Chapter 17
Large Cities as the Cradle of Sustainable Energy Innovation

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Abstract Large cities have empirically confirmed to act as the cradle of innovation. We explore whether this is also true for sustainable energy technology. We pose the question to what extent large cities act as concentrations of sustainable energy inventions and market introduction, and to what extent agglomeration and network factors are involved and large cities offer specific advantages. Our empirical outcomes tend to be mixed. In the past years, large cities have remained clusters of sustainable energy inventions, however, spread over a larger number of (single) cities. With regard to market introduction, large cities tend to be slightly more successful than smaller cities, however, this is not true for early market introduction. The weak and somewhat ambiguous relationships with large cities may be connected with the typical location of some sustainable energy sources, namely, as fixed natural assets in sparsely populated areas, like windy seashore and hills, strong coastal water currents, extended woodland, etc., favouring research in nearby small university towns. At the same time, the abundant knowledge (diversity) in large cities may enhance inventions with larger risk-taking in newness, specialization and global markets, and concomitantly, delay and longer time to market.

Keywords Sustainable energy technology · Invention · Market introduction · Agglomeration · Network factors

JEL Codes L21 · L26; O31 · Q4 · R11

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S. Suzuki, R. Patuelli (eds.), *A Broad View of Regional Science*, New Frontiers in Regional Science: Asian Perspectives 47,
https://doi.org/10.1007/978-981-33-4098-5_17

17.1 Introduction

To fight climate change, in particular reducing greenhouse gas emission has become a pressing issue in recent years on many levels, i.e. global, European Union, country governments, cities and universities, as evidenced by various assessment reports and long-term strategic visions (e.g. European Commission 2013, 2019; International Energy Agency 2019a, b; United Nations 2015). Technology, both existing and emerging ones, is an important source of new solutions, alongside knowledge on practical application.

Many empirical studies have confirmed that invention and innovation in large cities benefit from agglomeration economies. This study addresses the question whether this is also true for sustainable energy inventions aimed at mitigating greenhouse gas emission and broader use of renewable sources of energy. Agglomeration economies are often summarized as knowledge spillovers, non-traded local inputs and local skilled-labour pool (e.g. Anselin et al. 1997; Audretsch and Feldman 1996; Capello 2009; McCann 2006). Knowledge spillovers work through meetings and informal gatherings of researchers and business people, in which specific (tacit) knowledge easily circulates, an advantage that tends to be crucial in technology and markets with rapidly changing information. Non-traded local inputs refer to a more efficient (and cheaper) provision of highly specialized services if clients are grouped together in the same city (region) compared to being dispersed. And local skilled-labour pool refers to the potential of firms (research labs) to reduce labour acquisition and training costs, due to the presence of a pool of workers with already specialist skills. Agglomeration economies do not stop at the border of cities or clusters, meaning that high performing neighbouring regions have a positive influence on innovation performance in (main) clusters (e.g. Charlot et al. 2014; ÓhUallacháin and Leslie 2007). A connected but more recent approach—entrepreneurial ecosystems—has a strong focus on entrepreneurship and entrepreneurial risk-taking, mainly of young firms (Acs et al. 2017; Hayter 2016). Emphasis is put on institutional and organizational conditions, in particular on networks that facilitate entrepreneurial identification and commercialization of opportunities by these firms in their strategic choices.

Since the early 2000s, an alternative or extended concept of proximity has been developed, namely, *relational* proximity (e.g. Asheim and Isaksen 2002; Bathelt et al. 2004; Boschma 2005; Breschi and Lissoni 2001; Ertur and Koch 2011; Ponds et al. 2009). In this context, emphasis is put on actual demand for (new) knowledge and presence of common sets of values (beliefs) that facilitate knowledge spillovers over larger distances around the globe, for example, by travelling of key persons and using ICT support. Accordingly, the characteristics of knowledge networks can be seen as important conditions for invention and market introduction in large cities, and this moves our focus to multinational corporations (MNCs). MNCs account for a large share of worldwide research investment and they have an ability to connect cities and clusters through their internal global networks by maintaining a presence in different locations (Stek 2020). However, there is no consensus about influence of

