note that, under the perfection competition assumption, RPS is exogenous and no airlines have market power to change the price since a significant time delay by passing information between marketing department and operations department.

The results are shown in Tables 9 and 10. The price change only affects the profit efficiency/effectiveness and allocative efficiency/effectiveness. In general, the result is consistent with the one shown in Sect. 6 under imperfect competition; however, the difference between efficiency and effectiveness is diminished. For example, in productivity level analysis, we claim that the profit efficiency is larger than the profit effectiveness in industry level in 2008: $PE = 0.73$ and $PE^E = 0.35$ in Sect. 6.2; however, $PE = 0.77$ and $PE^E = 0.60$ in this "Appendix". Similar conclusions hold for change in profit efficiency and change in profit effectiveness. Take the economic crisis between 2007 and 2008 as an example, Sect. 6.3 showed $CPE = 0.85$ and $CPE^E = 0.59$; however, $CPE = 1.03$ and $CPE^E = 0.87$ in this "Appendix". The perfection competition case here also validated the effectiveness which complements the efficiency since $CPE^E = 0.87$ justified the 2008 economic crisis rather than the progress by $CPE = 1.03$.

Table 9 Productivity-level analysis of US airlines firms

Year	Firm no.	Efficiency			Effectiveness		
		PE	AE	TE	PE^E	AE^E	TE^E
2006	A	0.35	0.35	1.00	0.87	1.07	0.81
	B	0.40	0.48	0.83	0.86	1.02	0.85
	C	1.00	1.00	1.00	0.62	0.71	0.88
	D	0.19	0.42	0.45	0.85	1.02	0.83
	E	0.70	0.82	0.86	0.67	0.75	0.89
	F	0.86	0.86	1.00	0.60	0.70	0.87
	G	0.28	0.28	1.00	0.96	1.12	0.86
	H	0.56	0.56	1.00	0.92	1.03	0.89
	I	0.66	0.68	0.97	0.71	0.78	0.91
	J	0.21	0.45	0.46	0.81	0.93	0.87
	K	0.81	0.81	1.00	0.70	0.85	0.82
	L	0.90	0.90	1.00	0.68	0.76	0.89
	M	0.37	0.77	0.49	0.57	0.66	0.86
	Indu.	0.77	0.81	0.93	0.68	0.78	0.87
2007	A	0.39	0.41	0.95	0.87	1.04	0.84
	B	0.41	0.47	0.88	0.87	1.03	0.84
	C	0.99	0.99	1.00	0.63	0.71	0.89
	D	0.18	0.41	0.44	0.84	1.02	0.83
	E	0.73	0.85	0.85	0.70	0.78	0.89
	F	0.86	0.87	0.99	0.62	0.70	0.88
	G	0.29	0.33	0.87	0.93	1.13	0.83
	H	0.57	0.57	1.00	0.90	1.02	0.88

