# Long Term Productivity Gains in the Privatised British Passenger Rail Industry – a case study of Malmquist productivity index measurements.

## 1. Introduction

This paper assesses long term productivity in the privatised British passenger rail industry using a Malmquist productivity index (MPI). By assessing productivity with this approach, this allows the division of productivity gains into efficiency change (EC) and technical change (TC). Consequently, this enables an evaluation to be made of the effectiveness of the regulatory framework in incentivising the privatised industry towards productivity improvements, with efficiency improvement indicating eradication of (known) inefficiencies and progressive technical change development of the industry through ‘real’ advances in productivity. The subject also presents an opportunity to use and compare different underlying estimation methods of the Malmquist index, as this is normally solely derived from efficiencies estimated through Data Envelopment Analysis (DEA). A mass of literature exists, particularly in the air and sea port subject areas, which have used this approach. The econometric Corrected Ordinary Least Squares (COLS) and Stochastic Frontier Analysis (SFA) methods however are little used in this context, for reasons that are unclear.

The paper begins with an overview of the Railways Act 1993 and an outline of the privatised British passenger rail structure that it created, before the main research undertaken to date on the subject area is considered. The estimation approaches to be used are outlined, before results are presented and some of the issues arising out of the findings considered before conclusions are made.

## 2. British Rail, the Railways Act 1993 and What Followed

The railways in Great Britain were privatised by the Railways Act 1993 which ended almost fifty years of public ownership and by and large created the basic structure which is still in place today. Focusing on the passenger industry, services were divided initially into 25 train operating companies (area and/or line based and all former profit centres in British Rail), which private sector companies would bid to operate for a period of 7 years in most cases, but there were also some longer franchises of 10 and 15 years. Companies would lease rolling stock from one of three (now four) privately owned rolling stock leasing companies and purchase track access from the similarly privately owned Railtrack. Subsequent events led to the administration of Railtrack and its responsibilities taken over by the government owned but not for dividend Network Rail. Important in this context, franchises are normally awarded on the basis of services run, investments to be made, general plans for development of the franchise and some form of financial incentive to improve ‘performance’. This is either by reducing subsidies or increasing premium payments over the lifetime of the franchise. Rail fares are largely regulated, with the current level at RPI-0%. There does exist unregulated fares, but figures from the ORR (ORR, 2016) show that after achieving a market differential, changes in these fares have largely shadowed the regulated fare. This last aspect is important in this context, as it is through the necessity to maintain profitability in light of reducing payments from, or increasing payments to, the state that require the TOC to either increase passenger volumes and/or increase productivity and hence reduce unit costs.

## 3. Literature review

The literature on rail productivity in general is extensive, with Smith (2006) appropriately dividing this into ‘British only’ and ‘International’ studies. In the current context, only the former group will be considered. These have focused on the privatised passenger rail industry and fall between those on productivity and those on costs. Early studies were undertaken by Affuso et al (2002) and Cowie (2002). In the former case, the authors highlighted that privatisation and restructuring of the industry had uncovered failures within the system, specifically a backlog of network investment, hence sought to examine if productivity and efficiency in the privatised industry had overcome these inherited deficiencies. They used two approaches, a straight DEA and also a COLS distance frontier, and found efficiency improvements over the period 1995 to 2000 of 19.1% in the case of the DEA and 23.2% for COLS. As the DEA was carried out in a single estimation on the full panel and the COLS function omitted a time trend, these ‘efficiency’ improvements should be more accurately termed total factor productivity (TFP) improvement. Cowie (2002) estimated a simplistic Törnqvist productivity index for the first four years of the fully privatised structure, with passenger train kilometres specified as the output, and labour, traction rolling stock and infrastructure as the inputs. Total productivity was found to have risen by an impressive four per cent per annum over the period analysed, but even so such gains were found to be not as high as those made in the later period of public sector management. Pollitt and Smith (2001), in a cost-benefit review of rail privatisation to that date, found that major efficiencies had been achieved, consumers had benefited from lower prices, and the increased government subsidy had been largely recouped through privatisation proceeds.

With the benefit of hindsight, probably all of these studies were undertaken at too early a stage of the privatised era for any real insights to be gained, and need to be recognised for what they were, which were basically very early stage results. Major issues with the privatised structure began to emerge with the Hatfield accident, which subsequent research has found had a profound impact on the supply side of the industry. The accident occurred on 17th October 2000 and resulted in four fatalities when an intercity train derailed due to a broken rail which was known to be at risk. As a result, major speed restrictions were imposed across the whole network. Hatfield and subsequent events uncovered some serious issues with the robustness of the privatised structure, particularly with regard to responding to ‘shock’ or non-standard events. Cowie (2009), in a study of the effect of subsidy profiles on productivity over the lifetime of the first franchises, estimated productivity through a DEA based Malmquist productivity index (MPI). TFP was found to increase by an average annual rate of just over one percent per annum across the whole period, hence far lower than earlier studies, and this had mainly arisen out of (soft) technical change. Train Operating Company (TOC) subsidy profiles were found to have had a close association with productivity improvements. A key study in this area is Smith (2006), who compared TFP levels in the privatised industry with those in the former publicly owned British Rail. This was based on a translog total cost function from which measures of TFP (under three different contexts) were derived, and also a straight ‘cash’ cost computed Törnqvist index. The modelled estimates showed broadly similar patterns, but importantly from the current perspective indicated that it was in the early privatised era (i.e. pre Hatfield), where the highest levels of productivity improvement were achieved. These ranged from 1 to 2½% gains, which contrasted with estimated declines of between 1% and 2% per annum over the whole sample. In other words, the early gains (and more), were subsequently eradicated by the consequences of Hatfield.

In further studies, Smith et al. (2009) found that TOC costs increased by around 45 per cent between 2000 and 2006, which represented a 35 per cent increase when expressed on a cost per train kilometre basis. This the authors highlighted resulted in cost increases that equated to approximately £1.5 billion per year and led to a substantial increase in state subsidies to passenger train operators. One issue however not considered was the substantial increase in patronage that occurred over the same period. These rose by just under 17% (DfT, 2011), hence raises the question if all of these additional costs represented real cost increases. Purely in terms of train provision it did, but not all of these increases should then be equated with inefficiency of the operator. Further work undertaken by the same authors (Smith et al, 2010) examined the impact of passenger rail franchising on costs, productivity and efficiency, through a re-examination of past research findings. What they found was deteriorating productivity and rising costs in the British industry, which they highlighted was in direct contrast to experience in other (public) sectors and of more general experience with rail franchising elsewhere in Europe. Some evidence was found that this had been partly caused by exogenous factors such as rising diesel prices, but the authors maintained that cost increases were over and above such rises. Part of the reason was put down to the Strategic Rail Authority’s hitherto response to franchise failure, which to that point had generally been to renegotiate contracts, particularly with regard to enhanced contract extensions.

