An Agent-based Model Study on Subsidy Fraud in Technological Transition

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Abstract: The evolution of a society is inextricably linked to technological transition, which is based on both innovation and dissemination of technologies. To protect the vulnerable new generation of technology, government subsidies are one of the most common and effective tools. However, not all subsidy policies can lead to a healthy development of market shares. Subsidy fraud is one of the most problematic issues that can arise under an imperfect system. This paper identifies an interesting subsidy fraud like phenomenon via a validated agent-based model. After analysing the mechanism of the transition of technology in the model, we drive the condition upon which subsidy fraud could occur.

1 INTRODUCTION

Technological transitions are defined as a major technological change in the way social functions (e.g., transportation, communication, housing, food) are achieved. For example, switching from petroleum-fuelled cars to electrical vehicles, from fossil-fuelled power stations to solar power stations can both be regarded as technological transitions. Innovation and dissemination of technology are very important to the technological transition; hence the promotion of innovation and the clarification of the diffusion mechanism are the core goals pursued by modern management science.

One of the most common and effective means of helping the spread of new technologies is the use of government subsidies. In particular, the government provides subsidies through direct methods such as price reductions or exemptions for companies or consumers that use new technologies, or indirect forms such as tax incentives. To a certain extent, subsidies can compensate for the losses caused by the immature new technology and stimulate companies or consumers to use the new technology, thereby helping to promote technological improvement and increase the success rate of the realization of socio-technological change.

However, in the actual implementation process of government subsidies, many problems can arise. The most met problem is subsidy fraud, which refers to phenomena that individuals or firms provide incorrect information when applying for government subsidies or use subsidies in violation of the proposed intent and agreement[1-2]. More specifically, there are subsidies for different new energy sources in the low-carbon transition process, while the government promotes the diffusion of technologies through advocacy (as in the case of the policy tools spreader and subsidy introduced in Section 2.1.6 of the methodology). Unfortunately, there is a gap between actual policy effects and expectations, and when social resources and policies are jointly focused on specific things (e.g., low-carbon transition), it is naturally very easy for the phenomena such as subsidy fraud to arise under the influence of different policy dissemination efforts (e.g., spreader) and policy support efforts (e.g., subsidy). However, what is the mechanism of subsidy fraud?

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Analysing the mechanism of subsidy fraud and proposing solutions are particularly important to the government's subsidy policy. This article tries to analyse the mechanism of subsidy fraud through the mathematical analysis of a validated agent-based model.[3-10]

2 MODEL

This work is based on a baseline model of *A.Lopolito* [11]. Main parameters are set as the same value in the original study (refer to Appendix. Parameter setting).

2.1 Model Descriptions

The conceptual framework of the model is shown on Fig 1. There are many firm agents and few spreader agents (responsible for spreading the new technology). Each firm agent's behaviour is guided by three mechanisms: expectation, networking, and learning. They determine whether a firm agent should convert to a supporter or a switcher to the new technology, thus collectively determining the state of technological transition. There are also two policy tools: the subsidy policy controls the size of the subsidy; and the lobbying policy controls the number of spreader agents.

For the assumptions and mechanisms in the model and the significance of each parameter, we drew from the literature11.

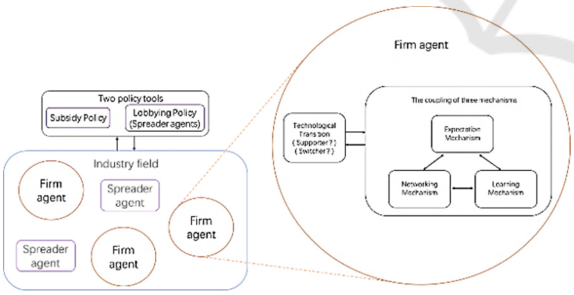

Figure 1: Conceptual framework of the agent-based model for technological transition.

