Technological Forecasting & Social Change 105 (2016) 140–157

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Quantifying technology–industry spillover effects based on patent citation network analysis of unmanned aerial vehicle (UAV)

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ARTICLE INFO

Article history:
Received 14 March 2015
Received in revised form 12 December 2015
Accepted 27 January 2016
Available online 19 February 2016

Keywords:
Unmanned aerial vehicle
Technology industry spillovers
Patent citation analysis
Technology concordance
MERIT concordance

ABSTRACT

Unmanned aerial vehicle (UAV) technologies have been fast developing over the past 20 years and are expected to generate extensive spillovers into other industry sectors. However, no previous studies have investigated such spillover effects. In this study, we propose the framework of two-mode network analysis to quantify the spillover effects of UAV technology into various industries using patent citation data of the United States Patent and Trademark Office. A two-mode matrix consists of rows corresponding to UAV technologies and columns corresponding to beneficiary industries, and the value depicts the spillover probability obtained using International Patent Classification codes and the technology/industry concordance table. The out- and in-degree centralities of the spillover network are used to identify strong spillover-generating UAV technologies and strong spillover-receiving industries, respectively. We observed that the weapon industry received extensive spillover effects during the period 2005–2009. Based on Mann–Kendall tests, the spillover effects of UAV-related software technologies exhibited a consistently upward trend during both the last 10 and 20 years. The past significant trend of spillovers can help us to forecast future trends. The proposed quantification method can be readily applied to investigate other specific technology–industry spillover patterns.

1. Introduction

With the development of various technologies, unmanned vehicle systems (UVSs) present a new platform for operational work. In particular, unmanned aerial vehicles (UAVs; also known as remotely piloted vehicles (RPVs) and drones widely) have received attention for decades. A UAV is an aircraft that flies without an onboard human crew. Since the mid-1970s, militaries around the world have nurtured UAV development programs. For military purposes, UAVs were originally used for reconnaissance flights and as targets for surface-to-air weapons. However, in terms of civilian uses, UAVs have recently been applied to aid in search and rescue, surveillance, agriculture, and other missions in various locations around the world. Furthermore, in the future, the roles of UAVs will be developed as they reach higher altitudes and longer endurance using new renewable energies such as solar heat (Blockley and Shyy, 2010). From a market perspective, related technologies will represent a fast-developing area in the next few years (Finn and Wright, 2012).

As an aerospace technology, UAV technology is composed of various fields of knowledge ranging from artificial intelligence to core software and hardware engineering. The aerospace industry is classified as a multi-technology industry (Pavitt, 1998), which leads to spillovers into other industry sectors and the development of other advanced technologies (Park et al., 2010). Thus, it is becoming increasingly difficult to overlook the aspects of industry spillover effects. We used UAV patents, which are assumed to be representative of the technological innovations in this area, and the patent citation flow, as a knowledge flow that is usually assumed to be an indicator of spillover (Verspagen, 1997; Verspagen and De Loo, 1999; Lim, 2009). A few previous studies have briefly addressed the overall trends in UAV technology by examining patent data but not in sufficient detail for an understanding of the spillovers of UAV technologies (Shiue and Chang, 2010).

High-resolution-camera-equipped drones with reduced weight and enhanced stability can foster various industries such as military, agriculture, telecommunications, and oil production. Moreover, as the technology evolves with many other unanticipated sectors, UAV technologies can have a spillover effect on different sectors, which can lead to unexpected social changes. However, unlike forecasting the immediate benefits from using drones, it is not easy to predict the flows of technology spillover. Consequently, it is necessary to investigate the trend of spillovers of UAV technologies not only to understand the immediate outputs of the technology development but also to forecast related future social impacts.

However, no previous studies have quantified the spillover effects of specific technology on beneficiary industries (Nakagawa et al., 2009; Sun and Liu, 2012; Yoon et al., 2015). Thus, it is necessary to develop a new framework to quantify spillover effects between technology and

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http://dx.doi.org/10.1016/j.techfore.2016.01.025
0040-1625/

industries. In this paper, we propose the framework of two-mode network analysis to quantify the spillover effects. This analysis is applied to find the relation between UAV technologies and various related industries.

To measure the spillover effects of UAV technologies on other industries, we utilize the International Patent Classification (IPC) codes of the UAV patents of leading inventor institutions from the United States Patent and Trademark Office (USPTO). The primary assumption of this study is that the IPC codes of the patents can correspond to a specific technology and industry (Schmoch, 2008; Verspagen et al., 1994). First, we construct a technology–industry spillover matrix by matching the IPC codes of the UAV patents with the technology (Schmoch, 2008) and the IPC codes of the forward-cited patents of UAV patents with the industry based on the International Standard Industrial Classification (ISIC) (Verspagen et al., 1994). Second, we construct a matrix for each period, 1995–1999, 2000–2004, 2005–2009, and 2010–2014, which represent the four stages of technological progress. We also analyze the spillovers for each corporation or institution among those that have registered the most UAV patents. In this manner, we measure the trends of spillovers over the last 20 years and compare the out- and in-degree centralities of the UAV technology and industry based on each corporation or institution.

