Ecological Theory Explains Why Diverse Island Economies Are More Stable

Kristen A. Vitro[1]
Miranda E. Welsh[2]
Todd K. BenDor[1,*]
Aaron Moody[3]

[1] *Department of City and Regional Planning*
University of North Carolina at Chapel Hill
Chapel Hill, NC 27599
**Corresponding Author: bendor@unc.edu*

[2] *Thompson Writing Program*
College of Arts and Sciences
Duke University
Durham, NC 27708

[3] *Department of Geography*
University of North Carolina at Chapel Hill
Chapel Hill, NC 27599

Significant work in ecology and economics has derived sophisticated frameworks for understanding system stability over time. Despite the potential of ecological methods to identify the processes underlying variation in stability, these methods have yet to be rigorously applied to economic systems. In this paper, a framework is presented for describing economic system stability as analogous to biological communities. As a proof of concept, this framework is applied to island export economies and demonstrates that economic stability increases with sectoral diversity. Furthermore, this relationship was driven not by the portfolio effect, as is commonly assumed, but by the mechanism of overyielding, whereby individual abundance (analogous to sector size or value) increases with diversity. The results suggest several means of managing export economies for stability. On a broader level, the results illustrate the importance of continued collaboration between the fields of economic development and ecology in facilitating our understanding of complex systems.

1. Introduction

In ecology, the term "stability" has been used to describe a variety of concepts [1, 2]. Endogenous perspectives on stability primarily focus on dynamic stability, which is often described by equations representing population dynamics [3]. Mathematically, the equilibrium point

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can be calculated, and the stability of that equilibrium determined by analyzing the eigenvalues of the system. Exogenous perspectives on stability typically examine an ecological community's response to or recovery from an outside disturbance or perturbation [4–6]. In complex systems research, stability is the result of evolutionary processes that lead to a set of separated stable or periodic structures (i.e., an ordered class 2 process) [7, 8].

Diversity-stability relationships have long been a subject of contention in the fields of economics and economic development. Traditionally, the stability of diverse economies is often attributed to the portfolio effect, in which economies that have more sectors are more stable because individual sectors respond to perturbation differently [9, 10]. Over time, economists and other economic development researchers have come to argue for a more nuanced approach to evaluating the relationship between economic diversity within an economy and overall stability [11, 12], noting that the portfolio-based approach may not sufficiently explain the relationship. A variety of diversity indices have been developed (e.g., Ogive and Herfindahl–Hirschman indices [13]), and the underlying mechanisms of diversity-stability relationships are still debated among economists [14, 15]. Overall, there has been a movement away from a static approach to understanding diversity and stability, with more emphasis placed on dynamic models that address the ever-changing economic outputs and system interactions within and among national economies (e.g., [16]).

Influential work by regional economics scholars, such as [17], has called for a robust application and evaluation of ecologically based measures of diversity and stability in economic systems. In light of this, we assess the viability of applying a system-level stability index developed for ecological communities to an economic system. In the ecological version of this index, stability is quantified by summing the mean, variance and covariance of biological species' abundance over time.

As a proof of concept, we examine dynamic stability in the *export* economies of island nations, as defined by the United Nations [18]. Islands have long been used as model systems in ecology and evolution, not because they represent a large diversity of sizes, but because they are discrete, bounded entities; for example, the processes of immigration and extinction can be reliably observed. As such, their properties and function can more reliably be ascribed to endogenous factors.

While many other analogies could be drawn, we focus on island economies for several reasons. First, island economies provide a comparable analog for species movement and colonization throughout a patchy and geographically bound landscape [19]. Second, in addition to heavy dependence on imports and exports, island economies often struggle to diversify, with heavy reliance on tourism, fishing or resource-extraction industries, leaving them open to exogenous economic shocks [20, 21]. As a result, our analysis largely disregards exogenous effects (save for the 2008 financial crash; see Table A.3). Additionally, due to current data limitations, we are unable to examine the type of economic network spillover effects that would explicitly take into account the relative "centrality" of individual islands within economic networks. For more on this, we recommend Hay and Flynn's examination of the impacts of external shocks and internal structural changes on the behavior of discrete systems [22].

In the broader context of economics, continental economies might be more influenced by the economies of their neighbors, and there could be some spillover of economic stability if a nation is surrounded by diverse and stable economies, regardless of its own endogenous instability (in isolation). Finally, growing island nations are especially vulnerable to geographic and economic constraints [23]; thus, focusing our analysis on such economies may provide further insight into economic development policy.

While the ecological motivation to study islands partly arises due to their semi-closed characteristics (in terms of species and material flow), we fully realize that the analog to a semi-closed economic system would not be an island economy; it would be an economy with no imports or exports. In reality, however, no economies are completely closed, and islands are likely to be more extensively connected to other economies as a result of often-limited natural resource conditions that require the import and export of goods [24].

Furthermore, to consider the economic analogs of species abundance, it would be best to consider GDP, other measures of gross output, or perhaps capital stocks, rather than exports only. However, without standardized, worldwide data collection schemes that would allow disaggregated analysis of total economic output, this presents a very difficult data availability problem. As a result, in this paper we focus solely on island exports, which are a primary component of most island economies and for which data is standardized, readily available and more temporally and geographically complete than non-export economic sectors.