2.1.1 Basic Assumption

As the basic assumption, the model assumes that there are two technologies in the market, the new technology and the old (traditional) technology. All firms can freely choose one of the technologies to produce goods in the next round. As the production is completed, firms can further freely choose whether to switch to a different technology or continue to use the same technology.

The model consists of a finite number of firm agents, $I = \{1, 2, \cdots, N_f\}, N_f \ll \infty$. It assumes that all firms produce the same goods, and the market is in the perfect competition state. Hence for all firms that use traditional technology, their extra profit equal to zero,

$$\Pi_{i,t} = R_{i,t} - C_{i,t} = 0 \tag{1}$$

where $\Pi_{i,t}$, $R_{i,t}$ and $C_{i,t}$ represent the profit, revenue and cost associated with the production at time t of firm i which uses traditional technology.

As for firms using the new technology, risks and profits coexist. These firms have an opportunity to obtain extra profits, in the meantime, because the new technology is often imperfect, they may suffer the losses caused by unknown risks:

$$\Pi_{i,t}^{n} = \begin{cases} R^n - C_{i,t}^{n} & (with\ probability \quad p) \\ 0.5R^n - C_{i,t}^{n} & (with\ probability \quad 1-p) \end{cases} \tag{2}$$

where p stands for the probability that the firm will obtain the maximum profit by using the new technology.

2.1.2 Expectation Mechanism

The basic structure of the expectation mechanism is shown in Fig 2. Parameter $ex_{i,t}$ represents the expectation to the new technology of firm i at time t, which is affected by the following two ways:

(1) By the profit by using the new technology

$$ex_{i,t+1} = ex_{i,t} + \Pi_{i,t}^{n} \tag{3}$$

(2) By the encounter with a spreader of the new technology

$$ex_{i,t} = ex_{i,t} + \eta \tag{4}$$

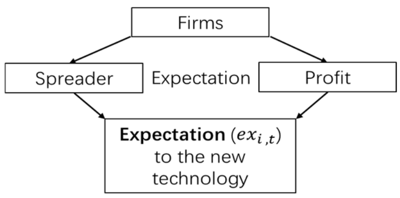

Figure 2: Expectation mechanism affected by the profit from the new technology or by the encounter with spreaders of the new technology.

2.1.3 Networking Mechanism

The basic structure of the networking mechanism is shown in Fig 3. It mainly has the following two functions.

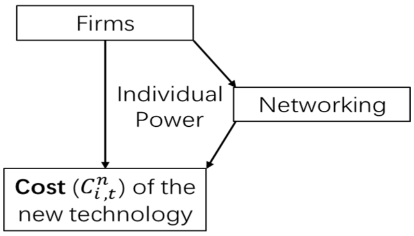

Figure 3: Networking mechanism affected by the so-called individual power and its sum over the whole network.

I. The formation of a user network of the new technology

In our model, all the firm agents interact with each other in a social space. We divide the distribution space into several patches. Firms residing in the same patch have closer social proximity. The formation process of the network is shown in Fig 4.

(1) To establish a tie between firm i and firm j, the following conditions need to be satisfied
   1) Both firm i and j are supporters of the new technology
   2) The Social proximity between firm i and j is less than the threshold value

(2) If a firm is no longer a supporter of the new technology, all the ties from this firm will disappear simultaneously.

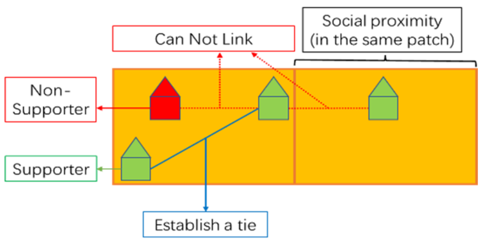

Figure 4: The formation of a user network for the new technology.

