Emerging technological trajectories and new mobility solutions. A large-scale investigation on transport-related innovative start-ups and implications for policy

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Abstract
Innovation in the transport industry is expected from the integration of new technologies and the development of new concepts of mobility. The current transport landscape is experiencing radical changes, as witnessed by the emergence of a multitude of new applications, business models and specialisations, as well as by the entry of new players. The purpose of the paper is to provide a large-scale investigation of technological trajectories and new mobility solutions outlined by start-ups and young companies in the global transport industry. The paper employs network analysis to detect productive and innovative activities of firms founded between 2001 and 2016. Our findings highlight that three clusters of interconnected technologies and transport-related solutions are emerging: new cars prototypes and alternative vehicles prompt innovation in autonomous driving; technologies for transport sharing and public transit data analysis stimulate new solutions in urban livability; management systems, platform development and vehicle-optimization technologies bring innovative specializations in the integrated logistics services. Results provide policy-makers, venture capitalists, as well as open innovation teams in large corporations, with quantitative and relevant findings on transport-related innovative solutions.

Keywords
Transport, innovation, network analysis, start-ups, technologies, CrunchBase

Highlights:

- Metadata provide information on firms' products, services and technologies.
- A network analysis on metadata enables detection of R&D and productive efforts.
- Our investigation outlines new mobility solutions and technological trajectories.
- Emerging trajectories give rise to clusters of interconnected technologies and mobility solutions.
- Results provide relevant findings and have policy implications.

1. Introduction

Consensus exists on the need of a radical transformation of mobility to address rising and unprecedented challenges worldwide (Banister 2000; European Commission 2012; Lyons & Davidson 2016; OECD/ITF 2010a;). Passenger and freight transport demand has increased considerably in the last decades and is predicted to rise further (Jaber & Glocker 2015). In its Transport Outlook, the International Transport Forum estimates an increase in global surface passenger volumes to 2050 ranging from 120% to 230%, depending on future fuel prices and transport policies at urban levels (OECD/ITF 2015d). Road and rail freight transports will also show an increase between 230% and 420% over the same period, as well as total international freight volume (+430% by 2050). Non-OECD countries will be majorly responsible for those trends. Despite a robust shift away from current patterns, total CO2 emissions are expected to mount at the global level, respectively between 30% and 110% from passenger transport, between 230% and 420% from freight, and, according to different scenarios, by a factor of 3.9 in trade-related international freight transport. The transport sector's quota of global CO2 emissions, already accounting for about 23% in 2013, will further increase in the future (with about 75% coming from road vehicles; IEA 2015; OECD/ITF 2015a).

How to offset the unabated growth in transport demand while preventing increase in CO2 emissions is a central question in on-going academic and policy debates (Hysing 2009). Current technologies and available mobility options offer only partial responses, especially when considered separately. Effective actions need simultaneous changes in multiple parts of the transport system (Hyard 2013; OECD/ITF 2010b; Wiesenthal et al. 2011), such as infrastructures, vehicles, services, and government policies. Moreover, technological solutions, such as energy efficiency improvements and/or increased use of less carbon intensive fuels, have only partially succeeded in offsetting the growth in road transport demand. As a result, as predicted by the rebound effect theory, absolute environmental pressures have continued to rise (Gillingham et al. 2016; Font Vivanco et al. 2016).

Although, major innovations in the transport industry are increasingly expected from the development of new concepts of mobility and the potential integration of new technologies (Citylab 2014; OECD/ITF 2010c; Wiesenthal et al. 2015). Technological advances are creating new opportunities, and start-ups (e.g., powerful high-tech corporations, IT companies, data management companies and energy companies) are offering disruptive solutions as in the case of the automotive sector (Cohen & Kietzmann 2014, Dodourova & Bevis 2014). As a consequence, the transport industry has received increasing venture capital interest over the last few years. According to Volvo Group Venture Capital (Volvo Group 2013), the amount of venture capital going to transportation start-ups quadrupled in 2014 to $7 billion and doubled to $14 billion in 2015. Moreover, governments at the national and local level are also changing their priorities by introducing a set of measures to create more efficient and sustainable transportation systems and by increasingly favouring tech firms in experimenting their innovative solutions.

To our knowledge, a systematic, comprehensive and up-to-date study on transport-related innovation has yet to be completed (Wiesenthal et al. 2015). Attention at both academic and policy levels has been mostly paid to the automotive industry and large car manufacturers (AEA, 2012; Bonilla et al., 2014; Juliussen & Robinson, 2010;

Zapata & Nieuwenhuis, 2010). Studies are often top-down, investigating innovation activities starting from companies' annual reports and financial efforts in corporate R&D investments. Such 'case by case' analyses would not allow taking a large picture of new solutions, applications, or technologies towards which innovative companies are directing their R&D and productive efforts. Moreover, literature on innovation in the transport industry have largely ignored the role of newcomers and start-ups, except leading ones such as Tesla. Start-ups and young companies provide a key level of analysis for scholars in the examination of production and innovation activities as well as for policy makers in the design and implementation of targeted measures to support productive and R&D activities in the transport sector. The ability to monitor latest market and technological developments is also critical for large manufacturers to support their external growth strategies (Dilk et al. 2008; Dodourova & Bevis 2014; Karlsson & Sköld 2013). Increasing interdependences and new mobility solutions have the potential to drastically change firms' hierarchies, as for the supposed process of commoditization in the automotive industry (PwC 2013).