MNCs on knowledge flows and benefits for invention performance in large cities. Within MNCs, a high level of trust may facilitate research collaboration between different cities and introduction of new knowledge to cities through MNCs acting as connecting pipelines (Bathelt et al. 2004; Gertler and Levitte 2005). This in contrast with evidence suggesting that the presence of MNCs in a city may have a detrimental effect due to 'reverse knowledge flow', taking place when important and highly innovative local firms are acquired and integrated (Ambos et al. 2006; Frost and Zhou 2005; Ostergaard and Park 2015).

Finally, we discuss a mechanism of a different kind, namely, path dependence, drawing on growing doubt about strength of agglomeration factors (Fitjar and Rodríguez-Pose 2017) and on emphasis put on an evolutionary perspective. Path dependence can be seen as a collective attitude of major actors in cities (clusters) that is influencing change (or lack of change) in innovation activity and its spatial pattern (Boschma and Frenken 2006; Crescenzi and Rodríguez-Pose 2011). Path dependence grows on the basis of capabilities, skills, experience, institutions, resources, networks, etc. developed in the recent past. In a cluster's development trajectory, path dependence is low in the stage of new path creation in which a cluster produces radically new technologies and products (Martin and Sunley 2003; Neffke et al. 2011; Tidd et al. 2005). In contrast, path dependence tends to be relatively high in a stage where industries, universities, and policymakers in a cluster become locked into initially successful paths that may block further progress (Martin and Simmie 2008).

Against the above theoretical background, we address the question as to what extent innovation in sustainable energy is concentrated in large cities (clusters) and how its performance is connected to agglomeration factors and network factors, and concomitant entrepreneurial advantages, in the presence of different path dependence.

The first novelty of this essay is the attention to technology on sustainable energy, e.g. solar PV, wind energy, advanced biofuels, hydrogen and fuel cells, river-based and sea-based hydro energy (currents, tides), and also sustainable transport technology. This choice is of course inspired by the need for climate change, in particular to reduce CO_2 and other greenhouse gasses and to avoid dependence on fossil energy. A second novelty is the attention to two different and sometimes overlapping stages in innovation processes, namely, knowledge creation/invention and bringing the inventions to market (market introduction) (Tidd 2001; Tidd et al. 2005). In the first part of this essay, the focus is on inventions in sustainable energy technology in localized clusters, while in the second part, the focus is on young university spin-off firms as a channel of commercialization of such inventions.

This essay is written to express gratitude to Peter Nijkamp. Personally speaking by the first author, Peter Nijkamp acted as co-promotor of my PhD research (1993) and later as co-author of several related studies, thereby favouring open-mindedness in choices concerning theory and research design, while keeping strict quality standards. This essay includes several of these choices, namely, spatial innovation theory and entrepreneurial orientation approach; scientometric data (patents) and qualitative interviews on firm behaviour; standard regression modelling and rough-set analysis.

17.2 Sustainable Energy Transition

Energy systems often act as rigid systems in response to technical innovation. This situation follows from the systems' nature as a socio-technical system, consisting of many interacting physical/technology elements, such as power plants, distribution grids, technology firms, metering systems, etc. but also of related social elements, including end-consumers, firms, government policy, regulation, legitimacy, standards, pricing-regimes, etc. All these elements together with strong linkages constitute the socio-technical system of energy, and partially also of transport systems (engine, fuel) (e.g. Dóci et al. 2015; Geels 2011, 2012; Markard et al. 2016). As a result, bringing about changes in energy systems, particularly substitution of energy sources, is not just an act of new technology creation (improvement) and market introduction, instead, it implicates the involvement of large numbers of actors—on the technical and social side—along with their networks and interconnections, which may cause certain 'resistance' to transitional change.