In a follow up study, Smith and Wheat (2012) examined the effect of contract types on costs by estimating a restricted translog model of TOC controllable costs, with inputs specified as staff and rolling stock characteristics, and the outputs in terms of train density, route kilometre, stations, train punctuality and signals passed at danger (SPADS), but did not include any output relating to passenger journeys. A dummy variable to represent post Hatfield operating conditions was also included, as well as further dummies to represent different contract types (management and renegotiated). Their results showed that operators on management contracts experienced a large deterioration in eﬃciency following the change of contract, although did achieve efficiency improvements through to competitive refranchising. Costs for renegotiated franchises on the other hand were found to be no higher (statistically) than industry best practice, although costs across all companies were found to be rising. This last result clearly suggests that long run productivity has been decreasing.

To summarise, to some extent the study of costs and productivity in the privatised British passenger rail has been characterised by a system that over the period has been subjected to a number of organisational and operational ‘shocks’, and these have tended to be reflected in the research results. Generally speaking, early studies found strong gains in productivity, whilst later studies have found clear evidence that these advances were eradicated by events following the Hatfield accident. Post Hatfield, productivity has failed to recapture the earlier gains, and in fact the research suggests this has been in decline. It seems appropriate therefore to now examine the topic from a far longer time horizon, hence what should emerge are the (real) long run effects of privatisation on productivity.

## 4. Data and Specification of Inputs and Output

As noted in the literature review, to date most if not all studies on efficiency and productivity in the subject area have used a supply side measure as the stated output, specifically train kilometres. This would seem to be entirely appropriate, as in most cases TOCs are contracted primarily to provide rail services, rather than carry passengers, hence train kilometres is consistent with that prime aim. As a consequence, profit maximisation occurs through sales/revenue maximisation. The aim of the operator therefore will be to fill the available capacity in order to maximise operator revenue, as the marginal cost of carrying an extra passenger is minimal. Use of the measure also provides consistency with previous studies into British passenger rail productivity.

The inputs used in this study are labour (annual staff levels), tractive rolling stock (primarily the number of multiple units employed) and line length, as these are the main inputs into the production of rail services/rail passenger kilometres – in terms of costs, these reflect around 80% of TOC operating costs. Some debate exists as to whether in a rail network where operations and the permanent way are vertically separated, the infrastructure component should be included. The basic argument is that the input is out with the direct control of the train operator (see for example Smith and Wheat, 2014). In this case however, the assessment is not of individual operator productivity but rather of the whole system and structure put in place on privatisation. As such, the infrastructure represents a key factor input and one that on its own accounts for around 35% of TOC costs (plus is directly subsidised by a further £2bn a year from the DfT Rail Group). For the purposes of this research therefore, it is included.

All data was compiled from three main sources, the TAS Rail Industry Monitor (see for example TAS, 2017) for the annual financial figures and some operational statistics and annual staff figures for each TOC, the Office of Road and Rail Regulation (see for example ORR, 2017) to obtain a full set of operational statistics and finally through internet searches to obtain rolling stock figures for throughout the whole period reviewed.

One further issue to consider is that since privatisation, there have been a number of important changes to the franchise map. Most notably, of the 25 initial franchises seven have been either partially or fully absorbed into other franchises, and one new franchise established in 2004 (Transpennine Express). This results in an unbalanced panel data set, hence the DEA based MPI had to be estimated over multiple periods rather than in one single estimation. Whilst regulatory driven, such changes in operational areas are not uncommon and in many respects should be considered to be the norm in any long run productivity assessment.

5. Conceptual Considerations and Approaches to Malmquist Productivity Assessment

Before examining the available methods for estimating total factor productivity, some important conceptual issues with TFP assessment are briefly considered, in particular the issue of adverse technical change and the relationship between technical and efficiency change.

Most, if not all, TFP studies find periods of negative technical change, however the implications of this or why this occurs are seldom if ever discussed. It does nevertheless raise the question with regard to what this actually represents? At one level, technical change is about the bounds of the production frontier, or at the macro level the bounds of the production possibility curve. Once production knowledge/technology is advanced, then it cannot be undone, TC therefore ‘should’ always be equal to or above one. There are cases however where technical change can become negative, and this case study has one very clear example. The increase of regulatory operating controls can reduce the production possibility set, hence creating adverse technical change. Any similar measures which affects operational performance will have such an effect, such as the aforementioned network wide speed restrictions that resulted from the Hatfield accident. A second case is where there is major structural change, normally created by a significant change in demand conditions. Julien et al (2017) for example in a TFP assessment of top, Caribbean and Small Island Developing States (SIDS) container ports found fairly large deteriorations in technical change following the economic crash of 2008/9. The impact of such events can be to change the whole production economics of the industry to such an extent that the effect is to set it back by a number of years, hence adverse technical change. One final possibility is where industries are in decline, hence falling investment levels (due to falling returns) leads to sweating of the assets which leads to deterioration and declining productivity over time, which would be (or certainly should be) captured in declining technical change. In all three cases however, such events and occurrences tend to be relatively rare hence in effect TC should generally be positive (and in annual terms, small). Furthermore, increases in TC create technical inefficiencies (adverse EC) as best practice is advanced. Subsequent EC driven TFP gain therefore is simply eradicating the inefficiency created by technical progress. Not only therefore should TC be positive, but over the medium and longer terms it should be the sole, or certainly by far the main, cause of TFP improvement.