The purpose of the paper is to provide a large-scale investigation of technological trajectories and new mobility solutions outlined by young and innovative companies in the global transport industry. Using metadata, collected from AngelList and CrunchBase, on innovative companies founded between 2001 and 2016, a network analysis is employed to describe in which technologies, applications, mobility solutions are worldwide start-ups investing and how and to what extent they are linked by technological and market complementarities. The underlying hypothesis is that the nature of innovative activities can be proxied by metadata, which are keywords and terms that help to describe items, and in relation to the database reveal start-ups' technological and deployment strategies, markets, and scope of business. We thus refer to technological trajectories as the paths by which innovations in a given field or technological paradigm occur (Nelson & Winter 1982; Dosi 1982). Accordingly, new mobility solutions are understood as transport-related product, services and business models defining the range of existing firms' specializations. From this perspective, the paper well complements existing studies, which have been mainly focused on incumbent manufacturers. Moreover, the analysis may contribute in partially overcoming some limits of standard industrial classification codes, conventional datasets, and product categories by implicitly recognising the highly fragmented and cross-industry nature of many transport-related initiatives. The presence of cross cutting technologies makes the detection of new transport-related solutions and technological trajectories extremely challenging. Intelligent Transport System (ITS) well exemplifies this: the "cross nature" of ITS applications throughout all transport modes implies that many of the underlying ICT and software developments are carried out by companies outside the transport sector (Wiesenthal et al. 2011). Results provide policy-makers, venture capitalists, as well as open innovation teams in large corporations, with quantitative and relevant findings on transport-related innovative solutions.

The rest of the paper is organized as follows. In section 2, the literature background is presented, in which the difficulties to identify emerging industries and innovative technologies in the transport industry are emphasised both from a theoretical and empirical point of view. Sections 3 and 4 respectively present the method and data. Section 5 discusses the results. Section 6 draws conclusions and provides some policy implications.

2. Theoretical background

The detection of emerging technological innovation is not an easy task (Cohen 2010; Phaal et al. 2011). The recognition of the relevance of new industries for future economic growth and the need for a better understanding of their features to define effective policies have stimulated a considerable and growing interest in advanced economies (Roe & Potts 2016). Relatively few studies have investigated the emergence of new industries; lack of agreement still exists on what constitutes emerging industries and on how to identify and classify them (Halaweh 2013; Monfardini et al. 2012; Rotolo et al. 2015).

The emergence of new industries can be the result either of existing technologies and solutions entering new application fields or the development of innovative technologies (Meier zu Köcker et al. 2011). In most cases, the latter have the potential to be adapted to increase performance and productivity in multiple traditional sectors by enabling the production of new goods and services, as well as the restructuring of existing industrial processes (Giannopoulos et al. 2012). Forbes and Kirsch (2011, p. 589) well exemplify those difficulties: “empirically, emerging industries are difficult to study, because it is often hard to identify emerging industries until after they have matured. In addition, many emerging industries fail, and it is even more difficult to find and study failed industries”. This is true especially for the transport landscape, which is experiencing radical changes, as witnessed by the emergence of a multitude of new applications, business models and specialisations, as well as by the entry of new players, some of them already leading high-tech firms. Standard industrial classifications, conventional datasets and product categories have turned out to be too rigid to appreciate the changing and wide range of new technologies, solutions, products, and services (Nathan & Rosso 2015; OECD 2013). Emerging technological trajectories and new mobility solutions often stem from cross-sector technological flows between related, but distinct, sectors, making feasible their evolution, combination, or even integration (Bodas Freitas et al. 2013). Networking and collaboration play a relevant role in emerging industries to take advantage of technological complementarities with activities of related variety (Audretsch & Feldman 1996; Essletzbichler 2015; Frenken et al. 2007). Technological spillovers explain in many cases geographical agglomeration and clustering tendencies in emerging industries (Crespo et al. 2014; Marra et al. 2017). Impressive breakthroughs in electronic control modules, sensors, and rapid innovations in driverless systems are inspiring further solutions that integrate ICT and the Internet of Things. These technology-driven trends are gradually bringing together and on the same competitive arena major car manufacturers and leading software companies, such as Apple and Alphabet.

However, not only rapid technological changes and upcoming innovations, but also new business models, changes in consumer needs and societal challenges can explain the development of entirely new products and services (Hyard 2013; Pozzi 2014; Marletto 2014). Apart from climate change and the resulting need to reduce the social impacts of transport, consumer mobility behaviours are changing, as well as city policies, which are increasingly discouraging private vehicles and promoting a multimodal approach. According to Meeker (2016), the share of young people (16 to 44 years) who hold a driver’s license dropped from 92% in 1982 to 77% in 2015. At the same time, millennials are progressively more willing to share a car (about 50% in Asian-Pacific countries and 20% in North America) and almost half of them expect vehicle technology to do everything a smartphone can do. A large shift in individual mobility behaviour impacts the mobility system as a whole, especially at urban levels where sufficient scale may provide conditions for new business models (McKinsey & Stanford University 2016; van Wee 2015).

