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Critical Performance Factors for Large World Cities – In Search of Qualitative Causal Patterns by means of Rough Set Analysis*

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Abstract. In the currently emerging ‘*urban century*’, large cities and urban agglomerations are increasingly turning into (socio-)economic and political powerhouses of world-wide importance. This paper offers a comparative assessment of the multidimensional performance profile of major cities in our world, with particular emphasis on the livability and economic potential of these cities. We use an explanatory cohesive framework in the present study, which finds its origin in the so-called ‘*urban piazza*’ model. Next, using an extensive database on various rankings of 40 global cities (the so-called GPCI data base), the relative performance of these cities is ‘explained’ in a qualitative sense by means of a non-parametric ordinal ranking method, known as rough set analysis. The approach allows us to identify in a qualitative sense the driving forces that altogether are responsible for the economic and livability achievements of these cities. Our analysis is based on a novel triple-layer rough set analysis of the performance of the cities concerned. The empirical analysis highlights the combined explanatory ‘power’ of several success conditions and drivers of the cities concerned. Our empirical results demonstrate that in particular geographical accessibility and R&D of these urban areas appears to play in many cases an important role in shaping their strong position.

Key words: urbanization; cities; performance; rough set analysis; piazza model

1 The Urban Planet

Demographic changes will be decisive for the future geography of our world (Tellier 2007). According to UN projections, our planet will house approx. 9 bln people by the year 2050. The rise with some 2.5 to 3.0 bln humans in the next 35 years – a time span covering a little bit more than one generation – is however, not equally spread over the world. There are significant regional differences, with a massive expected population rise in Africa, Asia and Latin America.

*This paper was inspired by several studies that have been produced in the context of the Joint Programming Initiative ‘*Urban Europe*’ (see also Arribas-Bel et al. 2013). It is devoted to one of the icons in regional science, Manfred Fischer.

Another inevitable demographic megatrend for the decades to come is the massive population drift to the city. Cities will grow bigger – or rise in numbers – not only due to the global population rise, but also as a result of movements of people from peripheral and rural areas to urban agglomerations. There is a general consensus that the rate of urbanization is growing faster than the global population rise, so that our planet will become urban in nature¹ (see for more details also Kourtit 2014, 2015).

The above sketched rapid urbanization development will take place in particular in the developing world, so that growth of urban agglomerations will become a dominant characteristic of settlement patterns in the Third World. Other regions will be less affected by the disproportionately fast urbanization, while some regions (e.g., in Japan, Germany, Italy, Poland) may even face situations of shrinking cities (see also Kourtit 2015).

This study aims to provide a new urban analytics for tracing the determinants of the economic (market attractiveness, economic vitality, business environment) and livability (working, cost of living, security, life support functions) achievement of large cities in our world, based on a ‘big data’ system for these cities. This urban performance analysis is undertaken at the level of both aggregate and fine-gained data on these cities.

Large cities are, in general, powerful and effective growth engines in a modern global world. The rising importance of urban agglomerations emerges from so-called agglomeration externalities, partly in the form of MAR (Marshall-Arrow-Romer) externalities, and partly in the form of social network (or Jacobs ‘melting pot’) externalities of urbanization. Nonetheless, the relative efficiency of cities (in terms of productivity, resource use etc.) may differ significantly, and hence it is a matter of empirical research to trace which city has the highest performance and under which conditions (see also Kourtit 2014, 2015).

The emerging new urbanization patterns that manifest themselves world-wide prompt an avalanche of new policy and research challenges and concerns. Particularly in such domains as income distribution, climate change, quality of life, food, energy, safety, mobility, poverty and social cohesion, major problems in cities are expected. In the developing world, it is foreseen that housing problems – in particular, slums – will continue to exist and will have a detrimental effect on the daily well-being of a significant share of the world population. Even more severe problems are anticipated for the decades to come: sea level rise, floods, social tensions, refugee flows, extreme weather conditions, traffic deadlocks, and so forth. It goes without saying that ideally urban economic development has to proceed in tandem with urban ecological sustainability. At present, more than 75 percent of the global environmental impacts are produced by just over 50 percent of the world population, leaving behind a threatening ecological footprint. Is economic growth and productivity able to cope with these issues? Such major and world-wide concerns call for strict governance systems and response mechanisms, but this

¹In a standard textbook on urban economics by Mills, Hamilton (1994), the authors raise the question: ‘What are urban areas?’. They argue that there are many urban concepts: town, city, urban area, metropolitan area, and the like. Some of these concepts are based on legal definitions, and hence these definitions vary across nations. Others are based on population figures and reflect the fact that in urban areas the average population density is higher than elsewhere. The authors provide the following basic description: ‘Thus the fundamental and generic definition of an *urban area*, or *metropolitan area*, is a place with a much higher population density than elsewhere’ (p. 3). It is thus apparent that the concept ‘urban’ is not a clearly operational term. In our study, we use this term as a general description of a place or area with a relatively high concentration of people in a demarcated built environment. To be slightly more precise, in the present study, we adopt the following nomenclature in the present paper (see the *Dictionary of Human Geography*, edited by Gregory et al. (2009)):

- *urbanization*: has often been understood as a process of human distancing from first nature. In cities, nature became a residual or artificial category limited to parks, zoos and urban – mostly ornamental – gardens.
- *city*: today, a more generic usage of this term refers to an urban demographic, economic and above all political and jurisdictional unit, usually bigger than a town.
- *agglomeration*: the association of productive activities in close proximity to one another. It typically gives rise to external economies associated with the collective use of the infrastructure of transportation, communication facilities and other services. Agglomeration also facilitates the rapid circulation of capital, commodities and labour.
- *urban areas*: may be cities or towns and are characterized by a higher population density in comparison with the areas surrounding them.

is exactly the Achilles heel of modern urban planning and policy-making. Clearly, we also need reliable and comparable databases on urban development and their backgrounds, in order to develop effective policy intervention tools (Batty 2013, Vaz 2016, Vaz, Arsanjani 2015, Vaz et al. 2015).

