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Peer effects in the diffusion of innovations: Theory and simulation

Hang Xiong[a,b,*], Diane Payne[a,b], Stephen Kinsella[c]

[a] School of Sociology, University College Dublin, Ireland
[b] Geary Institute for Public Policy, University College Dublin, Ireland
[c] School of Economics, University of Limerick, Ireland

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ABSTRACT

This paper presents a theoretical framework for studying peer effects in the diffusion of innovations. The underlying mechanisms of peer effects are generally under-discussed in existing studies. By investigating diffusion processes in the real world and reviewing previous studies, we find that information transmission, experience sharing and externalities are the basic mechanisms through which peer effects occur. They are termed as *information effect, experience effect* and *externality effect*, respectively. The three effects could occur through different types of relationships in a social network. Each of them plays a different role at different stages of a diffusion process. A simulation model incorporating multiple effects in a multiplex network is developed to provide a theoretical study. We simulate the experience effect and the externality effect in a context of rural diffusion. It generates the widely acknowledged patterns of diffusion in various scenarios. The experiments conducted using the model show that peer effects as a whole can be substantially misestimated if the underlying mechanisms are ignored.

1. Introduction

An individual's behaviour could be significantly influenced by other individuals in the same group. This is especially true when uncertainties are involved in the behaviour, typically like deciding whether to adopt an innovation (i.e., the idea, practice, or object that are perceived as new; Rogers, 2003). Such influences of social interactions have been referred to as many different terms in social sciences, including 'peer influence' (Duncan, Haller and Portes, 1968), 'interdependence preference' (Pollak, 1976), 'social learning' (Bandura and McClelland, 1977), 'imitation' (Conlisk, 1980), 'social contagion' (Burt, 1987), 'neighbourhood effects' (Crane, 1991), 'herd behaviour' (Banerjee, 1992), 'social effects' (Manski, 1993), 'conformity' (Bernheim, 1994) or 'peer effects' (Sacerdote, 2001). In this study, we choose to use *peer effects* because of its semantic precision in the context of the diffusion of innovations that we study and its prevalence in recent literature (e.g., Bramoulle, Djebbari and Fortin, 2009; Goldsmith-Pinkham and Imbens, 2013; Dahl, Løken and Mogstad, 2014).

Peer effects, as well as other similar terms, are rarely defined explicitly (save for Manski (1993)). In the study, we take peer effects as *the various influences on taking a specific action that an individual receives from other individuals in the same group*. All individuals in the group have similar potential to take the action. They can influence one another individually or collectively. Taking the group as a social network, the influence that a node (individual) receives can be imposed by a singular node, by a cluster of nodes, or from the network as a whole.

There have been many studies on how an individual's behaviour to adopt an innovation is influenced by peer effects (such as Coleman, Katz and Menzel, 1966; Sacerdote, 2001; Dahl, Løken and Mogstad, 2014). These studies have described many forms of peer effects in different settings. In addition, they either take peer effects as an aggregate influence or focus on a specific influence in the whole diffusion process. We are not aware of any attempt to examine the underlying causal mechanisms and to structure them into a unified framework. It turns out a promising way of doing so is to identify the mechanisms at different stages of the dynamic diffusion process. This paper presents a theoretical framework in three steps. First, we use two cases from the real world to demonstrate what roles peer effects play in whole diffusion processes. Additionally, we review various forms of peer effects that have been discussed in literature. Second, based on the case study and literature study, we propose a theoretical framework consisting of three basic mechanisms that peer effects underlie: information effect, experience effect and externality effect. Third, we develop a simulation model incorporating experience effect and externality effect in a multiplex network to demonstrate how the theoretical framework can be applied. in the revised manuscript. Through the

* Corresponding author at: Geary Institute for Public Policy, University College Dublin, Ireland. Tel.: +353 867265200.
E-mail address: hang.xiong@ucd.ie (H. Xiong).

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computational experiments conducted using the model, we show that peer effects can be misestimated if not delving into their specific underlying mechanisms.

2. Case and literature studies

2.1. Case study

We examined the complete diffusion process of a *high-value crop* (HVC. the crops with higher, usually substantially higher, return to farmers than the crop they traditionally farm) in two cases. They each occurred in an administrative village, consisting of a number of nature villages (hereafter 'village', differentiate from 'administrative village') in central China.

2.1.1. Case I: the diffusion of AS farming in GRV

Golden Rooster Village (GRV) is an administrative village located in rural Wuhan, a city in central China. It is consisted of 367 households split in 10 nature villages. The households traditionally farm rice and cotton. To increase income, a new crop *Artemisia selengensis* (AS), was introduced to the households for farming in 2001. Only a few households grew the new crop in the first place. As it became known that farming the new crop was more profitable, other households joined in gradually in the subsequent years. By 2009, all households capable of growing the new crop had adopted it.