In terms of approaches to TFP assessment, the standard Malmquist index as put forward by Färe et al (1994) is expressed as:

 $TFP\left(x^{t},x^{s},q^{t},q^{s}\right)=\left[\frac{d^{s}(q^{t},x^{t})d^{t}\left(q^{t},x^{t}\right)}{d^{s}(q^{s},x^{s})d^{t}\left(q^{s},x^{s}\right)}\right]^{\frac{1}{2}}$ [1a]

Which as stated divides total factor productivity into efficiency change (EC) and technical change (TC):

 $TFP\left(x^{t},x^{s},q^{t},q^{s}\right)=\frac{d^{t}\left(q\_{t}x\_{t}\right)}{d^{s}\left(q\_{s}x\_{s}\right)}\left[\frac{d^{t}\left(q\_{t},x\_{t}\right)}{d^{s}\left(q\_{t,}x\_{t}\right)}x\frac{d^{t}\left(q\_{s},x\_{s}\right)}{d^{s}\left(q\_{s,}x\_{s}\right)}\right]^{\frac{1}{2}}$ [1b]

Conceptually, efficiency change is the change in the relative production position of the firm to the efficiency frontier between the time periods under review, normally consecutive years, and hence where found to be positive is effectively efficiency catch up, but will be negative during strong periods of frontier shift (i.e. technical change). Whilst at the general level therefore, technical change is the shift in the production frontier between the two time periods, it is harder to define at the firm level. Generally speaking, for the firm TC occurs where its production position has moved beyond the previous production frontier (see figure 1) or where the shift in its production position reduces the gap between the two frontiers. In order to assess the MPI, under the data envelopment approach (DEA), four formal measures of efficiency are required. These consist of assessing the current year production position to the current frontier, the previous year production position to the previous frontier, the current year production position to the previous frontier and finally the previous year production position to the current frontier. All of these measurements are illustrated in Figure 1.

Figure 1: TFP assessment under the DEA efficiency estimation method



Source: Adapted from Coelli et al (1998)

In figure 1, efficiency assessment is based on an assumption of output maximisation, hence the productivity problem to be solved is to produce as much output from a given set of inputs. The example firm P has two production positions, point Ps in time period s and production point Pt in the following time period, year t. Hence, in practical terms, from equation 1b efficiency change is assessed by:

 $EC=\frac{\left(P\_{t}/P\_{tFt}\right)}{\left(P\_{s}/P\_{sFs}\right)}$ [2a]

Consequently if efficiency is higher in year t than in s, this represents an efficiency gain and [2a] will produce a value greater than one. Technical change is assessed by:

 $TC=Geomean \left[\left(\frac{P\_{s}/P\_{sFs}}{P\_{t}/P\_{tFs}}\right),\left(\frac{P\_{t}/P\_{tFt}}{P\_{s}/P\_{sFt}}\right)\right]$ [2b]

A positive technical change would take place if the firm’s production position in year t was found to be closer to the frontier in year s than the firm’s production position in year s, hence the estimated ‘efficiency’ value would be higher and thus produce a value of TC of greater than one. The same applies for the second comparison against the frontier in year t, and an average (the geometric mean) is taken of the two.

In terms of the efficiency measures for the MPI, in theory these can be generated from any efficiency assessment method, however in practice this is normally done using DEA. Furthermore, if an econometric approach is used following the same basic principles, namely a year by year efficiency assessment, this requires a separate production function to be estimated for each individual year. As a consequence, the imposition of the assumption of CRS on the production function results in the input parameter estimates ‘absorbing’ any technical change that occurs from one year to the next. It will therefore only ever estimate efficiency change, and consequently not full TFP. Under such approaches therefore, in order to derive a full TFP assessment the full panel needs to be employed. In the current context, two approaches to econometric efficiency estimation are used to complement the results of the DEA:

* a Corrected Ordinary Least Squares (COLS) full panel production frontier efficiency measurement
* a Stochastic Frontier Analysis (SFA) full panel production frontier efficiency measurement

The principles behind the DEA approach have been covered above hence are not outlined further, moreover these are extensively documented elsewhere (see for example Fare et al, 1994, Coelli et al 1998). As regards the econometric approaches, both use an estimate of an underlying production function from which to derive efficiency measures, differences arise in how the residual is used to produce the efficiency estimates, and hence these are detailed below.

### 5.1 COLS Full Panel Assessment

Unlike the DEA based approach where TFP assessment is through a year-on-year comparison, under the COLS approach the whole time period is considered as a single entity. In this example, the general form of the translog production function is used with time variables added:

$$Ln TrKm\_{ik}=a+b\_{L}Ln\left(LAB\_{ik}\right)+b\_{R}Ln\left(TRS\_{ik}\right)+b\_{N}Ln\left(LNE\_{ik}\right)+c\_{LL}\frac{1}{2}Ln(LAB\_{ik})^{2}+c\_{RR}\frac{1}{2}Ln(TRS\_{ik})^{2}+c\_{NN}\frac{1}{2}Ln(LNE\_{ik})^{2}+c\_{LR}Ln\left(LAB\_{ik}\right)Ln\left(TRS\_{ik}\right)+c\_{LN}Ln\left(LAB\_{ik}\right)Ln\left(LNE\_{ik}\right)+c\_{RN}Ln\left(TRS\_{ik}\right)Ln\left(LNE\_{ik}\right)+g\_{t}t\_{k}+g\_{tt}\frac{1}{2}t\_{k}^{2}+h\_{tL}t\_{k}Ln\left(LAB\_{ik}\right)+h\_{tR}t\_{k}Ln\left(TRS\_{ik}\right)+h\_{tN}t\_{k}Ln\left(LNE\_{ik}\right)+e\_{ik} $$

 [3a]

The assumption of CRS needs to be imposed with the special case of unitary scale returns, hence the following constraints are required:

 $b\_{L}+b\_{R}+b\_{N}=1$ [3b]

 $c\_{LL}+c\_{LR}+c\_{LN}=0$ [3c]

 $c\_{RR}+c\_{LR}+c\_{RN}=0$ [3d]

 $c\_{NN}+c\_{LN}+c\_{RN}=0$ [3e]

 $h\_{tL}+h\_{tR}+h\_{tN}=0$ [3f]

Under a COLS approach, the full value of the residual is judged to represent the firm’s efficiency, hence efficiency in the current year t is given by:

 $Effy\_{iTT}= exp\left(e\_{it}-e\_{X}^{+}\right)$ [4a]

And in the previous year s as:

 $Effy\_{iSS}= exp\left(e\_{is}-e\_{X}^{+}\right)$ [4b]

Where $e\_{X}^{+}$ represents the largest positive residual across the whole panel. Efficiency change in year t is therefore given by:

$$EC\_{it}=\frac{Effy\_{iTT}}{Effy\_{iSS}}$$

Technical change is calculated as an average of the rate of change of output with respect to time in years t and s, hence the geometric mean of:

 $TC\_{it}=\frac{dTrKm\_{it}}{dt}=g\_{t}+g\_{tt}t\_{t}+h\_{tB}Ln(LAB\_{it})+h\_{tA}Ln(TRS\_{it})+h\_{tE}Ln(LNE\_{it})$ [4c]

And:

 $TC\_{is}=\frac{dTrKm\_{is}}{dt}=g\_{t}+g\_{tt}t\_{s}+h\_{tB}Ln(LAB\_{is})+h\_{tA}Ln(TRS\_{is})+h\_{tE}Ln(LNE\_{is})$ [4d]

Hence:

 $TC\_{ist}=Geomean\left(TC\_{t}, TC\_{s}\right)$ [4e]

And for completeness, TFP(change) is given by:

 $TFP\_{it}=EC\_{it}×TC\_{ist}$ [4f]

### 5.2 Stochastic Full Panel Assessment

As above, the first requirement for productivity assessment is the imposition of (unitary) constant returns to scale, however due to issues with the underlying MLE estimation method and the associated decomposition of the residual element, the normal procedure is to impose the CRS assumption by dividing each element by one of the inputs (Coelli et al, 1998). In this case the input chosen is per thousand kilometres of line length, hence the function to be estimated is:

$Ln\left(\frac{TrKm\_{it}}{Line\_{it}}\right) =a+b\_{B}Ln\left(\frac{Lab\_{it}}{Line\_{it}}\right)+b\_{A}Ln\left(\frac{TRS\_{it}}{Line\_{it}}\right)+c\_{BB}\frac{1}{2}Ln\left(\frac{Lab\_{it}}{Line\_{it}}\right)^{2}+c\_{AA}\frac{1}{2}Ln\left(\frac{TRS\_{it}}{Line\_{it}}\right)^{2}+c\_{BA}Ln\left(\frac{Lab\_{it}}{Line\_{it}}\right)Ln\left(\frac{TRS\_{it}}{Line\_{it}}\right)+g\_{t}t+g\_{tt}\frac{1}{2}t^{2}+h\_{tB}tLn\left(\frac{Lab\_{it}}{Line\_{it}}\right)+h\_{tA}tLn\left(\frac{TRS\_{it}}{Line\_{it}}\right)+v\_{it}-u\_{it}$

 [5a]

Unlike the COLS approach, in an SFA assessment the residual component is broken down into uit, which is the measure of inefficiency, and vit, which is the random (noise) component, thus efficiency in the current year is given by:

 $Effy\_{it}=exp\left(-u\_{it}\right)$. [5b]

And in the previous year s as:

 $Effy\_{is}=exp\left(-u\_{is}\right)$. [5c]

Hence efficiency change is:

$$EC\_{it}=\frac{Effy\_{it}}{Effy\_{is}}$$

TC and TFP are derived in exactly the same manner as for the COLS case.

To clarify, in a COLS assessment all of the residual is assumed to be due to inefficiency, whilst in the SFA some of this is attributed to a stochastic element. To considerably simplify, in an SFA assessment a distribution is assumed of the (in)efficiency, in this case a half normal, and the stochastic term used to best fit that (in)efficiency distribution.

## 6. TFP Results

### 6.1 DEA Malmquist Results

British passenger rail Malmquist productivity was assessed first through the common DEA approach to efficiency/TFP assessment using the DEAP computer package (Coelli, 1996). The results are presented in Table 1a and associated figure 2a.

Table 1a: Total Factor Productivity DEA Efficiency Based Estimates, British Passenger Rail, 1998 to 2015.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Year | Annual |   |   | Cumulative |   |
|   | EC | TC | TFP | EC | TC | TFP |
| 1998 | 1.0050 | 1.0146 | 1.0196 | 1.0050 | 1.0146 | 1.0196 |
| 1999 | 0.9641 | 1.0768 | 1.0383 | 0.9689 | 1.0926 | 1.0586 |
| 2000 | 1.0465 | 1.0025 | 1.0489 | 1.0140 | 1.0952 | 1.1104 |
| 2001 | 1.0417 | 0.9609 | 1.0009 | 1.0562 | 1.0524 | 1.1114 |
| 2002 | 0.9468 | 1.0383 | 0.9859 | 1.0001 | 1.0927 | 1.0957 |
| 2003 | 1.0426 | 0.9801 | 1.0218 | 1.0427 | 1.0709 | 1.1196 |
| 2004 | 1.0962 | 1.0150 | 1.1127 | 1.1430 | 1.0870 | 1.2458 |
| 2005 | 0.9869 | 1.0409 | 1.0274 | 1.1281 | 1.1314 | 1.2800 |
| 2006 | 1.0707 | 0.9144 | 0.9789 | 1.2078 | 1.0346 | 1.2530 |
| 2007 | 0.9961 | 0.9963 | 0.9925 | 1.2031 | 1.0309 | 1.2436 |
| 2008 | 1.0338 | 0.9839 | 1.0172 | 1.2437 | 1.0142 | 1.2650 |
| 2009 | 0.9694 | 1.0670 | 1.0343 | 1.2057 | 1.0821 | 1.3085 |
| 2010 | 1.0305 | 0.9909 | 1.0212 | 1.2425 | 1.0722 | 1.3362 |
| 2011 | 0.9999 | 1.0254 | 1.0253 | 1.2424 | 1.0994 | 1.3700 |
| 2012 | 0.9908 | 1.0114 | 1.0022 | 1.2310 | 1.1120 | 1.3731 |
| 2013 | 0.9960 | 0.9920 | 0.9880 | 1.2260 | 1.1030 | 1.3566 |
| 2014 | 1.0123 | 0.9845 | 0.9965 | 1.2411 | 1.0859 | 1.3519 |
| 2015 | 0.9752 | 1.0064 | 0.9816 | 1.2104 | 1.0929 | 1.3270 |
|   |   |   |   |  |   |   |
| Annual Mean | 1.0107 | 1.0049 | 1.0158 |  |   |   |
| Cumulative Change |   |   |   | 1.2104 | 1.0929 | 1.3270 |

Figure 2a: British Passenger Rail Productivity, Efficiency Change, Technical Change and Total Factor Productivity Change, 1998 to 2015