Another feature of emerging industries is the disproportionately large role played by start-ups and innovative companies. While producers may be incumbent firms, *de alio* or *de novo* entrants (Agarwal & Shah 2014; Lange et al. 2009), emerging industries generally present a more fragmented structure with a multitude of start-ups and innovative SMEs. Most innovation in the industry takes place in young high-tech companies and are often characterized by an innovative spirit, large intangible assets, negative cash flow, technological uncertainty, and low liquidation value. This is the case of many promising and ambitious start-ups hitting the market with products and services (Breitzman & Hicks 2008; Marra et al. 2017; Rasmussen et al. 2012). Those firms and their products and services have high growth potential rather than actual high growth. Some authors evidence that *de alio* entrants are, on average, more successful than *de novo* firms even if the latter are larger in number (Dinlersoz & MacMillan 2009; Geroski 2003). According to CBInsights (2016), in the first months of 2016, about 450 million dollars were invested across 36 deals involving auto tech start-ups, that is those using software to improve safety, convenience, and efficiency in cars (i.e. assisted driving/ autonomous software, driver safety tools, connected vehicle/driving data, fleet telematics, Vehicle-to-Vehicle communication, and auto cybersecurity). Investments in auto tech start-ups increased from 197 million dollars in 2011 to a projected 847 million dollars in 2016.

From an empirical perspective, while scientometric research has developed sophisticated techniques to detect paths in science and technology based on citations and patent data (for a recent review, see Rotolo et al. 2015), the classification of emerging industries and the analysis of disruptive trends, new solutions, and product or service specializations within them cannot rely on consolidated methods.

A qualitative categorisation about clusters of innovations emerging in response to sustainability transportation goals at urban level has been proposed by Goldman and Gorham (2006). They identify four main clusters: *new mobility*, referring to creative technologies and new business models providing competitive alternatives to private cars; *city logistics*, ranging from neighbourhood drop-off points, centralized urban distribution, and logistics centres to environmental zones; *intelligent system management*, encompassing the relationship between infrastructures and public institutions that operate it and embrace measures such as congestion charging, comprehensive bus system management, and automated traffic enforcement; *livability*, including solutions such as pedestrian realms, breaking the driving routine, bus rapid transit, and shared space.

Studies of transport innovation and technological trends have traditionally followed a sectoral or single technology perspective, not taking into account the increasing portion of the technological development coming from outside the transport industry (Bonilla et al. 2014; Dodourova & Bevis 2014; European Commission 2013; Wiesenthal et al. 2015; Yong et al. 2015). This is the case, for instance, of alternative fuels and new technologies other than conventional internal combustion engines or autonomous vehicles where niche firms have entered the market coming from non-transport sectors (Schade & Krail 2012). Monfardini et al. (2012) recently propose a classification system filled with different data sources (firm capital raising data, cross-sector mergers and acquisitions data, firm patenting data and sector growth estimates) and identify mobility by including 76 four-digits NACE rev.2 codes. Even if it well exemplifies the complex number of cross-sectoral horizontal and vertical linkages that characterize mobility industries, it remains too general and cannot offer a comprehensive view of underlying industrial patterns and technological flows between industries.

An increasing body of work has investigated technological cross-industry flows by referring to network analysis. This methodology is useful for the investigation of the emerging technological patterns in industries such as mobility, ICT, and biotechnology, in which products, markets and technologies are many and heterogeneous, and informal exchanges of unique and idiosyncratic assets (i.e., know-how) dominate (Crespo et al. 2014). For example, Shin and Park (2007) identify core technologies in Korea's ICT industry with network analysis tools. Porter et al. (2005) find what types of relationships are crucial to the innovative capacity of high-tech clusters in biotech through networks comparison. Lee et al. (2009) by means of network analysis on ICT patent data analyse business opportunities based on their technological capabilities.

3. Method

To identify new mobility solutions and transport-related technologies and detect emerging trajectories, the paper exploits network analysis tools. We propose a network of transport keywords on new mobility products, services, and technologies, where links between tag_i and tag_j result from the co-existence of tag_i and tag_j in the same start-up, which is based on a two-mode matrix X_t, where rows represent the tags and columns represent the companies. For example, tags A and B are linked in the network if these coexist in the same company and the weight is heavier if the number of companies in which the two tags coexist is larger. Therefore, for tags A and B, the weight of the edge A–B is 7 since these coexist in seven different companies and the weight of the edge A–C is 2 since these coexist in two different companies, and so on. Heavier edges represent the actual links between new mobility solutions and emerging technologies, through which transport companies invest resources and typically drive their business and R&D activities.

The square matrix indicating the number of links between tag_i and tag_j would be called the adjacency matrix A_t, which is computed as the product of X_t and X'_t.

$$X_t = \begin{pmatrix} 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix} \quad (1)$$

$$A_t = X_t X'_t = \begin{pmatrix} - & 0 & 2 & 2 \\ 0 & - & 0 & 1 \\ 2 & 0 & - & 3 \\ 2 & 1 & 3 & - \end{pmatrix} \quad (2)$$

The proposed network analysis has been developed at three levels: the network level, node level, and cluster level. To visualize the data, we have used the open-source software package Gephi (Bastian et al. 2009).