In the spring of 2001, the village committee of GRV received a batch of AS seed-stalks that were imported from a city 2000 km away in the south. The committee then distributed a bundle of seed-stalks to each household for free and encouraged them to plant. This action informed all households about the existence of the new crop. However, a mere awareness was not sufficient to motivate the households to adopt. Unless otherwise being reasonably assured of the profitability and the suitability, the households would not take the risk. Unsurprisingly, only about 20 households planted the new crop in the first year, and many of them just tried in a very small plot of their land. These earliest growers made a big success as the profit of farming the AS was almost 10 times higher than that of farming traditional crops. Knowing their achievements, some of their fellow farmers started to follow suit. The first difficulty that the followers encountered was obtaining seed-stalks, which can only remain fresh for two weeks. It turned out that the only practical source was the earlier adopters in the villages. The seed-stalks were so scarce at that time that a household could obtain them exclusively from its close relatives. Those who managed to obtain the seed-stalks in a given year then shared them with other households next year, and so forth. In addition, the potential adopters could learn the planting techniques and skills, or acquired the market information from the earlier adopters. The adopters wanted more households to join in so that more brokers could come, so they were generally quite open to share. By 2005, more than 70% of the households had adopted the new crop. Since the majority of the households by then had adopted, the non-adopters were put under some pressure to join in. The pressure was mainly from the use of irrigation. There was nearly a half-year time during which both AS and cotton were active on the land. However, farming AS requires much more water than farming cotton. The water in a AS plot could penetrate into the adjacent cotton plots belonging to different households with negative consequences. In this situation, the households with many neighbouring plots that grew the new crop would be 'coerced' into taking the concerted action.

2.1.2. Case II: the diffusion of grapes farming in CSV

Celestial Star Village (CSV) is located in a city that is approximately 230 km away from Wuhan. This administrative village is made up of nine villages and 356 households. Like in GRV, the villagers traditionally farm rice and cotton. Two households first tried planting grapes in the late 1980s and succeeded. The new crop, although challenged the households in both financial investment and farming skills, was adopted by most households eventually. After about 20 years of diffusion, more than 90% of the suitable farmland had been used to grow grapes by 2009.

The first grower knew of farming grapes from an advertisement. He then brought some seedlings as well as guidance documents from a supplier from another province and started to grow grapes in 1988. It turned out that farming grapes was much more profitable than farming the traditional two crops. After a couple of years, the information was passed to two households in another village. They then started to grow grapes, too, in 1992. When they also succeeded, many of their relatives fellow suit. The relatives then transmitted the information to their other households, and so forth. However, this process went slowly compared to the diffusion of farming AS in GRV. By 1997, 10 years after grapes were first grown in these villages, only about 50 out of 356 households have chosen to participate, and the acreage covered was about 200 mu out of nearly 1600 mu which is suitable for planting grapes in the villages. This was mainly due to the higher barriers to entry for farming grapes. The barriers include the initial investment (financial barrier) and farming techniques required (technical barrier). The initial investment (mainly on the seedlings and the infrastructures) of farming grapes on a plot of 1 mu was higher than the average annual pure income of a household. At that time, the seedlings could only be bought from the suppliers from the other province, which was costly and risky. The earlier adopters tended to hide the successful techniques they discovered in order to remain competitive in the market. In 1997, some experienced adopters started to sell the seedlings they cultivated themselves. The prices they offered were much lower than that in the outside market. This largely reduced the cost and risk to adopt. Meanwhile, in order to promote their sales, the seedling sellers shared some techniques they have with buyers. New adopters could thus access to the detailed and localised techniques and skills. This also stimulated the households in the same village to learn from one another. Since then, both the financial barrier and the technical barrier have been largely lowered. Therefore, many more households began to adopt. In the following years, the roads and irrigation channels were substantially improved in the villages. More and more households are motivated to participate in farming grapes.

2.1.3. Peer effects in the diffusion processes

The two cases each presents a complete diffusion process of an innovation in a well-defined population. They are complete processes because they cover the period from the outset of the diffusion to the end of it; that is, from the point when the first adopter emerged to the period that all potential adopters have adopted. The two cases demonstrate some common patterns in the diffusion of innovations. First, the whole diffusion process can be essentially divided into three stages, early, intermediate and late according to the proportion of adopting households. Second, peer effects play roles in all stages and a different form of peer effects plays a dominant role in a different stage.

The three stages of the AS diffusion in GRV are 2001, 2002–2005 and 2006–2009, and those of the grape diffusion in CSV are 1988 to 1996, 1997–2004 and 2005–2009. In the first stage, the main influence that a household received from his fellow farmers was the idea of farming the new crop. It mainly included the information about the existence of the new crop. Along with this information, a household usually also gained some basic knowledge about the suitability and profitability of farming the crop (such as the general techniques, the market demand, the investment needed). However, for most households, the information are