Static and Dynamic Economic Resilience Indicators for Agrifood Supply Chains: The Covid-19 Pandemic in Latin America and the Caribbean

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Abstract

Given its enormous adverse effects on production systems and the economy, the recent COVID-19 pandemic has heightened interest in studying resilience in agrifood systems; however, only a few studies have used formal methods for resilience measurement. This study's overall objective was to identify, develop, and use indicators to measure the resilience of the agrifood supply chain. Specific research objectives were 1) to identify and develop survey-based indicators of the economic resilience of agribusinesses; 2) to use the indicators to measure and analyze the economic resilience of the agrifood supply chain in Latin America and the Caribbean (LAC) to the COVID-19 pandemic; and 3) to evaluate differences in the economic resilience of agribusinesses in the different supply chain stages to the COVID-19 pandemic. Data for the study were collected through two online surveys conducted in 2020 and 2022. Two resilience indicators were identified and developed: a static (SRES) and a dynamic (DRES) indicator. SRES measures the ability of businesses to avoid business losses within each study period. DRES measures firms' capacity to recover business activity after an initial negative revenue shock. Study results reflect that, on average, the LAC agrifood supply chain firms in the sample were able to adapt and recover from the disruptions of a global health pandemic. The effects of the pandemic were not homogeneous across firms, nor was their adaptive resilience to the disruption.

Introduction

The Oxford English Dictionary (OED) defines resilience as "elasticity; the power of resuming an original shape or position after compression, bending, etc.," and "the quality or fact of being able to recover quickly or easily from, or resist being affected by, a misfortune, shock, illness, etc.; robustness; adaptability" (Oxford English Dictionary [OED], 2022). For its part, the Intergovernmental Panel on Climate Change (IPCC) provides the following definition: "the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure while also maintaining the capacity for adaptation, learning and transformation" (IPCC, 2018). Although the first reference of the term dates to the seventeenth century (OED, 2022), it was not until 1973 when the ecologist Crawford Stanley Holling proposed its use as a quantifiable characteristic of a system, i.e., "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973). The term has also been adopted in the social and environmental sciences to denote characteristics of individuals, households, and communities (e.g., Béné, 2020; Rose, 2009; Werner, 1992). For example, one definition of food system resilience is "the capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances" (Tendall et al., 2015).

Given its enormous adverse effects on production systems and the economy, the recent COVID-19 pandemic has heightened interest in studying food systems and agriculture resilience.[1] A literature review on Google Scholar using the keywords "pandemic" and

[1] Throughout the manuscript we use the term agrifood system instead of food system, as many important agricultural products are not used as food (e.g., cotton, rubber, and ornamentals).

"resilience" and "agriculture" resulted in thousands of pages of papers related to these terms. However, only a few studies used formal methods for resilience measurement. Béné (2020) argued that one reason behind the paucity of quantitative studies is the lack of conceptual models and measurement approaches related to agrifood systems resilience. Therefore, this study's overall objective was to identify, develop, and use indicators to measure the resilience of the agricultural supply chain in LAC during the COVID-19 pandemic. Specific research objectives were 1) to identify and develop survey-based indicators of the economic resilience of agribusinesses[2], 2) to use the indicators to measure and analyze the economic resilience of the LAC agrifood supply chain during the COVID-19 pandemic, and 3) to evaluate differences in the economic resilience of agribusinesses in the different supply chain stages to the COVID-19 pandemic.

This study makes three main contributions to the literature. First, we introduce the static economic resilience indicator to analyze agrifood supply chains. This indicator, used to evaluate the economic impact of disasters, has not been used to analyze agrifood supply chains (Dormady et al., 2019; Rose, 2004, 2007, 2017). We expand on this literature by suggesting additional dynamic and static resilience indicators, which can be used to study resilience along the entire agrifood supply chain. Second, we show how the indicators can be calculated using survey data. Finally, we provide one of the first quantitative assessments of the resilience of agribusiness in LAC during the pandemic of COVID-19.

[2]The terms "agribusiness" and "enterprise," "firm" or "business" of the agrifood chain are used synonymously. The terms refer to small (e.g., an individual agricultural producer), medium, or large (e.g., a dairy processor belonging to an international company) business units that carry out productive and/or commercial activities with agricultural, fisheries, and/or forestry sectors products.

Literature Review

A body of literature has already emerged on the concept of the resilience of food systems (e.g., Béné, 2020; Pingali et al., 2005; Tendall et al., 2015). A key component of these conceptualizations is identifying a close link between food systems' resilience and the "stability" dimension of the "food security" concept (Tendall et al., 2015).[3] More resilient food systems are generally considered more stable.

Given the conceptual link between resilience and food security, a significant focus of the literature measuring agricultural and food systems resilience is the effect of disasters on households' food security, predominantly small agricultural households (Béné, 2020). For example, the WFP/FAO "Resilience Measurement Technical Working Group" proposed a "resilience model" with the food security of households as the primary outcome of interest and vulnerability, resilience capacity, and shocks as the predictors (Constas et al., 2014).

The focus on small agricultural households is justified given the current agricultural and food system structure in low- and middle-income countries, which still rely significantly on small producers to feed their populations (Samberg et al., 2016). The emphasis on small agricultural households is not without shortcomings. First, the approach mixes the role of farm households as consumers and producers; however, in many instances, the information needed (e.g., for policy analysis and decisions) is only related to agricultural production activities. Second, the concentration on small producers leaves many agricultural producers and other

[3] A widely accepted definition of food security states that "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit 1996). This definition recognizes four dimensions of food security: food availability, food access, utilization, and stability (Food and Agriculture Organization of the United Nations [FAO], 2006).

agricultural and food supply chain stages (e.g., processors, input providers, and distributors) out of the analyses.

The literature measuring resilience in agrifood systems also seems to conflate three concepts: resilience per se, resilience capacities, and resilience outcomes (Béné, 2020). Whereas resilience is the actual ability of the food system to withstand or recover from shocks, resilience capacities are the elements the actors of the food system have at their disposal to respond to disruptions (Béné et al., 2015; Béné, 2020). These elements include financial capacities (e.g., savings, access to credit), social capital (e.g., connections and networks), and human capital (e.g., knowledge and education). Finally, what are often reported or discussed as agrifood measurements of resilience are the outcomes of resilience, including food security and nutrition indicators (e.g., Feed the Future FEEDBACK, 2015; Hirvonen et al., 2021).

A string of literature has also emerged in economics related to the economic resilience to disasters (e.g., Rose, 2007; Rose 2017; Dormady et al., 2019). The most recent contribution to this literature focused on a production theory framework for analyzing resilience at the firm level (Dormady et al., 2019). In addition to presenting a theoretical framework for the analyses of economic resilience, these authors also provided theory-based operational metrics of economic resilience and suggested approaches for cost-effectiveness and trade-off analyses of resilience tactics at the firm level. This theoretical development is important for studying resilience in supply chains, as it can be consistently applied to all the chain stages.

In summary, there is already a body of literature on the conceptualization of agrifood systems resilience. In most cases, resilience has been linked to the stability dimension of the food security concept; thus, many efforts to develop operational metrics of resilience have focused on this link, mainly in the context of small agricultural households in low- and middle-income countries. The literature review also demonstrates that the measurement of an agrifood system's resilience ability is conflated with resilience capacities and outcomes. A production theory approach has been proposed recently to analyze economic resilience. We use these theoretical developments as the framework for our empirical analyses.

Theoretical framework

The framework for the analysis is based on the definitions and characterizations of economic resilience put forward by Adam Rose and coauthors (Dormady et al., 2019; Rose, 2004, 2007, 2017). These authors distinguished two dimensions of economic resilience: static and dynamic. Static economic resilience is the efficient use of resources at a given time to maintain high-performance levels after a shock. Dynamic economic resilience is the efficient use of resources over time to achieve system recovery after the shock. Both definitions highlight a shock or disruption to the system, emphasize the efficient use of resources, and imply economic agents' optimizing behavior.

