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How technological, environmental and managerial performance contribute to the productivity change of Malaysian Construction Firms

Abstract

Purpose: Total Factor Productivity (TFP) change is an important driver of long-run economic growth in the construction sector. However, examining TFP alone is insufficient to identify the cause of TFP changes. Therefore, this paper employs the infrequently used Geometric Young Index (GYI) and Stochastic Frontier Analysis (SFA) to measure and decompose the TFP Index (TFPI) at the firm-level from 2009 to 2018 based on Malaysian construction firms' data.

Design/methodology/approach: To improve the TFPI estimation, normally unobserved environmental variables were included in the GYI-TFPI model. These are the physical operation of the firm (inland versus marine operation) and regional locality (West Malaysia versus East Malaysia). Consequently, the complete components of TFPI (i.e., technological, environmental, managerial, and statistical noise) can be accurately decomposed.

Findings: The results reveal that TFP change is affected by technological stagnation and improvements in technical efficiency but a decline in scale-mix efficiency. Moreover, the effect of environmental efficiency on TFP is most profound. In this case, being a marine construction firm and operating in East Malaysia can reduce TFPI by up to 38%. The result, therefore, indicates the need for progressive policies to improve long-term productivity.

Originality/value: This study contributes to knowledge by demonstrating how TFP components can be completely modelled using an aggregator index with good axiomatic properties and SFA. In addition, this paper is the first to apply and include the GYI and environmental variables in modelling construction productivity, which is of crucial importance in formulating appropriate policies.

Practical implications: Monitoring and evaluating productivity change allows an informed decision to be made by managers/policy makers to improve firms' competitiveness. Incentives and policies to improve innovation, competition, training, removing unnecessary taxes and regulation on outputs (inputs) could enhance the technological, technical and scale-mix of resources. Furthermore, improving public infrastructure, particularly in East Malaysia could improve regionality locality in relation to the environmental index.

Keywords:

Construction firms; total factor productivity; Geometric Young Index; stochastic frontier analysis; environmental variables; developing economies; Malaysia.

Paper type:

Research paper

Introduction

The construction sector is a particularly important industry for a country because of its contribution to national income. The industry fosters economic growth through backward and forward linkages by providing infrastructure and facilities, and consumes a substantial amount of goods and services from other industries (Ali et al., 2019). However, since the 1990s, a comparison of productivity changes in different industries indicates that construction has been plagued by slow productivity growth globally, with no other worse performing industry (Barbosa et al., 2017). Therefore, the decline in productivity in the sector can affect its growth rate and also other industries. However, to date, the causes of the decline in the industry's productivity are uncertain (The Economist, 2017). Consequently, this has created difficulties in formulating appropriate policies.

The growth output of the industry is driven by labour, capital and Total Factor Productivity (TFP). TFP is the ratio of outputs to inputs (e.g., capital, labour and materials), and reflects the overall efficiency while labour productivity or output per labour only considers partial productivity (Chia et al., 2018). It also contributes to economic growth and is influenced by technological progress and managerial performance – although these are not the only ones affecting TFP growth. According to the law of diminishing returns, at a certain threshold, any increase in labour or capital will no longer contribute to an increase in output (Acemoglu, 2009): it is caused by the depreciation of both labour and capital over the period. In this case, labour- and capital-led growth can be unsustainable (Kurniawan and Managi, 2018). There is growing literature that supports environmental variables as being heterogeneous against the current concept of the homogeneous production frontier (Njuki et al., 2018). Here, environmental variables are any variables that are physically involved in the production process but not within the control of the firm, i.e., physical and regional factors (O'Donnell and Nguyen, 2013). Previously, however, these environmental variables have been usually unobserved in productivity measurement, especially in the construction sector.

An appropriate TFP index enables the aggregation of quantity outputs and inputs to be accurate and complete, as this allows productivity growth to be understood better, without which the interpretation of TFP changes can be limited. In addition, TFP indices with suitable properties can be decomposed into different efficiency components (EC), including a technology index (TI), environmental index (EI), technical efficiency index (TEI) and scale-mix efficiency index (SMEI) (O'Donnell, 2014). The EC indicates changes in technology that embody all firms, how environmental variables affect production, how well managers use technology and how well managers leverage the firm's output (input) size and mix its output (input) (O'Donnell, 2016).

In the case of Malaysian databases, output and input prices are unavailable. Without prices, there are only a few TFP indices available with good axiomatic properties. Of these, the Geometric Young Index (GYI) is a multiplicative index that satisfies many of the important axioms of index theory. The aggregate output (input) index can be modelled against several outputs (inputs) using stochastic frontier analysis (SFA) to model inefficiency and statistical noise, and the estimated parameters from SFA can be used to estimate EC (O'Donnell, 2016). SFA also has the advantage of enabling statistical tests to be used to assess model assumptions and validity (Njuki et al., 2018). In previous studies, the indices used to measure construction productivity change mostly apply a non-parametric approach, such as piecewise frontier analysis, i.e., Data Envelopment Analysis (DEA), and lack the axiomatic properties needed.

The Malaysian construction industry is an important sector of the country's economy. In 2018, it accounted for 4.7% of Malaysia's GDP (Department of Statistics, 2019). Indirectly, the sector contributes significantly to other sectors because it consumes a large quantity of manufacturing products (Abas, 2017). In general, the industry's productivity performance is associated with the productivity performances of its firms, most of which may have access to the same technology. Nevertheless, differences in productivity between firms can be huge. Some can be endowed with different *managerial* capabilities and operate in different environments (O'Donnell, 2016).

Therefore, an in-depth evaluation of Malaysian construction firms is needed to help them improve their TFP performance over the long term, thereby improving the industry's fortune and the country's economy. Thus, there is a need to examine 1) the lack of productivity growth in the sector, 2) the lack of application of an appropriate TFP index and parametric approach and 3) modelling techniques that include environmental variables to date.

In response, this study analyses the TFP and EC changes of 48 Malaysian large construction firms from 2009 to 2018 based on the GYI and SFA: the focus on large firms is important because they contribute more to productivity growth than smaller firms (Ciani et al., 2020). It is also the first to apply the GYI-SFA approach and decompose environmental variables in the construction industry context.