At network level, we refer to some main metrics. The average degree of all the nodes in the graph and the average weighted degree, representing respectively the total number of edges incident to each node and the number of edges for each node, weighted by each edge. Several metrics are employed to measure the degree of interconnection within the network: density, diameter, and average path length. The higher the degree of interconnection, the higher is the chance to exploit complementarities between technologies, products and markets. The density D of the network is defined as the ratio of the number of edges to the maximum number of edges possible within the network. D varies between 0 and 1: the closer it is to 1, the denser the network is. The diameter of the network is the longest among all the shortest paths in the network and the average path length (l) is calculated by adding together the shortest path between each pair of nodes divided by the total number of pairs:

$$l = \frac{1}{n \cdot (n-1)} \cdot \sum_{i \neq j} d(v_i, v_j) \quad (3)$$

where v_i and v_j are generic nodes of the network and n is the total number of vertices in the network. This gives the average number of steps needed to get from one network node to another.

At the node level of analysis, the most widely studied concept related to the structural importance or prominence of a node in the network is centrality (Borgatti et al. 2009). Centrality indices are to quantify an intuitive feeling that in most networks some nodes or edges are more central than others. Conceptually, the simplest measure is degree centrality, which is defined as the number of links incident upon a node (i.e., the number of ties that a node has). This measure considers only direct links, i.e. direct linkages to that node. The betweenness centrality $g(v)$ quantifies the number of times a node (v) lies "between" other nodes in the network by measuring the fraction of paths connecting all pairs of nodes and containing the node of interest (Freeman, 1977; Brandes, 2001):

$$g(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}} \quad (4)$$

At the cluster level, the average clustering coefficient is a measure of the degree to which nodes in a graph tend to aggregate together and is calculated by averaging the cluster coefficient (*C*) of the *v-th* node.

$$C_v = 2e_v / k_v(k_v - 1) \quad (5)$$

where k_v is the number of neighbours of the *v-th* node and e_v is the number of connections between all these neighbours (for more information on the algorithm, see Latapy, 2008). That is, if tags A, B, and C are all related to D, and if A is linked to B and B is linked to C, then it is highly likely that A is linked to C. When a given network's clustering measures is high, network robustness increases: in effect, in a cluster in which each tag is linked to every other tag, it is unlikely that a given tag will be essential. Modularity is another measure of network structure and determines the division of the network into aggregates. High network modularity means dense connections between the nodes within modules and sparse connections between nodes in different modules (Blondel et al. 2008).

4. Data

Data have been collected from AngelList and CrunchBase. AngelList is a popular online database and platform for start-ups where entrepreneurs and investors connect and close financing deals (Pasquini et al. 2016). AngelList has been online since February 2010 and it has a free and publicly accessible API. It is the third largest equity crowd-funding platform in the world (Massolution 2015). Over 60% of the firms that raised a seed round in 2013 have an AngelList profile, and more than half of these firms attempted to raise funds on the platform, based on a comparison to the Crunchbase database (Bernstein et al. 2015). CrunchBase is the world's most comprehensive database on high-tech companies and is accessible to anyone through an application-programming interface (API). Founded in 2007, it began as a simple crowd-sourced database to track high-tech start-ups covered on TechCrunch (one of the most highly regarded blogs concerning technological innovation on the web). Today, CrunchBase comprises more than 500,000 data points profiling companies, people, and funding institutions and claims to have more than 50,000 active contributors and about two million user accesses each month.

Companies listed on AngelList and CrunchBase are active all over the world in several high-tech industries, including finance, hardware, mobile, e-commerce, advertising, marketing, analytics, and so on. For most start-ups and SMEs, the databases include information such as the city of registration and operating offices, number of employees, category code or main technology orientation, investors, type and amount of the investments, number and timing of financing rounds, the website of companies and tags related to markets, products, services, technologies, and so on. Data from AngelList and CrunchBase is increasingly used in research (Klein, 2016; Pasquini et al., 2016; Hahn et al., 2014; Cheng et al., 2016).

Our dataset includes 1,549 start-ups and SMEs, founded between 2001 and 2016, and active in the transport industry, for which available data concerning the founding of the company, industry category code, metadata (i.e., tags), number of employees, funding information, and office locations are available. Further underlying the decision to use a large sample, data selection criteria reflect the focus on innovative and young companies for which available information attached to them allows for the descriptive purpose of the study.

Metadata are tags and keywords, which are micro-description of business activities generated spontaneously («bottom-up» by companies' owners and employees, and other contributors), are not bound to SIC codes («top-down»), and provide lots of up-to-date information on businesses. Nowadays, open data source provide powerful tagging systems useful to classify businesses. Then, a company active in the transport industry, can be referred to the 6-digit SIC code 411913 ("Transportation sharing service"), or can be described by means of keywords on its market, the scope of its business, its deployment and its technological strategies. With no doubt, "car sharing", "per to peer", "neighbourhood community", "mobile app", "urban routes", "idle cars", better describe what the company does.

5. Results and discussion

The network of transport companies worldwide has 1,952 nodes (tags) and 11,970 edges. The graph is represented by some major nodes effectively describing the areas that catalyse transport firms' efforts: mobile-app, sustainability, data-analysis, road and air transport, logistics, urban transport, trucking industry, sharing economy, GPS-tracking, software development, and fleet management.

