# APPENDIX A: THE LOUVAIN METHOD

The Louvain method aims to optimize the modularity of a network (Newman, 2004) to measure the closeness of communities in the given partition comparing with a null model. In our empirical studies, we first calculate the modularity value, , with the formula:

(Eq. A1)

In this formula, and are two nodes in . is the number of edges. is the edge weight between and . is the degree of . is a binary variable to indicate whether and belong to the same community ( =1) or not ().

The Louvain method involves two levels of iteration based upon the tree structure. The first level (step B in the following part) uses a bottom-up clustering approach, and the second level (step A in the following part) adapts a swap method that avoids putting nodes in the same community so they could not be adjusted later. The specific steps of Louvain method are:

Step A: Initially regarding every node as a community, we traverse all nodes. For a certain selected node, if by moving it to the community of its neighbor, we can get , the variance of after moving a node, of the network. We try to move it to the community of every neighbor of it until we get the maximum . If the maximum , we do not move this node, else this node is moved to the community which brings the maximum gain of modularity. Keep doing in this way until does not increase.

Step B: Inducing nodes in every community (i.e. transform community to node), do step A iteratively until could not grow anymore.

Finally, there is a function **,** where is the node set in and is the community index set. In this way, attaches each node to a community.