The paper is structured as follows. First, it reviews the literature concerning the construction industry and methods used to measure its productivity, construction firms, and the background of Malaysian construction firms. The GYI and parametric specifications of SFA and efficiency components are then presented, followed by the sources of data, results and discussion. The final section comprises concluding remarks and recommendations.

Literature Review

Review of recent literature

There is little empirical evidence to date to determine the actual cause of the construction sector's slow productivity growth, and only a few studies at the firm level. Table 1 provides an overview of those with empirical content concerning changes in the EC – showing that changes in the *technological* index (TI) (shift in the frontier) are improving for firms in developed economies (Horta et al., 2013, Chiang et al., 2012, Park et al., 2015, Kapelko et al., 2015, Lee et al., 2016). In contrast, the results from *developing economies* are mixed. In this case, progress in TI (technical change) occurs with China's firms, as discussed by Chiang et al. (2012) and Park et al. (2015), whereas in Malaysia, there is a decline in TI (Azman et al., 2019).

The results for the *technical efficiency* index (TEI) (movement in the frontier), amongst construction firms are mixed where TEI was found positive in China, Hong Kong, Malaysia (Chiang et al., 2012, Azman et al., 2019). On the other hand, TEI was found negative in

Portugal, Spain and South Korea (Park et al., 2015, Kapelko et al., 2015, Lee et al., 2016) TEI measures how well managers use existing knowledge or technologies (e.g., construction techniques and methods) when the inputs or outputs are predetermined (O'Donnell, 2016).

The scale-mix efficiency index (SMEI) is another important measure of managerial performance, indicating how well managers manage firm size and mixes of inputs or outputs. However, only one study of construction firms was able to measure SMEI because it uses the Färe-Primont index number (FPI) – an appropriate productivity index because it can aggregate quantity inputs and outputs completely (Azman et al., 2019). The study indicates that SMEI positively affects construction firm productivity in Malaysia. In Portugal and Spain, the scale of the efficiency index (SEI) was found to be positive (Kapelko et al., 2015). Nevertheless, in their study, the mix efficiency part was missing. This is because this and many other studies apply an incomplete productivity index such as the Malmquist Productivity Index (MPI), in which SMEI cannot be measured. The mix efficiency part will be missing, and the index cannot make accurate multiperiod and multilateral comparisons and thus adds further to the risks of measurement error (O'Donnell, 2012).

Using a trans log production function and the Kumbhakar et al. (2000) decomposition method, Pires and Garcia (2012) have compared productivity between countries. They found that TFP was enhanced by an improvement in TI and allocative efficiency index (AEI) in developed economies. The allocative efficiency index is quite similar to the SMEI but a somewhat different in economic interpretation as it requires the prices of inputs and outputs. Compared to the manufacturing industry, in Indonesia, use of the Cobb-Douglass production function and Lee and Schmidt (1993) decomposition method shows that TI has improved industry productivity. However, the TEI and scale efficiency index (SEI) (part of SMEI) declined (Ikhsan, 2007). In a study of Middle East microfinance institutions using MPI and the

Lovell (2003) decomposition method, TI has declined, and the contribution to productivity change has been largely due to TEI and SEI.

At the construction industry level, using a trans log production function and the Kumbhakar et al. (2000) decomposition method, Wang et al. (2021) found that TI and AEI have a significant positive impact in China, while TEI has contribute to an adverse effect. However, a previous result by Chancellor and Lu (2016) using FPI and the O'Donnell (2012) decomposition method indicates that China's construction industry is mainly driven by scale efficiency instead of TI. In Australia, using the Malmquist index and Lovell (2003) decomposition method, it was found that TI is the important productivity growth in most states except for Tasmania, while TEI has contributed to improvement except for Queensland (Li and Liu, 2010).

In terms of accuracy, knowing whether TI is an important factor requires a statistical test based on a parametric approach such as Stochastic Frontier Analysis (SFA). However, only certain index numbers such as GYI can use parametric approach, which means the strength of TI's effect on TFP is unknown in the absence of such a test (O'Donnell, 2014). In this case, a technological regress (downward technological index), for instance, can be an artefact of improved measurement over time due to incorrect extreme observations along the frontier (Headey et al., 2010). Likewise, such non-parametric approaches as DEA have also been frequently used with MPI, but these cannot determine the randomness involved (random irregularity in the form of 'statistical noise'), which can affect the distance function measurement (O'Donnell, 2012).

(Insert Table 1)

Meanwhile, there is clear scope for using the environmental variables of the stochastic production frontier and piecewise production frontier – found to be very important in measuring the productivity of agricultural farming and health providers. These are such physical variables involved in the production process as rain, drought, weather, seasons, physical location and regionality (O'Donnell, 2016). For example, temperature has a negative effect while rain positively affects agricultural productivity in the United States (Njuki et al., 2018), with the regionality (remoteness) of different public hospitals in Australia affecting its productivity change (O'Donnell and Nguyen, 2013). In the construction industry, there has been growing interest in such environmental variables as weather, which is an important variable affecting productivity because construction firms are exposed to this condition directly (Al Refaie et al., 2020, Moohialdin et al., 2019, Al Refaie et al., 2021, Li et al., 2019). However, there have been no applications to date regarding the decomposition of the environmental productivity component, which is important for construction productivity to be modelled more accurately in heterogeneous production frontier settings.

Based on the review of construction research and other industries, an alternative to the current approach to measure TFP and decomposition of its components is needed. In this case, modelling techniques that enable heterogeneous environmental variables, suitable aggregator indices such as GYI, parametric approach, and the O'Donnell (2016) productivity decomposition method may resolve the current obstacle to more accurate productivity measurement at industry and global levels.

Background of Malaysian construction firms

Many policies have been introduced into Malaysia since 2009. In terms of macroeconomic policy, the government launched its *New Economic Model* – a more market-oriented policy intended to reduce the 2008 Global Financial Crisis's impact and propel the country into becoming a high-income nation (New Economic Advisory Council, 2010). In terms of the construction industry, the government introduced the microeconomic reforms of imposing the obligatory requirement for public projects to use the country's *Industrialized Building System* (IBS) in late 2008, the introduction of *IBS Roadmap 2011-2015* and the *Construction Industry Transformation Plan 2016-2020* (Construction Industry Development Board, 2016). Several policies have been aimed at renewing infrastructure development: large infrastructure projects, for instance, have been carried out as part of the government's attempt to improve public transportation across all of Malaysia (Construction Industry Development Board, 2016). In addition, there has been a significant housing development boom in recent years (Malaysia Productivity Corporation, 2018).

