IDB WORKING PAPER SERIES Nº IDB-WP-1396

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Competitiveness, Technology, and Innovation Division
Compete Caribbean Partnership Facility

March 2023

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Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Mohan, Preeya.
COVID-19, firm innovation strategy and production efficiency: a stochastic frontier analysis of caribbean firms / Preeya Mohan, Eric Strobl.
p. cm. — (IDB Working Papers Series ; 1396)
Includes bibliographic references.
1. Technological innovations-Caribbean Area. 2. Business enterprises-Technological innovations-Caribbean Area.
3. Industrial productivity-Caribbean Area. 4. Coronavirus infections-Economic aspects-Caribbean Area.
I. Strobl, Eric, 1969- . II. Inter-American Development Bank. Competitiveness, Technology and Innovation Division.
III. Title. IV. Series.
IDB-WP-1396

http://www.iadb.org

COVID-19, FIRM INNOVATION STRATEGY AND PRODUCTION EFFICIENCY

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COMPETE CARIBBEAN

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ABSTRACT

While Caribbean Small Island Developing States (SIDS) have been exposed to frequent external shocks in the past, the Coronavirus disease of 2019 (COVID-19) pandemic is like no other, representing the largest economic shock experienced globally in decades. The objective of this paper is to contribute to a better understanding of the innovation strategy and production efficiency of Caribbean firms during COVID-19. More specifically, it adopted a Stochastic Frontier Analysis (SFA) to investigate COVID-19, innovation, and technical efficiency for 13 Caribbean countries using the Innovation, Firm Performance, and Gender (IFPG) firm-level dataset. The results indicate that firms expect average technical efficiency to fall by over 100 percent because of COVID-19. Pre-COVID-19, 39 percent of firms implemented general innovations (product, process, organizational, and marketing) over the past three years, and 50 percent green innovations (environmental improvements), while the pandemic negatively affected 42 percent of these innovations. Firms that carried out general innovations experienced a positive effect on technical efficiency, while green innovations had a negative effect. During COVID-19 only 12 percent of firms initiated general innovations and 17 percent green innovations. These general innovations improved technical efficiency, while innovations that were affected by COVID-19 had a negative effect, and green innovations did not necessarily have a positive effect.

JEL Codes: D22, D24, O32, Q55

Keywords: innovation, green innovation, COVID-19, production function, technical efficiency, stochastic frontier analysis, small island developing states

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INTRODUCTION

Innovation is a necessity for businesses that want to survive in an uncertain world characterized by digital transformation, changing consumer demand, and environmental concerns, compounded by recurring external shocks. On the one hand, such crises reduce production and make business opportunities less certain, and firms may be less willing to invest in innovative activity, which is costly and risky. Alternatively, periods of downturn provide an opportunity for businesses to restructure productive facilities and implement innovative strategies in anticipation of a recovery. The Coronavirus disease of 2019 (COVID-19) pandemic, an unprecedented shock for the world economy, impacted firms by reducing—and in some cases completely shutting down—their operations by wiping out demand, creating new market needs, and reducing access to finance, which may inhibit their willingness and ability to innovate.

Firms in Caribbean Small Island Developing States (SIDS) were hit particularly hard by the crisis and its aftermath (Acevedo, et al, 2021). The use of the internet and adoption of digital technologies were critical to sustaining business continuity during the virus outbreak. To meet the demands of the post-pandemic environment, businesses have launched new products or services and/or adapted to flexible working conditions—with many more people working remotely—relying more on information and communication technology (ICT) and digital technology in their operations (Santos, 2020). As economies seek to rebuild, there has also been a push for green growth strategies, given that the climate crisis requires urgent attention (OECD, 2020). Firms must therefore plan strategically, alter their operations, and innovate in order to adjust to the new normal and thrive (Lee and Trimi, 2020). There is nonetheless a lack of understanding across the region of how to maintain production efficiency during external shocks, in general, and COVID-19, in particular.

While SIDS are exposed to frequent external shocks, COVID-19 has been like no other. Prior to the pandemic, the Caribbean region was characterized by a less than dynamic private sector that hindered the growth of innovative businesses (Ruprah, Melgarejo and Sierra, 2014; Mohan, Strobl and Watson, 2016; Mohan,

Strobl and Watson., 2017). Caribbean firms tend to be micro and small and concentrated in the retail and tourism sectors. These are exactly the types of firms that have been hard hit by the pandemic and lack the necessary resources to implement innovative strategies. Caribbean policymakers nonetheless recognize the private sector as an important partner to boost economic participation and create new growth opportunities in the post-COVID-19 era.

To contribute to a better understanding of firm innovation practices and production efficiency in times of crisis, this paper investigates the effect of COVID-19 on firm innovation and technical efficiency using a Stochastic Frontier Analysis (SFA) and the innovation, firm performance, and gender (IFPG) firm-level dataset for 13 Caribbean countries. The SFA provides comparative estimates of the firm's production function and its technical efficiency pre- and post-COVID-19. The study then examines whether general (product, process, marketing, and organizational) and green (environmental improvements) innovations implemented prior to and during the pandemic had an effect on technical efficiency while controlling for firm characteristics as well as sector and country effects.