Examining the overall and annual means in Table 1a, over the whole time period the DEA based results estimate that TFP rose by just over 1.5% per annum, which ranges from a high of just under 5% to a low of a 2% decline. Most improvement came as a consequence of efficiency change (just over 1% pa), along with small gains in technical change (around 0.5% pa). Examining how TFP evolved over the time period however produces a more confused picture. Figure 2a for example shows large swings in all three elements, and no real consistency or general patterns in terms of periods of progressive/regressive development in any of the three measures. This is a common occurrence in transport productivity studies that use this approach, due to the fact that positive technical change shifts best practice, which in turn creates inefficiencies that did not exist before, i.e. adverse efficiency change. As a consequence, the two plots of the annual averages continually cross over time, with the TFP trend slotting somewhere between the two. What this does is tend to mask any general patterns or trends. That said, figure 1a does suggest that TFP and EC improved more strongly over the first ten years of the period, and this is confirmed in Table 1b through the calculation of mean values to and from 2009.

Table 1b: Annual mean values, EC, TC and TFP, 1998 to 2009 and 2009 to 2015

|  |  |  |  |
| --- | --- | --- | --- |
| Period | EC | TC | TFP |
| Annual mean value 1998 to 2009 | 1.0157 | 1.0066 | 1.0227 |
| Annual mean value 2009 to 2015 | 0.9961 | 1.0107 | 1.0069 |

The division at 2009 provides an interesting contrast, as the first period is characterised by relatively large and inconsistent improvements in efficiency in addition to small gains in technical change, whilst by the second period efficiency gains had largely been exhausted and the prime driver of TFP was technical change. The very early efficiency gains would also appear to suggest a level of inefficiency ‘inherited’ from the former state operator British Rail (BR), and similarly the very early (i.e. pre Hatfield) improvements in technical progress would indicate that the constraints that BR was operating under, the most obvious being the limit on the level of external borrowings, did have an adverse effect on technical progress.

Also shown in Table 1a is the cumulative effect that annual productivity improvements had over the time period, and these are shown graphically in Figure 2b.

Figure 2b: British Passenger Rail Productivity, Cumulative Effects of Efficiency Change, Technical Change and Total Factor Productivity Change

The cumulative figures tend to bring out general trends far better than the annual mean values, and do clearly confirm the general slowdown (but more consistent) TFP gain in the second part of the period. Shown particularly well is the progress of technical change. Nevertheless, whilst it does produce a clearer insight than results based on the annual means, several issues still remain. Most notably the results still tend to be quite ‘clunky’ and at times interpretation becomes difficult. Furthermore, the period 2002 to 2008 produces very large gains in EC, but net reductions in TC, with the net impact on TFP of a 15% gain and all of this coming from EC. Contained in that period is a TC fall of over 8% in a single year (2006), which relatively speaking is a rate of decline that in reality is difficult to believe, particularly given that overall TFP only fell by just over 2%. This tends to suggest method estimation issues rather than real technical change, and these are discussed below. One final point is that in half of the sixteen time periods reviewed there is adverse technical change, although the effect of this in the later years are put more in context by the cumulative values (only a very minor decrease). Nevertheless, whilst one of those instances (2001) is because of line speed restrictions as a result of the Hatfield accident, the others are very difficult to explain, particularly the highlighted large decline in 2006.

### 6.2 Econometric Results

Before presenting the TFP results based on econometric efficiency assessment, the actual results of the production function/frontier estimations used to derive the COLS and SFA efficiencies are given in Table 2.

Table 2: Parametric production function/frontier estimates, COLS and SFA

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Parameter | Variable | COLS |   |   | SFA |   |
|   |  | Estimate | SE | T Value | Estimate | SE | T Value |
| a | Constant | -5.0000 | 0.3901 | -12.8170 | -0.3713 | 0.6998 | -0.5310 |
| bL | Labour | 1.6262 | 0.3407 | 4.7740 | 2.7693 | 0.5758 | 4.8090 |
| bR | Rolling Stock | -0.7131 | 0.2494 | -2.8590 | 0.1312 | 0.4465 | 0.2940 |
| bN | Line | 0.0869 | 0.1576 | 0.5510 | -1.9005 |   |   |
| cLL | Labour Squared | -0.0611 | 0.0364 | -1.6800 | -1.1560 | 0.2438 | -4.7420 |
| cRR | TRS Squared | -0.5455 | 0.1547 | -3.5270 | 0.2611 | 0.1415 | 1.8460 |
| cNN | Line Squared | -0.3741 | 0.0814 | -4.5960 | 0.0014 |   |   |
| cLR | Labour/TRS | -0.1198 | 0.0422 | -2.8350 | 0.4468 | 0.1733 | 2.5780 |
| cLN | Labour/Line | -0.0064 | 0.0048 | -1.3150 | 0.7093 |   |   |
| cRN | TRS/Line | 0.3999 | 0.1081 | 3.6990 | -0.7079 |   |   |
| gT | Time | 0.1456 | 0.0619 | 2.3530 | -0.0174 | 0.0178 | -0.9780 |
| gTT | Time squared | -0.0258 | 0.0608 | -0.4240 | 0.0014 | 0.0013 | 1.0940 |
| hTL | Time/Labour | 0.0393 | 0.0145 | 2.7140 | 0.0074 | 0.0074 | 0.9990 |
| hTL | Time/TRS | -0.0337 | 0.0111 | -3.0350 | -0.0126 | 0.0058 | -2.1930 |
| hRL | Time/Line | -0.0056 | 0.0077 | -0.7330 | 0.0052 |   |   |
|   |  |   |   |   |  |   |   |
| λ |  |   |  |   | 5.9798 | 1.0067 | 5.9400 |
| σ |   |   |   |   | 0.7068 | 0.0013 | 530.4030 |

In general, most of the coeﬃcients are found to be statistically signiﬁcant, although some of the time elements are more marginal. For both estimations, at the sample mean marginal products were found to be consistent with priors and economic theory, i.e. increases in any of the three inputs increases the output. Finally, with regards to the stochastic frontier, the null hypothesis that there are no inefficiency effects (sigma) is rejected. Both functions therefore are deemed to be appropriate to use to estimate efficiencies and derive TFP measures.

### 6.3 COLS Frontier Derived TFP Results

For the TFP measures, the COLS derived results are presented in a similar fashion to the DEA based findings in Table 3 for annual mean values and the overall cumulative effect.