2. Differentiating Measures of Stability

To quantify system-level stability, we use the widely recognized ecological stability index proposed by Lehman and Tilman in [4]:

$$S_T = \frac{\sum_i \mu_i}{\sum_i \sigma_i} = \frac{\sum_i \mu_i}{\sqrt{\sum_i \mathrm{Var}_i + \sum_{i\neq j} \mathrm{Cov}_{i,j}}}. \tag{1}$$

In ecological communities, this index measures system stability over a given time period (S_T) as the sum of the temporally averaged abundance or biomass for each species (μ_i), divided by the square root of the sum of individual variances (Var_i) and the sum of all pairwise covariances ($\mathrm{Cov}_{i,j}$). Following the framework in [4] for the ecological diversity-stability index, we substitute economic sectors for species (i.e., economic sectors are analogs of species). Given this approach, the total trade value of each of the sectors can be substituted for species abundance or biomass, where $\overline{E}_i$ represents the average trade value of exports over a specified time period (e.g., temporally averaged) for economic sector i within island k's economy:

$$S_k = \frac{\sum_i \overline{E}_i}{\sqrt{\sum_i \mathrm{Var}(E_i) + \sum_{i \neq j} \mathrm{Cov}\left(E_i, E_j\right)}}. \tag{2}$$

In both statistical and phenomenological models of ecological systems, regardless of whether equilibrium dynamics are assumed, increases in species diversity are generally expected to increase community stability [25]. In the model from [4], the aggregate measure of community stability can increase in three non-mutually exclusive (and potentially interacting) ways: (1) by decreasing the summed variance of individual species abundance (as the relative dominance of individual species or economic sectors decreases with diversity, a mechanism often referred to as the "portfolio" or "insurance" effect); (2) by decreasing the summed covariance (as pairwise interactions become increasingly independent or negative with increasing diversity, known as the "negative covariance" effect); or (3) by increasing the summed means (as resources are more completely utilized with increasing species diversity when species occupy different niches, known as "overyielding").

2.1 The Portfolio Effect

The portfolio effect is an effect of statistical averaging: on average, the sum of randomly fluctuating and independent variables has lower variance ($\sum_i \mathrm{Var}_i$) than a single randomly fluctuating variable [26]. In addition, because total community abundance has an upper limit, as diversity increases, the abundance of individual species decreases [26]. A decrease in individual abundances causes a greater proportional decrease in abundance variance [27]. For example, during biological invasions, exotic species often outcompete their native counterparts and become exceedingly abundant. Over time, this increases the variance in community abundance (i.e., lower "evenness" [28]) as one species comes to dominate while other species persist at low abundance. Ecologically, the portfolio effect may result from differences in species' responses to environmental fluctuations or disturbance, with a smoothing effect on community-level fluctuation over time [29–32]. The portfolio effect can also result from functional redundancy: each species added to a functional group can decrease the abundance of other species in that group, or functionally redundant species present at high diversity can compensate for species loss [4, 5, 33].

Analogously, in economic systems, a large diversity of economic sectors—and activities within each sector—can increase functional redundancy within the economy, buffering it from large economic fluctuations in the event that one sector or activity collapses [9, 10]. Differential responses of individual sectors to variable markets can also have a smoothing effect on economic fluctuation at the national level. Thus, if the portfolio effect is at least partially responsible for increases in economic stability with sector diversity, we would expect to observe a negative relationship between sector diversity and the summed variance in value across sectors ($\sum_i \mathrm{Var}(E_i)$).

2.2 Competition Effects

Negative covariance effects (i.e., competition effects) refer to increasingly negative pairwise covariances ($\sum \mathrm{Cov}_{i,j}$) with increasing diversity [4]. Ecologically, this sum would decrease with diversity if more species varied independently or if interspecific competition increased, thus increasing the number of interactions with a negative covariance [34]. This represents a "zero sum" theory of diversity and stability: as diversity increases among species that utilize similar resources, when abundance of species *A* increases, abundance of species *B* will decrease due to competition. In economic systems, negative covariance effects would manifest if fluctuations in sector productivity became more independent, or if sectoral competition for natural or technological resources increased with increasing diversity [25]. If negative covariance effects are at least partially responsible for increases in economic stability with sector diversity, we would expect a negative relationship between sector diversity and $\sum_{i \neq j} \mathrm{Cov}\left(E_i, E_j\right)$.

It is important to note that negative covariances need not necessarily involve competition. They can also indicate inverse dependence on a common cause. For example, an analysis of growth in Australia's Great Barrier Reef versus oxygen production in the boreal forests of Canada would likely reveal negative covariance. While these two ecosystems do not interact directly, they both depend on a common factor: the sunlight in opposite hemispheres. Moreover, positive covariances can result from mutualistic interactions, which are common in economic systems and could potentially enhance overyielding enough to stabilize the system. We leave this as a topic for future investigation.

2.3 Overyielding

Overyielding is the third mechanism through which increased diversity can increase stability, this time via increases in total mean abundance or biomass ($\sum \mu_i$) with increasing diversity [35–38]. In ecological communities, an increase in total mean abundance or biomass can result from niche complementarity among species: if each species (or population within a given species) requires slightly different conditions than other species in the community, then additional species will rarely displace initial species [39]. Instead, added species will occupy previously unoccupied niches in the community [33].