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LITERATURE REVIEW

A substantial amount of literature supports the significant positive relationship between innovation and firm performance (Verhees and Meulenberg, 2004; Rosenbusch, Brinckmann, and Bausch, 2011), and firm innovation capabilities and performance (Freeman, 2004; Lin and Chen, 2007; O'Cass and Sok, 2014; Oura, Zilber, and Lopes, 2016; Zulu-Chisanga et al., 2016). There is, however, much less research on external shocks and firm innovation. Among the handful of studies, most research has focused on financial events, namely the 2007/2008 Global Financial Crisis and the 1997 Asian Financial Crisis (Filipetti and Archibugi, 2011; Paunov, 2012; Hud and Hussinger, 2015; Zouaghi, Sanchez, and Martínez, 2018; Nemlioglu and Mallick, 2021), while others have looked at disaster events (Oh and Oetzel, 2011; Oetzel and Oh, 2021) and political risks (Darendeli and Hill, 2016). Studies on external shocks and firm innovation strategy are limited and remain ambiguous. On the one hand, the research suggests that during periods of crisis, innovation is a key factor for firm survival (Caballero and Hammour, 1991; Cucculelli and Peruzzi, 2020) and performance (Nickell, Nicolitsas, and Patterson, 2001; Makkonen et al., 2014). Innovative approaches act to mitigate the negative effects of a harmful event and may allow the firm to potentially emerge stronger by increasing firm productivity, competitiveness, and growth (Hall et al., 2016; Hausman and Wesley, 2014). In particular, young, fast-growing firms and new enterprises tend to increase innovative activities during crises (Archibugi, Fillipetti, and Frenz, 2013). Alternatively, the literature also suggests that when faced with a period of downturn, firms may reduce and even postpone or stop innovative activity given the increased level of uncertainty over economic recovery, investment returns, and high costs (Archibugi, Fillippetti, and Frenz, 2013; Paunov, 2012). Indeed, firms are likely to invest only when there is a market for their goods and services. The unprecedented nature of the COVID-19 pandemic makes investment in innovative activities even more risky. The effects of external shocks on a firm's innovation performance also indicate that the impacts of these shocks may be more damaging (Valerie, 2007) where there are weaker innovation systems and a

shortage of basic public goods. This is the case in developing countries such as the Caribbean.

There are a few, nevertheless comprehensive papers which suggest that firms' innovation strategy improved performance during COVID-19. Adam and Alarifi (2021) studied SME managers in Saudi Arabia using an online questionnaire and structural equation modelling and showed that the innovation practices adopted in the face of COVID-19 had a positive impact on the performance and likelihood of business survival. Han and Qian (2020) used a fixed effects model and found that the innovative abilities of large and small Chinese listed companies increased during the pandemic, but varied by industry.[1] Using the World Bank's COVID-19 Survey and the Business Enterprise Survey across 28 developed and developing countries, Krammer (2021) provides evidence that innovative firms are more likely to adapt to a COVID-19 scenario than non-innovative firms.

[1] The Global Industry Classification Standard was used for the companies in the sample, all of them from 11 industries including information technology, utilities, medical and health, materials, industry, real estate, essential consumer goods, energy, telecomm, finance, and non-essential consumer goods.

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COVID-19, INNOVATION AND PRODUCTION EFFICIENCY AND CARIBBEAN FIRMS

The role of innovation and productivity in economic growth is poorly understood in Caribbean SIDS, mainly due to a lack of data on firms. The Compete Caribbean Partnership Facility, in collaboration with the Inter-American Development Bank and the World Bank, has made significant strides in producing internationally comparable, statistically relevant data at the firm level. This facilitates empirical analysis that can determine what drives firm performance and innovation in the region. The evidence from this data indicates that pre-COVID-19 innovation and productivity are quite low and, indeed, are acute constraints to growth and development in Caribbean SIDS.

Among the first of such studies, Ruprah, Melgarejo, and Sierra (2014) highlight that the characteristics of Caribbean businesses are not typically associated with a dynamic innovative private sector since they are generally small, old, and concentrated in tourism and retail, and ownership is predominantly local. The study used the Latin American and Caribbean Enterprise Survey (LACES) and showed that Caribbean firms performed poorly over the period 2007–2010 in terms of sales growth, employment growth, and productivity, even adjusting for lower rates of growth in the region over the period. Caribbean businesses tended to be smaller (three quarters had fewer than 20 full-time employees), older (more than 20 years in operation), and less involved in foreign trade than their small economy counterparts. Moreover, Caribbean firms were concentrated in tourism and retail, and ownership was predominantly local.