The metrics for static resilience used in this study are based on the direct static economic resilience index (SRES) proposed by Rose (2009) and Dormady et al. (2019). This indicator is intended to measure the amount of business activity reduction prevented by implementing resilience tactics relative to the maximum business reduction given a shock. It is calculated as follows (Rose, 2009):

$$SRES_t = [(\%\Delta DYmax_t - \%\Delta DY_t)/\%\Delta DYmax_t]x100, \quad (1)$$

where $\%\Delta DYmax_t$ is the estimated maximum percent reduction in business activity, $\%\Delta DY_t$ is the actual percent reduction in business activity, and the index t denotes the time. Therefore, the index provides an easy-to-understand and direct measure of the resilience of agribusinesses to disruptions. Moreover, the index underlines firms' optimizing behavior and response to shocks.

$\%\Delta DYmax_t$ measures the loss of business activity if a firm does not adjust the production process after a shock. $\%\Delta DY_t$, in contrast, gauges the change in business activity after the firm adjusts the production process. The difference between $\%\Delta DYmax_t$ and $\%\Delta DY_t$ corresponds to the loss prevented due to the adjustments (Figure 1a). A 0% value indicates the lowest levels of static economic resilience, and 100% indicates the highest possible static resilience level.

The following dynamic resilience economic indicator (DRES) is proposed:

$$DRES_t = [(\%\Delta DY_0 - \%\Delta DY_t)/\%\Delta DY_0]x100 \quad (2)$$

where $\%\Delta DY_0$ is the reduction in business activity in the period when the shock takes place. The difference between $\%\Delta DY_0$ and $\%\Delta DY_t$ measures the reduction in the gap between expected production and observed production after a shock. Therefore, the $DRES_t$ indicator quantifies the speed of business recovery after the shock (see Figure 1b).

Two versions of each indicator were considered. The first version is related to the original SRES indicator focused on production only (i.e., output)(SRESo and DRESo) (Rose, 2009). The second indicator relates to total revenue or sales (SRESs and DRESs) to capture the ability of agribusiness operations to produce output (e.g., raw or processed agricultural products or related agricultural goods and services, including inputs and services) and sell and distribute it to markets. This is important in the context of the pandemic, where distribution channels were affected, but not the production process in some cases. Moreover, the SRES and DRES revenue-based indicators are the most appropriate for businesses whose output is not measured in quantities but in terms of sales or total revenue (in monetary terms).

There are two options to obtain data to calculate the static resilience indicators. A first approach, in theory, would use output supply, revenue, or production functions to estimate the maximum changes in outputs or revenues and data on actual changes in output or revenues.

However, these functions are usually not available. Therefore, a more realistic approach involves eliciting all the information on observed and estimated maximum changes in output and revenues from producers using survey questions (Dormady et al., 2019). This second approach was used in this study. In contrast, dynamic resilience indicators only require data on changes in output or revenue due to a shock, which can be elicited using surveys or direct observation.[4] The questions used to calculate the resilience indicators are described below.

Data

Data for the study were collected through two online surveys. The first survey was conducted between June and August 2020, during the first year of the pandemic. A total of 1,258 agribusiness participants from 22 LAC countries[5] participated in the first survey by answering the resilience questions. The second survey was conducted between March and June 2022, the third pandemic year, and included 1,209 agribusiness participants from the same 22 countries (we referred to this survey as the 2021 survey as the questions asked were about the business activity of the previous year).[6] The surveys targeted two respondent groups: main actors and supporters of the agricultural supply chain. The main actors in the value chain are those who work as producers, intermediaries, processors, traders, exporters, importers, production technicians, suppliers of inputs or services, or employed in any of the above activities. Supply chain supporting agents include individuals providing support services to the industry, including government officials, policymakers, extension agents, academics, analysts, and consultants.

[4] However, even when the main interest of the analyst is on dynamic resilience, we found the questions about maximum potential changes in output to be useful metrics of the business context.
[5] These include Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Haiti, Honduras, México, Nicaragua, Panamá, Paraguay, Perú, Puerto Rico, Dominican Republic, Surinam, Uruguay, and Venezuela.
[6] Data form the surveys are considered and analyzed as two different cross sections. About 46% of individuals in the first survey provided emails and they were contacted again in the second survey, but only about 10% of these individuals responded to the second survey (i.e., about 60 observations). In addition, our IRB protocol did not allow us to link emails with survey responses.

The study collected information about the pandemic's impact on agribusiness operations' economic conditions (including its effects on profits, costs, revenues, and output prices), challenges, and responses to the pandemic. The surveys also included questions to quantify the economic resilience of agribusiness operations in the region. Finally, the surveys included questions about the characteristics of the agribusiness operation (size, location, and production activities) and the respondent (gender, age, education, and role in the agribusiness enterprise). Agribusinesses in the agrifood value chain were classified into four stages: agricultural production, processing, logistics and distribution, and input suppliers.

The instrument for the first survey was developed by a team of agricultural researchers from six Latin American countries and the United States representing nine organizations involved in research and development activities. A pilot survey was conducted with about 30 respondents and the entire research group to evaluate survey length, flow, and understanding. The instrument used in the first survey was modified slightly for the second round, but most questions remained the same.

Participants were recruited via social media advertisements (Facebook and LinkedIn), emails, and messages (WhatsApp) directed to groups of individuals working in the agricultural supply chain in the region. Survey instruments, advertising, and messages were available in Spanish and Portuguese. Online surveys also provided an inexpensive avenue to reach many agribusiness participants in the region, especially during the first year of the pandemic (in many cases, this was one of the few avenues to reach them). However, it is important to highlight the fact that this results in a convenience sample (i.e., a nonprobability form of sampling with unknown values of the probability of participation) and may not be representative of the entire population of agrifood supply chain firms in the region. Study participants self-select if they want to participate; thus, study results only apply to participants.

Resilience questions

Two sets of questions about resilience were asked in both surveys, one related to the revenue resilience indicator and another to the output resilience indicator. The revenue resilience indicator questions were asked of all agricultural supply chain actors. The output resilience questions were only directed to producers and processors as the output of these agribusinesses is easily measured in terms of quantities produced (see Appendix).

In the first survey, the set of questions associated with the total revenue resilience indicator started with this question: “In relation to what was expected before the pandemic, how do you think the crisis generated by COVID-19 affected your enterprise’s total revenue or total sales during 2020?” Respondents were given four options to answer this question: “increased,” “decreased,” “no change,” and “I don’t know.” Those selecting the “no change” option were not asked a subsequent question to measure the change in business activity due to COVID-19. Those choosing the “increased” or “decreased” option were asked this open-ended follow-up question: “You indicated your total revenue/total sales increased/decreased. By what percentage?” Except for those choosing the “I don’t know” option, which is considered a missing value, answers to this set of questions were used as measures of %ΔDY, the actual percent of change in business activity.

All respondents that responded “increased,” “decreased,” or “no change” in total revenue/total sales due to COVID-19 were subsequently asked the following question: “If your enterprise had not made any effort to adapt to the crisis, how much do you estimate the total revenues/total sales would have decreased?” The answer to this question was used as the measure of %ΔDYmax.

The set of questions related to the output resilience index had a sequence and content similar to the revenue resilience question, except that the words “total output” were used instead of the words “total revenues or total sales” (see Appendix). For example, the first question in the section was, “In relation to what was expected before the pandemic, how do you think the crisis generated by COVID-19 affected your enterprise’s *total output* during the year 2020?”

The time frame for the questions was also changed in the second survey carried out in early 2022. All the questions in the second survey referred to the impact of COVID-19 in 2021; thus, for example, the first question related to total revenue was, “In relation to what was expected before the pandemic, how do you think the crisis generated by COVID-19 affected your enterprise’s total revenue or total sales during the ***year 2021***? (See Appendix).”