Take, for example, the addition of a shade-tolerant shrub to a forest of shade-intolerant trees. In this scenario, the average biomass of the shrub-tree community is higher than the tree community alone because it includes an additional average (the shrubs) without decreasing the average biomass of the trees. As diversity increases and more available niches become filled, the sum of average species abundances increases, resulting in an increase in community stability over time. The same size disturbance causes less of a proportional drop in the total productivity of communities with packed niches and high productivity [38]. Niche complementarity in economic systems could result from a lack of direct competition between sectors for different technological or natural resources. For example, the addition of a luxury sector is unlikely to affect the value of an agricultural sector, leading to a kind of economic overyielding and increased system-level economic stability with diversity. If overyielding was at least partially responsible for increases in stability with diversity, we would expect to observe a positive relationship between sectoral diversity and summed productivity ($\sum_i \overline{E}_i$).

3. Data and Methods

In this paper, we primarily focus on stability in the endogenous sense, as a measure of the amount of variation in system-level responses over time, to investigate the mechanism of island economic diversity-stability relationships from an ecological perspective. While several metrics of diversity exist [40], the theoretical context explored in this manuscript considers “diversity” as the simple count of species present in a community, regardless of their relative abundance [41]. In applying this to economic systems, we define “diversity” as the number of sectors in which an island economy produces exports.

Using the United Nations Comtrade database [42], we obtained commodity export data through a publicly accessible data portal for officially listed UN islands (UNEP 2006). A total of 53 United Nations member islands had complete time series (2002–2012) data available and reported data as independent economic entities. The analyses performed utilized the Harmonized System (HS) data series, which classifies economic trade data in an increasingly specific manner using two-, four- and six-digit commodity codes.

We used the average number of two-digit Harmonized System commodity codes to quantify export sector diversity over the study period. Looking forward, future work in this area should investigate the impacts of the resolution of commodity codes, exploring the effects of diversity at different levels of economic organization. This is analogous to exploring the effects of within-species genetic diversity or taxa-level diversity on stability in ecology. However, it is made more complex by the breakdown of data availability; as export sectors are disaggregated, missing data rates increase dramatically.

Data from 2013 and 2014 was not included in this analysis due to inconsistencies in reporting and the “flagging” of estimates as potentially inaccurate: not all islands have reported 2014 trade data, and some estimates from 2013 have not been confirmed. For each given sector, if no trade value was reported, it was assigned a value of zero to reflect the absence of trade categorized in that sector for that particular year.

Sector-level diversity was computed as the average number of codes present between 2002 and 2012. It is important to note that when using the average number of sectors, small exports in a number of sectors can be viewed as “artificially” increasing diversity, as one might argue that the diversity measure should have essentially the same value when a sector’s exports are zero or close to zero. This would suggest the use of a metric that incorporates “evenness” in the diversity across sectors (i.e., how close in numbers each sector’s exports are to each other; e.g., Shannon’s diversity index; [43]). However, some of the mechanisms that we investigate involve measuring the effects of species diversity on evenness; competition and functional redundancy are expected to make abundances more even, so using a metric that incorporates evenness would confound our tests of these mechanisms. Moreover, the addition of a single individual of a species could still be important if that individual occupies a previously unoccupied niche, causing total productivity to increase (e.g., overyielding).

For this study, we define the unit of analysis as the island. Individual species, whose populations can be observed over time, are component parts of the community. Just as the abundance of individual species is often estimated using discrete measures of productivity in ecology, we use the annual value of each export sector to quantify its economic abundance. Both measure rates of production. Applying this logic to economic analysis, the units being observed are the annual export values of each sector, but the units of analysis represent the aggregation of these individual sectors: the islands themselves. This distinction is quite important, because it dictates the structure that should be used in coding the analysis.

One of the unique aspects of the Comtrade dataset is that for any given country-year, if a particular sector or subsector is not reported, the trade value for that sector is unknown. While it is unimportant if, for a given country, a commodity code is not present in any of the years, it does present a problem if some of the years do have trade values reported for a given commodity code. If omitted, the mean trade value and variance for that sector will be altered. Additionally, in order to compute the covariance of two sectors, the vector length of the data in each must be the same. It should be noted that not all islands reported export data for each year between 2002 and 2012, and GDP was not available for all islands that are territories of other nations. The missing values were recoded as zeros for calculation purposes. To determine if missing years had any influence on the models, all regression analyses were conducted on both "complete" cases, which used only the islands with export data for all years and sectors within the selected time period, and on the full set of island data. The stability of each island was calculated using equation (2) (see Table A.1). These values were used to perform ordinary least-squares (OLS) regression analysis on five specified models (see Table A.2).