Table 3 – British Passenger Rail Productivity, TFP, EC, TC, 1998 to 2015, COLS efficiency based results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Year  | Annual Means |   | Cumulative Effect |   |
|   | EC | TC | TFP | EC | TC | TFP |
| 1998 | 1.0063 | 1.0117 | 1.0181 | 1.0063 | 1.0117 | 1.0181 |
| 1999 | 1.0310 | 1.0111 | 1.0424 | 1.0376 | 1.0229 | 1.0613 |
| 2000 | 1.0284 | 1.0104 | 1.0390 | 1.0670 | 1.0335 | 1.1027 |
| 2001 | 0.9767 | 1.0102 | 0.9867 | 1.0422 | 1.0440 | 1.0880 |
| 2002 | 0.9776 | 1.0099 | 0.9873 | 1.0188 | 1.0544 | 1.0742 |
| 2003 | 1.0175 | 1.0091 | 1.0268 | 1.0366 | 1.0640 | 1.1029 |
| 2004 | 0.9844 | 1.0087 | 0.9929 | 1.0204 | 1.0732 | 1.0951 |
| 2005 | 1.0301 | 1.0082 | 1.0385 | 1.0511 | 1.0820 | 1.1373 |
| 2006 | 0.9795 | 1.0074 | 0.9868 | 1.0296 | 1.0899 | 1.1222 |
| 2007 | 0.9853 | 1.0073 | 0.9925 | 1.0145 | 1.0979 | 1.1138 |
| 2008 | 0.9774 | 1.0065 | 0.9837 | 0.9915 | 1.1050 | 1.0957 |
| 2009 | 1.0295 | 1.0053 | 1.0349 | 1.0207 | 1.1109 | 1.1339 |
| 2010 | 1.0148 | 1.0043 | 1.0192 | 1.0359 | 1.1157 | 1.1557 |
| 2011 | 1.0211 | 1.0037 | 1.0249 | 1.0577 | 1.1198 | 1.1844 |
| 2012 | 0.9969 | 1.0032 | 1.0002 | 1.0545 | 1.1234 | 1.1846 |
| 2013 | 0.9857 | 1.0028 | 0.9884 | 1.0394 | 1.1265 | 1.1709 |
| 2014 | 0.9920 | 1.0022 | 0.9943 | 1.0311 | 1.1291 | 1.1642 |
| 2015 | 0.9773 | 1.0020 | 0.9793 | 1.0077 | 1.1313 | 1.1400 |
|   |   |   |   |   |   |   |
| Annual Mean | 1.0004 | 1.0069 | 1.0073 |   |   |   |
| Cumulative Change |   |   |   | 1.0077 | 1.1313 | 1.1400 |

Whilst in direction the results are broadly comparable with the DEA generated figures, the first point of difference is that the COLS estimates are considerably under those based on DEA, and the cumulative effect of this across the whole time period is significant. Reasons for this are unclear, but some issues are discussed below. The results nevertheless broadly confirm the DEA based findings with respect to higher productivity gains made through both technical progress and efficiency change in the immediate post BR era, and more generally larger productivity gains across the whole first half of the period. The cumulative effect of this is found to be just over 13% to 2009, however unlike the DEA estimates, most of this increase is estimated to have arisen out of TC (11%), with only 2% coming from efficiency change. A third difference from the DEA results is that the pattern of technical change is found to be far more consistent, and this is shown in figure 3.

Figure 3 – British Passenger Rail Productivity, TFP, EC, TC, 1998 to 2015, Stochastic Frontier Based Estimates

What Figure 3 shows is a clear trend of positive technical change at a slowly decreasing rate across the whole period. In many ways this progressive aspect makes sense, as productivity should be viewed as a long run concept (and in turn, efficiency as a short run concept), and hence modelling technical progress over time would appear to match better with the reality of the situation being studied. A clear example of this is the effect of the Hatfield restrictions, which the DEA estimated as a significant reduction in technical change, whilst the COLS has modelled as short run inefficiency. Given in the medium to longer term speed restrictions were removed, this longer time horizon would appear to be a more appropriate reflection of the reality. Priors would also suggest that, due to the incorporation of a time trend, econometric approaches will tend to put more emphasis on technical change to generate TFP gains rather than efficiency gains, and this facet does appear to be borne out by the results. Experience with other industries, in particular the port sector (Julien et al, 2017), also produced a similar emphasis on TC based TFP improvement.

An indirect effect of this high level of consistency in TC however, is that most changes in TFP are therefore associated with variations in EC. This is confirmed by calculation of the correlation co-efficient, which calculates to 0.9911 for EC/TFP compared to a statistically insignificant 0.1112 for TC/TFP. This has been interpreted by some studies as a second causal relationship, however what is actually occurring is that EC is causing short term deviations in TFP away from the long term trend, which is being primarily driven by TC.

### 6.4 Stochastic Frontier Derived TFP Results

Again the TFP measures are presented as before and shown in Table 4 and Figure 4 for annual mean values and the overall cumulative effect.

Table 4 – British Passenger Rail Productivity, TFP, EC, TC, 1998 to 2015, Stochastic Frontier Based Estimates