Mohan, Strobl, and Watson (2016) also used the LACES dataset to identify the relationship between productivity and innovative activity at the firm level in the Caribbean. The findings show that innovative firms exhibited higher labor productivity compared to non-innovative firms,

and differences in firm characteristics accounted for some of the observed differences in productivity, such as size, access to public support for innovation, ownership of patents, export behavior, foreign ownership, and cooperation with other institutions for promoting innovation. However, even after allowing for these differences, the productivity mean for innovative firms was higher and there was less dispersion in productivity than for non-innovative firms.

In a follow up study Mohan, Strobl, and Watson (2017) used the Productivity, Technology, Innovation (PROTEqIN) survey to explore the impact of barriers to innovation in the Caribbean. The study showed that the proportion of firms that were innovators was relatively small (26 percent of surveyed firms), but there was a larger proportion of potential innovators (59 percent of surveyed firms). The study also provided empirical results showing that financing and cost, market, knowledge, and policy and regulation barriers negatively affected innovation, with the cost barrier having the largest negative impact. Moreover, potentially innovative firms experienced more stringent barriers than existing innovators, regardless of the barrier considered.

There is currently no empirical research on COVID-19 related to firm productivity and innovation in Caribbean SIDS. COVID-19 has nonetheless transformed the private sector, be it in the Caribbean or internationally. It has brought with it a dramatic reduction in firm sales and a reduction in new market needs. In particular, it has been difficult for micro and small firms that lack the resources to absorb the shock, as well as for firms in retail and tourism. According to the OECD as many as 2.7 million companies in Latin America and the Caribbean are likely to close, most of them micro-enterprises, which would incur the loss of 8.5 million jobs (OECD et al. 2020).

Firms have had to be innovative to survive during the COVID-19 crisis. They have had to change their operations and economic activities. The use of the internet and the adoption of digital technologies have been critical to sustaining continuity in most businesses. Businesses have launched new products and services and/or adapted to remote, teleworking, and other flexible ways of working, as well as to virtual meetings using information communications technology and digital technology (Santos, 2020). However, in the Caribbean there is a huge digital divide, notably a lack of high-speed broadband internet and a lack of appropriate digital skills. Women have also been disproportionally affected by the crisis in the region, whether at home or in the private sector, which may place female owned and managed firms at a disadvantage. There has also been a push for green growth strategies as economies seek to rebuild, given that the climate crisis in the Caribbean requires urgent attention.

4

DATA AND METHODOLOGY

4.1. Data

Our data source is the 2021 IFPG firm-level dataset for the Caribbean collected by the Compete Caribbean Partnership Facility, a multi-donor program financed by the Inter-American Development Bank, the United Kingdom's Foreign and Commonwealth Development Office, the Caribbean Development Bank, and the Government of Canada. This data is a representative cross-sectional enterprise survey covering 1,979 firms across 13 Caribbean countries (Barbados, Belize, Jamaica, Guyana, Suriname, Antigua-Barbuda, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, the Bahamas, and Trinidad and Tobago) across all sectors, and conducted in 2020 during the COVID-19 pandemic.[2]

While the survey collected a vast array of information related to firm performance, the study here is focused on three groups of variables. The first set relates to the factors that determine a firm's production function in order to estimate technical efficiency. In this regard, information was used to estimate technical efficiency during two phases, the pre-pandemic phase and the COVID-19 phase. For the former, respondents were asked to provide information on total sales, and the breakdown of the cost of inputs, where these were grouped into the net value of fixed assets, costs of labor, and outlay on other inputs (raw materials, energy, etc.). For the latter, where the survey was undertaken during the pandemic, respondents were asked whether sales and outlays on labor and other inputs would be negatively affected by COVID-19, and, if so, by what percentage. Using this information, an outline of expected sales, labor costs, and input expenditure during COVID-19 was drawn up. Since no specific question was raised concerning the expected effect on the net value of assets, it was assumed that this would be the same as for the previous period.

The second group of variables processed from the data set were those relating to innovation. In this regard, enterprises were asked whether they had introduced any general

[2] For further details of the data collection see IDB (2021).

innovations related to a variety of areas, including new goods or services, methods of production, logistics, information processing and communication, methods for accounting and administrative operations, business practices, work organization, and promotion. If the answer in any of these cases was affirmative, we created dummy variables to indicate as such. The respondents were also asked if any of these innovations were negatively affected by the COVID-19 crisis, and we similarly created a categorical variable to represent this. Businesses were also asked whether they had introduced, since the advent of COVID-19, any new innovation, in any of the categories listed above, and for this we also generated an indicator variable. A set of questions was also posed with regard to 'green' innovations in the last three years, where these were defined as innovations leading to environmental improvements intentionally or unintentionally related to reduced material consumption, reduced energy consumption, reduced CO_2 footprint, less polluting or hazardous materials, reduced soil, water, noise or air pollution, or recycled waste, water, or materials. Again, businesses were asked whether such innovations were affected by COVID-19 and if similar new innovations had been introduced following the outbreak. In the same way as for general innovations, dummies were created to look at green innovations in the past, asking whether these innovations were affected by COVID-19, and if any new innovations had been introduced since the outbreak.