Metrics used to describe the transport network worldwide are the average degree of all the nodes in the graph and the average weighted degree (Table 1, first column "Extended"). These metrics should be interpreted as a proxy of the degree of interrelatedness of firms' technologies and specializations in the transport industry. Values, respectively 12.1 and 22.1, indicate that technologies and products (nodes) developed in the industry require high level of complementarities on average. The values of the diameter and the average path length confirm such a result. These two metrics suggest a high level of interconnection in the industry around the globe, despite the high number of nodes in the network, which indicates that the transport industry is extended and diversified. More in depth, the diameter reveals that the most opposite technological choices in the network are only 9 steps apart, while the average technological distance is 2.9. Nonetheless, the low value of graph density (0,006) can be explained by multiple small clusters of nodes gravitating around (and weakly linked to) the core structure of the network, representing marginal business and technological firms' choices in the industry.

According to betweenness centrality, a node is central if it acts as a bridge along the shortest path between two other nodes. In the transport network, most central nodes are road transport, corporate moving, public transport route planning, urban transport, safe driving, marine transport, logistics, and ride sharing. This means that these nodes represent technologies, products and markets having an enabling role in providing the means to combine unconnected technologies and thus to exploit new business solutions.

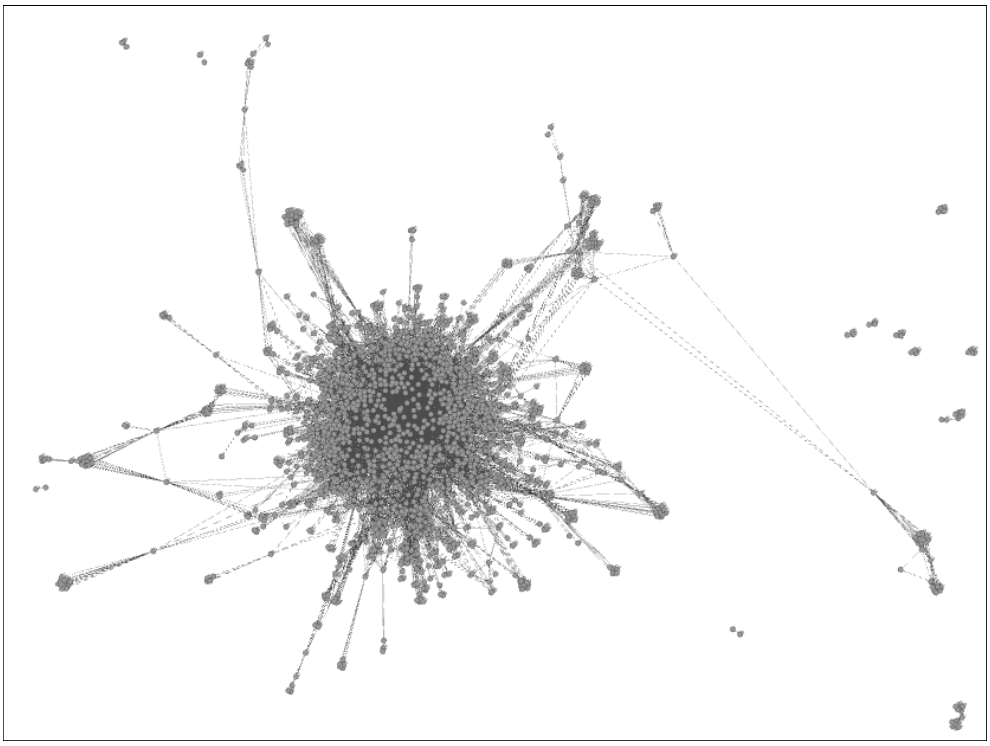
*** Insert here Table 1 ***

Table 1: Descriptive statistics on worldwide transport network (Extended and restricted view)

Metrics	**Extended**	**Restricted**
Number of nodes	1,952	88
Number of edges	11,790	1371
Avg. Degree	12.1	31.2
Avg. Weighted Degree	22.1	169.7
Network Diameter	9	2
Graph Density	0.006	0.4
Modularity	0.5	0.2
Avg. Path Lenght	2.9	1.6
Avg. Clustering Coeff.	0.8	0.2

*** Insert here Figure 1 ***

Figure 1: Transport network (Extended view)