In a conceptual approach to socio-technical transitions, the so-called regime is seen as the solid structure that accounts for stability in the system, referring to sets of rules that direct and coordinate social and economic groups in reproducing system activities, for example, through lock-in mechanisms, in particular sunk cost impacts, vested interests, established user preferences and practices, experienced business models, etc. (Geels 2011, 2012). Under these circumstances, experimentation in real life with sustainable technology solutions and 'attacking the regime', seems only possible in protected *niches*, outside the influence of conventional market forces and regulation (Lopolito et al. 2011; Quitzau et al. 2012; Raven et al. 2016; Smith and Raven 2012). Niches provide room for nurturing novel projects enabling learning about market introduction (user preferences, business models) and adjustment in regulation (standards) by means of real-life experimentation. The previously addressed agglomeration economies point to large cities (clusters) as better endowed with diversity in knowledge flows and higher levels of specialized advanced services and labour markets compared to smaller cities, and therefore as better facilitator of real life experimentation in niches.

It needs to be mentioned that there is difference in knowledge demand and interaction, i.e. between science-based activity and engineering-based activity (Binz and Truffer 2017; Tidd 2001). In the first, communication can stretch easily over larger distances, due to a stronger standardization of knowledge like in chemistry (new materials). By contrast, in engineering-based research, closer distances are required due to less standardized situations, e.g. in electric vehicle industry and wind turbines, eventually causing more or new concentrations.

17.3 Invention Activity in Sustainable Energy Clusters

17.3.1 Introduction

In this section we investigate first, the extent in which invention activity in sustainable energy is concentrated in large cities (clusters) and whether this has been subject to change in the past decade, and secondly, to what extent invention performance in clusters is connected to agglomeration and network factors. Clusters in this section are conceived as 'geographic concentrations of industries related by knowledge, skills, inputs, demand, and/or other linkages' (Delgado et al. 2016). We make use of patents because the focus is on invention performance, which is primarily reflected in patent output (e.g. Acs et al. 2002; Hagedoorn and Cloodt 2003; Jaffe et al. 1993) and we draw on the database of United States Patent & Trademark Office (USPTO). Concentration refers to the intensity of patent output in geographic space based on the stated place of residence of inventors. Because patents may, in some cases, be assigned to organizations far away from where the actual invention activity took place, inventor locations are the more reliable geographic indicator of invention activity. In the cluster identification process, addresses involved are geo-located by using TwoFishes, an open source geocoder. Next, the location of inventors is plotted on a map and clusters are identified by using the standard 'heat map' algorithm, formally known as kernel density estimation (for technical details, see Stek 2020).

17.3.2 Spatial Patterns of Invention, Agglomeration and Network Factors

We focus on changing patterns of spatial concentration of patents (clusters) in years between 2000 and 2011 and on estimation of a model of invention performance, including agglomeration, knowledge networks, and path dependence in most recent years (2008–2011). With regard to spatial patterns, we observe the following (Table 17.1). The number of sustainable energy clusters rapidly increases during the years 2000–2011 from 89 to 171 (+92%). Although the number of clusters is growing, the overall share of clustered patents remains almost similar as indicated by 60 and 57%. Accordingly, growth of the number of clusters goes along with reduced average size of clusters, as indicated by a reduction from 33.2 to 18.8 patents

Table 17.1 Number and size of clusters of sustainable energy invention activity

	2000–2003	2004–2007	2008–2011
Total patents	4950	4769	5661
Total clusters	89	108	171
Clustered patents (share in all patents)	2958 (60%)	2835 (59%)	3215 (57%)
Av. number of patents per cluster	33.2	26.2	18.8

Table 17.2 Model estimation of cluster invention performance (2008–2011)[a]