Malaysia's *Construction Industry Transformation Plan (CITP) 2016-2020* emphasises the importance of construction firms becoming more competitive in domestic as well as foreign markets (Construction Industry Development Board, 2016) – prompting more competitive Malaysian construction firms to provide construction services that match the market's needs in terms of price, quality and time and compete to gain a foothold in foreign markets. However, concerns have been expressed over the competitiveness of construction firms in recent years: whether they can compete with the increasing market share of foreign construction firms in the domestic market, and their lack of internationalisation perceived by policymakers as a lack of competitiveness (Construction Industry Development Board, 2017a). However, their competitiveness can only be established if their level of productivity can be measured with sufficient accuracy.

High productivity is associated with resilience to business competition and economic risks (İmrohoroğlu and Tüzel, 2014). However, while Malaysia experienced steady growth in its per capita GDP from 1970 to 2010, construction industry *labour productivity* stagnated (Chia et al., 2014). Despite increasing from 2010 to 2016 due to the renewal of infrastructure investments and more market orientation policies after the 2008 Global Financial Crisis (Gen and Ng, 2017), construction industry’s labour productivity from 1985 to 2016 was the least of all the country’s major industries (Gen and Ng, 2017). Therefore, low productivity growth can hinder the industry’s sustainable development in the long run, and making a large investment in the industry could provide only temporary and unsustainable activity and may not improve productivity as expected.

Recently, the Construction Industry Development Board (CIDB) has claimed that the implementation of CITP from 2016 to 2020 has increased the use of IBS in the public sector from 24% to 87% and from 14% to 41% by the private sector. During the same period, there was an increase in IBS registered manufacturers and installers by 37% and 40%, respectively, (Construction Industry Development Board, 2020). In terms of productivity, general workers' labour productivity has increased from MYR 27,000 to MYR 45,000 (Construction Industry Development Board, 2021). However, this may not give a clear picture of performance because labour productivity omits capital stock and materials, while it may not represent large construction firms because of the segmentation in the industry (such as the use of subcontracting to smaller firms) (Pan et al., 2019).

The model

Data sources

The data are drawn from Malaysian construction firms’ annual reports listed on the Malaysian Stock Exchange covering the 10-year period from 2009 to 2018. According to the country’s regulations, this comprises 48 registered large general and specialist construction contractors capable of constructing projects above MYR 10 million (equivalent to USD 2.4 million in March 2022). As Table 1 shows, 80% of the main output (q1) comprises construction-related revenues. Therefore, they are a representative data sample of large construction firms in Malaysia.

The model consists of three inputs and two outputs to measure TFP and its efficiency components (Table 2). These are expenses for labour ($x1$), materials ($x2$) and capital (fixed assets) ($x3$). In addition, physical location and regional locality are included as part of the heterogeneous production environment. In this case, they are coded based on Eqs (3) and (4) of their environments: for example firm 46 (refer to Table 6) primarily derived its revenue as a marine construction firm and operated mainly in East Malaysia. Period (t) represents the annual period studied. The revenue is divided into main output ($q1$) and secondary output ($q2$), representing construction-related output and non-construction output, respectively. Before computing TFP, the outputs and inputs are deflated to a common base year.

(Insert Table 2)

The Geometric Young Index

As described by O'Donnell (2018), the GYI output aggregator index can be expressed as

$$TFPI_{ksit}^{GY} = \prod_{n=1}^{N} \left(\frac{q_{nit}}{q_{nks}}\right)^{\bar{r}_n} \prod_{m=1}^{M} \left(\frac{x_{mks}}{x_{mit}}\right)^{\bar{s}_m} \qquad (1)$$

where q_{nit} are outputs, $\bar{r}_n$ is the share of outputs, X_{mit} are inputs and $\bar{s}_m$ is the share of inputs. Here, k and s denote a firm (k) at a period (s) used as a relative point of reference, i.e., k =1, s = 1. Therefore, $TFPI_{it}^{GY}$ is $Q(q_{it})/\, X(x_{it})$, and $Q(.)$ and $X(.)$ are aggregator functions, which can also be written as $TFPI_{ksit}^{GY}$ is $\frac{Q(q_{it})}{X(x_{it})} / \frac{Q(q_{ks})}{X(x_{ks})}$ that equals Eq. (1).

Total factor productivity (TFP) is the ratio of aggregate outputs to aggregate inputs: it can also be expressed as an output quantity index divided by an input quantity index (O'Donnell, 2018). If the information relating to price data and production technologies is not available, then revenue and input share may be used to calculate the output and input aggregator index. In this case, the GYI assumes that revenue- or cost-share are suitable relative value measures (O’Donnell, 2016). Comparatively, FPI assumes that the marginal rate of transformation/technical substitution is the suitable measure of relative value (O'Donnell, 2012).

As mentioned in the previous paragraph, a suitable index number is required to aggregate the output and input quantities. In this case, the GYI is a class of multiplicative indices that satisfy several important axioms from index number theory and is crucial for a complete estimation of TFP and the decomposition of EC (O'Donnell, 2016), including:

a) The identity axiom: $X(x_{it}, x_{it}) = 1$
b) Transitivity test: $X_{hs,it} = X_{hs,gr}X_{gr,it}$
c) Circularity: $TFP_{ks,rl}TFP_{rl,it}TFP_{it,ks} = 1$
d) Multiplicatively completeness: $Q(q_{it})/\ X(x_{it})$.

First, (a) if two firms produce the same output with the same inputs, the value should be unity. Second, (b) the index that compares the inputs of a comparison firm/period with the inputs of a base firm/period is identical to the index number computed when the comparison is made through an intermediate firm/period. Third, (c) the multiplications of such TFP indices may result in the value of unity. Fourth, (d) the index can be expressed in terms of aggregate quantities. Multiplicative completeness is essential because the comparison between firm (i) in period (t) and firm (h) in period (s) needs to be consistent, even with changes in the production frontier.