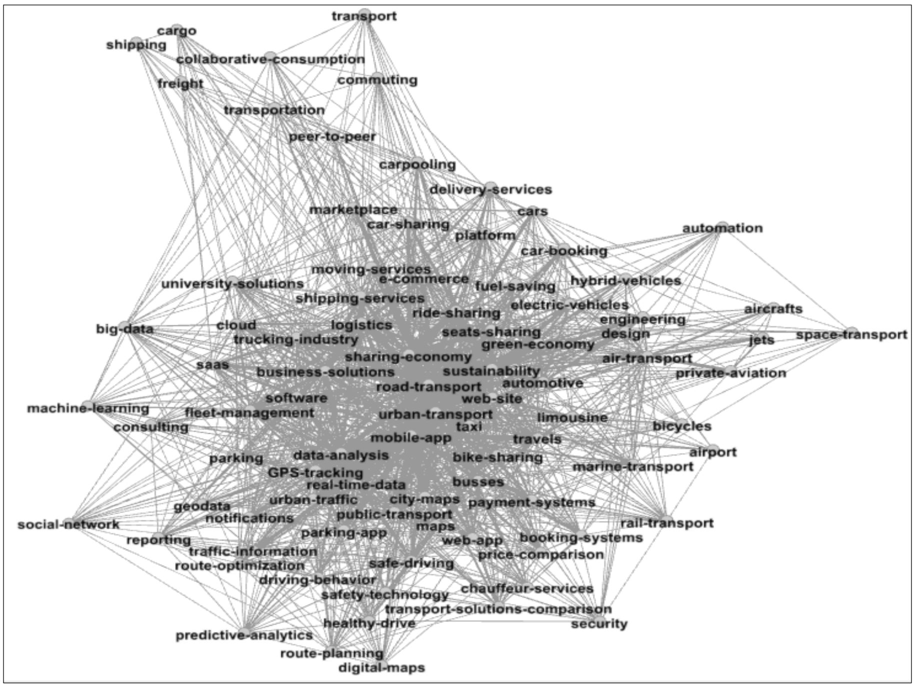


Source: Own elaboration on AngelList and Crunchbase (2016)

Narrowing the extension of the network enables displaying the most relevant complementarities (that is, driving innovation in the industry) between technologies, products and markets. Setting the degree range at the minimum level of 30, the size of the graph (88 nodes and 1,371 edges) allows to visualize complementarities between urban transport and mobile app, automotive and sharing economy, data analysis and public transport, city maps and real-time data, travels and urban traffic, shipping services and electric vehicles. Such complementarities represent the core structure of the industry, as indicated by the average degree at 31.2, and often combined with several other technologies and solutions, as indicated by the average weighted degree at 169.7. Other metrics such as diameter (2), density (0.4) and average path length (1.6) reveal that these technological complementarities in transport industry are very close to each other. Last, the modularity and clustering coefficient at 0.2 confirm their combined use in transport business (see Table 1, second column "Restricted").

*** Insert here Figure 2 ***

Figure 2: Transport network (Restricted view)

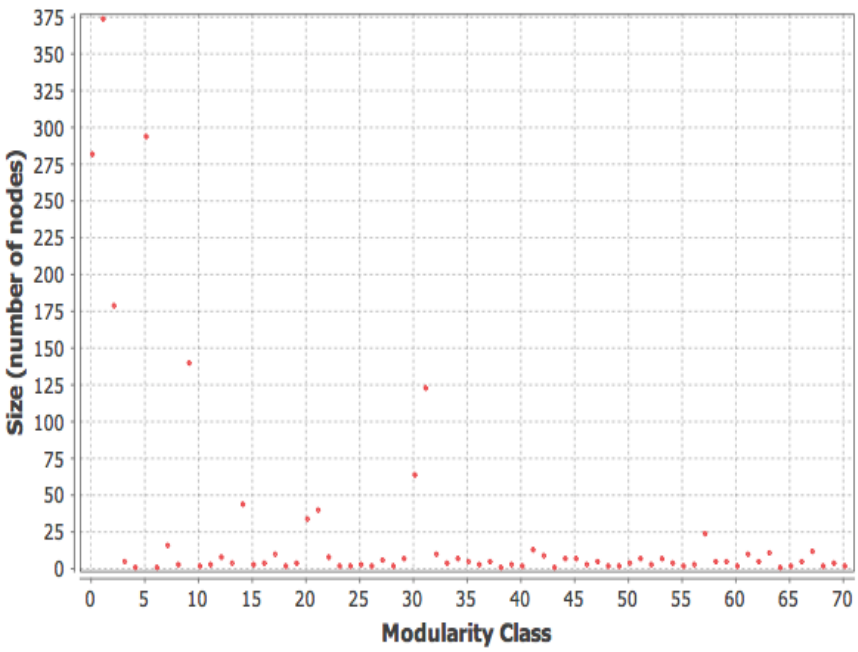


Source: Own elaboration on AngelList and Crunchbase (2016)

Both clustering coefficient (0.8) and modularity (0.5) suggest the existence of clusters in the network. A more in depth analysis of modularity reveals that network structure is divided into 71 aggregates (Figure 3).

*** Insert here Figure 3 ***

Figure 3: Clusters size distribution



Not all technological aggregates have the same magnitude. As can be noticed from Figure 3, only three clusters have more than 200 nodes: the first aggregate (modularity class 1) has 282 nodes, the second one (modularity class 3) has 373 nodes and the third cluster (modularity class 6) has 295 nodes. For the reasons we explain below, the first cluster can be labelled "autonomous driving", the second "urban livability2 and "logistics ecosystem". Within each cluster, we detect technological trajectories in the transport industry identifying the most weighted and connected nodes.

The *autonomous driving* cluster encompasses start-ups represented by tags that involve different technological configurations and digital infrastructures related to the automated and autonomous driving. More in detail, two mainly (weightiest/heavier) technological trajectories (walks) further characterise the aggregate.