Indicators	Agglomeration	Knowledge Networks	Path Dependence	Agglomeration and Knowl. Networks
Agglomeration				
Cluster size	0.11 (0.056)*			0.14 (0.057)**
Adjacent clusters	−0.086 (0.017)***			−0.082 (0.016)***
Specialization	0.13 (0.042) ***			0.12 (0.044)***
Corporate R&D	0.11 (0.20)			0.13 (0.19)
Knowledge networks (flow)				
Inbound (MNC)		0.039 (0.063)		0.028 (0.044)
Outbound (MNC)		−0.33 (0.17)*		−0.37 (0.15)**
Simple degree centrality		0.053 (0.079)		
Weighted degree centrality		0.30 (0.10) ***		0.32 (0.089)***
Path dependence				
Past invention performance			0.32 (0.059) ***	
Constant	−0.48 (0.30)	−1.0 (0.24) ***	−1.2 (0.080)***	−0.082 (0.34)
Adj. R^2	0.193	0.054	0.271	0.249
Clusters (*n*)	103	103	103	103

[a] Beta-coefficients with standard error in brackets; significance: *p<0.1, **p<0.05, ***p<0.01

(−43%). In accord, inventive activity in sustainable energy technology has not grown in a few large clusters but spread over a large number of small clusters. A development like this is in line with rapid expansion of a sector's spatial distribution and formation of newer and smaller clusters, as tends to be typical for a technology sector's initial growth phase (Ter Wal and Boschma 2011).

In the next step, invention activity in the years 2008–2011 is explored using OLS estimation. In order to limit heterogeneity in the sample, the estimation is limited to science-based invention activity (Table 17.2). The estimation encompasses four sub-models, agglomeration and knowledge networks, past performance and a combined agglomeration and knowledge network model. A detailed description of the model indicators is provided in Appendix 1, and model diagnostics like VIF and heteroscedasticity are available in Stek (2020), which shows that the diagnostics are within accepted boundaries.

The agglomeration model consists of two scale-based indicators (cluster size and adjacent clusters), a specialization-based indicator and an indicator which describes the presence of corporate R&D. The partial model's predictive power is quite modest (0.19). Both scale-based indicators are statistically significant, however, adjacent clusters has a negative association with invention activity. Accordingly, clusters tend to benefit from agglomeration economies while invention in adjacent clusters has a negative influence, potentially connected to competition or short in resources (knowledge) as many small clusters have emerged. In addition, the specialization indicator is positively associated with cluster invention performance and it is significant. The benefits of specialization may among others include availability of more scientifically advanced knowledge and stronger expertise in the labour market. Next, the extent in which private sector companies are involved (as owners of patents) is positive but not significant.

The knowledge network part of the model encompasses two indicators on knowledge inflow and knowledge outflow and two indicators related to the cluster's position in knowledge networks (degree centrality) (Appendix 1). The knowledge flow indicators are calculated using the inventor-assignee network between clusters which are typically embedded within MNCs, with an outbound link indicating knowledge outflow (from a remote lab in the cluster to headquarters elsewhere) and an inbound link indicating inflow (from a remote lab elsewhere to headquarters in the cluster). Further, the centrality indicators are calculated using the co-invention network, and they provide insight into the number of other (different) sustainable energy clusters with which a cluster is connected (simple degree centrality), indicating network diversity. The average number of co-invention links per inventor (weighted degree centrality) is a measure of the size of the co-invention network relative to the size of the cluster. The predictive power of the network model is rather weak (0.054) and also below that of the agglomeration model. This suggests that proximity in more basic scientific research activity, like in advanced material science, photonics, advanced aerodynamics, etc. still matters and that networking outside the cluster is of minor importance at this stage. In detail, two indicators are statistically significant. Knowledge outflow is negatively associated with cluster invention performance. A possible explanation is the phenomenon of 'reverse knowledge flow', in which locally produced MNC knowledge flows out to a large extent and corporation-controlled remote labs are less connected to the local cluster (Ambos et al. 2006; Frost and Zhou 2005). In addition, the weighted degree centrality is positively associated with cluster invention performance, suggesting that other forms of research collaboration (non-MNC) tend to strengthen local linkages and knowledge spillovers.

As a final step, we explored a combined agglomeration and network model (deleting those indicators evidencing multicollinearity). The result is an overall strength of 0.249 which is almost similar to that of the path dependence factor (0.271). We need to mention that it is difficult to read strength of the relationship between path dependence and invention performance without results from comparable studies, but it seems plausible that due to dynamic changes in location patterns and needs of sustainable energy research, the relationship has remained rather weak.

