ABSTRACT
Diversity is one of the defining characteristics of complex adaptive systems – systems made up of heterogeneous agents whose interactions form a dynamic network resulting in emergent behaviour. Recent research shows that various types of diversity increase with the scale of the system. This paper uses ideas and methods from community ecology to define business types as functional traits and to calculate functional diversity as a measure of the economic diversification in an urban system. It asks how functional diversity changes with the size of the city within an urban region. Using Keihanshin Metropolitan Area in Japan as an example, the paper concludes that while functional diversity scales with city size, it reaches saturation due to the limitations of the business types classification systems. It argues that regardless of the observed saturation, the method can reveal the structural complexity of the city, showing what types of industries form its economy. It also discovers functions common to all cities in the region, and calls for further development of the method by introducing the multidimensional analysis and additional measures of diversity.

INTRODUCTION
It is argued that cities belong to a special class of systems called complex adaptive systems (Bettencourt, Lobo, Helbing, Kühnert, & West, 2007). Complexity science studies such systems, encompassing a wide range of fields from both natural and social sciences. Complexity thinking is also used in the context of economic geography (Martin & Sunley, 2007) as a part of a wider programme of evolutionary economic geography (Boschma & Martin, 2010) and complexity economics (Dopfer, Foster, & Potts, 2004).

The science of cities is one of the research paradigms that emerged from the complexity sciences framework, whose goal is to find general laws that govern all urban systems. Batty (2013) builds the science of cities around the concept of scaling, asking how the elements, as well the entire system, change in shape and size as both its elements and its whole grow and change. Although empirical studies of scaling show that many urban indicators are power law
functions of population size (Bettencourt et al., 2007), Arcaute et al. (2015) argue that popu-
lation size alone does not provide enough information to describe or predict the state of a city
because the main relevant emergent behaviours are encoded in the diversity and heterogeneities
of cities. Measuring diversity could therefore help to explain how and why cities grow and attract
capital and labour.

Diversity is one of the defining characteristics of complex adaptive systems (Page, 2010), but
as noted by Youn et al. (2016), there have been surprisingly few quantitative studies into possible
and underlying dynamics that govern the diversity of cities.

This paper asks how functional diversity changes with the size of the city within an urban
region. It applies ideas and methods from community ecology to complexity thinking in evol-
utionary economic geography to define and measure diversity based on industry functions
(types) within a city. It explores how the diversity changes with the scale of the city and how
it is spatially distributed over a regional system. It looks at the case study of Keihanshin Metropo-
lan area, the second biggest metropolitan region in Japan and one of the most productive
economic areas in the world. The results reveal that diversity is a function of scale, highly con-
centrated in the biggest cities of the region, and that there is a minimum level of functionality
shared by all cities in the region.

DIVERSITY IN NATURAL AND SOCIAL SYSTEMS

Recent studies show that while firms are specialized entities, countries are diversified (Hidalgo &
Hausmann, 2009; Tacchella, Cristelli, Caldarelli, Gabrielli, & Pietronero, 2013). Therefore,
diversity can be used as an indicator of complexity of the system and the economic complexity
index developed by Hidalgo and Hausmann (2009) provides more accurate predictions of
gross domestic product (GDP) per capita growth than traditional measures of governance
(Hausmann et al., 2014). By analyzing diversity in cities instead of nations, Schiff (2015)
shows that population size and density have a significant impact on consumer product variety.
Youn et al. (2016) focus on establishment diversity and the abundance of business categories
rather than on product variety. They reveal that the distribution of business types in US cities
is characterized by a universal rank-size curve in which specific business types predictably increase
or decrease their relative rankings and frequencies as a function of city size.

At a regional level, evolutionary economic geographers are interested in how regions diversify
into new industries (Boschma & Frenken, 2006; Boschma, 2017; Neffke, Henning, & Boschma,
2011) and how diversification is related to regional resilience (Hassink, 2010). The concept of
relatedness suggests that economic diversification of regions depends on the existing set of
local capabilities and that regions tend to diversify in new activities related to their existing activi-
ties (Boschma, 2017). However, the focus of these studies is often conceptual or comparative in
nature, while quantitative studies are usually focused on product space analysis. Contributions of
non-business organizations are often neglected (Vallance, 2016).