Statistical analyses

Given the study’s descriptive nature, we conducted three types of statistical analyses. First, we calculated summary statistics of respondents’ and firms’ characteristics and resilience indicators. Second, we provided graphic descriptions of the distributions of the resilience indicators. Finally, we used regression analyses to evaluate the association between the static and dynamic resilience indicators and businesses and respondents’ characteristics (type of actor, supply chain stage, participation in exports, type of agricultural products, firm size, and time of the survey). Heteroskedastic consistent standard errors were used for inference in the regression analyses.

Results and Discussion

Sample characteristics summary statistics

The characteristics of the sample respondents and the business they represent are summarized in Table 1. Most respondents (66%) were main actors in the agribusiness value chain. Most of the respondents were involved in agricultural production (58%), followed by processing (18%), logistics and distribution (13%), and finally, agrifood input suppliers (11%). Thus, the sample included all actors from the agrifood value chain. Moreover, the sample reflected that most businesses in the chain are involved in agricultural production activities.

The sample also included companies engaged in or related to various agricultural production activities, including fruit and vegetable production (36%), livestock and poultry production (37%), legumes and oilseeds (18%), cereals (26%), tropical export crops (30%), and several other products (all accounting for less than 10% of the sample). Participation in these activities adds to more than 100%, as most agribusinesses are related to more than one agricultural production activity. Regarding regional representation, the sample had a slight majority of respondents from Central America and Mexico (51%) relative to South America (45%). In contrast, the Caribbean region only accounted for 3% of the sample.

Although a large proportion of respondents were in urban areas (72%) and had professional education levels (95%), overall, they represented firms of various sizes, from micro to large enterprises. For example, most respondents (40%) worked with companies with fewer than ten employees, and a significant proportion worked for enterprises with more than 200 employees (18%).

The sample characteristics of survey respondents in 2020 and 2021 were very similar, with a few exceptions. The 2021 survey had a more significant proportion of respondents with professional education (98%) relative to the sample in 2020 (92%). The first survey also had a more substantial proportion of respondents from South American countries compared to Central America and Mexico (51% versus 43%). In contrast, in the second survey, 38% of respondents were from South America, and 59% were from Central America and Mexico.

Although the survey was not constructed to represent the population of agribusinesses in the region, the firm size distribution includes firms of all sizes in various countries. This allowed us to evaluate resilience across firms of different sizes across the region. The distribution of agribusiness in the agrifood chain stages in the sample was also heterogeneous (i.e., percentage of agricultural producers and processors, etc.), although no official regional statistics were available for comparison purposes.

Resilience indicators - Revenue

The calculation of resilience indicators for the agrifood supply chain businesses (agricultural production, processing, logistics and distribution, and input suppliers) required two components. The first was the observed change in business activity, %ΔDY. The second component was the expected maximum losses in business activity had the company not adopted any resilience tactic after the disruption, %ΔDYmax (Table 2). On average, agrifood supply chain actors in the sample experienced an 18.2% and 9% reduction in income due to the pandemic in 2020 and 2021, respectively. Thus, the pandemic's revenue impact was significantly reduced (about one-half or more for all actors) in 2021 relative to 2020. In addition, in both survey periods, the agricultural production stage reported the most significant reduction in revenue, followed by the logistics and distribution and processing stages, and, lastly, the stage composed of agrifood input suppliers. However, the average reduction revenues were not significantly different across stages except for agrifood input suppliers in 2020, who reported the lowest revenue reductions.

The estimated average maximum potential losses due to the pandemic for all respondents were -53.7% and -44.8% for 2020 and 2021, respectively, which indicates that about half of agribusinesses' revenue would have been lost had they not made any changes to their business activities (Table 2). Moreover, the average values of the estimated maximum potential losses were similar across all the supply chain stages. These maximum estimated values reflect overall business conditions due to the pandemic; hence, the adverse business conditions due to the pandemic improved only slightly in their second year (on average).

The average values of the static resilience indicators for revenues (SRESs) across all firms represented in the surveys were 62.9% and 73.2% in 2020 and 2021, respectively. Therefore, agribusinesses in the sample were able to avoid, on average, 62.9% of potential revenue losses due to the pandemic in 2020; the average percentage of revenue losses avoided in 2021 was 73.2%.

When comparing average SRESs across stages, agrifood input suppliers were the most resilient, as they had the highest average indicator values in both survey periods (71.5% in 2020 and 77% in 2021). Conversely, the agricultural production stage was the least resilient from a static perspective, with 61.2% and 71.7% resilience values in 2020 and 2021, respectively. SRESs values in both periods identified food processors as the second most resilient stage and logistics and distribution as the third, although the revenue resilience indicators average for producers, processors, and companies engaged in logistics and distribution were not statistically different.

Because the maximum potential business losses are likely to change from period to period, SRESs indicators should not be compared directly without considering the maximum possible business losses used for the calculations. SRES indices from different periods can be compared directly only when maximum expected losses remain constant over time. As maximum potential losses did not change much in our data (about 20% or less), the increase of the SRESs values between 2020 and 2021 within each supply chain group provided evidence of improvement in average static revenue resilience.

The empirical distributions of the SRESs indicators are presented in Figures 2 to 5. The figures show high levels of heterogeneity in static revenue resilience across and within supply chain stages. For example, Figure 2 shows that during the first year of the pandemic, about 11% of all agribusinesses had SRESs indicator values of 20% or less, indicating that about 1 in 10 firms in the sample could avoid only 20% or less of maximum expected losses during this period. At the same time, about 33.5% of firms avoided 90% or more of the maximum estimated losses during the same period. The proportion of businesses avoiding high losses (i.e., 90% or above) increased to more than 50% in 2021 (see Figure 4). Moreover, the proportion of firms avoiding high losses was higher in the input suppliers stage in both study periods (Figures 3 and 5).

In contrast to the SRES indicators, which do not always allow direct comparisons across time, DSERs indicators provide compatible time metrics; however, panel data is needed to calculate these indices at the firm level. As available cross-sectional information is limited in this study, we calculated the DSERs indicators for each supply chain stage using average observed changes in revenue in each period.

The agrifood chain group with the highest DRESs indicator (56.7%) was the input supplier stage; hence, inputs suppliers in 2021 were able to reduce 56.7% of the revenue losses experienced in 2020. The stage with the lowest DRESs indicator was the food processing stage (49.4%). Therefore, the agrifood supplier stage experienced the fastest rate of recovery and the food processing stage the slowest. In addition, on average, pandemic-induced revenue losses were reduced by at least to about one-half between 2020 and 2021 in all agrifood supply stages.

Resilience indicators - Output

Table 3 shows the average values of observed and maximum expected output losses due to the pandemic and the corresponding output-based SRESo and DRESo indicators. Only agricultural producers and food processors were included in these analyses, as only these two stages provided output-related data. On average, agricultural producers reported a 12.2% and 9.3% reduction in output due to the pandemic in 2020 and 2021, respectively. Food processors reported output reductions of 12.8% and 5.9%. Hence, in the first year of the pandemic, observed output losses were significantly lower than observed revenue losses (see Table 2), but the gap between the two closes in the second year. This provides evidence that revenue losses experienced during the pandemic were more significant than output losses during the first year of the pandemic.

Within each supply chain stage, the average values for maximum expected changes in output were similar across years and analogous to their corresponding maximum expected revenue losses (Table 3). However, when compared across supply chain groups, food processors reported larger maximum expected changes than producers.

The SRESo values suggest a very high level of static output resilience. In 2020, agricultural producers in the sample could avoid 73.8% of potential output losses, similar to the

SRESo of food processors (68.9%). In 2021, the difference in SRESo indicators between agricultural producers and processors was smaller, and the overall values were also very high (about 75%).

In 2020, SRESo indicators for agricultural producers and processors were larger than their corresponding SRESs indicators. This implies that during the first year of the pandemic, these stages were more resilient in terms of output, which also highlights the need to study revenue resilience. In contrast, the 2021 SRESs and SRESo indicators for producers and processors were similar, suggesting a comparable capacity by these firms to avoid output and revenue losses due to the pandemic's adverse effects after they had more time to adjust their operations.