We calculated community-level stability (see equation (2); Table A.1) for each island using sector-level trade values for exports. Using the community-stability framework described previously, trade values of exports were used as analogs for species abundance or productivity in an ecosystem (akin to biomass as an ecological measure). With average sector diversity as the independent variable, we used OLS regression to test the relationship between diversity and the aggregate measure of stability (S_k), as well as the individual components of stability ($\sum_i \overline{E}_i$, $\sum_i \mathrm{Var}(E_i)$ and $\sum_{i \neq j} \mathrm{Cov}(E_i, E_j)$). The two-digit export-sector classification system results in an upper limit to the measure of sector diversity ($n = 97$). Because we found a positive relationship between diversity and export-sector productivity ($\sum \mu_i$), we used OLS regression to test whether total economic productivity (average GDP in 2015 USD; accessed from the World Bank's (2015) GDP database [44]) also varied with average export sector diversity. Two islands (Faraoe Islands and Mayotte) do not report independent GDP information and were excluded from models that included GDP. In all analyses, variables were log transformed to meet assumptions of normality (see Appendix A.1 for notes on transformations and Table A.2 for full regression results).

Finally, the exogenous shock of the 2008 global financial crisis was analyzed by qualitatively comparing regression results from data subsets before and after the financial crisis (i.e., 2002–2007 and 2009–2012) to determine if this event substantially affected variable relationships. Since the financial crisis occurred in 2008, this year is excluded from this sensitivity analysis. These subsets of data were regressed using the five specified models (see Table 1 and Table A.2) and using only those islands present in both time periods (see Table A.3). No major changes in significance levels were observed between these two time periods.

	Islands with Complete Data (2000–2012)		All Islands	
	R^2	p-value	R^2	p-value
Model 1: Stability $= f(\text{Diversity})$	0.0376	0.3134	0.407	< 0.0001
Model 2: $\ln\left(\sum_i \overline{E}_i\right) = f(\text{Diversity})$	0.5232	<0.0001	0.6728	< 0.0001
Model 3: $\ln(\sum_i \text{Var}(E_i)) = f(\text{Diversity})$	0.4633	<0.0001	0.534	< 0.0001
Model 4: $\ln\left(\sum_{i\neq j} \text{Cov}\left(E_i,\ E_j\right)\right) = f(\text{Diversity})$	0.5359	<0.0001	0.5806	< 0.0001
Model 5: $\ln(\text{GDP}) = f(\text{Diversity})$	0.4866	<0.0001	0.542	< 0.0001

Table 1. Regression summary statistics for models specified. For Model 1, the aggregate stability calculation was regressed on average diversity. For Models 2 through 4, natural logarithmic transformations of the components of diversity were regressed against average sector diversity. Model 5 regressed the natural logarithmic transformation of average GDP on average sector diversity. Individual coefficient estimates and their associated p-values can be found in Table A.2. All relationships were positive, as shown in Figure 1.

4. Results

Regression results are summarized in Table 1. When the full dataset was used, average diversity had a significant positive effect on aggregate system-level stability ($p < 0.0001$). However, this significance did not hold for the subset of complete data, likely due to a limited number of observations (particularly at the low end of the range of sectoral diversity). For each component part of stability ($\sum \mu_i$, $\sum \text{Var}_i$ and $\sum \text{Cov}_{i,j}$), a significant positive linear relationship with average diversity was observed ($p < 0.0001$ for all models; Table 1). A significant positive linear relationship was also observed between average GDP and average diversity ($p < 0.0001$; Table 1; see Appendix S2 for information on influential cases). These results were qualitatively similar, regardless of whether the entire dataset or the subset of complete cases was used.