The first is related to the wide variety of products, services, and technologies, connected to the vehicle automation, and in particular to what OECD/ITF recently described as the "something everywhere" potential deployment trajectories in autonomous driving (OECD/ITF 2015b). This approach involves the improvement of conventional vehicles by the development of automated driving systems aimed to increase safety, reduce congestion, lower stress for car occupants, and so on. Start-up companies are mainly focusing on road safety, being the real challenge of autonomous driving both from a technological and social acceptability perspectives (Fagnant & Kockelman 2015). Tags in this walks, such as safety technology, distracted driving, stability control, safe driving, distraction alerts, fatigue-level detection, biometric technology, advanced collision avoidance systems, enhanced limits on driver hours, input-output sensors, blind spot warning devices, and camera vision systems well explain where new firms are directing their innovative and commercial efforts. According to tags such as vehicles-travelling-connections, ultrasound sensors, GPS, high definition maps, and map data, resources are also focused on the development of technologies that allow real-time connectivity between vehicles (so-called V2V) and between vehicles and infrastructures (V2i) as well as control algorithms for advanced driver assistance.

A second emerging technological trajectory in the *autonomous driving* cluster refers to companies promoting a more radical shift by developing alternative vehicles and new transport services, according to tags such as drones, remotely piloted aircrafts systems, drone delivery services, autonomous vehicles, and magnetic levitation cars. On-board driverless navigation systems are ideated to develop autonomous vehicles; they also require technologies such as high definition maps and real-time road capture via computer vision to which start-ups contribute. Drone technology is generally open-sourced, inexpensive, and thus accessible, so start-ups and SMEs are involved from the design and manufacturing of hardware, hardware parts and peripherals, to the providing of counter-drone systems that perform drone detection or drone disabling.

The *urban livability* aggregate refers to companies involved in developing and testing technologies, products, and services aimed to radically replace present urban mobility systems, thus contributing in the improvement of the overall health and economic welfare of city residents. As known, urban areas are becoming the preferred place where new transport behaviours are emerging and new and innovative solutions with which experimentation is easier. Higher density of demand, shorter average distances travelled, and frequent congestions are favouring the deployment of forms of mobility different from the traditional ones mainly based on shared vehicles (cars, bicycles, etc.) and new for-hire passenger transport services (like Uber, Lyft, etc.), also exploiting the potential applications deriving from the use and amalgamation of massive, often real-time, data (OECD/ITF 2016a; Cramer & Krueger 2016).

Two technological trajectories can be identified in the urban livability aggregate as well. According to a walk of tags such as car sharing, commuters network, bicycle monorail pods, bike sharing, ridesharing, car-pooling, van-pooling, ride-sourcing, scooter sharing, shuttle services, e-bikes, electric pedicab and so on, the first describe start-ups strategies focused on non-polluting modes as primary means of travel in cites and the potential shift from the vehicle “ownership” to vehicle “user-ship”. Two main transport options are promoted: carpooling (space sharing among a group of friends) and car-sharing (time sharing). Several Commercial Transport apps (CTAs) are developed. Two other shared transport alternatives of urban mobility are pursued: ridesharing or shared taxis, which represent an expansion to the existing taxi system where different passengers or parties share the same vehicle for parts of their rides, and on-demand minibus services (Harding et al. 2016). Transport companies are also spending efforts on building platforms connecting commuters, co-workers, bikers, or cyclists who share the same daily route to share the commute to work together, or offering services for people to rent their idle cars by the hour to those in need of wheels.

The changeful landscape of urban transportation can be further described through the integration of shared mobility systems with various traffic operations-based applications such as real time traffic management. More in depth, this second technological trajectory directly relates to technological and market opportunities for better managing transport operations and for more effective planning of transport networks and services opened by the sourcing, accessing, and sharing of data. Tags in this walk such as urban traffic, traffic data estimation, e-ticket app, public transit information systems, parking apps, parking tracking, multi-modal transport systems, arrival time prediction system and so on, highlight an approach to transport services and their planning based on users’ choices, real-time data flows, maps of alternative routes, pricing comparison, and current network status oriented to the creation of a multimodal transportation system (OECD/ITF 2015c).

Multimodal transportation in which information is controlled and shared becomes the new norm, as greater system interoperability enables consumers to get from point A to point B via multiple, connected modes of transportation on a single fixed price charged on a single payment system. Aligned with this purpose, start-ups, SMEs, and private companies require and manage public transport data and collaborate in developing innovative solutions ranging from large physical networks to mobile applications designed to alter routes, fill empty seats, combine fare media, and offer real-time arrival and departure information. These solutions are both for planners and citizens: from software that helps manage the city’s bus or train routes using a map viewer, to recognition algorithms capable of analysing videos and quantifying movements and behaviours of citizens; from apps that make catching city parking easy by using advanced analytics platforms able to capture sound level and road surface temperature, to platforms for people with all types of disability in need to move with no obstacles in city (OECD/ITF 2016b).

The *logistics ecosystem* cluster refers to start-ups mainly involved in offering solutions to trucking industry and logistics companies. Such B2B companies are attracting increasing funding from investors, from $40 million in 2010 to almost $200 million in 2015 (World Economic Forum 2016) and are mainly focusing on technologies and services that allow companies to improve the collection of data from all along the value chain.

According to tags such as supply-chain solutions, logistics, moving services, driver-quality control, route optimization, fleet tracking, fleet management, and software as service, the emerging technological trajectory concerns fleet management high-tech systems, platforms that provide shippers with instant access and real-time visibility to trucks via mobile app and cloud-based software, the manufacturing of sensors to monitor where the trucks drive, how fast it drives and the capabilities of the driver. Combining real-time data with sensors that monitor the health of the engine and equipment. it is possible to predict how often trucks break down, when maintenance is required, and thus automatically book maintenance at the location that requires the least downtime for the transportation company.