II. The reduction of cost for the new technology

We call all the shareable strategic resources (except knowledge) individual power. The cost of a firm agent using the new technology for production is affected by two factors: the individual power ($I^{power}_{i,t}$) of this firm, and the sum of individual power of all firms in the network (N^{power}_t).

$$C^n_{i,t+1} = C^n_{i,t} - c \cdot I^{power}_{i,t} - n \cdot N^{power}_t \quad (5)$$

where c and n are coefficients that adjust the effectiveness of individual power of a firm and that of the whole network. The individual power is further affected by the profits:

$$I^{power}_{i,t+1} = I^{power}_{i,t} + \Pi_{i,t} \quad (6)$$

$$En_{i,j} = \begin{cases} I^{power}_{i,t} + I^{power}_{j,t} & if\ i\ and\ j\ are\ linked \\ 0 & if\ i\ and\ j\ are\ not\ linked \end{cases} \quad (7)$$

$$N^{power}_t = \sum_{\substack{i,j \\ i \neq j}} En_{i,j} \quad (8)$$

2.1.4 Learning Mechanism

The basic structure of the learning mechanism is shown in Fig 5, which is similar to the networking mechanism.

When a firm uses new technology to produce, it may succeed and obtain positive profits, or it may fail and get losses. Learning mechanism affects the failure rate through the knowledge owned by all the firms in the network.

(1) Knowledge ($K_{i,t}$)

$$\begin{aligned} K_{i,t=0} &= random \\ K_{i,t+1} &= K_{i,t} + \theta K_{i,t} \end{aligned} \quad (9)$$

(2) Knowledge network structure

1) $$Kf_{i,j} = \begin{cases} K_{i,t} + K_{j,t} & if\ i\ and\ j\ are\ linked \\ 0 & if\ i\ and\ j\ are\ not\ linked \end{cases}$$ (10)

2) $$NKn_t = \sum_{\substack{i,j \\ i \neq j}} Kf_{i,j} \quad (11)$$

(3) The decay of new technology failure rate

$$Rsk_{t+1} = Rsk_t - \varepsilon \cdot NKn_t \quad (12)$$

where NKn_t represents the network knowledge at time t, Rsk_t represents the failure rate of using new technology to produce.

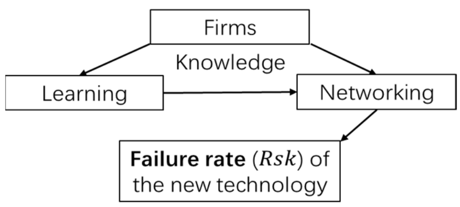

Figure 5: Learning mechanism.

2.1.5 Technological Transition

Firms become supporters of the new technology, when $ex_{i,t}$ exceeds a critical value. Firms that use the new technology are called switchers. A firm can become a switcher only if the expected profit of the new technology is positive, $E(\Pi_{i,t}^n) > 0$. Details can be found in the following items.

(1) Conditions for becoming a supporter ($ex_{i,t}$)

$$\begin{matrix} firm\ i \\ at\ time\ t \end{matrix} \rightarrow \begin{cases} ex_{i,t} > 0.75 \rightarrow\ supporter \\ ex_{i,t} \leq 0.75 \rightarrow not\ supporter \end{cases} \quad (13)$$

(2) Conditions for becoming a switcher ($E(\Pi_{i,t}^n)$)

$$\begin{matrix} firm\ i \\ at\ time\ t \end{matrix} \rightarrow \begin{cases} E(\Pi_{i,t}^n) \leq 0 \rightarrow \begin{matrix} tranditional \\ technology \end{matrix} \rightarrow \begin{matrix} not \\ switcher \end{matrix} \\ E(\Pi_{i,t}^n) > 0 \rightarrow \begin{matrix} new \\ technology \end{matrix} \rightarrow switcher \end{cases} \quad (14)$$

where the expectation profit to the new technology can be calculated by the flowing equation:

$$\begin{aligned} E(\Pi_{i,t}^n) &= E(R^n) - E(C_{i,t}^n) \\ &= ex_{i,t} \cdot R^n - \frac{1}{ex_{i,t}} \cdot C_{i,t}^n \end{aligned} \quad (15)$$

2.1.6 Policy Tools

Two policy tools are considered in this model: the subsidy policy and the lobbying policy.