Table 9 continued

Year	Firm no.	Efficiency			Effectiveness		
		PE	AE	TE	PE^E	AE^E	TE^E
	I	0.69	0.73	0.94	0.73	0.80	0.91
	J	0.24	0.55	0.44	0.79	0.92	0.85
	K	0.89	0.89	1.00	0.65	0.81	0.80
	L	0.91	0.91	0.99	0.68	0.76	0.90
	M	0.44	0.76	0.58	0.63	0.72	0.88
	Indu.	0.78	0.83	0.93	0.69	0.79	0.88
2008	A	0.45	0.45	1.00	0.85	0.98	0.87
	B	0.45	0.54	0.83	0.83	0.97	0.85
	C	0.96	0.97	0.99	0.52	0.59	0.88
	D	0.15	0.37	0.42	0.80	1.00	0.80
	E	0.73	0.85	0.85	0.62	0.70	0.88
	F	0.93	0.93	1.00	0.55	0.61	0.89
	G	0.38	0.38	1.00	0.97	1.14	0.85
	H	0.58	0.60	0.97	0.86	0.98	0.88
	I	0.66	0.70	0.93	0.59	0.65	0.91
	J	0.26	0.49	0.52	0.77	0.91	0.84
	K	0.87	0.89	0.98	0.61	0.75	0.81
	L	0.83	0.83	0.99	0.49	0.55	0.88
	M	0.61	0.82	0.74	0.63	0.70	0.89
	Indu.	0.77	0.82	0.93	0.60	0.68	0.88
2009	A	0.42	0.43	0.96	0.88	1.01	0.87
	B	0.42	0.48	0.88	0.89	1.02	0.87
	C	0.83	0.91	0.92	0.54	0.62	0.88
	D	0.15	0.40	0.37	0.81	1.00	0.81
	E	0.69	0.84	0.83	0.70	0.79	0.89
	G	0.57	0.57	1.00	0.98	1.14	0.86
	H	0.48	0.51	0.94	0.86	0.99	0.87
	J	0.30	0.46	0.65	0.87	1.01	0.86
	K	0.71	0.77	0.93	0.62	0.74	0.84
	L	0.84	0.88	0.95	0.69	0.77	0.89
	M	0.60	0.77	0.78	0.75	0.85	0.89
	N	1.00	1.00	1.00	0.60	0.67	0.90
	Indu.	0.77	0.83	0.91	0.67	0.76	0.88
2010	A	0.39	0.40	0.98	0.88	0.98	0.89
	B	0.42	0.45	0.92	0.89	0.98	0.90
	C	0.80	0.85	0.94	0.58	0.65	0.89
	D	0.15	0.39	0.38	0.78	0.94	0.82
	H	0.47	0.49	0.95	0.86	0.97	0.89
	L	0.66	0.71	0.92	0.65	0.75	0.87

Table 9 continued

Year	Firm no.	Efficiency			Effectiveness		
		PE	AE	TE	PE^E	AE^E	TE^E
	M	0.55	0.69	0.79	0.74	0.83	0.89
	N	1.00	1.00	1.00	0.68	0.75	0.91
	O	0.97	0.97	1.00	0.59	0.65	0.91
	P	0.28	0.35	0.79	0.85	0.98	0.87
	Indu.	0.80	0.83	0.95	0.66	0.74	0.89

Table 10 Productivity-change analysis of US airlines firms

Year	Firm no.	Change in efficiency					Change in effectiveness				
		CPE	CAE	CIE	MPI	CIT	CPE^E	CAE^E	CIE^E	MPI^E	CIT^E
06->07	A	1.11	1.17	0.95	0.95	1.01	1.00	0.97	1.04	1.29	1.25
	B	1.03	0.97	1.06	1.08	1.02	1.01	1.01	1.00	1.03	1.04
	C	0.99	0.99	1.00	1.00	1.00	1.01	1.00	1.01	1.00	0.99
	D	0.95	0.98	0.97	0.98	1.01	0.99	0.99	1.00	0.99	0.99
	E	1.03	1.04	0.99	1.03	1.05	1.04	1.04	1.00	1.07	1.07
	F	1.00	1.01	0.99	0.99	1.00	1.02	1.00	1.02	1.07	1.05
	G	1.03	1.18	0.87	0.87	1.00	0.97	1.01	0.96	0.95	0.99
	H	1.03	1.03	1.00	1.05	1.05	0.98	0.99	0.99	1.09	1.10
	I	1.04	1.07	0.98	1.04	1.07	1.03	1.03	1.00	1.00	1.00
	J	1.17	1.21	0.97	1.02	1.05	0.97	0.99	0.98	1.20	1.22
	K	1.10	1.10	1.00	1.04	1.04	0.93	0.95	0.98	1.06	1.09
	L	1.00	1.01	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	M	1.18	0.99	1.18	1.22	1.03	1.10	1.09	1.02	1.19	1.17
	Indu.	1.04	1.03	1.00	1.03	1.02	1.01	1.00	1.00	1.05	1.05
07->08	A	1.14	1.08	1.05	1.18	1.12	0.97	0.94	1.03	1.12	1.09
	B	1.09	1.16	0.94	1.40	1.49	0.95	0.94	1.01	1.03	1.01
	C	0.97	0.98	0.99	0.99	1.00	0.82	0.83	0.99	0.94	0.95
	D	0.84	0.89	0.95	1.00	1.06	0.95	0.98	0.96	0.85	0.89
	E	1.00	1.00	1.00	1.00	1.00	0.89	0.90	0.99	0.98	0.99
	F	1.08	1.07	1.01	1.01	1.00	0.89	0.88	1.01	1.03	1.02
	G	1.32	1.15	1.15	1.15	1.00	1.03	1.01	1.02	0.92	0.90
	H	1.01	1.04	0.97	1.55	1.59	0.96	0.95	1.00	1.02	1.02
	I	0.95	0.96	0.99	1.65	1.67	0.81	0.81	1.00	1.00	1.00
	J	1.07	0.90	1.19	1.20	1.01	0.98	0.99	0.99	0.95	0.96
	K	0.98	1.01	0.98	0.98	1.00	0.94	0.93	1.02	1.01	0.99
	L	0.92	0.92	1.00	1.00	1.00	0.71	0.72	0.99	0.93	0.94
	M	1.38	1.07	1.28	1.28	1.00	1.00	0.98	1.01	1.41	1.39
	Indu.	1.03	1.00	1.02	1.12	1.10	0.87	0.87	1.00	1.02	1.01