The third body of information extracted from the Survey consists of general enterprise features that could pertain to technical efficiency, including share of the largest owner/manager, share of foreign ownership, share of state ownership, whether the largest owner/manager was female, and the years of experience of the manager/owner. Names and definitions of all variables used in the empirical analysis are provided in Tables 1 and 3.

4.2. Methodology

In the traditional approach to productivity analysis by non-frontier models, there is the assumption that all economic agents are efficient and productivity growth takes place as a movement of the production frontier, i.e., technical change (Solow, 1957). In the event of technical inefficiency, the estimation of technical progress would be biased, and even in the absence of inefficiency, the accounting estimation of total factor productivity would be biased if individuals do not minimize cost, i.e., exhibit allocative inefficiency. The frontier approach accounts for possible inefficient behavior by measuring inefficiency as the potential increase in the observed value of production against the maximum technically achievable value defined by the production frontier (Coelli et al. 2005). To calculate a firm's inefficiency a SFA was employed, that assumes that the form of the production function is known and therefore other parameters of the production technology need to be estimated. Importantly, SFA allows for the measurement of inefficiency and any external shocks outside the control of the firm, such as COVID-19, and which affect output level (Coelli,1996; Coelli et al., 2005; O'Donnell, Chamber, and Quiggin, 2009; Wadud, 2003). This was estimated as follows:

$$\ln Y_i = \beta_0 + \beta_1 \ln(K_i) + \beta_2 \ln(L_i) + \beta_{13} \ln(M_i) + \beta_x X_i + (V_i - U_i) \quad (1)$$

where: where: i = 1,..., N are the number of firms in the sample; Y_i = sales from firm i; K_i = net value of fixed assests for firm i; L_i = total expenditure on labor for firm i; M_i = total value of other inputs i; X_i = vector of country and sector of operation indicator variables; V_i = error term for firm i; U_i = a non-negative random variable for firm i, accounting for technical inefficiency in the production function.

Crucially, the error term in (1) is broken down into two components. The first error component, V_i, is assumed to follow a symmetric distribution and is the standard error, and the other component, U_i, pinpoints the firm's technical inefficiency and is modelled to follow an exponential distribution, therefore calculated using the mode of its distribution. One should note that the variance of *U* was allowed to differ by country and sector of firms, and that standard errors were clustered at the country-sector level.

The concept of technical efficiency (*TE*), defined simply as $-U_i$, was used in all subsequent analysis to ease interpretation. Accordingly, if TE is equal to zero the firm is defined as being technically efficient and is at its maximum output level given the inputs used and technology available. If *TE* is less than zero the firm is defined as being technically inefficient. Equation (1) was estimated separately, in terms of firms' sales and inputs for the fiscal year preceding COVID-19 (TE_{PC}) as well as expected sales and inputs implemented in the wake of COVID-19 (TE_C), providing a pre-COVID-19 and an expected COVID-19 inefficiency score for each firm.

To determine whether COVID-19 induced general innovations or green innovations affecting a firm's efficiency, the following linear model was estimated separately for TE_{PC}:

$$TE_{PC} = \alpha_0 + \alpha_1 INNOV + \alpha_2 GREEN + \alpha_Z Z + \varepsilon_i \quad (2)$$

where: *INNOV* is an indicator variable of whether the firm introduced any kind of innovation in the last three years; *GREEN* is an indicator variable showing whether the firm introduced any green innovation in the last three years; and Z is a vector of other potential factors related to the technical efficiency of firms, as evidenced by the data, including predominantly female ownership or shareholder indicator variable (*FEMALE*), percentage of foreign ownership (*FOREIGN*), percentage of state ownership (*STATE*), years of experience of manager/owner (EXPERIENCE), an indicator variable for export activity (*EXPORT*), and percentage of ownership of largest owner (*LOWNER*). Equation (2) is estimated using OLS, clustering standard errors at the country-sector level. One should note that in this second stage we make the crucial assumption that the covariates included were not omitted variables correlated with the inputs in Equation (1). One should note that this may induce some inefficiency in the estimates in (1).[3]

Equation (2) was also estimated for the expected values owing to COVID-19, but several additional determinants related to the impact of COVID-19 were added:

$$TE_{PC} = \alpha_0 + \alpha_1 INNOV + \alpha_2 GREEN + \alpha_3 INNOVAFF + \alpha_4 GREENAFF + \alpha_5 INNOVCOV + \alpha_6 GREENCOV + \alpha_Z Z + \alpha i \quad (3)$$

where: *INNOVAFF* is an indicator variable determining whether an innovation implemented in the three years prior to COVID-19 was affected by the pandemic; *GREENAFF* is an indicator variable to determine whether the innovation implemented in the three years prior to COVID-19 was affected by the pandemic; *INNOVCOV* is an indicator variable indicating whether any innovation was introduced since the outbreak of COVID-19; and *GREENCOV* is an indicator variable indicating whether any such innovations were 'green'. Equation (3) is similarly estimated with OLS with standard errors clustered at the country-sector level.