The dynamic indicators of output resilience (DRESo) for agricultural producers and food processors were 23.8% and 53.9%, respectively, which implies that food processors' output was recovering faster than producers' output (Table 3). Still, output levels were, on average, below those expected before the pandemic.

The DRESo indicator for producers (23.8%) was lower than the corresponding DRESs value (51.1%), likely because the observed changes in the output (12.2%) were also smaller than the observed changes in revenue (18.4%). In contrast, the DRESo indicator for processors (53.9%) was similar to their DRESs value (49.4%), as the observed changes in output and revenue were also similar.

Regression results

Regression results evaluating the association between SRESs and SRESo and various characteristics of the respondents and the firms they represent are presented in Table 4. As the indices are not directly comparable across periods, we estimated separate regressions for 2020 and 2021.

Regression results show the models are useful in explaining the variability of the mean resilience indices (p-values for F-tests evaluating the overall significance of the regressions are all <0.01). R^2's are between 0.04 and 0.11, and few variables are consistently significant in all models; however, some patterns emerge from the results.

One variable is statistically significant (at a 5% level) in most models: one dummy identifying agribusiness working with fruits and vegetables. The SRES values of companies associated with fruit and vegetable production are between 4% to 7% lower than those not related to these products. These results align with previous expectations of resilience. Most fruits and vegetables are susceptible to spoilage if not transported promptly to the market. In effect, during the first months of the pandemic, fruit and vegetable producers in several Latin American and Caribbean countries reported problems with transportation and labor availability due to movement restrictions and lockdowns (Food and Agriculture Organization of the United Nations [FAO] & Economic Commission for Latin America and the Caribbean [ECLAC], 2020a).

Regression analysis results related to differences in resilience across agrifood supply stages confirm the differences found using a simple comparison of means. Input suppliers were the most revenue resilient, on average, relative to the other three agrifood supply chain stages, but only in 2020. Regarding output resilience, agrifood processors were identified as less resilient than agricultural producers, but only in 2020.

Results from the regressions using SRESs and SRESo data from 2020 identified the Central American and Caribbean regions as more resilient than South America. Data on COVID-19 cases from the area showed that South America had more cases than Central America and the

Caribbean in the first year of the pandemic, which might explain the difference in resilience across these regions in that year (Ritchie et al., 2020).

In both models using the 2020 data, the time trend coefficient indicates a 5% increase in reported resilience levels per month. This suggests that agribusiness' static revenue and output resilience in the region improved throughout the first year of the pandemic. As the pandemic evolved during the first year, firms had more time to adjust to the new conditions. In addition, governments in the region relaxed the initial stringent restrictions imposed due to COVID-19 later in the year (Organization for Economic Co-operation and Development [OECD], 2020). For example, Ecuador began confinement measures on March 16, 2020, the de-confinement plan started on May 4, and the nationwide curfew and driving restrictions ended in September (OECD, 2020).[7]

In the SRESs models (2020 and 2021), the dummies representing larger companies (relative to microenterprises, companies with fewer than ten employees) were positive and economically statistically significant (at 5% or 10% levels). For example, compared to microenterprises, the SRESs indicators of large companies were about 11%-13% higher. These results also align with previous expectations of resilience, as large operations are expected to be more adaptable to adverse shocks.

Finally, two variables related to export markets were consistently not associated with the resilience indicators: a dummy variable indicator for participation in export markets and one variable identifying a relation with tropical export products. This result is consistent with

[7] As a reviewer indicated, changes in the static resilience indices could be due only to changes in business conditions (reflected in maximum expected losses) rather than due to improvements in the ability to adjust to the shocks. We estimated separate regressions using expected maximum values losses and the observed losses as dependent variables and the same set explanatory variables, including the "time variable." We found that the estimated decrease in observed losses (i.e., the time related coefficient) was larger than the decrease in expected maximum losses, which suggests that estimated increase in resilience levels is in fact due to an increase in the ability of the firms to adjust to the negative business environment rather than due to improvements in the business conditions.

research reporting that agricultural trade remained stable during the pandemic (e.g., Arita et al., 2021).

Additional considerations about the proposed resilience indicators

Given the novelty of the proposed resilience indices, some discussion is needed regarding their construction and practical implementation. First, the main focus of the SRES indices, as discussed and used here, is on adaptive resilience (Dormady et al., 2019). In other words, these indices measure resilience related to actions responding to a shock (the question about the maximum change in revenue or output refers to "efforts to ***adapt*** to the crisis"). They do not measure inherent resilience, which is connected to adaptations made in preparation for a shock. Future work should consider asking a separate question to measure inherent resilience.[8]

The calculation of the DRES indicator requires an estimate of the change in business activity in a baseline period, which we assumed to be the beginning of the pandemic (t=0). Given the DRES indicator formula, the calculation of an index between 0% and 100% implicitly requires the shock effect on business activity in this baseline period to be equal to or larger than the shock effects in other periods (see Figure 1b). Alternative versions of the baseline "period" could be considered in different situations (e.g., an average of the shock effects in multiple periods from the beginning of the shock).

Another assumption of the proposed indicators related to their maximum and minimum values (0% and 100%) is that observed changes in business activity are negative or zero. However, as observed in our application, some firms experienced increased sales/output due to the pandemic. The use of these positive values in the formulas resulted in indicators with values above 100%. We transformed all these values to 100% for our analyses and to facilitate

[8] The question about maximum change in revenue due to shocks also provides a good starting point to measure inherent resilience as it also captures businesses' ability to "resist being affected" by them.

interpretations. It is thus implicit that companies that can benefit or are not affected by disruptions are 100% resilient. Additional analyses could be conducted to identify the characteristics of these firms. This also means that if the main objective of a study is the calculation of the resilience indicators, the resilience follow-up question is needed only if businesses experience losses but not if their production did not change or increase due to a disruption. Nonetheless, we find firms' estimated maximum losses due to a disruption a good metric of the business environment.

The resilience questions were developed and evaluated by a group of researchers with experience conducting surveys and were also pilot tested in the region; however, some concerns remain regarding their difficulty level and the fact that they are self-reported. This issue is particularly relevant for the data obtained about the estimated maximum change in business activity due to a shock, as this question is hypothetical and self-reported. For example, the index bounds and interpretation require observed losses in business activity to be lower or equal (in absolute value) to the maximum expected losses to avoid negative index values. In our survey, some respondents (about 9%) provided answers that failed to meet this condition (i.e., estimated decreases in output or revenue were larger than their estimated maximum values). Although these problems might be due to the intrinsic variability of the estimated values, they can also be a sign of question difficulty.[9] More work is recommended to analyze resilience questions' difficulty levels and explore alternatives to improve their understanding and accuracy. Negative index values could also be avoided, for instance, by linking the responses to the first and second questions so that the minimum value respondents provide about the maximum expected losses in business activity is always larger than or equal to observed losses. More work is also needed to

[9] The analyses were robust to two assumptions regarding these observations: 1) they are missing values, and 2) they reflect firms with 0% resilience levels.

assess how the self-reported measures of business activity changes due to the shocks compare to estimates obtained with observational data.

Summary and Conclusions

We identified, proposed, and demonstrated the use of two resilience indicators to measure agrifood supply chain adaptive resilience: a static (SRES) and a dynamic (DRES) indicator, which can be calculated using survey data. SRES measures the ability of businesses to avoid business losses within each study period. DRES measures firms' capacity to recover business activity after an initial negative revenue shock. Two versions of the indices are proposed, one related to revenue/sales (SRESs and DRESs) and another to output (SRESo and DRESo).