Fortunately, we observe nowadays a renewed and world-wide interest in urban challenges and responses, as well as in the strategic position of world cities in global networks (see Neal 2012, Taylor 2004). Major issues in this debate are:

- The impact of population dynamics on urbanization patterns (in particular, cross-border migration movements).
- The relationship between economic cycles and urban developments (including shrinking cities, such as Detroit or Leipzig).
- The acceleration in urbanization rates in the developing world, and the far-reaching consequences for the economy, society and ecology.
- The serious risks encountered by massive population concentrations, which may be subjected to major catastrophes (e.g., floods, social unrest, extreme weather conditions, terrorism, power cuts).
- The persistent – and sometimes sharpening – poverty traps in many large agglomerations in our world.
- The logistic control of extremely complex urban physical and virtual networks (e.g., commodity distribution, mass transit, volatility of geographic locations, digital data management for public policy etc.)
- The span of control of modern urban governance systems in the management and strategy development of the rising number of mega-cities on our planet.

It is clear that modern large cities are complex spatial entities, with a great heterogeneity in socio-economic, transport, business and ecological outcomes. Several cities appear to have a much better performance net outcome than others. And therefore, it is important to trace the drivers of the achievement levels of large cities in our world. It is clear that economic outcomes need to be explained from a broader perspective, while also the quality of life plays an important role. The theoretical underpinning of the design of our research can be found in the ‘urban piazza’ model in Figure 1, to be highlighted in Section 2.

Clearly, the great challenge for large cities in our world is to perform much better. Many cities in our world face sometimes similar, sometimes different problems in achieving a respected and recognized international profile. We talk more and more about global urban competition and competitiveness profiles of cities. This so-called ‘rat race’ (Kourtit, Nijkamp 2013b, Kourtit, Nijkamp, Suzuki 2013) does not mean that cities are in all respects competitors which operate on a ‘predator-prey’ basis, but it suggests that many world cities aim to reach a top position in a global competitive ranking system. The aim of the present paper is now to offer a methodology for comparing in a logical and systematic way a broad range of qualitative performance² indicators of a set of global cities, in total 40 in number. This comparative study uses a very extensive and rich database from the Global Power City Index system developed by the Japanese Mori Memorial Foundation (2012). This dataset comprises detailed information on numerous indicators for the cities under consideration. In the annual GPCI database reports, a qualitative ranking of these 40 cities – on the basis of their multidimensional performance profile – can be found. The challenging research question in this paper is now whether in a systematic way the determinants for the performance ranking of these cities can

²The ‘performance’ concept already has a long history in industrial management and business economics. In general terms, this concept can be defined as: ‘a person’s achievement under test conditions’ (*Oxford Encyclopaedic English Dictionary*). However, in productivity and efficiency studies, this concept is defined much more broadly and refers to a systematic operational measurement – often in comparison with relevant actors – of the economic achievement position of an actor or corporate organization. The latter meaning will also be adopted in our study on global large cities.

be identified. Given the qualitative rank-order information on the determinants, a combinatorial deterministic method will be used, so that factors that are of critical importance (i.e., necessary conditions) for the economic and ecological performance of cities can be traced. The comparative assessment methodology employed here originates from an artificial intelligence method, coined rough set analysis, which is very appropriate in assessing the critical success conditions (stimuli) that lead to a set of output indices (responses) from a number of competitors or alternative choice possibilities. This method which finds its origin essentially in ordinal multi-criteria analysis will concisely be presented in Subsection 2.2.

The paper is organized as follows. Section 2 will be devoted to the description of the framing and the database of our study. Then in Section 3, the operational methodology employed will be briefly outlined, and will offer an overview and interpretation of the empirical results. Section 4 will then conclude with some retrospective and prospective remarks.

2 Framing of the Research

2.1 Description of the database

The rising interest in city growth and size and in urban networks has in recent years prompted a wide variety of city concepts, such as smart city, global city, world city, mega-city, metropolis, ecumenopolis, megalopolis, connected city etc. (Doel, Hubard 2002, Kourtit, Nijkamp 2013b, Neal 2012, Sassen 1991, Taylor 2004). They all have different meanings, but are also often used interchangeably in the literature. In the present paper we will use the neutral term large city, which may in general mean that the city concerned – or the urban agglomeration – will have more than 1 mln inhabitants. Our interest is not in conceptual purity, but in the analytical question: what makes the difference? In other words, if a given large city can be characterized by a set of manifold performance indicators, which are the conditioning variables (critical success factors) that determine in a relative sense the success of the city at hand, and to what extent?

Clearly, in principle, the number of performance criteria, as well as the number of drivers (inputs or stimuli) is vast, while sometimes the distinction between drivers and output is not clear at all. Very often, economic characteristics – for instance, number of headquarters of international banks, financial services, international events or exhibitions, or economic image – are seen as performance variables (outputs), while public investments – e.g., international transport infrastructure, advanced IT networks, health care facilities – are often regarded as support conditions that may act as drivers (or inputs). But in a way, they might also partly be seen as endogenous success indicators. Thus, there will always be some ambiguity in the definition of drivers and responses (Kourtit 2015).

In our applied analysis, we will use the extensive and unique multi-dimensional database developed by the Institute for Urban Strategies (Mori Memorial Foundation 2012), which contains a systematically collected and annually updated vast amount of interesting urban data (starting from 2008) that are relevant for our purposes. The data base comprises 40 large cities, with a fair distribution between developing and developed countries. The data is a mix of survey data and ordinal response and perception data. This data base is subdivided into six main categories: *Economy, Research & Development, Cultural Interactions, Livability, Environment, and Accessibility*. These six categories in the database are next decomposed into a total of 69 empirically tested and mutually comparable sub-indicators for each of the 40 large cities in the world that are considered. This list of preselected cities is a priori given for our analysis; see Figure 2 for this complete list. A very interesting characteristic is also that the database considers the classes of relevant global and local actor-specific scores and rankings of the socio-economic performance of cities from the perspective of prominent stakeholders, in particular, residents, visitors, artists, researchers, and managers (see also Arribas-Bel et al. 2013, p. 252). This is thus a rich and original database, which is particularly suitable for applied comparative research on urban performance.