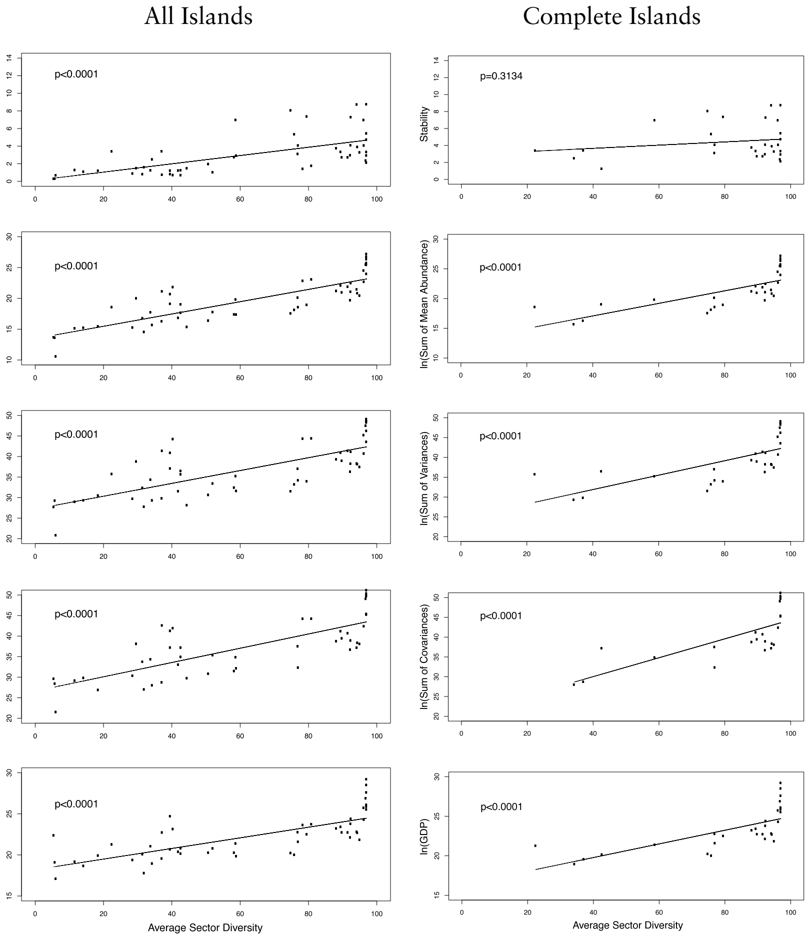

Figure 1. Scatter plots with best-fit lines and significance depicting Models 1–5 (see Table 1 for model specifics). Each variable is regressed on average sector diversity (x axis) as follows: row 1, calculated aggregate stability; row 2, natural logarithm of total mean abundance; row 3, natural logarithm of total sum of variances; row 4, natural logarithm of total sum of covariances; row 5, natural logarithm of GDP.

5. Discussion and Conclusions

Across all islands for which data was available, more diverse export economies were more stable. While this result was not robust to analyses that included only the islands for which complete data was available, the islands with complete data are not a random subsample of the world's islands: overwhelmingly, more complete data is available for islands with more diverse and stable economies (see Figure 1, row 1). For islands with complete data, the mean (and standard deviation) of stability and diversity are 4.45 (2.12) and 81.73 (21.62), respectively; these values for the full set of islands are 2.99 (2.28) and 61.36 (30.83). Because the lack of a relationship between diversity and the overall measure of stability when using islands with complete data is likely due to sampling bias and a limited number of observations ($n = 29$ compared to all islands, $n = 53$), we constrain the remainder of our discussion to results across all islands.

System-level ecological stability is a novel way to analyze the relationship between economic stability and diversity. Economic theory has long predicted sectoral diversity to be a primary driver of stability in economic systems [9, 10, 17], but the underlying mechanisms remain equivocal [14, 15]. Building on that prediction, a number of theories from community ecology recognize that positive diversity-stability relationships result from complex relationships among diversity, abundance and species interactions [5, 38, 45, 46]. Our results support a positive relationship between aggregate economic stability and average diversity ($R^2 \approx 0.4$, $p < 0.0001$).

In applying Lehman and Tilman's [4] community-level diversity-stability framework to view island economies and their exports through a biological lens, we see some notable trends. Our results suggest that the portfolio effect (variance effect; [29, 30, 32]) and negative covariance effects (competition effect; [25]) are not the primary drivers of a positive relationship between stability and diversity in island export economies, as their components of stability (sum of variances and sum of covariances, respectively) exhibit positive, not negative, relationships with sector diversity (Figure 1). Individual sector size does not appear to decrease with diversity, and competition between sectors for natural or technological resources does not appear to increase with diversity. (Referencing our previous discussion of the interaction between these effects, it is important to note that either or both the negative covariance and portfolio effects may be operable and masked in this analysis by strong overyielding.)

Overyielding—an increase in total abundance with diversity—is the only mechanism for a positive diversity-stability relationship in island export economies that was supported by our analyses. As such, observed increases in system-level stability with diversity can be explained by increases in total mean economic production ($\sum_i \overline{E}_i$): more diverse economies are both more stable and more productive. In other words, as economic sector diversity increases, extant sectors are able to maintain high productivity in the presence of new sectors because they occupy distinct niches [39]. Complementary resource use among sectors leads to a more complete utilization of resources, thus allowing more diverse economies to be more productive and stable [35–38, 47].

Our data does not support either of the variance mechanisms for increasing stability with diversity. On the contrary, variance measures ($\sum_i \mathrm{Var}(E_i)$ and $\sum_{i \neq j} \mathrm{Cov}\left(E_i, E_j\right)$) increased with diversity in island export economies. Both of the variance mechanisms for increasing stability with diversity assume increasingly independent fluctuations of sectoral productivity with diversity, and in island economies we see the opposite. In our data, the productivity of island economies and most of their component sectors increased in a near-linear fashion over time. In biological communities, upper limits to productivity may cause the abundance of individual species to decrease with diversity and thus result in negative diversity-variance relationships (the portfolio effect; [4]). If there is an upper limit to productivity in island export economies, an almost linear increase in GDP with diversity suggests that many have not reached it yet. From this relationship alone, we would not expect the portfolio effect to be the mechanism of positive diversity-stability relationships, and our analyses confirm that it is not.

The 2008 financial crisis did not appear to have an impact on the significance or fit of the models, as regression results were similar for the pre- and post-crisis time periods' data subsets (see Table A.3). We theorize that this is possibly due to the confluence of three factors, including: (1) our use of export trade data, which could obscure intra-island changes in commodity sales; (2) our use of two-digit HS commodity codes, which are broad enough that they may hide any impacts of the financial crisis on specific products or services, including luxury goods; and (3) our use of a stability metric that is based on relationships between sectors and productivity across sectors, rather than the absolute output of individual sectors.

We have outlined an approach for applying a basic ecological theory to a new domain of complex systems and demonstrated that this application can be used to examine the mechanism of diversity-stability relationships, or lack thereof, in human economies. This approach could be used to manage for economic stability in expanding economies [23] by identifying the components of stability that are not trending as desired and encouraging either: (1) overyielding, or sectors that use novel resources or operate in novel markets; (2) portfolio effects, or functionally redundant sectors that rely on different economic agents; or (3) negative covariance effects, or competition between sectors.