|  |  |  |  |
| --- | --- | --- | --- |
| Year | Annual Averages (Geometric Mean) | Cumulative Values |   |
|   | EC | TC | TFP | EC | TC | TFP |
| 1998 | 1.0013 | 1.0115 | 1.0128 | 1.0013 | 1.0115 | 1.0128 |
| 1999 | 1.0036 | 1.0108 | 1.0145 | 1.0050 | 1.0224 | 1.0275 |
| 2000 | 1.0075 | 1.0101 | 1.0177 | 1.0125 | 1.0328 | 1.0456 |
| 2001 | 0.9968 | 1.0100 | 1.0067 | 1.0092 | 1.0431 | 1.0527 |
| 2002 | 0.9942 | 1.0097 | 1.0039 | 1.0034 | 1.0532 | 1.0568 |
| 2003 | 1.0049 | 1.0089 | 1.0139 | 1.0083 | 1.0626 | 1.0715 |
| 2004 | 0.9974 | 1.0085 | 1.0058 | 1.0057 | 1.0716 | 1.0777 |
| 2005 | 1.0060 | 1.0080 | 1.0141 | 1.0117 | 1.0802 | 1.0929 |
| 2006 | 0.9978 | 1.0072 | 1.0050 | 1.0095 | 1.0880 | 1.0984 |
| 2007 | 0.9966 | 1.0072 | 1.0037 | 1.0061 | 1.0958 | 1.1025 |
| 2008 | 0.9952 | 1.0063 | 1.0015 | 1.0013 | 1.1027 | 1.1041 |
| 2009 | 1.0038 | 1.0052 | 1.0090 | 1.0051 | 1.1084 | 1.1140 |
| 2010 | 1.0037 | 1.0042 | 1.0079 | 1.0088 | 1.1130 | 1.1228 |
| 2011 | 1.0042 | 1.0035 | 1.0077 | 1.0130 | 1.1169 | 1.1315 |
| 2012 | 0.9988 | 1.0031 | 1.0019 | 1.0118 | 1.1204 | 1.1336 |
| 2013 | 0.9984 | 1.0026 | 1.0010 | 1.0102 | 1.1233 | 1.1348 |
| 2014 | 0.9989 | 1.0021 | 1.0010 | 1.0091 | 1.1257 | 1.1359 |
| 2015 | 0.9949 | 1.0019 | 0.9967 | 1.0039 | 1.1278 | 1.1322 |
| Annual Average | 1.0002 | 1.0067 | 1.0069 |   |  |   |
| Cumulative Values |   |   | 1.0039 | 1.1278 | 1.1322 |

In terms of overall means, these are almost identical to the COLS results, and whilst a high degree of consistency was expected from the two methods, the level found even exceeds those prior expectations. Again, a very high consistency is shown in Technical Change, and as before, this is estimated to increase at a decreasing rate across the whole period. Where the major difference occurs between the stochastic and the COLS is in the results relating to efficiency change, and this is shown more clearly in the Figure 4.

Figure 4 – British Passenger Rail Productivity, TFP, EC, TC, 1998 to 2015, Stochastic Frontier Based Estimates

What the stochastic method has produced, in marked contrast to the DEA and COLS results, are very low estimates of EC, which in terms of the annual means, hardly vary and all are found to lie within a very small range (1.3%). A concern is that these are almost too consistent, and that this very small level of variation from one year to another strongly suggests that the random component in the stochastic frontier had the effect of modelling efficiency change over time. An example given by Coelli et al (1998) of productivity in the Australian electricity industry similarly shows a very clear trend in the annual average efficiency change estimates, in that case one of a slowly declining EC. This evening out of short run deviations from the long-term trend in many respects is an unwanted aspect of this analysis, as one of the points of interest was not only if efficiency had improved in the industry, but if so how that had developed over the period.

### 6.5 Productivity Results by Sector

One final aspect considered is to break the TFP results down by market sector, in order to examine if TFP improvement has been consistent across the whole industry. Due to space considerations and also potential loss of focus, Table 5 only shows the COLS estimates, however in terms of direction and relative differences, the findings were generally consistent across the three methods used.

Table 5: COLS Production Frontier TFP results by sector, British Passenger Rail 1998 to 2015

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Regional Railways |   | London/South East |   | Intercity |   |   |
|   | EC | TC | TFP | EC | TC | TFP | EC | TC | TFP |
| 1998 | 1.0280 | 1.0142 | 1.0427 | 0.9944 | 1.0067 | 1.0010 | 0.9998 | 1.0176 | 1.0173 |
| 1999 | 1.0257 | 1.0134 | 1.0394 | 1.0280 | 1.0063 | 1.0345 | 1.0439 | 1.0167 | 1.0613 |
| 2000 | 1.0467 | 1.0126 | 1.0599 | 0.9960 | 1.0057 | 1.0016 | 1.0652 | 1.0160 | 1.0822 |
| 2001 | 0.9367 | 1.0131 | 0.9490 | 0.9669 | 1.0051 | 0.9718 | 1.0522 | 1.0157 | 1.0687 |
| 2002 | 0.9471 | 1.0130 | 0.9593 | 0.9696 | 1.0047 | 0.9742 | 1.0353 | 1.0154 | 1.0512 |
| 2003 | 1.0719 | 1.0116 | 1.0844 | 1.0192 | 1.0044 | 1.0237 | 0.9463 | 1.0145 | 0.9600 |
| 2004 | 0.9320 | 1.0103 | 0.9417 | 1.0062 | 1.0038 | 1.0100 | 1.0238 | 1.0167 | 1.0409 |
| 2005 | 1.0384 | 1.0100 | 1.0488 | 1.0042 | 1.0034 | 1.0076 | 1.0754 | 1.0158 | 1.0924 |
| 2006 | 0.9593 | 1.0088 | 0.9677 | 0.9550 | 1.0016 | 0.9566 | 1.0555 | 1.0159 | 1.0723 |
| 2007 | 0.9954 | 1.0082 | 1.0037 | 1.0032 | 1.0015 | 1.0047 | 0.9438 | 1.0153 | 0.9582 |
| 2008 | 0.9871 | 1.0075 | 0.9945 | 0.9356 | 1.0009 | 0.9365 | 1.0611 | 1.0144 | 1.0764 |
| 2009 | 1.0409 | 1.0061 | 1.0472 | 1.0024 | 1.0019 | 1.0043 | 1.0522 | 1.0090 | 1.0617 |
| 2010 | 1.0038 | 1.0059 | 1.0097 | 1.0282 | 1.0048 | 1.0331 | 1.0143 | 1.0015 | 1.0159 |
| 2011 | 1.0031 | 1.0058 | 1.0090 | 1.0534 | 1.0036 | 1.0572 | 1.0085 | 1.0008 | 1.0093 |
| 2012 | 0.9725 | 1.0050 | 0.9774 | 1.0056 | 1.0032 | 1.0088 | 1.0214 | 1.0009 | 1.0223 |
| 2013 | 0.9911 | 1.0054 | 0.9965 | 1.0048 | 1.0022 | 1.0070 | 0.9559 | 0.9998 | 0.9557 |
| 2014 | 0.9995 | 1.0044 | 1.0038 | 0.9947 | 1.0021 | 0.9968 | 0.9785 | 0.9994 | 0.9779 |
| 2015 | 0.9919 | 1.0040 | 0.9958 | 0.9416 | 1.0016 | 0.9431 | 1.0009 | 0.9998 | 1.0007 |
|   |   |   |   |   |   |   |   |   |   |
| Average | 0.9977 | 1.0088 | 1.0065 | 0.9945 | 1.0035 | 0.9980 | 1.0177 | 1.0103 | 1.0282 |

What table 5 shows is that most gains came from the Intercity sector, and furthermore, most of this was through efficiency improvements, which tended to fluctuate throughout the period. Strong gains were made in the early part of the period, whereas beyond 2009 efficiency gains have been more modest, with efficiency actually falling by a net 3%, and this a ‘pure’ efficiency fall, i.e. one not driven by technical change. Similarly, TC in the sector shows strong growth to 2009, but since then average values are effectively unchanged. These results are surprising, as the implication is that any inefficiencies inherited from the state operator were most prevalent in the Intercity sector, which of the three was by far the most commercially orientated, operating as it did without subsidy and with market based pricing.