[3] We did experiment with estimating a model that specifies the mean of the truncated normal distribution in terms of a linear function of the inputs, but this produced abnormally high standard errors; the implication that all inputs were insignificant predictors of output is likely to be unrealistic.

Finally, Equation (3) was re-estimated, but in this instance using the difference between technical efficiency before COVID-19 and the expected technical efficiency arising from COVID-19 (ΔTE) as the dependent variable, thus allowing one to determine factors associated with any expected changes in technical efficiency, as opposed to just levels of technical inefficiency. This means that any fixed unobservable remaining in the technical inefficiency terms can be removed by the first difference. Also, conceptually, innovation is a shift in the production function and in technical efficiency, so an innovation-augmented production function is better estimated in first difference. Given the limited nature of our data, ie., that it is cross-sectional and lacks extensive controls, it can be argued that all estimated coefficients are to be interpreted causally.

5

RESULTS

5.1. Production Function

Summary statistics of the variables used in estimating the stochastic production function, that is, Equation (1) are provided in Table 1. The average annual sales of the firms for the fiscal year prior to COVID-19 in the sample were US$ 2.5 million, but with considerable variation, hinting at large differences in firm size across sectors and countries. Examining the production function inputs, on average the costliest input was other input (inputs other than capital and labor), constituting nearly 52 percent of total input costs. In contrast, the capital stock cost was 35 percent, while the cost of labor was the cheapest, at 13 percent. During COVID-19 firms anticipated that their output would fall by 23 percent on average, while the costs of labor were anticipated to rise by over 70 percent, and the outlay on other inputs was likely to increase marginally. As noted above, because of data restrictions there was an assumption that the value of the capital stock remained constant prior to and during COVID-19. A study by Acevedo et al. (2021) using the IFPG data set supports this where it was found that approximately 2 percent of firms expected conditions to worsen related to working capital or fixed assets since the pandemic.

The results from estimating the stochastic production frontier are provided in Table 2, where Column (1) provides the results for the fiscal year previous to COVID-19 and Column (2) results during COVID-19. All inputs are highly statistically significant and positive. Given that output and inputs are estimated in log form, the estimated coefficients are interpreted as elasticities. Prior to COVID-19 the elasticity of other input (other than capital and labor) was highest, at 55 percent, followed by labor at 45 percent and capital at 2 percent. The estimated elasticities for the expected values of production inputs under COVID-19 were similar to those from the previous fiscal year (other input- 59 percent, labor- 36 percent, and capital- 5 percent). A z-test for each input in both periods could not reject the null hypothesis that they are not statistically different. One should note that for both periods one could reject the null hypothesis of constant returns to scale.

The estimated technical efficiency of the production function for the fiscal year previous to COVID-19 and the expected values during COVID-19, as well as their difference, are all shown in Table 2. The average technical efficiency was –0.0324 in the year preceding COVID-19, and is expected to fall to –0.0664 due to COVID-19, that is, over 100 percent. A t-test confirmed that the fall is statistically significant. There is also considerable variation (three times the mean) in technical efficiency across firms, in the year before COVID-19 and during COVID-19, as well as the difference between these two.

5.2. Determinants of Technical Efficiency

Summary statistics for firm innovative activity and the explanatory variables affecting technical efficiency estimated in Equations (2) and (3) are shown in Table 3. As can be seen, around 40 percent of firms carried out some form of general innovation over the three years prior to the pandemic, and almost 50 percent underwent some sort of green innovation. Of those implementing general innovation, approximately 11 percent felt that their innovation had been affected by COVID-19, and out of those firms conducting green innovations, 43 percent considered they had been affected by the pandemic. COVID-19 induced a little over 11 percent of firms to be innovative in a general sense, and 17 percent in an environmentally friendly sense. Looking at firm characteristics, the largest owner across the sample owned about 12 percent of the firm, whereas foreign and state ownership were on average 8 and 0.1 percent, respectively. Firm managers/owners had around 21 years' experience, and approximately 23 percent were female. A little over a third of firms did some exporting.

Results of estimating Equation (2), which looks at the pre-pandemic period, are provided in Column (1) of Table 4. General innovations increased technical efficiency. On the other hand, green innovations reduced technical efficiency. A t-test of the sum of the coefficients suggests that one cannot reject that the sum of the coefficients is significantly different from zero. With regard to non-innovation related factors, only manager/owner's experience was statistically significantly associated with technical efficiency of a firm, indicating that more experience leads to lower technical efficiency.