The GPCI database is based on a cross-section of identifiers of urban development, based on interviews and data collections from local stakeholders. Clearly, each city may

have its own desired performance profile with unique or place-specific indicators, but in an internationally comparative and competitive benchmark exercise cities have to be compared on common and identical indicators. As in a global force field it is the external world which decides on the successfulness of urban agglomerations.

This Global Power City Index (GPCI) database offers a multidimensional picture of the socio-economic performance and position of different global cities in the world from the perspective of attracting and retaining firms, talent and investment to these cities on the basis of inter alia quality of life, culture and accessibility, complemented with detailed information on the perceptions of relevant groups of stakeholders (see also [Tranos et al. 2014](#)). Table 1 offers a brief overview of the main classes of performance indicators derived from the GPCI-2012 data system (see also [Arribas-Bel et al. 2013](#), p. 252). This information is used in the GPCI analysis to create a performance ranking of all 40 cities. The main question is now: What are the drivers of this ranking?

In highlighting the rank orders of the individual urban indicators included in the six main categories used in the GPCI-2012, the information base demonstrates the different strengths of the socio-economic achievement levels of the leading global cities. This rich information base can also help to improve our understanding of the attractiveness of a particular large city (see also [Arribas-Bel et al. 2013](#), p. 252), for instance, through a benchmark analysis. These GPCI-data are updated annually in a careful and reliable way, so that in principle not only a cross-sectional comparison of cities can be made, but also a combined space-time panel assessment. In the present study however, we will limit ourselves to a cross-section assessment of the performance of cities, mainly since the relative changes in urban performance on an annual basis appear to be rather modest.

Table 1: List of performance indicators of the GPCI-2012

Indicator Group	Indicator
ECONOMY	
Market attractiveness	1 GDP
	2 GDP per capita
	3 GDP growth rate
Economic vitality	4 Total market value of listed shares on stock exchanges
	5 Number of world's top 300 companies
	6 Number of employees
Business environment	7 Unemployment rate
	8 Number of employees in service industry for enterprises
	9 Average wage level (compared to New York)
	10 Easiness of securing human resource
	11 Office area per employee
Regulations and risks	12 Index of economic freedom
	13 Corporate tax rate
	14 Index of country risk (political, economic, business, etc.)
RESEARCH & DEVELOPMENT	
Research background	15 Number of researchers
	16 World's top 200 universities
	17 Basic skill of mathematics and science
Readiness for accepting and supporting researchers	18 Readiness for accepting foreign researchers
	19 R&D expenditure
Achievement	20 Number of registered industrial property rights (patents)
	21 Number of highly-reputed prize winner
	22 Activeness of interaction between researchers and outputs of their achievement
Trendsetting potential	23 Trade value of audiovisual and related services
	24 Number of holdings of international conventions
	25 Number of holdings of world-class largest cultural events
	26 Environment of creative activities

Continued on next page

Table 1 – continued from previous page

Indicator Group	Indicator
Accommodation environment	27 Number of guest rooms of luxury hotels
	28 Number of hotels
Resource of attracting visitors	29 Number of world heritages (within 100km area)
	30 Cultural attractiveness, etc.
	31 Number of theatres and concert halls
	32 Number of major museums
	33 Number of stadiums
Shopping & Dining	34 Satisfactory level of shopping
	35 Satisfactory level of dining
Volume of interaction	36 Number of foreigners
	37 Number of visitors from abroad
	38 Number of foreign students
LIVABILITY	
Working environment	39 Total working hours
	40 Satisfactory level of employees' life from the viewpoint of managers
Cost of living	41 Average rent (residential)
	42 Average price level (compared to New York)
Security and safety	43 Number of murders
	44 Vulnerability
	45 Healthy Life Expectancy
	46 Activeness of community
Life support functions	47 Population density
	48 Number of medical doctors per residents
	49 Number of international schools per foreign residents
	50 Variety of retail shops
	51 Variety of restaurants
ECOLOGY AND NATURAL ENVIRONMENT	
Ecology	52 Number of companies with ISO 14001 certification
	53 Percentage of renewable energy
	54 Percentage of recycling
	55 CO2 emissions
Pollution degree	56 Density of suspended particulate matter (SPM)
	57 Density of sulfur dioxide (SO2)
	58 Density of nitrogen dioxide (NO2)
	59 Water quality
Natural environment	60 Situation of green coverage
	61 Average yearly temperature differences
ACCESSIBILITY	
Infrastructure of transportation	62 Travel time between inner-city areas and int'l airports
	63 Number of cities with international direct flights
	64 Number of travellers of international flights
	65 Number of runways
Infrastructure of inner-city transportation	66 Number of stations (subway)
	67 Punctuality of public transportation (train, subway, bus)
	68 Satisfactory level of commuting
	69 Taxi fare

Source: [Mori Memorial Foundation \(2012\)](#)

The data in the GPCI-database have a broad coverage. But they have to be treated in a logical and coherent framework, so as to identify in a systematic and consistent way the determinants and responses of urban systems in a comparative sense. All details on the collection, standardization, definition and geographical scale of the data can be found in the above mentioned GPCI-report. Annex A contains more detailed rankings of these cities on the basis of the above mentioned principles ([Arribas-Bel et al. 2013](#), p. 254).