## 7. Reflections on the Use of Different Approaches to TFP Assessment

The DEA based TFP results were found to produce higher estimates than those based on econometric methods. Whilst on an average annual basis differences were relatively small, these were considerably amplified when viewed from a cumulative perspective. To some extent this is a consequence of the relatively low values estimated, hence in relative terms when these are aggregated over time the difference then becomes considerable. From a general perspective therefore, this may be less of an issue than presented in this case. Nevertheless, whilst the basic DEA is known to produce higher efficiency estimates (Löthgren, 1998), within an MPI assessment this should even out over the period being examined. What it may suggest therefore is that the DEA approach is attributing an element of data ‘noise’ to productivity gain, and furthermore this may be exaggerated by changes in the weightings attached to the inputs from one year to the next. Bootstrapping the DEA estimates should overcome most of these issues, but as yet this has not been attempted in the MPI context due to computational difficulties.

A second issue was that the SFA and COLS approaches were found to place far more emphasis on TFP gain through technical change improvements. Why this happens is that an econometric efficiency assessment will include all of the inputs in the efficiency assessment in each time period, whilst DEA varies the weight placed on each input, and ultimately this can be zero. As a consequence, where ‘real’ technical improvements are introduced, the DEA based MPI is likely to considerably underestimate the short term effect this has on TC, but rather will spread this impact over a longer time period. Furthermore, the econometric approaches modelled technical change over the whole time period, whilst DEA only considered TC from purely a year-on-year perspective, with no connection from one time horizon to the next. In terms of the reality of the situation, over an extended time period all TFP improvement will be as a consequence of technical change, with efficiency change representing short run deviations from that long run trend. The econometric approaches, with the longer time horizon, far better reflected that reality, hence from that perspective may be considered to be higher in ecological validity.

With regard to the stochastic function, it was found that when efficiency change was expressed as annual means, the method had effectively modelled these changes over the long run, hence very little variation was found in these values. As such, this countered the very issue that was being examined. Both in this case and the cited Coelli et al (1998) example, efficiency change was found to be relative low, with an overall sample average in both cases of around 1% per annum. Research elsewhere (Julien et al 2017) indicates that where efficiency changes are found to be higher, then this modelling aspect over the period is far less pronounced and the method does identify short run efficiency change. Certainly in this case, the degree of consistency found between the COLS and the Stochastic estimations was very high, which suggests that the data set exhibited very little statistical noise, and this may also be why efficiencies differences were eradicated by the modelling procedure.

One final observation is that some of the values associated with efficiency and technical change under the DEA method were found to be unrealistically high. For example, 2006 produced an average EC gain of 7%, whilst in the same year TC fell on average by over 8%. Examination of these two years more closely suggests that what is actually happening is what can best be described as input slack exposure, where a small adverse decline in TC produces a large improvement in efficiency, but the reason is because the firm’s efficiency is now being assessed along an input slack rather than the efficiency frontier. This increase in the input slack is then incorrectly attributed to TC decline. There is also evidence that in 2009 the opposite occurred, where the large gain in TC is in actual fact as a result of input slack capture and not real technical progress. Again, bootstrapping the DEA estimates should overcome or certainly substantially reduce this effect. Nevertheless, this would still not overcome the short time horizon perspective of the DEA based approach, which may be consistent with efficiency as a short run concept, but contradictory to productivity and technical change as long run concepts.

## 8. Conclusions and Closing Discussion

Early studies on the privatised British passenger rail productivity indicate strong gains, whilst studies carried out after the Hatfield accident show these to have been entirely eradicated by the events that followed, and that post Hatfield productivity continued to decline. With the perspective of a longer time horizon, the results produced in this research indicate an annual average productivity gain of around 1% to 1½% since privatisation of the industry. Most of this was as a result of gains made during the first half of the period, with unitary productivity in the second half. Virtually all of these gains have come as a result of technical change.

Nevertheless, the productivity results found should be considered as conservative estimates. The considerable rise in patronage over the same period will have had a detrimental impact on train kilometre productivity – in simple terms, more passengers require more staff and most of this patronage growth has been accommodated on existing services. This factor will have been most prevalent when the results were broken down by sector - highest productivity gains were found in the Intercity sector, with this coming from both EC and TC. More modest improvements were found in the Regional sector and no change in the London and South East sector. Unreported estimates based on passenger kilometres as the output indicated similar productivity gains in the regional and intercity sectors, with unitary productivity in the LSE sector. This raises the whole issue of the choice of output to use as the base measure within transport efficiency studies. A supply side measure was used for the reasons highlighted, particularly to ensure consistency with previous research. Such measures also tend to be more in line with production theory and more deterministic in nature, i.e. variations in the inputs will have a more consistent effect on the output. When passenger based measures are used, this introduces other factors into the efficiency/productivity assessment, notably demand conditions in the operator market and the operator’s marketing effort, and this can produce greater inconsistencies in operator evaluation. There is no correct answer as to which output should be chosen or easy adjustment to offset any such limitations, hence the results produced need to be considered within the wider context of the issue being studied. In this case, it needs to be recognised that patronage growth has constrained train productivity and this effect appears to have been most prevalent in the Regional sector.

To conclude, the introduction of franchising into the British passenger rail sector has, in the long run, produced technical progress in production and ensured that firms maintain best practice, but future productivity gains may be more difficult to achieve due to a declining rate of technical progress. Further gains therefore could only be achieved through efficiency improvement, by for example attempting to further increase competitive pressures in the industry. Whether that would be desirable however, from a broader perspective, is a completely different matter.

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