Stochastic Frontier Analysis and Efficiency Components

Maximum Likelihood (ML) estimation is used to approximate the unknown parameters by numerically maximising the log-likelihood function. SFA is more reliable than non-parametric linear programming such as DEA because it can differentiate between randomness (statistical noise) and inefficiency (O'Donnell, 2014). Therefore, the SFA results are relatively free from the sensitivity to outliers. Output orientations are assumed to be suitable for this study and therefore only their equations are shown, with the model for SFA being

$$lnQ(q_{it}) = \propto \ + \lambda t + \ \sum_{j=1}^{J} \delta_j \ln z_{jit} + \sum_{m=1}^{M} \beta_m \ln x_{mit} + v_{it} - \ u_{it} \qquad (2)$$

where $Q(q_{it})$ is a GYI aggregated output; t is the period; J is a characteristic of the production environment; x_{mit} are inputs; $\propto$, λ, δ and β are parameters; v_{it} is statistical noise; and u_{it} is inefficiency. Here the production environment J comprises the physical variables involved in the production process, not to be confused with the market environment (level of competition) and institutional environment (level of regulation) (O'Donnell, 2018). Here, J is represented by the physical operation of firms that can be located based on their marine or inland operation because some specialise in marine construction. Also, regional locality is considered because firms can operate in either West Malaysia or East Malaysia and may therefore be separated by a vast geographical area, i.e., the South China Sea and East Malaysia being part of Borneo. Therefore, it is coded based on Eqs (3) and (4),

$z_{marine,t} = 1$, if firm specialises in marine construction and $z_{inland,t} = 0$ if specialising in inland operation (3)

$z_{East\ Malaysia,t} = 1$, if the firm operates in East Malaysia and $z_{inland,t} = 0$ if operating in West Malaysia (4)

Reorganising Eqs (1) and (2) gives

$$TFPI_{ksit}^{GY} = \left[\frac{exp(\lambda t)}{exp(\lambda s)}\right]\left[\prod_{j=1}^{J}\left(\frac{z_{jit}}{z_{jks}}\right)^{\delta_j}\right]\left[\frac{\exp\,(-U_{it})}{\exp\,(-U_{ks})}\right]$$

$$\left[\prod_{n=1}^{N}\left(\frac{q_{nit}}{q_{nks}}\right)^{\kappa_n}\prod_{m=1}^{M}\left(\frac{X_{mit}}{X_{mks}}\right)^{\tau_m}\right]\left[\frac{\exp\,(v_{it})}{\exp\,(v_{ks})}\right] \qquad (5)$$

where $\kappa_n = \bar{r}_n - \gamma_n$, $\tau_m = \beta_m - \bar{s}_m$. However, if firms are price takers in output markets, they are revenue maximisers and their output quantities and prices are strictly positive, then $\gamma_n = \bar{r}_n$.

In Eq. (5), the first term on the right-hand side is the output-oriented technological index (TI), the second term is the environmental index (EI), the third term is the technical efficiency index (OTE), the fourth term is the scale-mix efficiency index (OSMEI) and the last term is the statistical noise index (SNI). OSMEI can be further divided into the separate mix and scale efficiency indices providing they are additive indices (O'Donnell, 2018). Therefore, TFP Index (TFPI) is decomposed into several multiplicative efficiency components, i.e.

$$TFPI = OTI_{st} * OEI_{jksjit} * OTEI_{ksit} * OSMEI_{ksit} * SNI_{ksit} \tag{6}$$

Table 3 presents the economic interpretation of each component.

(Insert Table 3)

Results

Table 4 shows the yearly estimates based on the geometric mean, indicating that, except for period (t), most coefficients are significantly different from zero. An annual period (t) variable allows for the technological change to vary and shows that the yearly technological level was declining by 0.70%. According to the test statistic based on the z-value of the period (t) coefficient, the firms did not experience a significant regress ($p>0.05$) in the technology to produce outputs. The negative coefficients for marine (-34%) and East Malaysia (-13%) indicate physical characteristics can negatively affect the outputs. The nonnegative coefficients for labour (6.9%), material (82%) and fixed asset (15%) suggest the inputs are strongly disposable, which implies an increase in inputs cannot decrease or congest outputs. The sum of the coefficients is greater than unity (elasticity of scale = 1.037), which indicates increasing returns to scale.

(Insert Table 4)

The value of Γ close to one indicates the presence of technical inefficiency. However, it is common to use the likelihood ratio to test whether $H_0: \sigma^2 = 0$ against the alternative $H_1: \sigma^2 > 0$ to detect the presence of inefficiency. In this case, the values of the restricted log-likelihood function from the OLS and ML estimations used for the test indicate the null hypothesis should be rejected (p<0.10): therefore, inefficiency is present. Next, the likelihood ratio test is used of the null hypothesis of $H_0: \mathrm{g}(\theta) = 0$ against the alternative $H_1: \mathrm{g}(\theta) \neq 0$, where θ denotes a vector containing all the unknown SFA parameters (O'Donnell, 2018). In this case, the value of the unrestricted and restricted log-likelihood functions from the ML and restricted ML estimation again indicates the null hypothesis should be rejected (p<0.05).

If at least one of the explanatory variables is integrated of order one process I(1), the observed and predictor variables are cointegrated (even though some of the explanatory variables may be endogenous), and the least-squares estimators for the slope parameters will be super-consistent (Njuki et al., 2018). First, a unit root test based on Maddala and Wu (1999) is conducted to test if the panel data possess a unit root or non-stationarity. This rejects the null hypothesis (p<0.01): all variables are I(1). Moreover, the Pedroni (2004) test shows that all the variables are cointegrated. Therefore, the null hypothesis is again rejected (p<0.01). This suggests that both coefficient estimates, and standard errors are acceptable.