In explaining in a qualitative sense the rankings of the cities at hand on the basis of their performance profile, we have focused on two categories of responses or achievements, viz. the economic performance and the livability in each of these cities. Consequently, these two categories of endogenous variables are assumed to be determined by a wide range of background variables, so that all remaining indicators are assumed to be driving forces of these achievement rankings of these cities. This will be tested in our empirical work.

The methodological and conceptual framework of our research on the performance of 40 global cities originates from the ‘*urban piazza*’ architecture (see Figure 1). The ‘*urban piazza*’ architecture acts here as the integrated conceptual framework and navigation tool for assessing performance criteria of the global cities under varying condition variables (or stimuli). An extensive underpinning and treatment of the ‘*urban piazza*’ concept can be found in Kourtit (2015); we refer here also to Arribas-Bel et al. (2013) and Kourtit et al. (2014). The essence of the piazza model is that it offers a comprehensive ideal-typical representation of the urban force field that generates the performance of a given city.

Historically, the ‘*piazza model*’ is essentially based on the general functional coherence of and socio-economic independencies of activities in ancient Italian cities, in which all relevant forces (economic, social, political, logistic, etc.) were coming together in a central place or node which generated the heartbeat of the city concerned. It offers a broad framing of urban functionalities and mechanisms, from which we have selected a limited set of focused variables that are in agreement with the GPCI dataset. In our study, we assume that nowadays four such major drivers can be distinguished, which are of critical importance for two classes of response (or output) variables. The piazza architecture used in the present empirical analysis is therefore, decomposed into four main segments viz., *R&D*, *Cultural Interaction*, *Environment* and *Accessibility*, which form the four major condition variables to explain separately two major endogenous decision variables (or responses), viz., *XXQ Economic Performance* and *XXQ Livability* (see Figure 1). In other words, global cities seek to generate the highest possible productivity and quality of life (similar to the general XXQ-concept, introduced by Nijkamp (2008)) so as to attract and retain creative and talented actors (employees, self-employed people or entrepreneurs, but also residents and visitors) in order to generate positive externalities (Kourtit, Nijkamp 2013a,c).

Thus, the above two XXQ indicators are a measure of global cities’ performance in which inputs or efforts (*Cultural Interaction*, *R&D*, *Accessibility* and *Environment*) are linked to achievements of the city at hand (e.g., profitability, vitality, sustainability, etc.). Clearly, the piazza concept can be positioned in a broader context of recent spatial growth models (including absorptive capacity) and urban creativity analysis. It is evident that the presence and experience (individual values, preferences and visions) of creative minds can create critical conditions for enhancing the level of attractiveness of cities, leading to a concentration of innovative potential in geographical space (Kourtit, Nijkamp 2013a,b,c,d, Kourtit 2015). The piazza framework will now be used as an integrating basis for a broad urban assessment exercise, with the aim of tracing the roots of the economic success (*XXQ Economy*) and livability (*XXQ Livability*) of cities on the basis of their innovative capacity (*R&D*), cultural ambiance (*Cultural Interaction*), natural and ecological quality (*Environment*) and transport access and connectivity (*Accessibility*). The information contained in Table 1 is partly quantitative, partly qualitative in nature. To avoid an ambiguous analysis of heterogeneous data, all information was consistently translated into rank-order data.

Since the rankings of the 40 cities under investigation are based on multivariate data that are combined to create a qualitative rank order, it is necessary to seek for an analytical explanatory model that is able to encapsulate such qualitative data. Consequently, we need to look for a qualitative explanatory model, known as *rough set analysis*. This will be outlined in the next subsection.

2.2 *Rough set analysis as a research tool*

For the analytical part of our qualitative comparative assessment study, a multivariate qualitative classification method, called rough set analysis (RSA), is used. This method

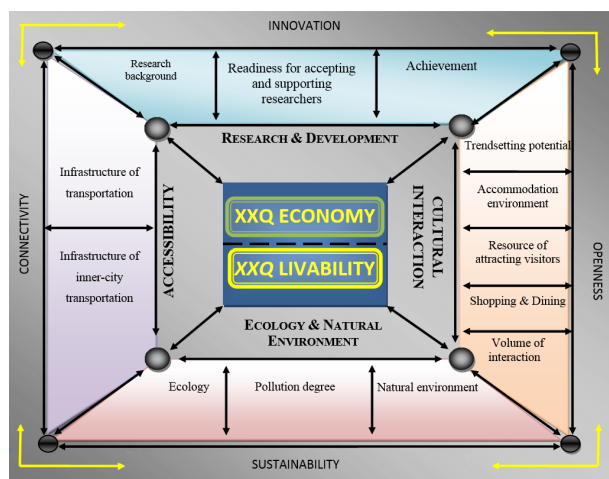


Figure 1: The 'urban piazza' for the performance structure of large cities

is inspired by the artificial intelligence methodology (for more details, see also Pawlak 1991, Pawlak, Slowinski 1996, van den Bergh et al. 1998, Slowinski, Stefanowski 1994, Greco et al. 1997). This approach will be used as the main methodology, in order to offer an explanatory non-parametric and qualitative model for assessing the critical success conditions that lead to a set of output indicators (responses) for each of the rivalry choice options. This rough set method will be applied to operationalize the conceptual piazza model depicted in Figure 1.