Study results reflect that the agrifood supply chain firms participating in the study were able to adapt to and are recovering from the disruptions of a global health pandemic. Estimated SRES indicators from the region's supply chain sample of businesses suggest that, on average, they were resilient in revenue generation and even more in production. Although agrifood supply chain firms from Latin America and the Caribbean in the study experienced high average revenue and output losses, especially in the first year of the pandemic, these losses would have been significantly higher (more than double) if they had not made any adjustments in response to the shock. Still, it is necessary to note that there is still a lot of room for improvement in their resilience levels, and an important question remains as to what the optimum resilience levels are.

The resilience indicators and supporting information analyses also show that the business context for the firms sampled in the region remained very difficult in the second year of the pandemic. However, supply chain survey participants avoided a larger percentage of potential losses in this second period relative to the first period. In addition, supply chain actors in the study were moving fast toward recovering the revenue they expected at that point in the prepandemic period. Outcome recovery for agricultural producers was proving more complex and moving slower.

The self-reported economic impacts of the pandemic were not homogeneous across firms in the study, nor were their adaptive resilience levels to the disruption. Input suppliers, for instance, were identified as more revenue resilient than other stages. Still, the magnitude of the differences in average resilience levels across supply stages was also not distinctively larger, probably reflecting an interconnected agrifood supply chain. Moreover, much of the observed heterogeneity in resilience levels across supply chain participants in the study remained unexplained. The sample included firms from over 20 countries that differ in natural, political, and economic conditions (among others), and the agrifood supply chain, by its nature, is also very diverse; thus, more work is needed to explore the source of heterogeneity in resilience levels across agribusinesses. The effect on business adaptive resilience of supporting policies and programs implemented on the private and public stage during the pandemic is particularly interesting. More work is also needed to understand better the specific type of adjustments and adaptations undertaken by agribusinesses during the pandemic (e.g., producers selling and delivering directly to consumers) and its effect on adaptive resilience.

Although the sample is not representative of the population, given the difficulties to collect data during the pandemic and the challenges to collecting data from businesses (e.g., it is not common in the region, firms are generally reluctant to share data, and the population frame for agribusiness seems to be largely unknown), study findings suggest some policy implications. First, given that all agrifood supply business stages were highly affected by the pandemic, supporting policies and programs should address the needs of all the agrifood supply stages (production, processing, distribution, etc.). Second, if possible, these programs should be continued even after the initial shock (the business environment remained difficult even in the second year of the pandemic). Third, although the study focused on adaptive resilience, policies and programs should also consider improvements to inherent resilience. Finally, policy analysis and implementation of inherent and adaptive resilience need to consider the economic costs and benefits by both the public and private sectors of improvements in resilience levels of the agrifood supply chain.

Resilience indicators, such as those introduced and developed in this study, can be helpful for all aspects related to managing the vulnerability of agrifood supply chains, since as expressed by the management guru Peter Drucker, “If you can’t measure it, you can’t manage it.” Agriculture still plays a significant role in the economies of many low- and middle-income countries, including Latin America and the Caribbean. A disruption in the agrifood system can risk their populations’ food security and social welfare (FAO & ECLAC, 2020b); thus, there is a need to analyze and measure the resilience of the agrifood supply chain actors. More specifically, resilience indicators can be used to target policies or initiatives aiming to improve the strength of an agrifood system. The proposed metrics may also be used as the outcome of interest in projects seeking to strengthen agrifood systems’ resilience.

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Table 1. Socio-demographic characteristics of resilience questions respondents

Characteristics	2020 (completed answers; n=1,258)	2021 (completed answers; n=1,209)	All respondents (completed answers; n=2,467)
Age -Mean (standard deviation)	39.4 (14.7)	40.3 (14.4)	39.8 (14.6)
		Category Percentage	
Main actors	61.9	69.9	65.8
Support actors	38.1	30.1	34.2
Agrifood supply chain stage			
Agricultural producers	60.6	54.3	57.5
Agrifood processors	15.7	20.0	17.8
Input suppliers	10.4	12.5	11.4
Logistic and distribution	13.3	13.3	13.3
Exporters	31.2	29.3	30.3
Gender			
Male	70.7	73.4	72.0
Female	29.3	26.6	28.0
Location			
Urban	72.4	72.1	72.3
Rural	27.6	27.9	27.7
Education			
High school or below	7.7	1.4	4.6
College education	43.9	55.9	49.8
Graduate level education	48.4	42.7	45.6
Company size (employees)			
Microenterprise (less than 10 employees)	46.4	34.1	40.3
Small enterprise (10-50 employees)	18.2	17.8	18.0
Medium-size enterprise (50-200 employees)	9.3	11.0	10.1
Large enterprise (more than 200 employees)	15.2	21.5	18.3
Company size (annual revenue)			
Less than $25,000	20.3	25.3	22.7
$25,000 - $50,000	13.5	6.8	10.2
$50,000 - $100,000	7.3	8.1	7.7
$100,000 - $1 million	13.8	12.8	13.3
$1 million to $2.5 million	5.1	4.9	5.0
More than $2.5 million	15.7	21.6	18.6
Agricultural production activity			
Fruits and vegetables	38.6	33.3	36.0

Livestock and poultry	40.0	34.0	37.0
Cereals	28.6	23.4	26.1
Tropical export crops	28.3	31.1	29.7
Legumes and oilseeds	18.5	16.5	17.5
Fisheries and aquaculture	7.7	8.3	8.0
Ornamentals	5.5	9.2	7.3
Silviculture	5.7	5.7	5.7
Other industries	8.2	8.4	8.3
Region			
South America	51.4	37.9	44.8
Central America and Mexico	43.2	58.6	50.8
The Caribbean	2.9	1.9	2.4

Table 2. Revenue-based economic resilience indicators: static resilience indicator (SRESs) and dynamic resilience indicator (DRESs)

Agrifood supply chain stage	Observed change (%ΔDY) (%)		Maximum change (%ΔDYmax) (%)		SRESs Indicator		DRESs Indicator
	2020 Mean (s.e.)	2021 Mean (s.e.)	2020 Mean (s.e.)	2021 Mean (s.e.)	2020 % (s.e.)	2021 % (s.e.)	%
Agricultural producers	18.4	9.0	53.3	44.1	61.2	71.7	51.1
	(1.1)	(1.2)	(1.0)	(1.0)	(1.2)	(1.3)	
Agrifood processors	16.2	8.2	56.7	46.7	64.9	75.5	49.4
	(2.4)	(1.9)	(2.1)	(1.7)	(2.3)	(1.9)	
Input suppliers	11.3**	4.6	49.2	44.4	71.5***	77.0*	56.7
	(2.5)	(2.4)	(2.0)	(2.1)	(2.7)	(2.3)	
Logistic and distribution	17.3	7.5	55.3	45.2	61.7	72.4	56.6
	(2.7)	(2.6)	(2.2)	(2.2)	(2.5)	(2.6)	
All respondents	17.2	8.1	53.7	44.8	62.9	73.2	52.9
	(0.9)	(0.9)	(0.8)	(0.8)	(0.9)	(0.9)	

Note: Asterisks (***, **, and *) indicate significance levels of 1%, 5%, and 10%, respectively, for each column's difference in means tests relative to the agricultural producers' group. Tests are conducted using regression models with dummies indicating agrifood processors, input suppliers, and the logistic and distribution group. Tests used heteroskedastic-consistent standard errors (s.e.).

Table 3. Output-based economic resilience indicators: static resilience indicator (SRESo) and dynamic resilience indicator (DRESo)

Agrifood supply chain stage	Observed change (%ΔDY) (%)		Maximum change (%ΔDYmax) (%)		SRESo Indicator		DRESo Indicator
	2020 Mean (s.e.)	2021 Mean (s.e.)	2020 Mean (s.e.)	2021 Mean (s.e.)	2020 % (s.e.)	2021 % (s.e.)	%
Agricultural producers	12.2	9.3	48.7	44.1	73.8	75.3	23.8
	(1.0)	(1.3)	(1.2)	(1.2)	(1.4)	(1.5)	
Agrifood processors	12.8	5.9	58.0 ***	49.2 **	68.9	75.2	53.9
	(2.7)	(2.5)	(2.5)	(1.9)	(2.7)	(2.3)	

Note: Asterisks (***, **, and *) indicate significance levels of 1%, 5%, and 10%, respectively, for each column's difference in means tests relative to the agricultural producers' group. Tests were conducted using regression models with a dummy indicating agrifood processors. Tests used heteroskedastic-consistent standard errors (s.e.).