Examining the results from Equation (3), which focuses on the period during COVID-19, one finds that there is an overall efficiency-boosting effect of general innovation, and that this effect is greater if the innovation was not affected by COVID-19 than in the case of those innovations taking place in the previous fiscal year, and, moreover, significantly so (as suggested by a z-test). However, for the firms where this innovation was said to be affected by COVID-19, the technical efficiency effect was significantly reduced. However, a t-test suggests that even for such firms, an overall positive impact of innovation on efficiency remains. In contrast, there was no significant effect from innovation undertaken as a result of COVID-19. There was no impact from green innovation introduced over the last few years, regardless of whether it was stated to have been affected by COVID-19, or in terms of green innovation introduced in response to the pandemic. In terms of the non-innovation related variables, again, only experience was a (negative) significant predictor of technical efficiency. While the impact of this was somewhat greater on predicted technical efficiency, a z-test suggests that the difference is not statistically meaningful.

The final regression exercise involves using the change of technical efficiency as the regressor, controlling for the same factors as used in Equation (3). Accordingly, of the non-innovation factors included in the empirical model, only LOWNER was significant, suggesting

TABLE 1
SUMMARY STATISTICS: PRODUCTION FUNCTION

Variables	Definition	Mean	Std dev	Min	Max
Y_{PC} (US$ million)	Sales	2.544	13.34	0.00587	490.8
K_{PC} (US$ million)	Capital Stock Value	0.475	1.902	0.000531	49.11
L_{PC} (US$ million)	Labor Cost	0.193	0.707	2.80e-05	10.82
M_{PC} (US$ million)	Cost of Other Inputs	1.317	9.404	0.000470	369.0
Y_{C} (US$ million)	Sales	1.939	11.22	0.000912	417.2
K_{C} (US$ million)	Capital Costs	0.475	1.902	0.000531	49.11
L_{C} (US$ million)	Labor Cost	0.330	1.333	3.39e-05	21.78
M_{C} (US$ million)	Cost of Other Inputs	1.247	9.408	0.000470	369.0
TE_{PC}	Technical Efficiency	-0.0348	0.175	-2.792	0
TE_{C}	Technical Efficiency	-0.0518	0.218	-3.571	0
ΔTE	TE_{PC}-TE_{C}	-0.0170	0.160	-2.309	0.876

Source: Authors' compilation based on the IFPG database.

TABLE 2
TECHNICAL EFFICIENCY ESTIMATION RESULTS

	(1)	(2)
log(M)	0.551***	0.585***
	(0.0179)	(0.0179)
log(K)	0.0194***	0.0449***
	(0.00646)	(0.00853)
log(L)	0.454***	0.360***
	(0.0226)	(0.0237)
SAMPLE:	PRE-COVID-19	COVID-19
Observations	1,883	1,883

Source: Authors' compilation based on the IFPG database.
Notes: (i) Country-sector clustered standard errors in parentheses, (ii)***, **, and * indicate 1, 5, and 10 percent significance levels, (iii) Country and sector dummies included but not reported, (iv) where σ_{μ} is modelled as a function of country and sector dummies.

that the larger the share of the largest owner, the greater the increase in expected technical efficiency. As for the expected technical efficiency regression in levels, one finds that general innovations undertaken in the three years prior to the pandemic and that were affected by COVID-19, reduced technical efficiency. Furthermore, the additional innovations introduced due to COVID-19 also lowered technical efficiency. If a green innovation was implemented prior to the pandemic and was affected by it, then this increased expected technical efficiency.

TABLE 3
SUMMARY STATISTICS – TECHNICAL EFFICIENCY DETERMINANTS

Variables	Definition	Mean	Std dev	Min	Max
LOWNER	% of largest owner	12.27	51.84	0	99
FOREIGN	% of foreign ownership	8.482	23.79	0	100
STATE	% of state ownership	0.0795	1.783	0	45
EXPERIENCE	Experience of owner (years)	21.25	13.25	1	58
EXPORT	Export incidence	0.364	0.481	0	1
FEMALE	Female owner incidence	0.227	0.419	0	1
INNOV	Innovation incidence before COVID-19	0.389	0.488	0	1
INNOVCOV	Innovation incidence during COVID-19	0.119	0.324	0	1
INNOVAFF	Innovation affected by COVID-19	0.415	0.693	0	4
GREEN	Green innovation before COVID-19	0.497	0.500	0	1
GREENAFF	Green innovation affected by COVID-19	0.437	0.496	0	1
GREENCOV	Green innovation during COVID-19	0.172	0.377	0	1

Source: Authors' compilation based on the IFPG database.