RSA is a deterministic method, which is based on combinatorial set theory (see also Baaijens, Nijkamp 1997, p. 11)(see also Baaijens and Nijkamp 1997, p.11), and may be regarded as a qualitative explanatory regression analysis in case of small samples. A disadvantage of a standard regression analysis is that, if the sample size of the model is limited, the reliability of the regression results is rapidly going down, especially in case of a large number of explanatory variables. In addition, in case the relevant variables have only a qualitative or nominal meaning (e.g., tourism loyalty, historical heritage), application of quantitative regression techniques becomes problematic. RSA is particularly suitable in case of qualitative information and small samples (see Kourtit, Nijkamp, van Leeuwen 2013). The main challenge of RSA is to provide an analytical approximation of logically consistent and permissible statements from the acquired available database. It takes for granted the general scope of regression analysis, viz. that a set of condition variables (explanatory variables, stimuli) impact a set of endogenous variables (responses or decision variables). The main idea is then to find out under which conditions the stimuli have a decisive impact on the responses. In contrast to regression analysis where impact coefficients are estimated, rough set analysis – based on qualitative information – then tries to identify the frequencies of occurrences from the data set, with which a set of stimuli exerts an influence on one or more response variables. This means essentially a deterministic analytics in tracing the impact of condition variables on endogenous variables. From this perspective, RSA is much richer in scope than simple correlation or regression analysis, also because it is able to consider simultaneously more than one endogenous variable, as is the case in one study.

The rough set method is thus suitable to deal with compound qualitative information, and offers a consistent description of a set of qualitative variables on the basis of lower and upper approximations in case numerical values of these variables do not exist. This information is considered as a finite set of objects, which can be described through a set of characteristic attributes. These attributes are supposed to construct the available information on the objects (alternatives, items). On the basis of a set of attributes, a rough set approach can categorize phenomena into groups with identical features by considering relevant measurements that may weaken the 'unobserved heterogeneity'.

RSA is also an original method for dealing with incomplete information patterns, and

may therefore be a useful approach for a transversal comparison of urban achievements from a broad multidimensional perspective (see [Orlowska 2013](#)). Data reduction is often the main element of RSA, as it allows to identify and represent hidden structures in the data (see also [Baaijens, Nijkamp 1997](#), p. 11). The result of a RSA of a multidimensional data set is ultimately a decision table which forms the basis for deriving deterministic decision rules, which are compatible and logically consistent with the qualitative pattern of the data. The decision rules are normally of a conditional (i.e. ‘*if ... then ...*’) nature and indicate also the strength of such conditional statements (i.e., the number of objects – or frequencies – for which this statement is true) (see [Kourtit, Nijkamp, van Leeuwen 2013](#))(see [Kourtit et al. 2013b](#)). These expressions describe the associations between the objects considered and their assignment to particular classes (see [Pawlak 1991, 1992](#))(see [Pawlak 1991; 1992](#)). We will not provide here an extensive discussion of the many set-theoretical technicalities of RSA. Detailed information on RSA both from a conceptual and an applied perspective can be found in [Pawlak \(1991\)](#), [Fayyad et al. \(1996\)](#), [Deogun et al. \(1997\)](#), [Famili et al. \(1997\)](#), [Slowinski \(1995\)](#), [van den Bergh et al. \(1998\)](#), [Ziarco \(1998\)](#), and [Wu et al. \(2004\)](#).

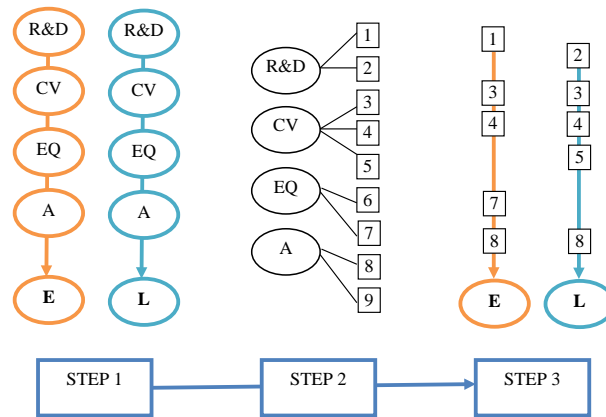
RSA can nowadays be applied by using standardized open access software. The RSA in the present study is performed with the support of the software programme Rough Set Data Explorer (*ROSE*). This programme is instrumental to calculate the basic minimal covering of conditional statements from a complex dataset.

We will now use the *ROSE* software here to compare, in a logical and systematic way, the performance indicators of the set of 40 global cities (i.e. the number of objects) from the GPCI data base in terms of 2 output variables (economy, livability) and 4 input variables (accessibility, R&D, cultural interaction, ecological & natural environment) (the number of attributes considered is thus 6), as outlined in [Table 1](#) and [Figure 1](#). In this way, rough set theory helps to provide insight into the multiple achievement categories of objects and to highlight the most prominent factors behind their achievements and performances (see also [Baaijens, Nijkamp 1997](#)). RSA provides thus an operational multidimensional classification method that helps identify important critical factors for a systematic performance analysis of competing objects. In the next section, we will present the empirical findings of the rough set analysis applied to the above mentioned GPCI data set.

3 Rough Set Analysis of Composite and Single Drivers of Urban Performance

Following the conceptual model of [Figure 1](#), we have – as mentioned above – chosen to focus on qualitative *XXQ Economy* and *XXQ Livability* indicators for the 40 cities under research. The reason for this choice is that these factors are both distinct from each other and can be well explained from a causality perspective by the other four (composite) factors (R&D, Cultural values, Environmental quality and Accessibility). Thus, the aim is to develop a qualitative explanatory model for the case of two types of performance indicators (decision variables) of GPCI cities as a result of the existence and functioning of four types of underlying drivers (condition variables, in rough set terminology). Thus, in fact, the urban piazza framework of [Figure 1](#) is translated into a qualitative causal model explaining (a set of) two endogenous output variables from (a set of) four exogenous explanatory (input) variables. These output and input variables are, in the RSA jargon, often called decision and condition variables, respectively.

Our RSA will be applied in three steps, as shown in [Figure 2](#). In the *first* step, we only use the main composite variables, both as decision (2) and condition (4) variables, to test globally the causal pattern implied by our conceptual model from [Figure 1](#). In the *second* step, we will have a closer look at the distinct sub-factors from the 4 condition variables which are the most influential ones for each of the two overall composite factor scores. Finally, in the *third* step, we will use the most important critical sub-factors that resulted from step 1 and 2 to explain the composite performance factors *XXQ Economy* and *XXQ Livability* as decision variables.