Table 4. OLS Estimation results for Revenue-based economic resilience indicators (SRESs) and Output-based economic resilience indicators (SRESo).

	SRESs				SRESo			
Variable	2020		2021		2020		2021	
Intercept	48.27	***	69.22	***	70.21	***	80.11	***
	(2.97)		(3.46)		(3.95)		(5.01)	
Agrifood processors[a]	2.80		1.68		-6.42	**	-1.36	
	(2.66)		(2.49)		(3.13)		(3.13)	
Input suppliers[a]	10.17	***	5.53					
	(2.98)		(2.90)					
Logistic and distribution[a]	1.77		2.61					
	(3.02)		(3.04)					
Central America and Mexico[b]	7.04	***	0.12		4.15		-6.99	**
	(2.14)		(2.01)		(2.88)		(2.81)	
The Caribbean[b]	15.64	***	-1.89		17.69	***	-13.83	
	(4.98)		(7.27)		(4.85)		(9.21)	
Exporters	-2.63		-0.70		-3.13		5.13	
	(2.14)		(2.19)		(3.01)		(3.15)	
Time (months into the pandemic)	5.64	***	0.30		5.35	***	1.71	
	(0.75)		(1.10)		(0.78)		(1.50)	
Small enterprises[c]	2.44		3.87	*	0.08		-6.68	*
	(2.42)		(2.60)		(3.43)		(3.90)	
Medium size enterprises[c]	5.58	*	5.05	*	1.39		-2.46	
	(3.27)		(3.10)		(4.53)		(4.77)	
Large enterprises[c]	12.73	***	11.54	***	4.50		0.45	
	(2.83)		(2.54)		(3.82)		(3.86)	
Fruits and vegetables	-5.65	***	-6.60	***	-7.99	***	-4.04	
	(2.05)		(2.22)		(2.67)		(2.96)	
Livestock and poultry	-3.76	*	-0.53		-3.31		-3.56	
	(2.03)		(2.13)		(2.78)		(2.94)	
Cereals and legumes	3.68	*	2.62		-1.32		0.41	
	(2.04)		(2.36)		(2.67)		(3.08)	
Tropical export products	-2.04		1.46		-3.31		-0.25	
	(2.21)		(2.17)		(3.03)		(2.95)	
Fisheries and aquaculture	-8.11	**	-0.67		-2.73		-5.33	
	(3.64)		(3.43)		(5.19)		(4.65)	
Other industries	-0.81		-2.16		0.16		-0.74	
	(2.97)		(2.84)		(3.67)		(4.08)	
R^2	0.1072		0.0421		0.0702		0.0418	
F-value	9.59		2.79		7.12		1.67	
Pr > F	<0.001		0.001		<0.001		0.0418	
n	1,095		1,010		622		530	

Note: Asterisks (***, **, and *) indicate significance levels of 1%, 5%, and 10%, respectively. [a]Agricultural producers are the baseline group. [b] South America is the baseline group. [c] microenterprises are the baseline group. Robust standard errors (s.e.) in parentheses.

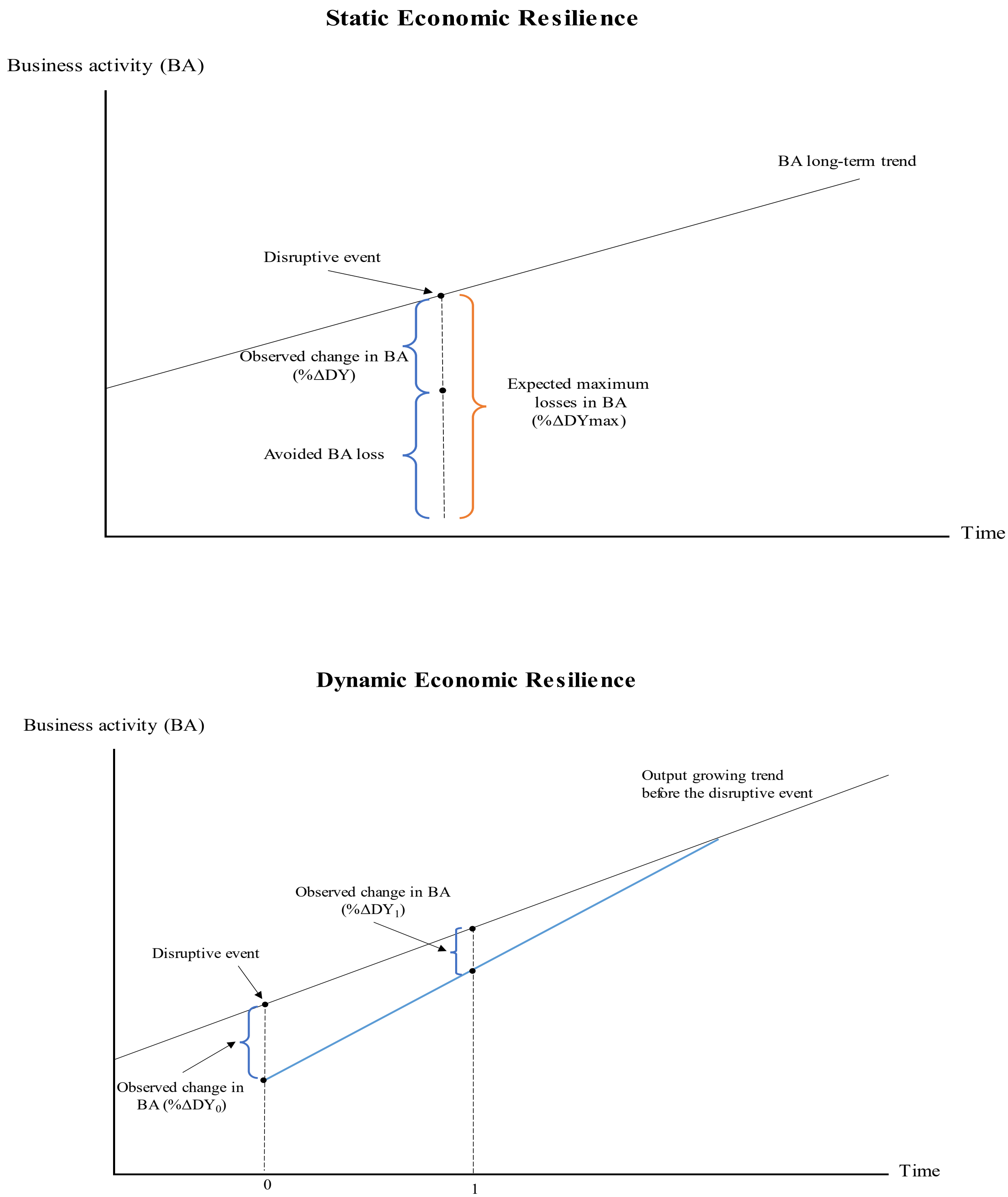

Figure 1. Graphical representation of the static economic resilience (SRES) indicator (1a, top), and dynamic resilience indicator (1b, bottom).