TABLE 4
TECHNICAL EFFICIENCY DETERMINANTS ESTIMATION RESULTS

	(1)	(2)	(3)
INNOV	0.0350***	0.0757***	0.0244
	(0.0120)	(0.0183)	(0.0171)
GREEN	-0.0380***	-0.0165	-0.00943
	(0.0120)	(0.0206)	(0.0180)
INNOVAFF		-0.0540***	-0.0343**
		(0.0160)	(0.0159)
INNOVCOV		-0.0167	-0.0412***
		(0.0153)	(0.0143)
GREENAFF		-0.00195	0.0354*
		(0.0206)	(0.0181)
GREENCOV		0.0112	-0.0163
		(0.0170)	(0.0121)
LOWNER	-8.67e-05	8.34e-05	0.000182*
	(0.000110)	(0.000116)	(0.000108)
FOREIGN	-0.000328	-0.000130	0.000206
	(0.000378)	(0.000261)	(0.000190)
STATE	0.000408	0.000217	0.000326
	(0.000249)	(0.000537)	(0.000479)
EXPERIENCE	-0.000796**	-0.00120**	-0.000394
	(0.000319)	(0.000473)	(0.000362)
FEMALE	0.00435	-0.0128	-0.0157
	(0.00850)	(0.0150)	(0.0122)
EXPORTER	-0.0226	-0.0101	0.0123
	(0.0162)	(0.0135)	(0.00992)
Constant	0.000134	-0.0190	-0.0154*
	(0.0106)	(0.0138)	(0.00862)
Sample:	PRE-COVID	COVID	COVID
Observations	1883	1883	1883
R-squared	0.029	0.026	0.030

Source: Authors' compilation based on the IFPG database.
Notes: (i) Country-sector clustered standard errors in parentheses, (ii)***, **, and * indicate 1, 5, and 10 percent significance levels.

6

DISCUSSION

6.1. Policy Implications

This paper provides empirical evidence on firm production efficiency and innovation strategy during COVID-19. It is arguable therefore, that it has significant policy relevance for Caribbean governments, given that the region aims to develop the private sector post-COVID-19, by designing and implementing appropriate policies and incentives for firms to grow and engage in innovative activity and reduce market failures. The findings suggest that as a result of the pandemic, firms expect their technical efficiency to fall (over 100 percent), driven by a fall in output (23 percent) and increased input costs (over 70 percent of labor costs). This highlights the need for governments in the region to increase credit support and financial assistance to firms, thereby cushioning the impact of the crisis, which is essential for their survival. Banks and other financial institutions in the region have also introduced measures to help businesses with their financial obligations, such as waiving late payments and offering short-term payment deferrals. While these measures help to mitigate the immediate impacts of the pandemic, they are not sufficient to drive long-term recovery of businesses. Song, Yang, and Tao (2020), in a study of firms in China, called on the finance providers to amend their policies and provide firms with the required finance to cope with the repercussions of COVID-19. In addition, a study by the IDB (2022) for the Caribbean, provides empirical evidence that firms in the region face severe challenges compared to other countries when it comes to access to finance, given the lack of depth and development of its financial markets. These conditions significantly deteriorated during COVID-19 with small and micro firms and women-owned firms being most adversely affected. The study recommends efforts targeted at macroeconomic stability and policy prudence, availability of credit information, and enforcement of property rights, contracts, and processes of resolving insolvency to support faster financial development in the region, thereby improving firms' access to credit.

The results of this study further showed that, prior to the pandemic, firms had implemented general innovations (40 percent) and green innovations (50 percent), but that a significant proportion of these innovations were negatively affected by COVID-19 (40 percent). Moreover, only a small number of firms were innovative during the outbreak (11 percent for general innovations and 17 percent for green innovations). According to Acevedo et al. (2021), firms in the region, and in particular small firms, have been less able to adopt digital solutions as innovations to cope during the pandemic. The results of the paper further show that when innovations were undertaken, the type of innovation realized mattered. General innovations implemented before the pandemic helped to improve technical efficiency, while similar innovations employed during COVID-19 did not have a boosting effect. On the other hand, green innovations implemented both before and during the pandemic did not improve technical efficiency and even negatively affected it. These results, supported by the findings of Adam and Alarifi (2021), Krammer (2021) and Han and Qian (2020,) in studies outside the Caribbean, have confirmed that the innovation practices of firms have a significant and positive effect on business performance and served to increase the chances of survival for these enterprises during COVID-19.

The findings of this study advocate the need for government incentives to boost firm innovation overall, not only through difficult times, in particular general innovations, and government support to remove barriers to innovation, since innovative firms stand a better chance during downturns. Mohan, Strobl, and Watson (2017) show that the most severe obstacles to innovation in the Caribbean, pre-COVID-19, are financing and cost barriers, followed by knowledge barriers, then market policy and regulation barriers. These barriers may play a more devastating role during COVID-19, in particular, cost barriers (IDB, 2022) and knowledge barriers (Acevedo et al., 2021). Public incentives to promote innovation can be directed towards supporting the existing innovation infrastructure already in place, or towards fostering new initiatives and ramping up such initiatives in times of crisis. In the Caribbean, government support during the pandemic focused primarily on supporting the continuation of business operations rather than innovative activities. Instead, Caribbean governments, in times of crisis, for example, COVID-19, should remove barriers to funding innovation (IDB, 2022) and promote the adoption of digital solutions and innovations (Acevedo et al., 2021) with a focus on small and female owned firms. Adam and Alarifi, 2021) showed that external support provided to small and micro firms in Saudi Arabia in the form of training, consultancy, or finance, had a significant role to play in improving the relationship between innovation practices and enterprise survival during COVID-19, which could similarly help firms in the Caribbean.