As a proof of concept, our results support a nuanced yet positive role of diversity in shaping the stability of island export economies. More importantly, our results demonstrate the potential for ecological methods to improve our understanding of economic systems and the value of interdisciplinary approaches in elucidating the properties of complex systems in general. Looking forward, we encourage future work to examine the generality of positive diversity-stability relationships, the interaction of different elements of stability and the mechanism of overyielding, particularly in regard to other, non-export activities and continental economies. We also encourage future work to investigate the effects of diversity at different economic levels, which would be analogous to examining the effects of intraspecific genetic diversity or taxon diversity on biological stability.

Appendix

A. Supporting Information

A.1 Logarithmic Transformations: Problems with the Sum of Covariances

Though logarithmic transformations are commonly used when fitting economic data (e.g., GDP), this presents a potential issue when the sum of the covariances is regressed on sector diversity: the sum of the covariances can take on a zero or negative value. Because the logarithm function is undefined when $x \leq 0$, this transformation results in an undefined value when there is substantial competition between sectors ($\sum_{i \neq j} \mathrm{Cov}(E_i, E_j) \leq 0$). In the event that a zero or negative value was encountered, it was excluded from the natural logarithm models. In total, six islands (Dominican Republic, French Polynesia, Maldives, Philippines, Saint Vincent and the Grenadines and Samoa) were removed from the covariance analysis. These islands were still included in the first model, in which aggregate stability was regressed on average diversity. Nonetheless, the untransformed sum of the covariances regressed on average diversity exhibited either non-significant or positive relationships for both the complete islands ($p = 0.18$; $R^2 = 0.06$) and all islands ($p = 0.03$, $R^2 = 0.09$) data subsets.

Reporter	S_k	$\sum_i \overline{E_i}$	$\sum_i \text{Var}(E_i)$	$\sum_{i\neq j} \text{Cov}(E_i, E_j)$	Average Diversity	Average GDP	Complete
Anguilla	0.890	4.294e+06	8.059e+12	1.523e+13	28.545	2.619e+08	false
Antigua and Barbuda	0.701	4.708e+07	3.037e+15	1.475e+15	42.636	1.088e+09	false
Aruba	4.074	1.172e+08	7.166e+14	1.103e+14	77.000	2.394e+09	true
Australia	2.126	1.512e+11	1.308e+21	3.746e+21	97.000	9.737e+11	true
Bahamas	3.111	5.516e+08	1.195e+16	1.949e+16	76.909	7.738e+09	true
Bahrain	1.763	1.051e+10	1.918e+19	1.635e+19	80.909	2.038e+10	false
Barbados	2.966	3.584e+08	5.877e+15	8.721e+15	92.273	4.075e+09	true
Bermuda	0.302	8.749e+05	1.086e+12	7.335e+12	5.455	5.230e+09	false
Brunei Darussalam	0.713	3.038e+09	1.652e+19	1.621e+18	40.364	1.133e+10	false
Cabo Verde	1.245	5.083e+07	8.406e+14	8.267e+14	33.818	1.395e+09	false
Comoros	1.206	5.146e+06	1.772e+13	4.750e+11	18.455	4.494e+08	false
Cook Islands	1.287	3.752e+06	3.858e+12	4.640e+12	11.636	2.131e+08	false
Cuba	0.823	9.754e+08	5.688e+17	8.376e+17	39.545	5.379e+10	false
Cyprus	4.099	1.430e+09	4.117e+16	8.052e+16	92.364	2.143e+10	true
Dominica	2.919	3.520e+07	5.367e+13	9.171e+13	58.909	4.154e+08	false
Dominican Rep.	7.291	5.845e+09	7.429e+17	-1.002e+17	92.455	3.943e+10	true
Faeroe Islands	1.499	4.867e+08	6.968e+16	3.579e+16	29.636	NA	false
Fiji	3.286	7.616e+08	1.849e+16	3.523e+16	95.000	3.053e+09	true
French Polynesia	7.364	1.685e+08	5.606e+14	−3.735e+13	79.545	5.955e+09	true
Greenland	6.972	4.059e+08	2.005e+15	1.384e+15	58.727	1.948e+09	true
Grenada	1.229	2.043e+07	5.022e+13	2.264e+14	41.909	7.120e+08	false
Iceland	3.345	3.931e+09	6.021e+17	7.794e+17	89.455	1.474e+10	true
Indonesia	2.360	1.177e+11	4.292e+20	2.061e+21	96.818	4.775e+11	true
Ireland	8.755	1.122e+11	1.201e+20	4.402e+19	97.000	2.163e+11	true
Jamaica	3.760	1.623e+09	1.179e+17	6.825e+16	88.182	1.215e+10	true
Japan	4.739	6.513e+11	2.157e+21	1.673e+22	97.000	4.861e+12	true
Kiribati	1.099	4.165e+06	5.466e+12	8.896e+12	14.182	1.274e+08	false
Madagascar	3.905	1.122e+09	3.668e+16	4.592e+16	94.364	7.158e+09	true
Maldives	3.400	1.176e+08	3.337e+15	-2.141e+15	22.455	1.737e+09	true
Malta	2.720	3.237e+09	9.388e+17	4.775e+17	91.545	7.462e+09	true
Mauritius	8.729	2.078e+09	4.251e+16	1.416e+16	94.182	8.103e+09	true
Mayotte	1.480	4.700e+06	1.696e+12	8.388e+12	44.455	NA	false
Montserrat	1.601	2.089e+06	1.163e+12	5.395e+11	31.909	5.308e+07	false
New Caledonia	2.725	1.273e+09	8.386e+16	1.344e+17	89.818	7.482e+09	true
New Zealand	3.336	2.579e+10	8.297e+18	5.148e+19	97.000	1.228e+11	true
Palau	0.302	8.181e+05	5.130e+12	2.232e+12	5.818	1.958e+08	false
Papua New Guinea	0.749	1.511e+09	9.353e+17	3.133e+18	37.182	7.438e+09	false
Philippines	6.964	4.448e+10	4.301e+19	-2.215e+18	96.182	1.497e+11	true
Saint Kitts and Nevis	2.751	3.582e+07	1.217e+14	4.777e+13	58.273	6.376e+08	false
Saint Lucia	1.027	5.262e+07	3.302e+14	2.293e+15	52.000	1.072e+09	false
Saint Vincent and the Grenadines	8.058	4.216e+07	4.976e+13	-2.239e+13	74.818	6.121e+08	true
Samoa	5.344	7.493e+07	2.636e+14	-6.709e+13	75.909	4.929e+08	true
Sao Tome and Principe	2.490	6.492e+06	5.335e+12	1.462e+12	34.273	1.703e+08	true
Seychelles	1.220	2.011e+08	1.276e+16	1.441e+16	39.545	9.528e+08	false
Singapore	2.937	2.784e+11	1.456e+21	7.530e+21	97.000	1.743e+11	true
Solomon Islands	1.258	1.837e+08	6.980e+15	1.437e+16	42.636	5.711e+08	true
Sri Lanka	4.071	7.147e+09	4.832e+17	2.600e+18	96.273	3.569e+10	true
Tonga	3.411	1.172e+07	8.798e+12	3.007e+12	37.091	3.134e+08	true
Trinidad and Tobago	1.414	8.309e+09	1.835e+19	1.620e+19	78.364	1.848e+10	false
Turks and Caicos Islands	1.963	1.320e+07	2.041e+13	2.483e+13	50.727	6.395e+08	false
Tuvalu	0.679	3.922e+04	1.112e+09	2.221e+09	6.091	2.680e+07	false
United Kingdom	5.442	4.110e+11	9.280e+20	4.775e+21	97.000	2.415e+12	true
Vanuatu	0.817	1.946e+07	1.130e+14	4.539e+14	31.455	5.267e+08	false