(Insert Fig. 1)

Figure 1(a) illustrates the firms' TFPI and EC based on the geometric mean. This Figure represents the TFPI and multiplicative components of the output-oriented technology index (OTI), environmental index (OEI), technical efficiency index (OTEI), scale-mix efficiency index (OSMEI) and statistical noise index (SNI). OTI appears to slowly decline at a minimal constant rate, while OEI has no changes during those periods. OTEI rises sharply until 2013, then gradually decreases until 2017, followed by a steep decline. This indicates that OSMEI declined steeply until 2012, steadily increased until 2015, followed by a steady decline.

(Insert Table 5)

Table 5 shows that, measured by geomean, TFPI, OTI, OEI, OTEI, OSMEI and SNI are 0.973, 0.968, 0.968, 0.954, 1.023 and 1.064, respectively, which indicates that TFPI experiences a negative average annual growth rate (AAGR) at -6.6%. In addition, OTI and OSMEI experience negative AAGR at -3.1% and -9.8%, respectively. For OTEI and SNI, both experience positive AAGR at 4.9% and 1.6%, respectively. OEI's AAGR has not changed over time because firms did not change their specialities (inland or marine) or location (West Malaysia or East Malaysia) during that period. OEI includes the environmental variables of the physical operation and regional locality of the firm.

(Insert Table 6)

The TFPI vary at the firm level, as illustrated by Figures 1(b) to 1(d) for Firms 1, 24 and 48, respectively. These firms represent top, middle and bottom TFPI scores. Table 6 illustrates the TFPI and EC for each firm using the indicator of colour scales. All firms experienced similar OTI at 0.968. The Table also shows that firms located at the top rung have higher OTEI, OSMEI and SNI (unexplained factors – measurement error, omitted variables, etc.). In contrast, firms with an average TFP primarily have high OTEI but low OSMEI. In this case, firms are at the bottom rung largely because of their low OTEI and OEI.

Case by case observation in Figure 1(b) shows that Firm 1 had the highest overall TFPI (2.003) compared to all the other firms. It had a high level of construction-related diversification, which means its primary revenue ($q1$) is derived from such different construction segments as the contracting segment, road, highway maintenance and property development. The firm experienced a steady TFPI and EC improvement from 2009 to 2015. However, TFPI and EC declines after 2015. The average OEI, OTEI, OSMEI and SNI are 1.000, 1.285, 1.379 and 1.167, respectively.

In Figure 1(c), Firm 24 is a general contractor with a diversified portfolio and is one of the largest firms in Malaysia. On average, Firm 24's TFPI is 1.016. Firm 24 experienced no changes in OEI at 1.00. OTEI and SNI contribute positively to its TFPI at 1.114 and 1.027, while OSMEI has a negative effect at 0.916. In another case, in Figure 1(d), Firm 48 specialises in oil and gas construction and experienced the lowest TFPI at 0.275. The contributing factor to the decline was the low value of OEI, OTEI and SNI at 0.711, 0.372 and 0.971, respectively. Nevertheless, Firm 48's OSMEI positively contributed to its TFPI at 1.103.

Table 7 shows the Pearson's correlation test between TFPI and EC – indicating that the correlation between TFPI and each EC is significant. Nevertheless, the correlations vary, being weak for TFPI-OTI, moderate for TFPI-SNI, strong for TFPI-OSMEI and very strong for TFPI-OTEI. They are moderate and very high when comparing TFPI (marine construction firms) and TFPI (firms operated in East Malaysia) with OEI. In addition, the t-test and Wilcoxon rank test indicate a mean difference between firms that operate inland versus firms that operate in marine conditions, and firms that operate in West Malaysia versus East Malaysia (Table 8). This indicates the important influence of environmental variables on the TFPI of construction firms.

(Insert Table 7)

(Insert Table 8)

Discussion

Although the OTI contributions to TFPI seem to have a declining trend, this is not significant. Horta et al. (2012) had similar result for firm efficiency in the Portugal's construction industry suggests R&D engagement was not important factor for efficiency improvement could ring an alarm on policymaking regarding the application of new technology. Amongst others, in Malaysia, the promise of the country's policymakers that the use of industrialised building systems (IBS) can enhance the industry's productivity has not created the anticipated spillover effect for firms to improve their productivity. However, it could be being obscured by the slow adoption of the technology, with the lack of innovation in the products and processes a potential leading cause (Yap et al., 2019).

It is possible that whether innovation can create benefits depends on investing in problem-solving research related to new industry requirements and evolving requirements (Kapelko and Abbott, 2017). However, adopting better technology may require an environment that removes barriers to technology diffusion. For example, strong institutions that govern a country's regulations could provide an environment that allows more competition and innovation through Schumpeterian creative destruction (Acemoglu and Dell, 2010, Acemoglu, 2009). Previous studies show that technological progress is common for most construction firms in developed economies (Chiang et al., 2012, Horta et al., 2013, Lee et al., 2016). Using the GYI aggregator, SFA to account for statistical noise, and the inclusion of environmental variables and statistical tests, the present study suggests the technological stagnation argument is more robust than the Azman et al. (2019) results. In their case, using FPI and the non-parametric approach, they found declining technology to be a problem for construction firms in Malaysia, but were unable to carry out a statistical analysis to confirm the trend due to the method's limitations.

In previous research into the construction sector, environmental variables, i.e., OEI were not considered when modelling productivity. Most studies assume a homogeneous physical environment (Luo et al., 2019, Hu and Liu, 2017, Ma et al., 2016, Li et al., 2019). The present research shows that environmental variables are amongst the most critical factors that need to be considered in modelling productivity component but, while they are known to be important in other sectors such as agriculture (Njuki et al., 2018) and healthcare (O'Donnell and Nguyen, 2013), they have not been regarded as such in the construction sector hitherto. The present study's finding that marine-based firms may be endowed with a smaller multiplier than their counterparts inland is possibly due to an overly cautious view of hazards and safety affecting the progress of the work (Choudhry, 2017). Meanwhile the influence of regional factors could be due to the vastness, remoteness and hinterland of East Malaysia requiring availability and a better mode of transportation and connectivity, which requires the establishment and/or improvement of public infrastructure (O'Donnell, 2016). Without this adjustment, the comparison between firms might not be accurate because firm managers cannot control those environmental factors. OTEI is the most crucial driver in this study as it correlates the most with TFPI. Therefore, it seems that a higher OTEI creates more improvement in TFPI compared to OSMEI. This study found that, on average, most firms improved their OTEI. Only a handful of firms can have a higher TFPI with a low OTEI while having a higher OSMEI. In previous studies, the changes in OTEI varied, suggesting that a firm's familiarity with the same projects, ownerships, design firms and subcontracting level might improve OTEI (Park et al., 2015). OTEI can be improved mainly through education and training because it is an application of current technology (Gong et al., 2019). Therefore, managers need to be aware of the technology available and select that which is appropriate to complete the task. That TFPI increases from 2009 to 2015 coincides with the Gen and Ng (2017) study indicating that labour productivity in the Malaysian Construction Industry improved from 2010 to 2016, which suggests the increase was probably due to the government's pro-market policies (New Economic Advisory Council, 2010). In this case, more market-oriented policies were established to improve lagged economic growth due to 2008 Global Financial Crisis such as removal of investment barriers, liberalisation of financial market and subsidy reform (International Monetary Fund, 2015, Sufian and Habibullah, 2010, Bank Negara, 2011, New Economic Advisory Council, 2010). In the present study, most firms with average and lower TFPI are those with lower OSMEI. Also, the firms' OSMEI was declining. Previous studies generally fail to account for changes in