This study has implications for firm innovation strategy in times of crisis. The results suggest that firms should continue to implement innovative activity before and during an external shock. Firms implementing innovations before COVID-19 experienced an improvement in their technical efficiency. These firms would therefore prove better able to adapt to the challenges imposed by the pandemic. Acevedo et al. (2021) show that Caribbean firms that adopted measures to avoid supply chain disruptions and expand access of digital payments and telecommunications performed better during the pandemic. This was particularly the case with general innovations and not necessarily with green innovations. The finding for green innovations is unsurprising and is in line with existing studies. While the literature confirms a positive relationship between green innovation

and environmental performance (Chen, 2008), these innovations do not necessarily improve firm performance (Rexhäuser and Rammer, 2014). In the Caribbean while green innovations can help improve the environment, firms need to pay more attention to how they appropriate their financial returns.

6.2. Limitations of the study

The econometric analysis presented in this paper is limited by the data available and the statistical models employed. To estimate the effects of COVID-19 on productivity one should strive for unbiased estimates of the production function elasticities and productivity. There are, however, important identification issues that challenge the estimation of production functions using OLS and these are well documented in the literature (Van Beveren, 2012). For one, there is endogeneity in the form of simultaneity, as the observed inputs (labour, capital and other) may be correlated with unobserved inputs such as managerial ability, quality of materials, and capacity utilization and productivity shocks like COVID-19. This correlation introduces biases in the estimators of the production function parameters. Moreover, these inputs are not independent because firms set them with the aim of profit maximization. The literature recommends the use of instrumental variables in the case of cross-sectional data such as factor prices. However, such an approach cannot be used for this study since the dataset falls short of providing plausible instruments for the endogenous variables.

The production function also suffers another endogeneity problem, that of selectivity bias, since the sample of firms may not be random. A firm's decision to be active in the market depends on its productivity level and its fixed inputs stock. Firms with a large capital stock may find it profitable to stay active in the market even if they face a negative productivity shock such as the pandemic. Hence, the fixed input stocks and the unobservable productivity levels of the firms observed are negatively correlated. If firm selection is not accounted for, the production function parameters for fixed inputs such as capital are overestimated. In the literature survival probabilities are calculated for observed firms in order to account for this selectivity bias (Olley and Pakes, 1996). A firm chooses its investment level as a function of its productivity and the firm's demand for investment can be used to back up the unobservable productivity. The data set used here prevents the calculation of such survival probabilities since a full panel does not exist to provide attrition rates.

The methodology employed in this study also suffers from omitted price bias because of the lack of firm level input and output prices. This occurs when the production function is estimated using sales revenue and/or input expenditure data, when output and or input prices are not equal across firms. It is common that these biases are not addressed in empirical studies because data on output and input prices specific to each firm are generally not available. Another weakness is that firms make production decisions at a more disaggregated level than is observed in the survey data, and firms' product choices are likely to be related to their individual productivity (Bernard et al., 2009). This productivity bias arises when endogenous product selection is not accounted for. Solving this bias, however, requires data on the evolution of firms' product mix over time but which is generally unavailable in firm survey data.

7

CONCLUSIONS

COVID-19 induced a complex global crisis in that the virus is as contagious economically as it is medically. While Caribbean countries have been exposed to frequent external shocks, in particular climatic events, the pandemic is like no other. Social distancing measures implemented by Governments to save lives brought economic activity to a near-standstill, affecting demand and supply sides of the value chain, leading to severe economic contraction, and closure of businesses. This paper has aimed to contribute to a better understanding of the COVID-19 pandemic on Caribbean firms' performance and innovation using the IFPG firm-level dataset and a SFA framework. It has provided empirical evidence on how the persistence of innovation and the type of innovation (general and green) have possibly helped firms to mitigate the negative effects of the crisis. Caribbean firms that implemented innovations prior to and during COVID-19 demonstrated improved technical efficiency, compared to firms that did not, while firms that employed green innovations before and during the pandemic did not experience a similar boost in technical efficiency. The findings arguably have significant policy relevance for the Caribbean, as government policy aims to develop the private sector by designing and implementing appropriate policies and incentives for firms to grow and engage in innovative activity and reduce market failures. It also provides valuable information for entrepreneurs and managers when crafting innovation strategy during a crisis, such as introducing new products and processes, marketing and organizational innovations and green innovations that may improve firm performance.

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