Table A.1. Calculated values of stability (S_k) and its components, as defined by equation (2).

	Complete Islands	All Islands
Model 1: Stability = f(Diversity)		
(Intercept)	2.9055$^{\wedge}$ (1.5532)	0.1044 (0.5457)
Diversity	0.0189 (0.0184)	0.0471*** (0.0080)
R^2	0.0376	0.407
Adj. R^2	0.0020	0.3953
Num. Obs.	29	53
F-statistic	1.055	35
p-value	0.3134	<0.0001
Model 2: $\ln\left(\sum_i \overline{E}_i\right) = f$(Diversity)		
(Intercept)	12.8559*** (1.6381)	13.4792*** (0.6673)
Diversity	0.1056*** (0.0194)	0.0997*** (0.0097)
R^2	0.5232	0.6728
Adj. R^2	0.5055	0.6664
Num. Obs.	29	53
F-statistic	29.62	104.9
p-value	<0.0001	< 0.0001
Model 3: $\ln(\sum_i \mathrm{Var}(E_i)) = f$(Diversity)		
(Intercept)	24.6166*** (3.1794)	27.2081*** (1.4009)
Diversity	0.1818*** (0.0377)	0.1563*** (0.0204)
R^2	0.4633	0.534
Adj. R^2	0.4434	0.5248
Num. Obs.	29	51
F-statistic	23.31	58.43
p-value	<0.0001	< 0.0001
Model 4: $\ln\left(\sum_{i \neq j} \mathrm{Cov}\left(E_i,\ E_j\right)\right) = f$(Diversity)		
(Intercept)	20.4712*** (4.1777)	26.6166*** (1.4820)
Diversity	0.2387*** (0.0485)	0.1738*** (0.0220)
R^2	0.5359	0.5806
Adj. R^2	0.5138	0.5713
Num. Obs.	23	47
F-statistic	24.25	62.29
p-value	<0.0001	< 0.0001
Model 5: ln(GDP) = f(Diversity)		
(Intercept)	16.3233*** (1.4412)	18.1992*** (0.5898)
Diversity	0.0863*** (0.0171)	0.0647*** (0.0085)
R^2	0.4866	0.542
Adj. R^2	0.4676	0.5327
Num. Obs.	29	51
F-statistic	25.59	58
p-value	<0.0001	< 0.0001

Table A.2. Full regression summaries of models as specified. For models 1 through 4, stability and its components (transformed using the natural logarithm function) are regressed against average sectoral diversity. Model 5 regresses the natural logarithm of GDP against average sectoral diversity. Terms in parenthesis represent standard errors for each estimate. For models involving logarithmic transformations, zero or negative values were omitted from model fitting. Studentized Breusch–Pagan heteroscedasticity tests do not indicate heteroskedastic errors for any model ($p > 0.01$ for all models). Significance codes for parameter estimates: $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\wedge}p < 0.1$.