Notes: E = XXQ Economy; L = XXQ Livability; R&D = Research & Development; CV = Cultural Interaction; EQ = Ecology & Natural Environment; A = Accessibility

Figure 2: Three steps in the rough set approach using composite factors and sub-factors

Table 2: Rough set rules explaining *XXQ Economy* by composite factors using 4 classes

Rule #	R&D	Cultural	Environment	Accessibility	Econ(D)	Coverage (%)
1	1				1	42
2				1	1	29
3			4	4	1	29
4		1	3		2	22
5			3	2	2	29
6	2	1	1		2	21
7	3		4		3	42
8	2	1	4		3	25

3.1 Explaining composite urban performance factors from composite driving forces (Step 1)

In the first step of our analysis we will explore how the 6 composite factors are related to each other. Therefore, the composite economic indicator from Table 1 is used as the decision variable (in rough set terms), to be explained by 4 background variables or condition variables. We classify now the 40 cities from the GPCI data base first into four groups, based on their *XXQ Economy* indicator. The rankings are denoted as 4 qualitative classes of features, viz. low, medium-low, medium-high and high. The RSA results show that for the *XXQ Economy* and *XXQ Livability* scores, all 4 conditional variables appear to be in the ‘core’ of the rough set classification. This means that each of them is relevant and necessary in explaining the level of *XXQ Economy*. Next, a sensitivity analysis shows that this finding also holds when distinguishing three classes of – rather than four classes – *XXQ Economy*, so that this result is rather robust.

The quality of classification (viz., in rough set terms, the significance of the combination of background variables playing an explanatory role) appears to be quite high, namely 0.80. With these settings, 8 so-called decision rules or logical statements that are consistent with the data can be derived from the rough set analysis (see Table 2).

The strongest decision rules appear to be rules 1 and 7, which both cover 42% of the dataset. These tell us that a low R&D level results in low economic development; and a medium-low level of R&D combined with a high level of environmental quality results on average in a medium-low economic score for the cities under consideration. There is apparently quite some degree of heterogeneity among the 40 cities in our sample, so that each separate statement from the total set of 8 all rules is somewhat difficult to interpret.

When we apply next a sensitivity analysis and split the cities into 3 groups, with the categories low, medium and high *XXQ Economy*, again all condition variables appear to

Table 3: Rough set rules explaining *XXQ Economy* by composite factors using 3 classes

Rule #	R&D	Cultural	Environment	Accessibility	Econ(D)	Coverage (%)
1	1		1		1	77
2	1			2	1	46
3		2	3	2	2	27
4	3				3	33
5		3			3	25

Table 4: Rough set rules explaining *XXQ Livability* by composite factors using 4 classes

Rule #	R&D	Cultural	Environment	Accessibility	Livability(D)	Coverage (%)
1		3			1	23
2	3		2		1	23
3	3			1	1	23
4	1			1	1	23
5			2	1	1	23
6		2			2	33
7		4		2	2	33
8			1	2	2	33
9	3	4	3		2	33
10	3		3	4	2	33
11			4	4	3	27
12			2	2	4	20
13	2	4	4		4	30
14	2	4		3	4	30
15	2		4	3	4	30

be in the core. However, the quality of the classification is slightly lower than before, viz. 0.68 for the economic system (Table 3).

Table 3 shows that the first two rules are the strongest ones, with a coverage of respectively 77 and 46 percent. It is clear that a low R&D, even with a medium accessibility, is related to a low economic performance. Apparently, R&D is a *sine non qua* for the economic achievements of cities. The other three rules all have a coverage above 25 percent. These indicate that a high level of R&D and a high level of cultural quality are related to high levels of economic performance.

Next, when we take a look at the *XXQ Livability* scores, again all condition variables appear to be in the core, with a classification quality of even 0.95. This results in a relatively large number of rules, again obtained through using a minimum of 20% of satisfaction (in rough set terms) and always a maximum number of 4 condition variables (see Table 4). Thus, all 4 explanatory factors may be seen as determinants of the urban output variables.

Next, when using again 3 classes of *XXQ Livability*, again all condition variables appear to be in the core; however, the quality of the classification is a little lower than before, namely 0.40. This also results in a lower number of satisfactory rules, namely only 6, of which 5 deal with low Livability scores. In addition, except for rule 5, all rules have a satisfaction level between 21 and 23%.

The clearest conclusion from the above results is that low levels of accessibility are related to low Livability scores. This holds for the strongest rule, number 5, with a satisfaction score of 38%, as well as for the 4 subsequent rules. Those first 4 rules indicate that even when levels of R&D or culture are high, but urban accessibility is low, Livability is low. Rule 6 indicates that a medium level of R&D with a medium level of culture is related to medium Livability scores. Clearly, these findings may be seen as rather plausible outcomes.

Table 5: Rough set rules explaining *XXQ Livability* by composite factors using 3 classes

Rule #	R&D	Cultural	Environment	Accessibility	Livability(D)	Coverage (%)
1	1				1	23
2	3			1	1	23
3		3		1	1	23
4		2		1	1	23
5			1	1	1	38
6	2	2			2	21

3.2 Analysis of sub-factors (Step 2)

The dataset we use is a very rich one. The 6 main indicators are grouped into various sub-factors (see Table 1), as are the sub-factors themselves. To see how these sub-sub factors relate to the main indicators, we perform in our rough set approach a heuristic search for reducts (a subset of attributes which can, by itself, fully characterize the information contained in the database) which, in other words, have a basic minimal covering (see also Pawlak 1991, Pawlak et al. 1995, Pawlak, Skowron 2007, Poel 1998, Polkowski 2003). Within the *ROSE* software program, attributes are added to the existing core by selecting the most promising indicators from this set and by trying different paths. A higher frequency rate means that the sub-factor is more important in explaining the level of the composite score. Appendix A shows the percentages of all sub-factors per composite factor.