Biodiversity is the central topic in the study in ecology. Community ecology studies patterns
in the diversity, abundance and composition of species at a given time and place, and the pro-
cesses underlying these patterns (Vellend, 2010). Recently, it has been suggested that the number
of traits rather than the number of species should play a more important role in community ecol-
ogy (McGill, Enquist, Weiher, & Westoby, 2006). Traits are well-defined and measurable prop-
erties of organisms. If they strongly influence organisational performance, they are considered to be
functional traits. Examples include basal metabolic rate, seed or egg size, adult body mass, and
potential photosynthetic rate (McGill et al., 2006). Due to the increasing focus on traits, func-
tional diversity developed as a measure of biodiversity that is generally concerned with the range
of things that organisms do in communities and ecosystems (Petchey & Gaston, 2006). It is
assumed to be a better predictor of ecosystem productivity and vulnerability than species diversity
Various measures are being developed to cover all aspects of functional diversity. It has been suggested that functional diversity cannot be summarized by a single indicator and that three independent measures are needed: functional richness, functional evenness and functional divergence (Mason, Mouillot, Lee, & Wilson, 2005; Villéger, Mason, & Mouillot, 2008). Functional richness can be defined as a volume of the functional space occupied by a community. It is often used by ecologists as a proxy measure for functional diversity and it is the measure used in this paper. Functional evenness measures the regularity of distribution of abundance (e.g., the number of establishments) in this volume. Functional divergence measures the divergence of the abundance in this volume.

General frameworks for the determination of traits in a given community consist of defining the matrix with values for selected functional traits for each species (Villéger et al., 2008). Translating this method to socioeconomic systems requires a conceptual definition of the units of analysis, i.e., communities, species and traits. For example, Youn et al. (2016) identify the establishment, a single physical location where business is conducted, as a basic unit of analysis. They focus on the frequency distribution of business types, which they define as the number of species, in cities which represent ecosystems.

METHODOLOGY AND DATA

In this paper business types are seen as traits rather than species. This is due to the nature of national organization classification systems which separate organizations based on what they do. For example, the Japan Standard Industrial Classification three-digit code 271 denotes Office Machinery and Equipment Manufacturing. While all establishments registered under code 271 can be thought of as belonging to the same species, it is more useful to consider them as establishments with a common trait. Adding additional traits into the analysis, such as the number of employees, ownership type, capital structure etc., can then help to differentiate further between various types of establishments. The number of different types of traits in a community (Mason et al., 2005; Page, 2010) is calculated using:

\[ FD_c = \frac{T_c}{T_n} \]  

where \( FD_c \) is functional diversity in city \( c \), \( T_c \) is the number of traits present in city \( c \), and \( T_n \) is the total number of traits. We measure \( T_c \) and \( T_n \) from the 2014 Economic Census for Business Frame – Tabulation of Establishments using three-digit classifications as defined by Japan Standard Industrial Classification. Based on this classification, the total number of possible traits is 525. For each trait in a community, we add 0 or 1 as a weight based on the absence or presence of establishments with those traits. The sum of weights represents \( T_c \).

A city is defined as a community metacommunity, meaning that functional diversity is calculated for each city and compared between cities from the same region. Keihanshin Metropolitan Area (Figure 1), as defined by Kanemoto and Tokuoka (2002), is selected as a metropolitan region (metacommunity) because of data availability and a high concentration of population and businesses. It consists of 73 cities with a total population of 17,499,597 people (2015 Population Census of Japan) and a total number of establishments of 772,349 (2014 Economic Census for Business Frame – Tabulations of Establishments).

RESULTS AND DISCUSSION

The results shown in Figure 2 confirm a strong linear relationship between the size of the city and the number of establishments and shows similar results to Youn et al.’s (2016) analysis of urban
employment areas in the United States. Figure 2(a) shows a concentration of both population and establishments in the core cities of the Keihanshin region (from right to left, Osaka, Kobe, Kyoto and Sakai), which together account for 37.4% of the total population and 47.8% of the total number of establishments in the region. We estimate scaling the exponent using ordinary least squares regression of log-transformed values for population and the number of establishments (Youn et al., 2016) (Figure 2b). The total number of establishments scales linearly with city size, where the scaling exponents are 1.04 and $R^2 = 0.95$.