(1) Subsidy Policy

This policy is realized by adjusting the size of the subsidy to cause an impact on the market.

After introduced the subsidy policy, the profit for each agent changes as follows:

$$\Pi_{i,t}^n = \Pi_{i,t}^n + subsidy \quad (16)$$

(2) Lobbying Policy

This policy mainly affects the market by adjusting the number of spreader agents. Spreader agents do not participate in the actual production of goods, on the other hand, they are effective in the market through the expectation mechanism. They will automatically find firm agents that do not have high expectations for the new technology. By lobbying these firm agents, spreaders can increase firms' expectations for the new technology $ex_{i,t}$, hence promoting the spread of the new technology.

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3 RESULTS

The model implementing is based on Netlogo platform. A population of N = 100 firms located on a grid sized 32×32, and the model includes spreader agents randomly moving within the social space to inform those firms that have not yet adopted the niche technology.

The parameterisation used is summarised in Table 1.

3.1 The Critical Condition

In the case of $Subsidy = 0$, we can derive:

$$E(\Pi_{i,t}^n) = ex_{i,t} \cdot R^n - \frac{1}{ex_{i,t}} \cdot C_{i,t}^n > 0 \quad \Leftrightarrow \quad ex_{i,t} > \sqrt{\frac{C_{i,t}^n}{R^n}} \quad (17)$$

Combined with the initial conditions $R_n = 1.5$, $C_{i,t=0}^n = 1$, we can deduce the condition for firms to become switcher without the subsidy:

$$E(\Pi_{i,t}^n) > 0 \quad \Leftrightarrow \quad ex_{i,t} > \sqrt{\frac{1}{1.5}} \approx 0.816 \quad (18)$$

Since the condition for firm i to become a supporter has been set as $ex_{i,t} \geq 0.75$, clearly the prerequisite for becoming a switcher is "being a supporter", which is also an intuitively plausible scenario. If the firm does not support a technology, it is almost impossible for it to use it.

However, due to the introduction of a subsidy, the structure of Eq. (17) has been changed into the following:

$$E\left(\Pi_{i,t}^{n}\right) = ex_{i,t} \cdot R^{n} - \frac{1}{ex_{i,t}} \cdot C_{i,t}^{n} + Subsidy > 0 \tag{19}$$

Hence a special case emerges: the condition to become a switcher can be weaker than the condition to become a supporter. From Eq. (19), we may calculate that the critical size of the subsidy is 20.8%. When $Subsidy \leq 20.8\%$, the condition to become a switcher is stronger than the condition to become a supporter. In other words, the prerequisite for becoming a switcher is to become a supporter. But when $Subsidy > 20.8\%$, the situation will change, and the prerequisite is no longer necessary. Because the government subsidies are too strong, many firms are willing to try to use new technology for production even if they have not yet become supporters of it. In such a scenario, many firms try out the new technology, not because they are optimistic about the technology, just because they are interested in the large number of subsidies. Even though these firms are willing to use niche technology for the production activities, they do not make any efforts, such as conducting the experiments or accessing the supporter network, to develop the new technology.

3.2 Numerical Experiments

Even if the same parameter settings are used, the model is still affected by random factors. To obtain meaningful results, we average the outputs of 100 experiments, each of which contains 2600 timesteps and is under the same initial conditions.

Through these numerical experiments, we found that when the subsidy rate is higher than 20.8%, both numbers of supporters and switchers quickly increase to 100%. But if we cancel the subsidy, the entire market reverses instantly. Although the number of supporters can remain above 80%, the number of switchers instantly becomes single digits, see the top panel of Fig. 6. This result means that the entire market is in an abnormally unhealthy state under the too high subsidy: Firms use the new technology just for the subsidies; when the subsidy is cancelled, those firms who are not the real supporters of the new technology leave the market instantly. Indeed, the state after the cancellation of subsidy is consistent with the stable state developed from the beginning without the subsidy. This means that government subsidies are completely ineffective. It is a completely failed policy because the government has spent huge amounts of money, but they did not reach the goal of promoting the new technology.