Another trajectory in the cluster concerns improving fuel efficiency to existing trucks and driver safety across commercial fleets: software elaborates data on controls, braking, and accelerations, and permits vehicle stabilization and increasing fuel economy, sophisticated radar sensors detect obstacles and respond in one-hundredth of a second. The economics of logistics are about maximizing "loaded" miles and minimizing "empty" ones. In an environment as complex and fast paced as today, start-ups' software solutions help carrier better manage their fleet, deciding which driver should take which load and thus properly coordinate the flow of goods from one point to another. By means of algorithms related to vehicle-optimization technology, fleet management and driver scheduling, logistics companies can manage all information concerning the size of fleet, objectives, factors, point values, the economic value of shipment, comparing it among many others, using real-time data. There also social networks dedicated to truck drivers where they can locate their colleagues on the road, plan their trips, as well as sell, buy, and find loads. These networks serve as benchmarking-platforms that provide information to the shipping industry by enabling companies to compare their ocean freight rates, and crowd shipping services connect people who post their driving route with people who want to get or ship something.

6. Conclusions

The transport industry will undergo potentially major changes in the next decades. The potential integration of new technologies and the development of more user-focused concepts of mobility are favouring the entry of newcomers, such as powerful high-tech corporations, IT companies, data management companies, and energy companies, which are proposing new business models, new approaches, and innovative ideas from software solutions to new vehicle concepts.

This paper provides a large-scale investigation of technological trajectories and new mobility solutions outlined by young and small innovative transport companies. To our knowledge, a similar analysis has never been performed before in the literature despite the increasing role of high-tech start-ups and small firms in shaping future technological, competitive, and industrial scenarios in the transport sector asks for more detailed information both at policy and managerial level about their current innovation and technological trajectories and, hence, prevailing R&D and productive efforts.

In our research, three relevant clusters are emerging respectively labelled as autonomous driving, urban livability, and logistic ecosystems. The first aggregate refers to the automated and autonomous driving technologies, the second focuses on innovations shaping urban mobility systems, and the third concerns new technologies and practices to support the trucking and logistics industry. In each cluster, further innovation paths may be identified. In the *autonomous driving* aggregate, start-ups and small firms are mostly involved on both development of autonomous cars prototypes and related components, and alternative vehicles such as drones or remotely piloted aircrafts. In the *urban livability* cluster, companies follow two trajectories, on large-scale deployment of shared vehicle fleets that provide on-demand transport and manipulation on public transit data. Last, also in the *logistics ecosystem* cluster, companies are involved on two technological trajectories about fleet management systems, supply chain platforms, and vehicle-optimization technologies.

By taking a comprehensive, reliable (evidence based), and detailed (based on descriptive tags) picture of products, markets, or technological areas towards which a considerable number of new innovative companies are *de facto* directing their R&D and productive efforts, evidence from network analysis provides a first informative basis to policy-makers and other investors such as venture capitalists, incubators, and open innovation teams in large corporations.

In a policy perspective, most countries are trying to exploit advances in emerging technologies and new mobility solutions on the ground they represent strong contributors to future economic growth. Little is known about firms' technological and deployment strategies, markets, and scope of business. Using data that more accurately reflects the range of cross-cutting solutions and technologies adopted by companies under observation might be helpful to better focus national research agenda and to design and implement effective innovation policies by also taking into account the cumulative and path-dependant nature of technological change and potential risks of lock-in. More specifically, a data repository containing metadata would allow policy makers to address some key policy issues referring, for instance, to which market and/or technological complementarities are companies exploiting, which technologies should be eventually prioritized, what potential fields of cooperation exist between firms to promote. This is especially true when considering the role of cross-cutting technologies and that many technological developments are brought by companies outside the transport industry (Wiesenthal et al. 2011).

A wide appraisal of the patterns linking emerging specializations provides useful information regarding areas in which cooperation between transport firms, high-tech companies, venture capitals, and other anchor institutions could be strengthened to accelerate product development and foster innovation by exploiting technological proximity and knowledge spillovers (Frenken et al. 2007; Horwitch & Mulloth 2010). The opportunity to integrate various complex technologies into the supply networks and clusters characterizing the supply chains of many transport sectors is also critical from large manufacturers' perspectives seeing their relative position in the market being threatened by new entrants (Dodourova & Bevis 2014; Karlsson & Sköld 2013; Dilk et al. 2008).

However, the reader should keep in mind that the analysis is speculative in at least two perspectives suggesting that caution should be used regarding the policy implications of these results. First, some limitations apply to our data since the observed dataset includes only start-ups founded between 2001 and 2016, excluding all other companies active in the time interval. Further research should be carried on in order to consider technological and deployment strategies of incumbent firms and large manufacturers.

The second limitation concerns the acknowledgment that new mobility solutions, applications and technological trajectories are not weighted by means of parameters concerning their economic and financial size. The relevance of the detected products, services, and technologies can suggest either a promising market or technology or an already consolidated one: in any case, along such trajectories, a considerable number of new innovative companies are investing in R&D and production. A deepening of the analysis at the firm level is needed to explain potential differences of innovative and business performance.

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