In sum, our results indicate that invention activity in sustainable energy technology has remained concentrated in large cities (clusters) in the past years, be-it with a substantial shift to a large number of smaller clusters and that agglomeration factors play a weak or modest role, however, more in single large cities and less in extended metropolitan areas. Network factors tend to be less important, including somewhat contradictory influences of newly created knowledge that is leaving clusters through

MNCs' internal flows and knowledge collaboration outside MNCs' internal networks.

17.4 Market Introduction of Sustainable Energy Inventions

17.4.1 Introduction

In this section we pay attention to the entrepreneurial side, namely development and market introduction of inventions by specific young firms, i.e. university spin-offs. We address the following question: to what extent is (early) market introduction concentrated in large cities (clusters) and in which ways are strategic choices in market introduction related to advantages of agglomeration and networking in large cities? University spin-off firms are defined as independent ventures established by graduates or university staff with the mission to bring novel university knowledge to market (some definitions are limited to only patented knowledge). Compared to other start-ups, university spin-offs lack market knowledge and practical skills in management and marketing but they enjoy more benefits from university support, not only concerning technology but also important additional knowledge and networks (Pirnay et al. 2003; Shane 2004; Van Geenhuizen and Soetanto 2009). We need to mention that in general market introduction is not only achieved through spin-off firms, but also through channels like collaborative research projects between university and large firms and licensing to firms (Taheri and van Geenhuizen 2016).

The empirical study draws on the population of university spin-off firms active in energy sustainability in the Nordic countries and The Netherlands, and on a selected sub-sample (Nejabat and Van Geenhuizen 2019). Selecting the northwest 'corner' of Europe is justified given the innovation profiles on the country level that are relatively strong compared to other EU countries; this with the exception of Norway and also The Netherlands in the past 10–15 years, given the end of the observation period in 2018 (Fagerberg and Fosaas 2014). A focus on Denmark, Finland, and Sweden, facing relatively favourable opportunities, enables us to 'picture' in more detail later stages following market introduction, not mainly early failure. Data on market introduction of sustainability inventions in above five countries were collected retrospectively for the years 2000–2018 using a multiple source approach, including face-to-face and/or telephone interview, questioning by email, web-site information, and other sources, like branch journals and reports of financial investors, etc.

17.4.2 Market Introduction, Strategic Choice and Role of Cities

Addressing market introduction of sustainable energy products, processes, etc. by university spin-off firms is rather new, and conforms to an overall weak attention to firm-specific factors and urban agglomeration conditions (Bjørnali and Ellingsen 2014; Pacheco et al. 2017; Triguero et al. 2013). Taking a firm's perspective, market introduction is connected to several strategic choices which are summarized in entrepreneurial orientation (EO) of a firm, as a posture that reflects innovativeness, risk-taking, pro-activeness, and competitive aggressiveness, etc. (Covin and Lumpkin 2011; Lumpkin and Dess 1996; Shan et al. 2016). The choices involved include the energy technology itself (some solutions have already been accepted in the market, while others face fierce resistance) (IEA 2018); the strategy archetype including first mover, followers, etc. coming with different opportunities but also risks (e.g. Lieberman and Montgomery 1998) and product/market focus or diversification and related choices in avoiding the risk of the 'valley of death' (Auerswald and Branscomp 2003); all of them reflected in practical business models and plans (Mohr et al. 2013; Roper and Tapinos 2016; Teece and Leih 2016). In the context of risk-taking and learning, we also use the competence-based view. This view posits that owning competence to better use resources, including identifying needs for new resources and how to acquire them with the risks involved, may increase competitiveness of firms and enhance a shorter time to market (Barney and Clark 2007; Rasmussen et al. 2014).

Market introduction is measured as 'reported first sales', eventually including a launching customer. We observe market introduction among 61% of the spin-off firms, and this market introduction is more often reached in the largest city and adjacent area compared to small cities, as indicated by 67 versus 53% (Table 17.3). The *p*-value suggests a weak trend of market introduction being favoured by advantages in large city areas.