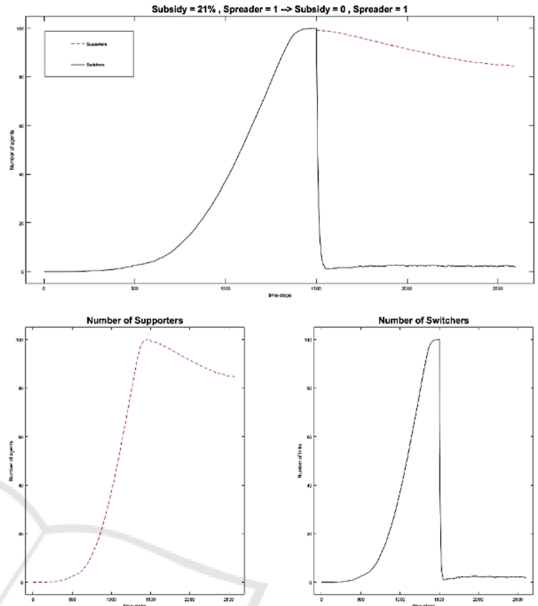

Figure 6: Critical value experiment (0 - 1500 timesteps: Subsidy = 21%, Spreader = 1. 1500 - 2600 timesteps: Subsidy = 0, Spreader = 1).

4 CONCLUSIONS

Government subsidies are an important factor to help niche technology grow in the early stage of technological development. By compensating for the lack of profitability of technology, it can increase the expected benefits of firms who have adopted the new technologies and attract more firms to complete the technological transition. However, due to regulatory loopholes and other reasons, companies that only hope to be decorated with the concept of new technology or just want to defraud subsidies will consume many social resources. Moreover, the fake illusion of prosperity of the new technologies will present an illusion to the industry and the government. Once the sign of bubble collapse emerges, these companies often get out fast causing chaos in the corresponding industrial field. Therefore, this article hopes to find the critical condition under which firms may commit subsidy fraud.

Currently, we have obtained interesting preliminary results and phenomena. At the same time, as illustrated in the introduction section, we find that subsidy fraud is prevalent in the low-carbon transition process, which will help future validation studies of the model. In addition, more rigorous and nuanced studies, such as the assumptions adopted by the model, need further refinement.

In the future, we also would like to further explore how to systematically avoid the risk of subsidy fraud and find a way to set up subsidy policies so that the development of new technologies can be sustained after the withdrawal of subsidies.

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APPENDIX

Table 1: Parameter setting.

Type	Denotation	Valuation	Type	Denotation	Valuation
$Global$	N_f	100	$Global$	$p_{t=0}$	0.5
	N_S	1		Rsk_t	$1 - p_t$
	NE	0.75		$externalP$	0
	η	0.02		$Radius$	$\frac{1}{\sqrt{\pi}}$
	π	0.001		$Cex_{t=0}$	0.5
	n	0.01	$Firm\ i$	$ex_{i,t}$	0.5
	c	0.01		$I_{i,t=0}^{power}$	[0, 0.3]
	θ	0.025		$K_{i,t=0}$	[0, 0.01]
	υ	2		$Cn_{i,t=0}$	0.5
	$Subsidy$	0		$E\left(\Pi_{i,t}^{n}\right)$	(15)
	R_n	1.5		$\Pi_{i,t}, \Pi_{i,t}^{n}$	(1), (2)
	N_t^{power}	(8)	$Link\ i,j$	$En_{i,j}$	(7)
	NKn_t	(11)		$Kf_{i,j}$	(10)