Figure 3 shows a strong relationship ($R^2 = 0.90$) between the size of the city and functional diversity calculated using equation (1). However, this relationship is logarithmic rather than...
linear. Cities strongly increase their functionality as they grow, but once they reach relatively high levels of functional diversity the growth slows. Youn et al. (2016) report that this saturation of types results from insufficient detail in the description of business types and show mathematically that urbanization actually creates an open-ended diversity.

Although the limited classification of business types could be problematic for studies of diversity in big cities, it is still sufficiently detailed to provide answers about the structure of cities and distribution of functionality across regions. Functions common to all cities, such as hospitals, post offices, schools, groceries shops etc., can be considered as core functions that make the city, while rare functions or those common just to big cities (start-up incubators, corporation headquarters, top universities etc.) can explain why some cities become regional centres, attracting people and capital. Comparing the functional traits lists for cities in Keihanshin Metropolitan Area reveals that approximately 19% of traits are common to all cities. The existence of these common traits shared by all cities is defined as a ‘functionality threshold’.

Figure 4 shows spatial distribution of functional diversity in Keihanshin Metropolitan Area. Core cities have high functional diversity (above 80%). However, Osaka is the only city with a
functional diversity above 90% (approximately 94%), confirming its status as the economic centre of the region. Cities around Osaka also have higher functional diversity and it seems they benefit from being close to the economic centre of the region.

The results confirm the usefulness of combining evolutionary economic geography with the ideas from community ecology to show the relationship between the scale of the city and economic diversification. Furthermore, by revealing the set of common traits for all cities, they show a point after which cities begin to differ in their functionality.

CONCLUSIONS

This paper applies ideas and methods from community ecology to complexity thinking in evolutionary economic geography to study diversity in urban regions, using Keihanshin Metropolitan Area in Japan as a case study.

It confirms the results of recent studies in urban diversification (Schiff, 2015; Youn et al., 2016) which show that diversity scales with the city size, but that there is a certain saturation due to the limitation of classifications of business types. Additionally, it reveals the existence of a ‘functionality threshold’, or a number of core traits common to all cities, and shows the spatial concentration of high levels of diversity in core cities and around Osaka as a regional capital.

The method used here represents a simple way of getting an insight into the structure of cities and differences in levels of diversity in some regions. To understand fully the diversity of particular systems, additional measures are required. These measures are being developed as part of community ecology and functional diversity research frameworks where both one- and multidimensional analyses are used. Future studies of urban diversification should go beyond using functional richness as a proxy for functional diversity and include functional evenness and functional divergence, too. However, it may be challenging to translate these methods
fully to data sets provided by census documents and it might be necessary for researchers to get access to additional data or collect data designed to fit these measures.

The methods presented in this paper are likely to be applicable to other city regions around the world, since most countries use similar two-, three- and four-digit industrial classification codes. Comparative studies could reveal interesting patterns of diversity between cities in various regions and explore how they diverge depending on the geographical, cultural and economic differences between the countries. This can have important benefits for the studies of two concepts in economic geography which both emerge from the system’s diversity: relatedness and resilience.

Having well-developed measures of diversity can also help policy-makers to understand possible development paths of their municipalities, cities and regions, especially in the context of negative demographic changes. By being able to estimate the effects of a shrinking population on economic diversity, policy-makers can set clear objectives for governmental programmes aimed at the preservation of economic diversity either by well-placed business incentives or by policies supporting positive demographic trends.

ACKNOWLEDGMENTS

The author thanks the editor, Marijana Sumpor, for guidance and support during the process of writing this paper. Thanks also to the reviewers and editorial team whose comments and corrections greatly improved the original manuscript. Finally, thanks to the Urban Research Plaza, Osaka City University, for supporting this research.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

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REFERENCES

Arcaute, E., Hatna, E., Ferguson, P., Youn, H., Johanssen, A., & Batty, M. (2015). Constructing cities, deconstructing scaling laws. *Journal of The Royal Society Interface*, 12(102), 20140745.