First, when looking at the 13 sub-actors of the *Economy* factor, 5 of them are never part of a minimal reduct. This means that they are the least related to the overall score on the Economy factor. However, 3 of the sub-factors have a score of 100 percent, which means that they are part of all minimal reducts and thus of the core of the dataset. These are: GDP per capita, presence of world top 300 companies, and office area per employee.

Livability is also composed of 13 sub-factors. Of these, 3 have a frequency score of 100 percent. Among those are the number of murders and the variety of shops and restaurants. Apparently, cities with a high degree of criminality can still have a high level of Livability. Furthermore, we can distinguish 1 core variable, namely, maturity of the community. In addition, 2 other variables have a high frequency score: average house rent and medical doctors per inhabitant.

Research and development is composed of 8 sub-factors, which all appear at least once in a minimal reduct. Two of them appear in every reduct and have a 100 percent frequency score; these are: interaction opportunities between researchers, and the number of winners of highly-reputed prizes.

Cultural interaction is composed of the highest number of different sub-factors, viz. 16. Of those, only one half appears in one of the minimal reducts. Three of them are in the core of the dataset: number of theatres and concert halls, number of visitors from abroad, and opportunities of cultural, historical and traditional Interaction.

The next composite factor is *Environment*, which consists of 9 sub-factors of which as many as four are part of the core. These are: CO2 emissions, density of suspended particulate matter (SPM), level of green coverage, and comfort level of temperature.

The final composite factor is *Accessibility*. Of the 10 sub-factors, 8 appear once or more times in a minimal reduct. One of them is a core variable, which is punctuality of public transportation. Apparently, this variable is very important in explaining high levels of accessibility. Furthermore, density of metro stations and the presence of direct international freighter flights appears to be also important.

This heuristics search exercise results in an interesting list of 18 single sub-factors that can be used to explain the composite factors *XXQ Economy* and *XXQ Livability* (see Table 6). Since 18 condition variables is a high number, we thus perform another heuristic search on the list of most important single factors with either *Economy* or *Livability* as decision variables. We selected all variables with a minimal reduct score of 50% and above for the final rule induction (variables are indicated in bold).

Table 6: The most important single sub-factors

	XXQ Economic	XXQ Livability
R&D		
Number of Researchers	34	4
World's Top 200 Universities	53	61
Readiness for Accepting Foreign Researchers	25	100
Cultural		
Number of International Visitors	88	
Level of Satisfaction for Dining	25	9
Number of Museums	2	22
Number Hotels		35
Environment		
CO2 Emissions	35	17
Density of Suspended Particulate Matter (SPM)	31	4
Level of Green Coverage	51	65
Comfort Level of Temperature	29	
Number of Companies with ISO 14001 Certification	81	52
Density of Sulfur Dioxide (SO2), Density of Nitrogen Dioxide (NO2)	15	87
Percentage of Renewable Energy Used	41	61
Accessibility		
Density of Metro Stations	80	100
Travel Time between Inner-city Areas and International Airports		9
Number of Passengers on International Flights	22	17
Transportation Fatalities per Population	20	

3.3 Explaining Economy and Livability from the most important critical sub-factors (Step 3)

Finally, the third step of the analysis performed in this study uses the sub-factors that are part of at least one of the minimal reducts. We impose a minimal coverage of 25 percent and a maximum number of attributes of 3 items.

When looking at the single factors explaining *XXQ Economy*, there are some interesting findings. Clearly, the presence of good universities appears to be beneficial. A low score for this variable, together with medium/low green coverage and a low number of international visitors, is related to a low score on *XXQ Economy*. This holds, for example, for Bangkok, Cairo, Fukuoka, Moscow and Mumbai. At the same time, a high score on top-200 universities, together with a high score on certificates, is related to a well performing Economy. This holds for example for Beijing, Hong Kong, London and Tokyo.

In addition, the number of international visitors affects the quality of the economy: rule 6 indicates that cities like Beijing, London, New York, Paris, Sydney and Barcelona, with a high number of international visitors, have a high score on *XXQ Economy*.

When looking at Livability, it appears that the urban density of metro-stations has a positive effect. In Beijing, Geneva, Toronto and Zurich the density is low and the livability of medium quality, while in Barcelona, Copenhagen, New York, Paris and Tokyo the density is high, as is Livability. Also the readiness for foreign researchers seems to positively affect *XXQ Livability*. In Cairo, Moscow, Mumbai and Sao Paulo, for example, this readiness is low, as is the Livability. Green coverage and the presence of top universities shows mixed results. Our hypothesis that the economic and ecological performance of large cities is largely determined by a combination of 4 categories of empirical evidence on 40 large cities is confirmed in our analysis, be it that individual exceptions may occur (just like in any normal regression analysis).

Table 7: Rough set rules explaining *XXQ Economy* by the most important single sub-factors

Rule	Top 200 Universities	Green coverage	International visitors	Certificates	XXQ Economy (D)	Coverage (%)
1	1	2			1	31
2	1	1	1		1	69
3	1	1		1	1	54
4			2	1	2	60
5		2	2		2	27
6			3		3	50
7	3			3	3	33

Table 8: Rough set rules explaining *XXQ Livability* by the most important single sub-factors

Rule	Top 200 Universities	Readiness for foreign researchers	Green coverage	Dioxide	Renewable	Metro	XXQ Livability (D)	Coverage (%)
1		1					1	31
2			2				1	31
3	2					1	2	36
4					2	1	2	29
5	1	3					2	29
6		3	1	2			2	36
7						3	3	38

4 Concluding Remarks

In an increasingly urbanized world, cities – or in a more general sense, urban agglomerations – are becoming engines of growth and sustainability. In the emerging ‘*New Urban World*’ (see Kourtit 2014, 2015), cities are not functioning as isolated islands, but have to compete in terms of their socio-economic and attractive achievements with other cities. Therefore, it is of utmost importance to identify the drivers of these achievements. In our study, we have presented the ‘urban piazza’ as a conceptual and coherent framework for mapping out the force field of modern cities, from the perspective of identifying and assessing the critical success factors for urban performance measured along two multidimensional criteria, viz. Economy and Livability.