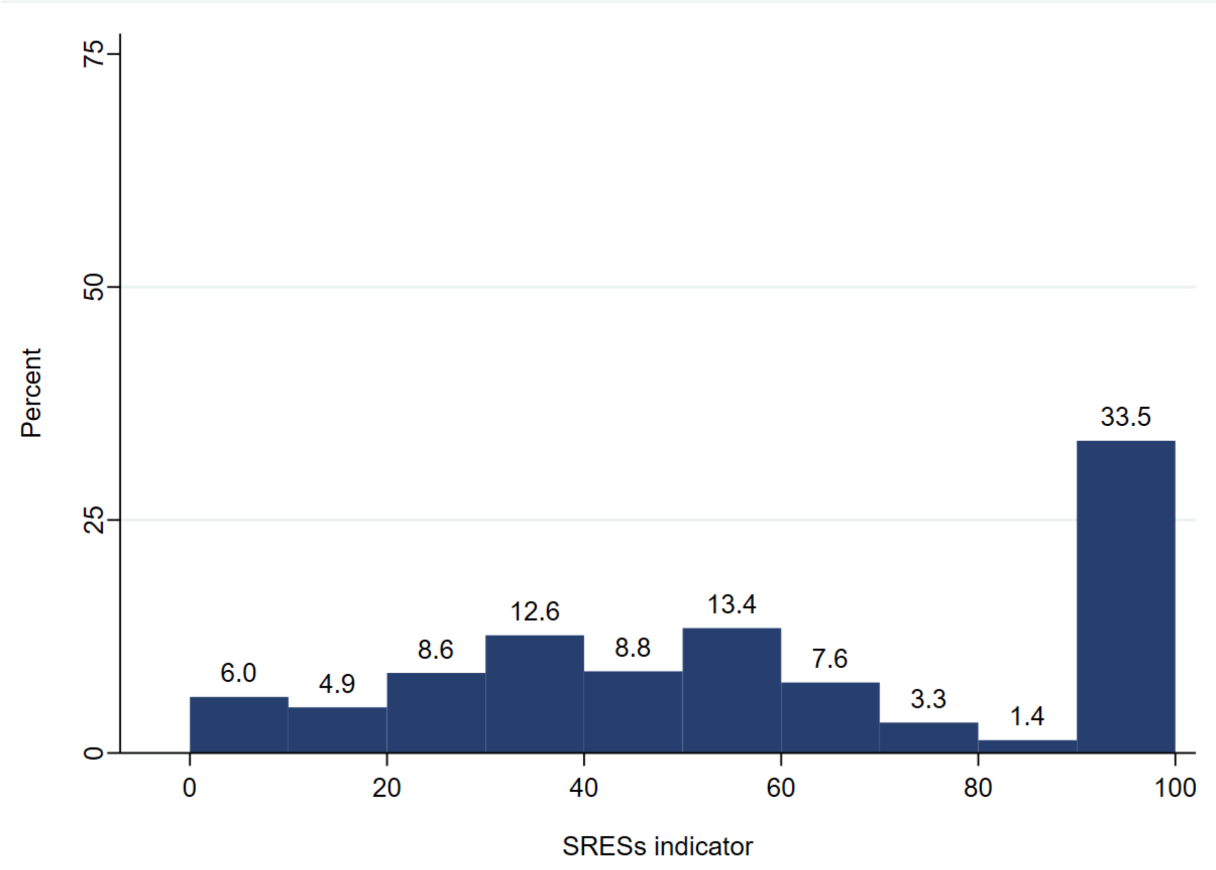

Figure 2. Empirical distribution of the revenue-based static economic resilience indicator (SRESs) for all agribusiness participants in 2020.

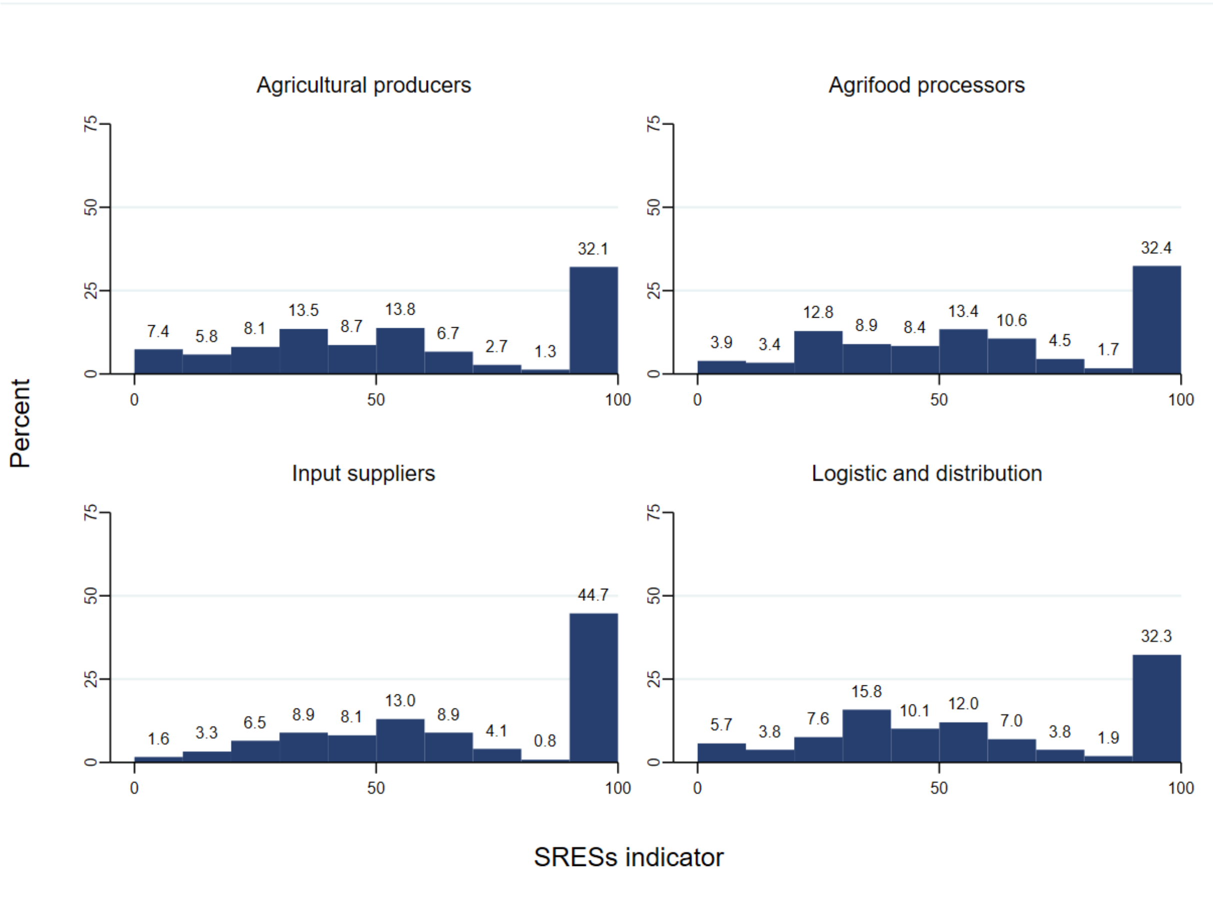

Figure 3. Empirical distribution of the revenue-based static economic resilience indicator (SRESs) for agribusiness participants by agrifood supply stage in 2020.