OSMEI because of using an index that fails to correctly aggregate the quantity involved (Azman et al., 2019). OSMEI measures how well managers can change the scale of firms' outputs and mix of outputs. Therefore, changes in policies that affect market prices, such as minimum wages, interest rates, taxes and subsidies, are needed to correct the decline (O'Donnell, 2012). A firm may change its scale and mix in response to changes in property market prices (due to low-interest rates). For example, managers may change their mix and scale to increase overall output if the price of outputs changes. Diversification in the construction industry creates positive and negative changes in OSMEI (Azman et al., 2021). Here, a firm may diversify into property development in response to price changes related to construction-related diversification, which brings a positive impact. However, although some firms may accumulate inputs over time, this does not necessarily translate into better outputs, hence scale inefficiency, especially in internationalisation strategy (Azman et al., 2022).

One of the most interesting results here is that, from 2015 to 2018, there was a significant decline in TFPI and EC. This resulted from the 2014-2016 oil glut and the oil price not recovering to its pre-2014-2016 level: in Malaysia, 22% of tax revenue was collected from oil and gas tax, and therefore government revenue was greatly affected, public development expenditure interrupted and private investor confidence undermined (Maji et al., 2017). In addition, at the same time in 2016, the political situation was unstable and investor confidence was low because of the corruption scandal involving sovereign funds controlled by the federal government brought pressure to the economy (Umezaki, 2019). As Table 9 shows, there was a resulting steep reduction in the value of projects in 2016 (Construction Industry Development Board, 2017b). In this case, OTEI had been primarily affected by the industry's downturn. Also, in 2018, there was a change in government when one of the longest-ruling parties which were in control of federal government was defeated, and the newly elected government decided to review or cancel many infrastructure projects associated with the former government's allegedly corrupt practices, which further affected the construction market that year (Shukry, 2019).

(Insert Table 9)

Practical implications

The analysis of productivity change in the construction industry could provide practical insights that could be used as the basis for management/government in monitoring and evaluating policies within the sector, as this allows managers to make informed decisions the in identifying strategies and best practices, improving their firms' competitiveness in the industry. However, given the industry's slow productivity growth worldwide, it is likely that applying the model outside Malaysia will also provide a major contribution to productivity change. In the case of Malaysia, it is suggested that policies to improve competition, reduce barriers in innovation/technology and improve education/training in construction are needed to improve technological change and technical efficiency, respectively. An additional need is for policies that enhance the scale-mix of resources through incentives, by changing wages, interest rates, taxes and subsidy adjustments, or amending restrictions on output (input) choices. For example, unnecessary taxes and regulations on outputs (inputs) need to be removed. Regarding OEI, the physical location factor facing a firm operating in marine environment may be an issue due to specialisation. However, regionality locality could be improved by providing and/or improving, public infrastructure (ports, railways, bridges and energy supply) which are lacking in East Malaysia. Future research will therefore benefit from using the GYI-SFA model in different applications and types of research worldwide.

Conclusion

This study develops a model based on the Geometric Young Index (GYI) and SFA to provide a robust measure of TFP so that technological, environmental and managerial performance can be decomposed. The GYI has special properties such as an identity axiom, transitivity, circularity and multiplicatively completeness compared to other indices. The computation of the GYI also does not require output and input prices. These properties enable accurate comparisons to be made between multilateral firms/longitudinal years and for TFP to be completely decomposed into several EC. The use of SFA makes it possible for TFP to be decomposed into several EC components. It also enables the measurement of the Statistical Noise Index (SNI) (that separates unexplained factors that affect the TFPI) and several statistical tests for model validation, which are not possible with a non-parametric method such as the popular Data Envelopment Analysis. Therefore, the GYI-SFA improves TFP measurement, and therefore allows better policy recommendations to be made.

In summary, firms that enjoyed high TFPI were typically inland construction firms in West Malaysia and had high technical and scale-mix efficiency. In contrast, firms with average TFPI have high technical efficiency but lower scale-mix efficiency. Firms with low TFPI were normally marine construction firms that operated in East Malaysia and had a lower technical efficiency spectrum.

Applying the model to data for 2009-2018 Malaysian construction firms helped identify technological stagnation amongst Malaysian construction firms. Also, improving current technology (OTEI) and flexibility to change the scale and mix of outputs (OSMEI) is vital for Malaysian construction firms' TFPI. In addition, it is the first to reveal the importance of the effects of environmental variables, i.e., OEI, on construction productivity, indicating that they need to be included in future research and policymaking. By providing OEI, a better comparison can be made because OEI can now be separated and policy regarding environmental variables can be made.