The organization of this paper is as follows. In Section 2, we review previous related studies. In Section 3, we introduce the patent data obtained from the USPTO. Finally, we discuss the results and conclude our study in Sections 4 and 5, respectively.

2. Literature review

2.1. Technology spillovers

Technology spillovers, which are often used interchangeably with R&D spillovers, are considered a source of economic growth by economists and policymakers. While technology transfer and adoptions that are frequently confused with technology spillover require extensive capital investment beyond knowledge sharing, technology spillovers are derived from externalities. Technology spillovers occur when a firm is given economic benefit from another firm's R&D activities and output without incurring any cost (Jaffe et al., 1992).

Griliches (1979) was apparently the first to use two types of spillovers: rent spillovers and pure knowledge spillovers. "Rent spillovers" indicate "the spillovers that are associated with the exchange of goods, and those arising purely from the process of research and development". However, "pure knowledge spillovers" may originate from "a variety of sources, such as the mobility of (R&D) workers, the exchange of information at technical conferences and in scientific and technological literature including patent documents, reverse engineering and industrial espionage". Technology, specifically patent information in this study, has been regarded as a particular type of knowledge accumulated from various firms and industries (Harabi, 1997; Lim, 2009; Nakagawa et al., 2009; Lee and Sohn, 2014; Ju and Sohn, 2014a,b; Suh and Sohn, 2015). Patent information is also useful in assessing innovation diffusion and in predicting future innovation trends (Saritas and Burmaoglu, 2015). In particular, knowledge spillovers can be measured by a patent and its citation data, which is called a 'paper trail' approach (Koo, 2005).

2.2. Patent citation analysis for spillovers

The analysis of patent citations has often been used to measure spillover effects, although this approach has the limitation that it is not sufficient to explain "whether interpersonal contacts had actually taken place between the cited and the citing inventors", according to the study of Breschi and Lissoni (2005). Patent citation flow or counts of patent citations have been continuously used to identify spillovers called "knowledge flows" between technologies, industries, and countries (Verspagen, 1997; Jaffe and Trajtenberg, 2002; Shih and Chang, 2009; Sun and Liu, 2012; Han and Sohn, 2016). Primary attempts have been made to quantify and differentiate two types of technology spillovers using patent data. Scherer (1982) measured industry technology flows using a flow matrix from the innovation-producing sector (rows) to the innovation-using sector (columns). Similarly, the Yale matrix was proposed, assigning IPC codes to a patent and the principal user and producing sectors of the Canadian Patent Office to each patent (DeBresson et al., 1994). However, Verspagen (1997) criticized that these technology flow approach cannot explain pure knowledge spillovers. The author proposed a matrix to measure such spillovers from a more 'technology-oriented' perspective and used data from the European patent office, which assigns each patented invention to a single 'main technology class' and one or several 'supplementary technology classes'. Furthermore, the author constructed a citation matrix by assuming that the citing patent (sector) received a spillover from the cited patent (sector) from the USPTO. This assumption was based on the interpretation that the cited patent apparently contained knowledge that was relevant to the citing patent. The author compared the correlations of two proposed matrices to the Yale technology matrix that is considered to represent economic transactions, which is similar to the technology linkage-based R&D input and output matrix developed by Scherer (1982). The conclusion was that the Yale or Scherer approach focused on measuring rent spillover effects, whereas the citation flow matrix measures different aspects of technology spillovers, namely knowledge spillovers. Based on previous studies, we expect that knowledge spillovers can be measured by patent citation data (Trajtenberg et al., 2000). Studies of technology spillovers in the aerospace industry are discussed in the next section.

2.3. Technology spillovers in the aerospace field

Although many studies have recognized the importance of aerospace technology in spillover research, the issue of measuring knowledge spillovers using patent citation has been controversial and is still a disputed subject in technology spillover in the aerospace field. Jaffe et al. (1998) quantitatively identified evidence of technology spillovers by examining seven Electro-Physics Branch (EPB) of NASA patents that received more than 10 citations and 53 patents that cited EPB patents. The authors conducted intensive interviews with inventors at the EPB and R&D directors of other companies who were involved in the 53 patents and determined that more than half of them were involved in reliable technology spillovers. Jaffe et al. (2003) also demonstrated the possible use of patent citations as proxies for both technological impact and knowledge spillovers by tracing the forward-cited patterns of 38 patents of the EPB of the NASA-Lewis Research Center. However, Niosi and Zhegu (2005) qualitatively discussed the geographical agglomeration of aerospace firms and argued that the patent citation method to measure the spillovers in aerospace field is useless because aerospace companies tend to maintain secrecy rather than apply for a patent. Nevertheless, a patent is frequently used as an indicator for identifying outcomes of R&D activities (Sohn et al., 2013; Han and Sohn, 2014), and patent citation analysis is the most straightforward approach for quantifying knowledge spillovers.

Based on numerous studies, we attempt to expand our understanding of the mechanisms that derive knowledge spillover from patent citation data. In this study, we analyze the knowledge flow from UAV patents to other forward-cited patents of UAV patents. We further investigate major UAV technologies that have been diffused into various industries along with major beneficiaries in the past 20 years. Before presenting the main framework that handles the patent citation data in Section 4, we explain the UAV patent data collected from the USPTO database in the following Section 3.