Batty, M. (2013). *The new science of cities*. Cambridge: MIT Press.

Bettencourt, L. M., Lobo, J., Helbing, D., Kühnert, C., & West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the National Academy of Sciences, USA*, 104(17), 7301–7306.

Boschma, R. (2017). Relatedness as driver of regional diversification: A research agenda. *Regional Studies*, 51(3), 351–364.

Boschma, R. A., & Frenken, K. (2006). Why is economic geography not an evolutionary science? Towards an evolutionary economic geography. *Journal of Economic Geography*, 6(3), 273–302.

Boschma, R., & Martin, R. (2010). The aims and scope of evolutionary economic geography. In R. Boschma, & R. Martin (Eds.), *The handbook of evolutionary economic geography*. Cheltenham: Edward Elgar.

Dopfer, K., Foster, J., & Potts, J. (2004). Micro–meso–macro. *Journal of Evolutionary Economics*, 14(3), 263–279.

Hassink, R. (2010). Regional resilience: A promising concept to explain differences in regional economic adaptability? *Cambridge Journal of Regions, Economy and Society*, 3(1), 45–58.

Hausmann, R., Hidalgo, C. A., Bustos, S., Coscia, M., Simoes, A., & Yildirim, M. A. (2014). *The atlas of economic complexity: Mapping paths to prosperity*. Cambridge: MIT Press.
Hidalgo, C. A., & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences, USA*, 106(26), 10570–10575.

Kanemoto, Y., & Tokuoka, K. (2002). Proposal for the standards of metropolitan areas of Japan. *Journal of Applied Regional Science*, 7, 1–15.

Martin, R., & Sunley, P. (2007). Complexity thinking and evolutionary economic geography. *Journal of Economic Geography*, 7(5), 573–601.

Mason, N. W., Mouillot, D., Lee, W. G., & Wilson, J. B. (2005). Functional richness, functional evenness and functional divergence: The primary components of functional diversity. *Oikos*, 111(1), 112–118.

McGill, B. J., Enquist, B. J., Weiher, E., & Westoby, M. (2006). Rebuilding community ecology from functional traits. *Trends in Ecology and Evolution*, 21(4), 178–185.

Neffke, F., Henning, M., & Boschma, R. (2011). How do regions diversify over time? Industry relatedness and the development of new growth paths in regions. *Economic Geography*, 87(3), 237–265.

Page, S. E. (2010). *Diversity and complexity*. Princeton: Princeton University Press.

Petchey, O. L., & Gaston, K. J. (2006). Functional diversity: Back to basics and looking forward. *Ecology Letters*, 9(6), 741–758.

Schiff, N. (2015). Cities and product variety: Evidence from restaurants. *Journal of Economic Geography*, 15(6), 1085–1123.

Schleuter, D., Daufresne, M., Massol, F., & Argillier, C. (2010). A user’s guide to functional diversity indices. *Ecological Monographs*, 80(3), 469–484.

Statistics Bureau of Japan. (2010). Retrieved from http://www.stat.go.jp/data/chiri/map/c_koku/daitoshi/pdf/2010.pdf

Tacchella, A., Cristelli, M., Caldarelli, G., Gabrielli, A., & Pietronero, L. (2013). Economic complexity: Conceptual grounding of a new metrics for global competitiveness. *Journal of Economic Dynamics and Control*, 37(8), 1683–1691.

Vallance, P. (2016). Universities, public research, and evolutionary economic geography. *Economic Geography*, 92(4), 355–377.

Vellend, M. (2010). Conceptual synthesis in community ecology. *Quarterly Review of Biology*, 85(2), 183–206.

Villéger, S., Mason, N. W., & Mouillot, D. (2008). New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology*, 89(8), 2290–2301.

Youn, H., Bettencourt, L. M., Lobo, J., Strumsky, D., Samaniego, H., & West, G. B. (2016). Scaling and universality in urban economic diversification. *Journal of The Royal Society Interface*, 13(114), 20150937.