Our study has used a comprehensive database for 40 cities all over the world to trace the drivers of urban performance, using the GPCI-database with qualitative rankings of all these cities. Our study has brought to light that there is not a ‘one size fits all’ result from our explanatory model. Different cities appear to have a varying performance through the influence of various important drivers. In many cases however, it turns out that accessibility and R&D may be seen as a major critical success condition, though in several cases in combination with other determinants of urban performance.

Urban performance analysis, as exemplified by our study, may become an important research tool in the future. Next to standard quantitative data, also qualitative information may prompt many insights into the success conditions of cities. Clearly, in the future, urban ‘big data’ may become another rich source of information, in order to better understand the fine-grained nature of urban dynamics and growth (Vaz 2016, Vaz, Arsanjani 2015, Vaz et al. 2014, 2015). It goes without saying that urban performance analysis may open new departures for research in the urban sciences. The rough set methodology applied here is a promising example of such a new analytical tool.

Clearly, RSA is able to act as an identifier in a complex pattern recognition exercise. Through a combinatorial algorithm, it offers a tool for conditional qualitative causal

statements, in particular, by examining the frequency of validity of a statement on the presence of an explanatory variable impacting – either as a single variable or in combination with other variables — one or more endogenous variables. Clearly, there are three marked differences with a standard regression model: rough set analysis handles qualitative (even nominal) information; it is deterministic in nature; it can handle multiple response variables.

Clearly, the present study has some limitations. The sample of 40 cities is not very large in number, but this is largely compensated for by the in-depth systematic and accurately tested information provided on each individual city. Next, the benchmark picture of these 40 cities has a limited time horizon of at most 3 years, so that a really dynamic longitudinal perspective is lacking. Thus, there is certainly scope for analytical improvement in the future, so that in the end also more advanced urban econometric models might be developed and tested.

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A Detailed Results

The frequency scores of the sub-sub factors in the six composite factors are recorded in Tables A.1 and A.2. When no number is shown, it means the variables are never part of a minimal reduct and therefore the least important ones in explaining the composite factors.

Table A.1: Frequency scores of the sub-sub factors of Economy

Economy	% frequency
GDP per Capita	100
World's Top 300 Companies	100
Office Area per Employee	100
Level of Economic Freedom	50
Number of Employees	50
Corporate Tax Rate	50
Nominal GDP	25
GDP Growth Rate	25
Total Market Value of Listed Shares on Stock Exchanges	
Number of Employees in Service Industry for Business Enterprises	
Wage Level	
Ease of Securing Human Resources	
Level of Political, Economic and Business Risk	

Table A.2: Frequency scores of the sub-sub factors of Livability

Livability	% frequency
Maturity of Community	100
Average House Rent	83
Medical Doctors per Population	83
Price Level	50
Healthy Life Expectancy Rate	50
Total Unemployment Rate	33
Population Density	33
Total Working Hours	17
Satisfaction of Employees for their Lives	17
International Schools per Foreign Population	17
Number of Murders per Population	
Variety of Retail Shops	
Variety of Restaurants	

Table A.3: Frequency scores of the sub-sub factors of Research and Development

Research and Development	% frequency	
	4 classes	3 classes
Number of Winners of Highly-Reputed Prizes	100	25
Interaction Opportunities Between Researchers	100	25
Number of Researchers	67	100
World's Top 200 Universities	67	100
Academic Performance in Mathematics and Science	67	25
Research and Development Expenditure	50	25
Number of Registered Industrial Property Rights (Patents)	33	
Readiness for Accepting Foreign Researchers	17	100

Table A.4: Frequency scores of the sub-sub factors of Cultural Interaction

Cultural Interaction	% frequency	
	4 classes	3 classes
Number of Theaters and Concert Halls	100	29
Number of Visitors from Abroad	100	57
Opportunities of Cultural, Historical and Traditional Interaction	100	
Number of Stadiums	50	14
Number of Large World-Class Cultural Events Held	50	57
Trade Value of Audiovisual and Related Services	50	
Number of International Conferences Held	25	43
Environment of Creative Activities	25	14
Number of Museums		100
Number of Guest Rooms of Luxury Hotels		100
Number of Hotels		
Level of Satisfaction for Shopping		86
Level of Satisfaction for Dining		100
Number of Foreign Residents		
Number of International Students		100
Number of World Heritage Sites (within 100km Area)		

Table A.5: Frequency scores of the sub-sub factors of Environment

Environment	% frequency	
	4 classes	3 classes
CO2 Emissions	100	100
Density of Suspended Particulate Matter (SPM)	100	100
Level of Green Coverage	100	100
Comfort Level of Temperature	100	100
Number of Companies with ISO 14001 Certification	50	100
Density of Sulfur Dioxide (SO ₂), Density of Nitrogen Dioxide (NO ₂)	50	100
Percentage of Renewable Energy Used		100
Percentage of Paper Recycled		
Water Quality		

Table A.6: Frequency scores of the sub-sub factors of Accessibility

Accessibility	% frequency	
	4 classes	3 classes
Punctuality of Public Transportation	100	
Density of Metro Stations	86	100
Cities with Direct International Freighter Flights	85	
Number of Cities with Direct International Flights	71	
Number of Runways	43	
Travel Time between Inner-city Areas and International Airports	43	100
Number of Passengers on International Flights	29	100
Convenience of Commuting	29	
Transportation Fatalities per Population		100
Taxi Fare		