If we zoom in on firm age at market introduction, we observe that most market introduction takes place at early age of the spin-off firms, a majority of almost 70% (Table 17.4) (Nejabat and Van Geenhuizen 2019). Regarding time to market introduction, we may assume that in large cities with abundant diversity in knowledge and advanced levels of specialization, market introduction is at earlier age of spin-offs compared to smaller cities and towns (e.g. Duranton and Puga 2001). Our results, however, suggest an opposing pattern, as indicated by a share of 63% of early market introduction in large cities, compared with 76% outside large cities (though without significance and drawing on a small sub-sample) (Table 17.4). This

Table 17.3 Market introduction (MI) of sustainable energy inventions over type of cities

Type of city	Success in MI	Failure in MI	Total
Large cities	41 (67.2%)	20 (32.8%)	61 (100%)
Small cities	25 (53.2%)	22 (46.8%)	47 (100%)
Total	66 (61.1%)	42 (38.9%)	108 (100%)

p-value: 0.13

Table 17.4 Firm age at market introduction (MI) over type of city

Type of city	Early MI (age 0–5)	Late MI (Age > 5)	All firms
Large cities	26 (63.4)	15 (36.6%)	41 (100%)
Small cities	19 (76%)	6 (24%)	25 (100%)
Total	45 (68.2%)	21 (31.8%)	66 (100%)

p-value: 0.28

opposing pattern could indicate that for certain energy technologies which require specific natural land sites for developing and testing, like windy hills and coastal sites (river mouths), but also huge wood-covered areas, etc., favourable laboratory environments and outdoor experimentation have been created in the nearest university town, like in Trondheim, Norway, a few rural areas in Denmark, like Odense, and in Finland, Lappeenranta. However, the pattern could also indicate an *ambiguous trend* among spin-offs in large cities in which they more often take up investigation of fundamental solutions and advanced technologies (in fact being stronger innovative and risk-taking) but these choices require more years of development and experimentation. As examples, we mention advanced materials research to improve conversion efficiency of solar cells, new membranes for use in upgrading in gasification, and completely new sources of biomass.

In order to gain deeper understanding of factors connected to market introduction and risks taken, we consciously composed (theoretical sampling) a small sample ($n = 37$) to perform rough-set analysis and identify meaningful types of spin-off firms given the 'dependent' variable' (decision attribute) of positive development or problematic (risky) development, the latter referring to substantially later market introduction or no introduction at all. We collected details on strategic choices, network building with diverse partners and access to financial capital (qualitative data), etc., as explained in Appendix 2.

We applied rough-set analysis to the selected sample (Pawlak 1991; Polkowski and Skowron 1998) for the following reasons. In contrast to traditional regression analysis, small samples can produce acceptable results (however, without statistical generalization), no assumption is made about a normal distribution of the data, and no emphasis is put on linear and cumulative ways of thinking. Instead, causal relations may be indicated by multiple interaction effects as expressed as combinations of conditions (rules) (Fiss 2011). The procedure is stepwise and works through attribute reduction, i.e. finding a smaller set of condition attributes with the same or close classificatory power as the original set of attributes. The analysis composes *decision rules* that are presented in an 'IF condition(s) THEN decision' format. Rough-set analysis is increasingly recognized in literature as a useful classificatory method, including elements of causal relations (e.g. Dimitras et al. 1999; Nijkamp et al. 2002; Taheri and van Geenhuizen 2016).