	Model 1 Stability = f(Diversity)	Model 2 $\ln\left(\sum_i \overline{E}_i\right) =$ f(Diversity)	Model 3 $\ln(\sum_i \mathrm{Var}(E_i)) =$ f(Diversity)
Pre-crisis (2002–2007)			
(Intercept)	2.3223 (1.4012)	13.7797*** (0.8215)	26.9437*** (1.6856)
Diversity	0.0381* (0.0189)	0.0929*** (0.0111)	0.1453*** (0.0227)
R^2	0.0864	0.6209	0.488
Adj. R^2	0.0652	0.6121	0.4761
Num. Obs.	45	45	45
F-statistic	4.067	70.44	40.98
p-value	0.0500	<0.0001	<0.0001
Post-crisis (2009–2012)			
(Intercept)	−0.4809 (1.6027)	14.6632*** (0.8822)	29.7966*** (1.8498)
Diversity	0.0807*** (0.0220)	0.0850*** (0.0121)	0.1163*** (0.0254)
R^2	0.2378	0.5333	0.3274
Adj. R^2	0.2201	0.5225	0.3117
Num. Obs.	45	45	45
F-statistic	13.42	49.14	20.93
p-value	0.0007	<0.0001	<0.0001

Table A.3 (*continues*)

	Model 4 $\ln\left(\sum_{i=\neq j}\mathrm{Cov}\left(E_i, E_j\right)\right) = f(\mathrm{Diversity})$	Model 5 $\ln(\mathrm{GDP}) = f(\mathrm{Diversity})$
Pre-crisis (2002–2007)		
(Intercept)	27.8580^{***} (2.1199)	17.4192^{***} (0.6995)
Diversity	0.1493^{***} (0.0274)	0.0707^{***} (0.0093)
R^2	0.4669	0.585
Adj. R^2	0.4512	0.5748
Num. Obs.	36	43
F-statistic	29.77	57.79
p-value	<0.0001	<0.0001
Post-crisis (2009–2012)		
(Intercept)	29.7907^{***} (2.0813)	20.7862^{***} (0.9579)
Diversity	0.1253^{***} (0.0280)	0.0278^{*} (0.0134)
R^2	0.3505	0.0954
Adj. R^2	0.3329	0.0733
Num. Obs.	39	43
F-statistic	19.96	4.323
p-value	<0.0001	0.0439

Table A.3. Analysis of the impact of the 2008 financial crisis in which pre- and post-crisis data (all islands) was regressed separately.

A.2 Influential Cases

The potential presence of influential cases was examined. For each given model specification, Cook’s D (distance) was calculated for all points, resulting in the identification of statistically influential points (see Table A.4). While some influential cases were identified, there is not a clear theoretical basis for the exclusion of these islands from the analysis (e.g., not subject to economic sanctions).

Untransformed	Complete Islands	All Islands
Model 1: Stability = *f*(Diversity)	N/A	Ireland Maldives
Model 2: $\ln\left(\sum_i \overline{E_i}\right) = f(\text{Diversity})$	Solomon Islands	Japan Singapore United Kingdom
Model 3: $\ln(\sum_i \text{Var}(E_i)) = f(\mathit{Diversity})$	Solomon Islands	Australia Japan Singapore
Model 4: $\ln\left(\sum_{i \neq j} \text{Cov}\left(E_i,\ E_j\right)\right) = f(\text{Diversity})$	Solomon Islands	Japan Singapore
Model 5: $\ln(\text{GDP}) = f(\text{Diversity})$	Solomon Islands	Japan United Kingdom Cuba
Natural Logarithm Transformed	**Complete Islands**	**All Islands**
Model 2: $\ln(\sum_i \text{Var}(E_i)) = f(\text{Diversity})$	Solomon Islands	Japan Tuvalu
Model 3: $\ln(\sum_i \text{Var}(E_i)) = f(\text{Diversity})$	United Kingdom	Brunei Darussalam Tuvalu
Model 4: $\ln\left(\sum_{i \neq j} \text{Cov}\left(E_i,\ E_j\right)\right) = f(\text{Diversity})$	N/A	N/A
Model 5: $\ln(\text{GDP}) = f(\text{Diversity})$	Solomon Islands United Kingdom	Bermuda Japan United Kingdom
Square Root Transformed	**Complete Islands**	**All Islands**
Model 3: $\ln(\sum_i \text{Var}(E_i)) = f(\text{Diversity})$	Solomon Islands	Australia Japan Singapore United Kingdom
Model 4: $\ln\left(\sum_{i \neq j} \text{Cov}\left(E_i,\ E_j\right)_j\right) = f(\text{Diversity})$	Solomon Islands	Japan Singapore United Kingdom

Table A.4. Summary of influential cases for each model, calculated using Cook's D (distance).

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