Table 10 continued

Year	Firm no.	Change in efficiency					Change in effectiveness				
		CPE	CAE	CIE	MPI	CIT	CPE^E	CAE^E	CIE^E	MPI^E	CIT^E
08->09	A	0.93	0.97	0.96	1.01	1.05	1.04	1.04	1.00	0.99	0.99
	B	0.94	0.88	1.07	1.27	1.19	1.07	1.05	1.02	1.02	1.00
	C	0.87	0.94	0.93	0.94	1.01	1.05	1.05	1.00	0.93	0.93
	D	0.98	1.09	0.90	1.32	1.46	1.02	1.00	1.02	0.99	0.97
	E	0.95	0.98	0.97	0.98	1.01	1.13	1.12	1.01	0.98	0.97
	G	1.50	1.50	1.00	1.05	1.05	1.02	1.00	1.02	0.89	0.88
	H	0.83	0.86	0.96	1.16	1.20	1.00	1.01	0.99	1.03	1.04
	J	1.16	0.94	1.23	1.45	1.18	1.13	1.11	1.02	1.07	1.05
	K	0.82	0.86	0.95	0.95	1.00	1.02	0.98	1.04	1.07	1.03
	L	1.01	1.06	0.96	0.99	1.04	1.41	1.40	1.01	0.92	0.91
	M	1.00	0.94	1.06	1.06	1.00	1.20	1.20	1.00	0.96	0.96
	F->N	1.08	1.08	1.00	1.55	1.55	1.10	1.09	1.01	0.94	0.93
	I->N	1.53	1.43	1.07	1.64	1.53	1.01	1.03	0.98	0.92	0.93
	Indu.	1.00	1.02	0.99	1.15	1.16	1.12	1.11	1.01	0.96	0.96
09->10	A	0.94	0.92	1.02	1.02	1.00	0.99	0.97	1.02	1.08	1.06
	B	0.99	0.95	1.04	1.04	1.00	1.00	0.97	1.03	1.15	1.11
	C	0.96	0.94	1.03	1.07	1.04	1.07	1.05	1.01	1.04	1.02
	D	0.99	0.97	1.02	1.02	1.00	0.96	0.95	1.01	1.13	1.12
	H	0.97	0.95	1.02	1.02	1.00	1.00	0.99	1.01	1.11	1.09
	K	0.92	0.92	1.00	1.00	1.00	1.05	1.01	1.03	1.08	1.05
	M	0.91	0.90	1.01	1.01	1.00	0.98	0.98	1.00	1.02	1.02
	N	1.00	1.00	1.00	1.05	1.05	1.13	1.12	1.01	1.03	1.03
	E->O	1.40	1.16	1.21	1.27	1.05	0.84	0.83	1.01	1.04	1.02
	L->O	1.16	1.10	1.05	1.12	1.07	0.86	0.85	1.02	1.04	1.02
	G->P	0.49	0.62	0.79	0.79	1.00	0.86	0.85	1.01	0.68	0.67
	J->P	0.93	0.76	1.22	1.22	1.00	0.98	0.97	1.01	0.68	0.67
	Indu.	1.03	0.99	1.04	1.08	1.03	1.01	0.99	1.01	1.04	1.03

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