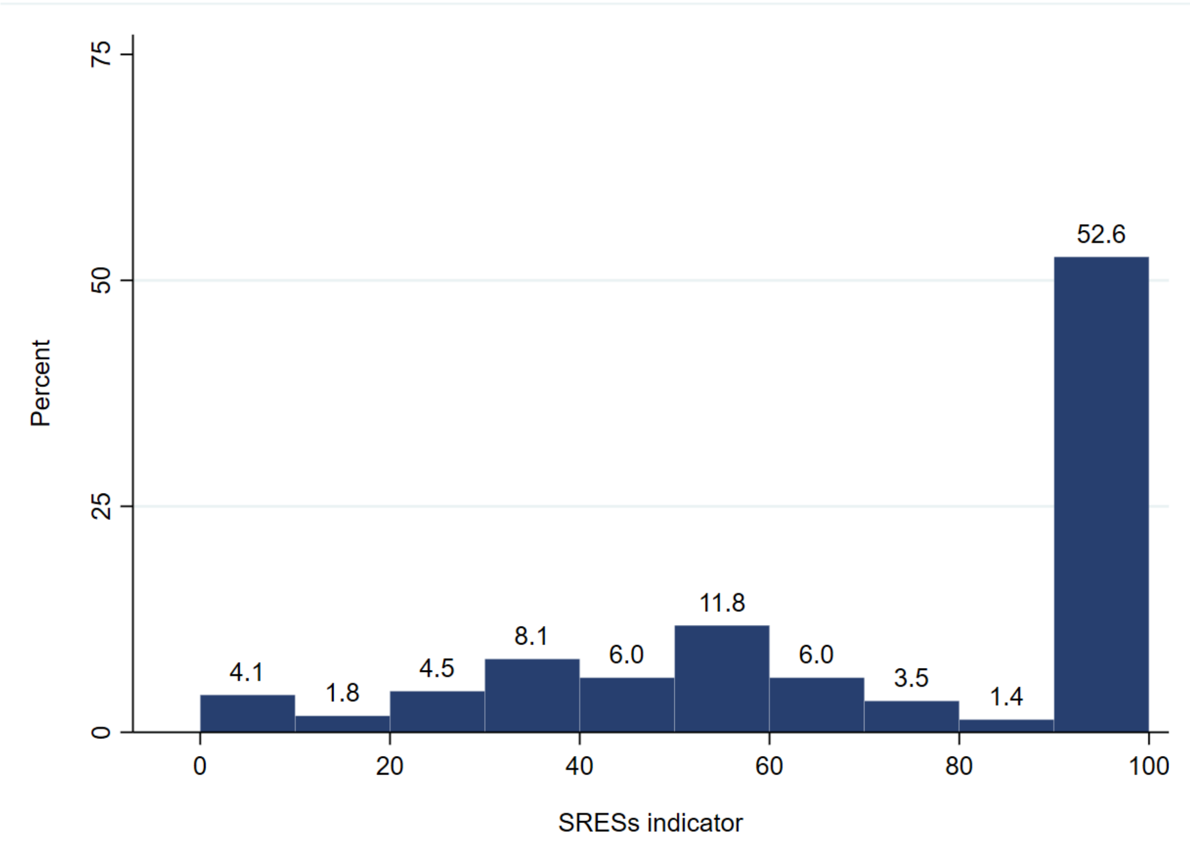

Figure 4. Empirical distribution of the revenue-based static economic resilience indicator (SRESs) for all agribusiness participants in 2021.

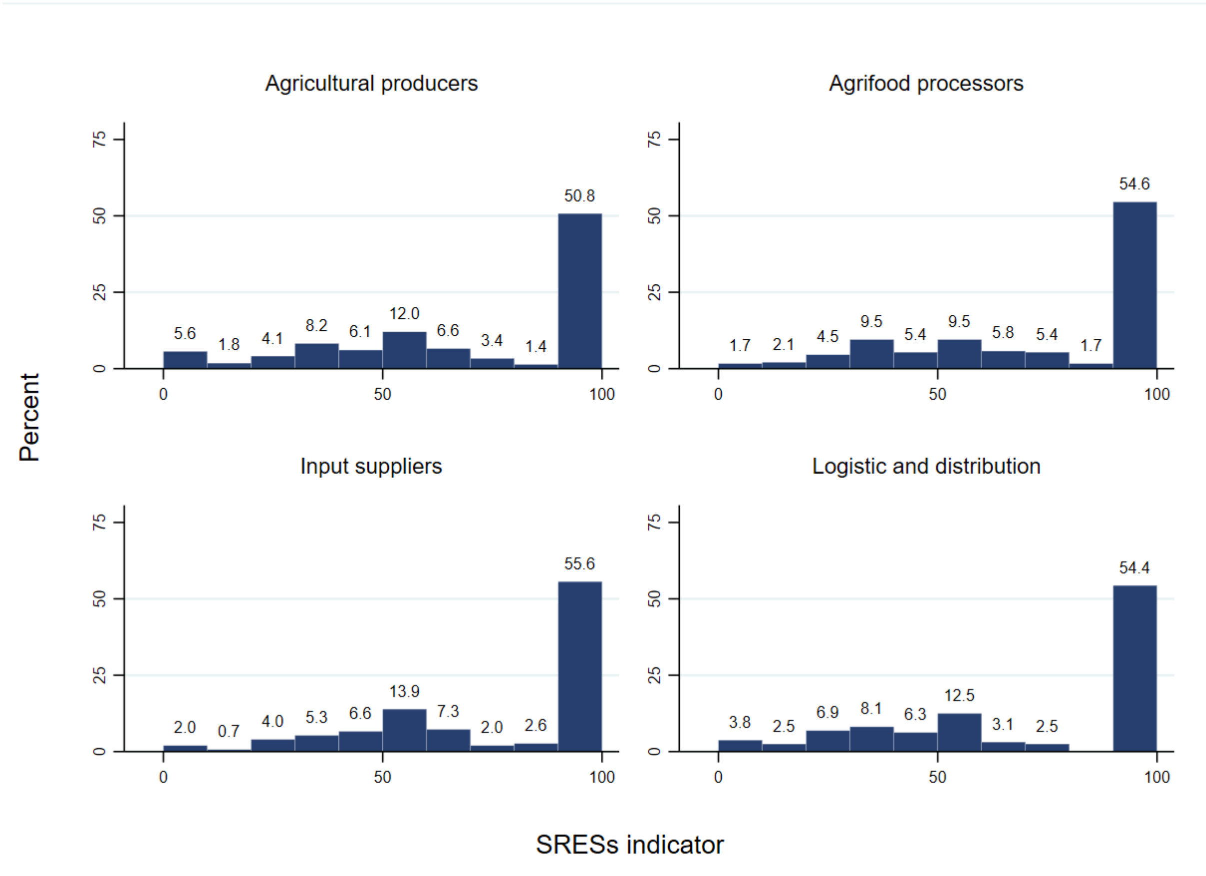

Figure 5. Empirical distribution of the revenue-based static economic resilience indicator (SRESs) for agribusiness participants by agrifood supply stage in 2021.

Appendix. Original resilience questions in Spanish (2021)

Questions about observed changes in income

Con relación a lo esperado antes de la pandemia ¿Cómo cree que la crisis generada por el COVID-19 afectó los **ingresos totales o ingresos por ventas** de la empresa en que trabaja durante el año 2021?

- ◯ Incrementaron
- ◯ No cambiaron
- ◯ Se redujeron
- ◯ No sé

Usted dijo que se incrementaron los ingresos totales / ingresos por ventas: ¿En qué porcentaje?

	0	20	40	60	80	100
Porcentaje						

Usted dijo que se redujeron los ingresos totales / ingresos por ventas: ¿En qué porcentaje?

	0	20	40	60	80	100
Porcentaje						

Question about estimated maximum revenue change

Si la empresa no hubiera hecho ningún esfuerzo para adaptarse a la crisis, en ¿Cuánto estima hubieran **caído** sus **ingresos totales / ingresos por ventas**?

	0	20	40	60	80	100
Porcentaje						

Questions about observed changes in output

Con relación a lo esperado antes de la pandemia ¿cómo cree que la crisis generada por el COVID-19 afectó el **<u>nivel de producción</u>** de la empresa en que trabaja durante el año 2021?

- ○ Aumentó
- ○ No cambió
- ○ Disminuyó
- ○ No sé

¿En qué porcentaje estima aumentó el nivel de producción?

	0	20	40	60	80	100
Porcentaje						

¿En qué porcentaje estima disminuyó el nivel de producción?

	0	20	40	60	80	100
Porcentaje						

Question about estimated maximum output change

Q87 Si usted no hubiera hecho ningún esfuerzo para adaptarse a la crisis, en ¿Cuánto estima hubiera **<u>caído</u> su nivel de producción**?

	0	20	40	60	80	100
Porcentaje						