We discuss the two strongest decision rules, first the ones concerning a positive development in the past 10 years (Nejabat and Van Geenhuizen 2019) (Table 17.5):

- Rule 1 indicates that the combination of operating in an Innovation Leader country (at the time Denmark, Finland, Sweden) and employing multiple

Table 17.5 Rules on bringing sustainable energy inventions to market ($n = 37$)

	Rules as combinations of condition attributes	Decision attribute[a]	Coverage[b]	Strength %[c]
Positive development				
1	Country (innovation leader, e.g. Sweden) & employing multiple networks	Positive	11	50.0
2	Practical competence (MSc) and gaining investment capital	Positive	7	31.8
Problematic/risky development				
1	Energy technology (solar PV) and employing a single network and strategy archetype (follower)	Risky/ problematic	7	46.7
2	Country (Norway) and maintained focus and scientific competence (PhD)	Risky/ problematic	4	26.7

Source: Adapted from Nejabat and Van Geenhuizen (2019)

[a] Similar to dependent variable

[b] Absolute number of cases covered by a rule

[c] Strength: share of such cases in all cases with the same value of the 'dependent' variable

collaboration networks, makes a positive development towards the market very likely, at strength of 50%.

- Similar, but weaker (at a strength of 32%), Rule 2 indicates that the combination of mainly Master level as highest founder education (practical orientation) and gaining of substantial investment capital, makes a positive development to market likely.

With regard to a problematic development, the two strongest rules are as follows:

- Regarding Rule 1, the combination of solar PV technology, a poor collaboration network and acting as follower, makes a problematic development likely, at strength of 47.5%. The rule means that despite taking smaller risks (as follower) strong network collaboration is required in bringing solar solutions to market, and this refers to (price) competition by Chinese solar cell producers emerging since the early 2000s.
- Rule 2 is less strong, at 27%, and indicates that spin-offs in Norway that employ high scientific skills (PhD) and maintain focus on the invention, are likely to develop in a problematic way. This rule suggests problematic risks of continuing basic research and scientific orientation, and neglecting closer interaction with the market. Such spin-offs may face the 'valley of death' or have gained substantial investment capital at unfavourable conditions (short refunding period).

We summarize the previous results as follows in view of what type of advantages large cities may provide. The strongest rules on positive development inform us about relevance of facilitating building of multiple networks (rich composition of stakeholders) and networks of financial investors in a multi-level situation where also the country level (NIS) counts.

In a final step we connect previous understandings by addressing which strategic choices and competence situations among university spin-of firms are facilitated in

Table 17.6 Tentative city-size advantages for spin-offs' strategic choice and competence

		Relative advantages	
		Large cities	Small ones
Strategic choice	– Scientific orientation and involved in advanced/ basic technology	+[a]	–
	– Involved in technology connected to local land/sea site assets (coastal currents, wind, etc.)	–	+
	– Acting as first mover, coming with high risks, including failure	+[a]	–
	– Involved in highly specialized solutions (need for early internationalization)	+[a]	–
	– Multiple networking, specifically with regard to financial investment and signalling constraints	+	+
Competence	– 'Easy-going' mentality in a 'creative milieu'	+[a]	–

[a] Often not known how risks are eventually mitigated

large cities and which in smaller cities. The tentative picture that arises is the following (Table 17.6). A larger scale and potentials of specialization in an overall information-rich environment in large cities enable young firms to adopt more risky strategies, like being engaged in fundamental/basic technology, acting as first mover and creating a new market, targeting small specialized markets requiring internationalization from start, and with regard to competences, an 'easy-going' mentality in firm foundation, etc. Concomitant risks tend to be severe, but most probably cannot be quickly mitigated in large cities, despite generic advantages of enabling multiple networking locally, including financial investment and signalling constraints, e.g. from regulation and emerging competition. In contrast, a part of small cities enables to develop specialization connected to natural endowment of the nearby region with sustainable energy resources (wind, current water, wood, oil/gas), while external networks tend to compensate lack of local networks facilitating quick market introduction. According to these trends, our results conform to ambiguity about the role of large cities in (speed of) market introduction.