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Tables

Table 1. Overview of the construction research literature relating to the productivity of construction firms

Source of TFP change	Sign	Country	Years obs.	Method	Orientation	Author(s)
Technological index (TI)	+	Asia (largely Japan and South Korea's firms)	1995-2003	MPI-DEA	Output	(Horta et al., 2013)
TI and technical efficiency index (TEI)	+/+	China	2004-2010	MPI-DEA	Input	(Chiang et al., 2012)
TI	+	China	2005-2011	MPI-DEA	Input	(Park et al., 2015)
TI and TEI	+/+	Hong Kong	2004-2010	MPI-DEA	Input	(Chiang et al., 2012)
TI and TEI	+/-	Japan	2005-2011	MPI-DEA	Input	(Park et al., 2015)
TI, TEI, SMEI	-/+/+	Malaysia	2003-2016	FPI-DEA	Input /Output	(Azman et al., 2019)
TI	+	North America (largely United States' firms)	1995-2003	MPI-DEA	Output	(Horta et al., 2013)
TI, TEI and SEI	+/-/+	Portugal	2002-2011	Luenberger-DEA	Input	(Kapelko et al., 2015)
TI and TEI	+/-	South Korea	2005-2011	MPI-DEA	Input	(Park et al., 2015)
TI and TEI	+/-	South Korea	2006-2012	MPI-DEA	Output	(Lee et al., 2016)
TI, TEI and SEI	+/-/+	Spain	2002-2011	Luenberger-DEA	Input	(Kapelko et al., 2015)

'+' means positive change while '-' means negative change. TI = technological index, TEI = technical efficiency index, SEI = scale efficiency index, SMEI = scale-mix efficiency index, MI = Malmquist index and FPI = Färe-Primont

Table 2. Descriptive statistics of variables used to model total factor productivity

Variable (in '000 MYR)	Mean	Std. Dev	Min	Max
Main output ($q1$)	662,646	1,019,297	202	6,631,093
Secondary output ($q2$)	166,084	480,418	9	4,890,382
Labour ($x1$)	849,017	1,823,110	748	11,124,830
Material ($x2$)	50,667	101,363	854	739,107
Capital ($x3$)	668,256	1,035,578	10,331	6,225,564
Physical operation	0.06	0.24	0	1
Regional locality	0.08	0.27	0	1
Period (t = annual)	5.50	2.87	1	10

Table 3. TFP's efficiency components

Efficiency	**Term**	**Domain**	**Explanation**
$\boldsymbol{OTI_{st}}$	Technological index	Technology	The technological change which envelopes the production function of all firms in a period.
$\boldsymbol{OEI_{jksjit}}$	Environmental index	Physical environment	The physical environment endowed a different group of firms.
$\boldsymbol{OTEI_{ksit}}$	Technical efficiency index	Managerial	Measures the maximum aggregate output the firm could produce if its input vector and output mix are held fixed. It measures how well a firm (manager) uses technology.
$\boldsymbol{OSMEI_{ksit}}$	Scale-mix efficiency index	Managerial	Measures the gap from restricted to unrestricted frontier surfaces. It measures the economies of scale and substitution obtained by changing the output scale and the output mix by a firm (manager).
$\boldsymbol{SNI_{it}}$	Statistical noise index	Unexplained factors	This represents functional form, measurement, omitted variables and variable errors.

Table 4. Maximum Likelihood (ML) estimates

Variable	Slope parameter	Std. Error
Period (t)	-0.007	0.006
Marine	-0.340***	0.086
East Malaysia	-0.133**	0.058
Labour	0.069***	0.025
Material	0.816***	0.027
Fixed asset	0.152***	0.016
σ^2	1.571***	0.222
Γ	0.979***	0.005
M	-2.480***	0.402
Elasticity of scale	1.037	-

Significant at the *** 1%, ** 5% and *10% level

Table 5. Yearly estimates of the firms' TFPI and EC based on their geometric mean

Year	TFPI	OTI	OEI	OTEI	OSMEI	SNI
2009	1.047	1.000	0.968	0.910	1.136	1.046
2010	1.053	0.993	0.968	0.959	1.085	1.053
2011	1.011	0.986	0.968	0.988	1.011	1.060
2012	1.003	0.979	0.968	0.985	0.994	1.080
2013	1.047	0.972	0.968	1.004	1.032	1.074
2014	0.975	0.965	0.968	0.931	1.047	1.070
2015	1.027	0.958	0.968	0.977	1.045	1.085
2016	0.956	0.951	0.968	0.968	1.006	1.065
2017	0.879	0.945	0.968	0.950	0.955	1.058
2018	0.776	0.938	0.968	0.875	0.935	1.045
Yearly growth	-6.648%	-3.130%	0.000%	4.912%	-9.806%	1.683%
Geomean	0.973	0.968	0.968	0.954	1.023	1.064
Min	0.032	0.938	0.623	0.046	0.326	0.929
Max	4.098	1.000	1.000	1.443	3.709	3.903

Table 6. TFPI (highest to lowest) and efficiency components

FIRM	NAME	TYPE	MARINE	E.MAL	%AAGR	TFPI	OTI	OEI	OTEI	OSMEI	SNI
1	PROTASCO	G			-3.0	2.003	0.968	1.000	1.285	1.379	1.167
2	BINA PURI	G			0.1	1.919	0.968	1.000	1.255	1.402	1.126
3	TRC SYNERGY	G			-42.6	1.867	0.968	1.000	1.256	1.361	1.128
4	GADANG	G			51.9	1.723	0.968	1.000	1.270	1.211	1.157
5	MITRAJAYA	G			7.3	1.647	0.968	1.000	1.273	1.144	1.167
6	AGESON	G			-28.6	1.592	0.968	1.000	1.262	1.145	1.138
7	PLB ENGINEERING	G			10.4	1.588	0.968	1.000	1.268	1.120	1.154
8	BINTAI KINDEN	S-E			-14.4	1.519	0.968	1.000	0.901	1.729	1.007
9	MELATI EHSAN	G			20.7	1.476	0.968	1.000	1.230	1.090	1.137
10	FAJARBARU	G			-19.6	1.450	0.968	1.000	1.095	1.207	1.133
11	MUHIBBAH	ME	/		-13.3	1.436	0.968	0.711	1.325	1.244	1.264
12	MERGE ENERGY	G			89.1	1.423	0.968	1.000	1.174	1.156	1.083
13	MUDAJAYA GROUP	G			-58.7	1.375	0.968	1.000	1.205	1.052	1.121
14	SYCAL VENTURES	G			24.8	1.366	0.968	1.000	1.232	1.028	1.114
15	MTD ACPI	G			3.4	1.364	0.968	1.000	1.155	1.165	1.047
16	IREKA	G			-31.0	1.281	0.968	1.000	1.187	1.049	1.062
17	LFE CORPORATION	S-E/M			18.5	1.258	0.968	1.000	0.699	1.879	0.988
18	AHMAD ZAKI	G			12.6	1.216	0.968	1.000	1.163	1.020	1.059
19	KKB ENGINEERING	S-S		/	-14.1	1.194	0.968	0.875	1.223	0.996	1.156
20	BINA DARULAMAN	G			23.0	1.089	0.968	1.000	1.148	0.936	1.047
21	CREST BUILDER	G			0.0	1.066	0.968	1.000	1.175	0.888	1.054
22	HO HUP	G			0.1	1.055	0.968	1.000	1.057	0.901	1.143
23	DKLS INDUSTRIES	G			5.7	1.018	0.968	1.000	1.146	0.878	1.045
24	IJM CORP	G			-8.1	1.016	0.968	1.000	1.114	0.916	1.027
25	JAKS RESOURCES	G			-52.6	1.010	0.968	1.000	1.070	0.944	1.032
26	SUNWAY	G			-18.8	1.008	0.968	1.000	1.121	0.892	1.042
27	SALCON	S-W			-13.8	1.006	0.968	1.000	1.083	0.896	1.070
28	EUPE CORP	G			-20.3	0.990	0.968	1.000	1.143	0.863	1.037
29	NAIM HOLDINGS	G		/	-22.0	0.947	0.968	0.875	1.201	0.844	1.103
30	YFG	S-E/M			-7.3	0.924	0.968	1.000	0.565	1.705	0.991
31	GAMUDA	G			7.1	0.924	0.968	1.000	1.083	0.860	1.024
32	KELINGTON	S-M			-34.4	0.915	0.968	1.000	0.554	1.740	0.980
33	MRCB	G			-21.8	0.886	0.968	1.000	1.073	0.837	1.018
34	WCT HOLDINGS	G			-1.8	0.868	0.968	1.000	0.964	0.931	0.998
35	SBC CORPORATION	G			-8.7	0.859	0.968	1.000	1.112	0.778	1.025
36	KNUSFORD	G			-25.4	0.803	0.968	1.000	0.733	1.114	1.017
37	BREM HOLDING	G			0.2	0.765	0.968	1.000	1.195	0.574	1.152
38	KUMP JETSON	G			33.4	0.755	0.968	1.000	0.749	1.051	0.989
39	TSR CAPITAL	G			-30.6	0.730	0.968	1.000	0.752	0.993	1.009
40	ZECON	G		/	-14.0	0.700	0.968	0.875	0.891	0.915	1.014

41	LIEN HOE	G			-29.4	0.607	0.968	1.000	0.906	0.580	1.192
42	ZELAN	G			1712.5	0.559	0.968	1.000	0.719	0.804	0.999
43	SEREMBAN	S-S			-22.3	0.465	0.968	1.000	0.473	1.040	0.976
44	PINTARAS JAYA	S-F			-5.2	0.446	0.968	1.000	0.511	0.923	0.978
45	EKOVEST	G			181.8	0.418	0.968	1.000	0.703	0.596	1.029
46	HOCK SENG LEE	ME	/	/	-33.3	0.365	0.968	0.623	0.587	1.051	0.981
47	MGB	S-R			47.2	0.306	0.968	1.000	0.388	0.808	1.006
48	DIALOG	S-O	/		-18.9	0.275	0.968	0.711	0.372	1.103	0.971

Type of primary revenue: G = general contracting, ME = marine engineering, SE = electrical specialist, SF = foundation specialist, SM = mechanical specialist, SO = oil and gas structure, SR = roofing specialist, SS = structural steel and SW = water and sewerage specialist. MARINE = physical location (environmental) and E.MAL – East Malaysia = regional locality (environmental). %AAGR = percentage Average Annual Growth Rate

Table 7. Pearson's correlation test between TFPI and EC

Correlation between	t-statistic	df	Correlation	Interpretation
TFPI and OTI	2.862	478	0.129***	Weak
TFPI and OTEI	21.923	478	0.708***	Very strong
TFPI and OSMEI	15.417	478	0.576***	Strong
TFPI and SNI	11.565	478	0.467***	Moderate
TFPI (marine) and OEI (marine)	2.533	28	0.431**	Moderate
TFPI (East Malaysia) and OEI (East Malaysia)	5.331	38	0.654***	Strong

Significant at the *** 1%, ** 5% and *10% level; df = degree of freedom

Table 8. Comparing the TFPI values for groups 1 and 2

Compare	t-test	Wilcoxon rank test
Group 1 vs Group 2 Mean in group 1: 1.157 Mean in group 2: 0.700	t = 4.382*** df = 32.88	W = 9942***
Group 3 vs Group 4 Mean in group 3: 1.156 Mean in group 4: 0.830	t = 4.617*** df = 53	W = 11961***

Significant at the *** 1%, ** 5%, and *10% level; df = degree of freedom. Group 1 = inland operation vs Group 2 = marine operation. Group 3 = West Malaysia vs Group 4 = East Malaysia

Table 9. Value of construction projects awarded by sector and type of project (adapted from Construction Industry Development Board, 2017a)

Sector and Type	2013	2014	2015	2016
Total Private	161,363.78	117,127.32	178,143.68	34,311.26
Residential	34,781.71	51,097.83	39,075.50	11,265.92
Non-Residential	91,973.73	49,374.63	38,964.58	15,072.84
Social Amenities	4,833.52	2,575.03	3,561.94	1,575.82
Infrastructure	29,774.82	14,079.83	96,541.66	6,396.68
Total Government	23,653.56	24,724.12	50,882.08	6,045.07
Residential	2,139.25	2,677.18	1,560.38	909.06
Non-Residential	3,925.24	4,049.74	3,546.58	681.61
Social Amenities	3,343.55	2,940.88	5,110.49	1,047.74
Infrastructure	14,245.52	15,056.32	40,664.63	3,406.66
Grand Total	185,017.34	141,851.44	229,025.76	40,356.33