17.5 Final Remarks

We have addressed the question as to what extent innovation in sustainable energy is concentrated in large cities (clusters) and how its performance is connected to agglomeration and network factors and concomitant entrepreneurial advantages, given different presence of path dependence. Our results on invention activity and bringing inventions to market, indeed indicate importance of large cities for sustainable energy invention, be-it in an increasing number of *smaller* large cities, but also weak importance of large cities in market introduction. The pattern suggests *low* *path dependence*, pointing to quickly changing location qualities and networks in a period of rapid technological change and emergence of new clusters. In more detail, with regard to time to market introduction, we observed a weak trend of more often *early* market introduction in small cities. These preliminary outcomes, (somewhat) contradicting agglomeration advantages, may be connected with specificities of sustainable energy sources as being partially land-based and seashore-based and consequently exploited outside large cities in research in small (university) towns. In addition, large cities provide opportunities for highly creative and scientific inventions and bringing them to market by young firms, however, with market introduction taking a longer time, compared to more practical inventions in smaller cities.

The limitations faced in our study call for further research. First, the results have been derived from sustainable energy technology, while *other technologies* may be less connected to characteristics of specific landscapes and coastal sites, producing other results on the role of large and small cities. Secondly, the methodologies used (quantitative and qualitative modelling) and the explorative character of the underlying studies call for developing larger databases that enable a rigorous testing and extending of the results, thereby taking advantage of complementarity of quantitative and qualitative research. And finally, there is a need to investigate the ways in which entrepreneurial risks connected to higher levels of innovativeness in large cities are mitigated, e.g. through training programmes in incubators or accelerators.

Appendix 1: Measurement and OLS Model Indicators after Transformation (*n* Clusters = 103)

Indicator	Measured as	Min	Mean	Max
Dependent variable				
Invention performance	Citations per inventor 2008–2011	−2.3	−0.68	2.6
Independent variables				
Agglomeration				
Cluster size (log)	Number of patents	−0.35	1.7	6.3
Size adjacent clusters (log)	Patents outside main cluster within 0–200 km from this cluster	−2.3	2.6	8.6
Specialization (log)	Sustainable energy patent share in all patents	−9.5	−6.4	−2.0
Corporate R&D	Corporate patent share in all sustainable energy patents	Nil	0.87	1.0
Knowledge networks				
Inbound flow	Assignee-inventor links per inventor, e.g. from MNC remote lab toward headquarter in cluster	Nil	0.61	6.7
Outbound flow	Inventor-assignee links per inventor, e.g. from MNC remote lab in cluster toward headquarter elsewhere	Nil	0.52	2.2

(continued)

Indicator	Measured as	Min	Mean	Max
Simple degree centrality	Co-invention network, total number of connections to different (unique) clusters	−2.3	1.7	3.6
Weighted degree centrality	Co-invention network, number of connections to other clusters per inventor	−2.3	−1.1	0.90
Past invention performance	Citations per inventor 2004–2007	−2.3	−0.20	2.5

All data are drawn from scientometric sources

Appendix 2: Measurement and Descriptive Results of Selected Sample in Rough-Set Analysis ($n = 37$)

Variables	Attributes' share
Condition attributes ('independent' variables)	
Strategic choice	
Energy technology	Solar: 35.1%; wind: 18.9%; other (biofuels, fuel cells, combination, etc.): 27.0%; automotive: 18.9%
Value creation	Core (fundamentals) of energy technology: 67.6% Additional application of technology: 32.4%
Strategy archetype	First mover: 35.1% Otherwise (follower/customer intimate): 64.9%
Diversification/focus	Diversification: 27.0%; focus: 73.0%
Competence	
Market/business experience	Business experience: 56.7%; no business experience: 43.3%
Technical/practical competence	PhD: 70.3%; only master: 29.7%
Interaction in entrepreneurial ecosystems	
Developing networks	Multiple: 54.1%; otherwise (no/one-sided): 45.9%
Accessing investment capital	No: 54.0%; yes: 46.0%
Countries' profile in innovation	Finland, Denmark, Sweden (innovation leaders): 43.2% Norway (innovation follower): 18.9% Netherlands (innovation follower): 37.8%
Decision attribute ('dependent' variable)	
Development in bringing inventions to market	Positive: 59.5%; problematic: 40.5%

Source: Adapted from Nejabat and van Geenhuizen (2019)

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