An Agent-Based Model Study on Subsidy Fraud Risk in Technological Transition

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Keywords: Agent-Based Model, Technological Transition, Subsidy Fraud, Subsidy Policy.

Abstract: In modern society, government subsidy policies play a pivotal role in developing new technologies. Although subsidy policies have a long history, the resulting subsidy fraud problem consumes social resources and hinders the development of new technologies. In this paper, we attempt to derive the factors affecting the risk of performing the subsidy fraud based on a validated agent-based model for technological transition. We first review the literature on subsidies and the definition of subsidy policies. We perform a mathematical analysis of the agent-based model and calculate the critical value for subsidy rates, which may cause a dramatic change in the probability of subsidy fraud to occur. We conducted a series of numerical experiments to show the validity of the critical subsidy rates. And we also correlates and classifies three scenarios between the situation of technology diffusion and development and the risk of subsidy fraud. Finally, the causal factors of subsidy fraud are examined by analyzing the various stakeholders involved in the subsidy fraud in the actual situation.

1 INTRODUCTION

Technological innovation is of great importance for the development of human society. Especially in modern societies, national innovation ability is essential in measuring modern countries' development level and their potential. There is a critical need for the government to help and stimulate technological innovation in the country. Subsidies for specific industries, particularly for those new technology industries, are widely used to achieve this goal.

As the opposite of taxation, subsidies to enterprises are considered part of government spending and non-reimbursable payments by the government to targeted enterprises. However, when we strictly define the concept of "subsidy," we find that the concept has been evolving, and the definition has been formally made differently across countries, regions, and industries.

The World Trade Organization (1999) defines the concept of "subsidies" in great detail to reconcile the interests of the members of each organization. The core idea is that "subsidies" are defined as indirect financial support in the form of direct transfers (grants, loans, capital injections, etc.), tax breaks, and government (other than the general infrastructure) purchases to specific industries or enterprises, either with a direct government capacity or indirectly through the establishment of agents.

However, according to R.Steenblik (2003), statisticians and economists classify subsidies into different types depending on what is covered and how they are calculated. For example, distinctions are made according to the target, the benefits route, etc. Different calculation methods will result in benefits for different recipients of subsidies, which may further result in different results on the calculation of the size and impact of subsidies. In the literature, however, it has been noted that differences in the analysis of subsidies within different industries are often a consequence of historical factors and the prerogatives of the policy groups targeted by the research rather than inherent differences within the sectors under investigation (World Trade Organisation, 1999). This fundamental conflict of interest, in turn, makes it more challenging to make an unambiguous definition of "subsidy" that can be widely accepted. As Hendrik S. Houthakker (1972) states: "My starting point was also an attempt to define subsidies. However, in the course of doing so, I concluded that the concept of a subsidy is just too elusive. " Rather than reading too much into the

Yang, H., Wu, X. and Chen, Y.
An Agent-Based Model Study on Subsidy Fraud Risk in Technological Transition.
DOI: 10.5220/0011801200003393
In *Proceedings of the 15th International Conference on Agents and Artificial Intelligence (ICAART 2023) - Volume 1*, pages 412-421
ISBN: 978-989-758-623-1; ISSN: 2184-433X

definition of subsidies in our study, we take a fundamental approach, defining a subsidy as "a gratuitous payment based on the cost of production of the firm."

Sound effects are only occasionally produced by subsidy policies. Subsidy fraud is a crime that accompanies subsidy policy and has long plagued the government. In traditional studies, subsidy fraud is often associated with tax evasion. The neoclassical economic model of tax fraud proposed by Allingham and Sandmo (1972) is considered one of the cornerstones of the financial analysis of tax evasion. It shows how individuals decide to evade taxes and how the government will eventually punish them. However, the model cannot explain the low levels of fraud at soft penalty and detection rates (Chica M et al., 2021). In the study by Prichard et al. (2014), an attempt was made to explore the reasons for the failure of the above model. Two possible paths were introduced to address the limitations of the neoclassical model, namely the empirical research and the agent-based model (ABM). This paper will mathematically derive the critical factor that may cause subsidy fraud by analyzing an established ABM for technological transformation.

In our previous study (Yang et al., 2021), we conducted a preliminary analysis of the agent-based model proposed by Lopolito.A et al. (2013). In this paper, we shall extend our previous study to complete the following three tasks:

(1) Derive the critical subsidy rates.

(2) Conduct numerical experiments to show the effects of these critical rates.

(3) Relate the derived subsidy rates with the subsidy fraud in reality.

2 MODEL

2.1 Model Descriptions

The conceptual framework of the agent-based model for technological transition is shown in Fig 1.

Our model has two types of agents, firm agent and spreader agent. The firm agent may transform from the primary state to the supporter state and/or switcher state through the coupling of three mechanisms. The supporter state means "the state in which the agent supports the new technology," and the switcher state means "the state in which the state uses the new technology for its production activities."

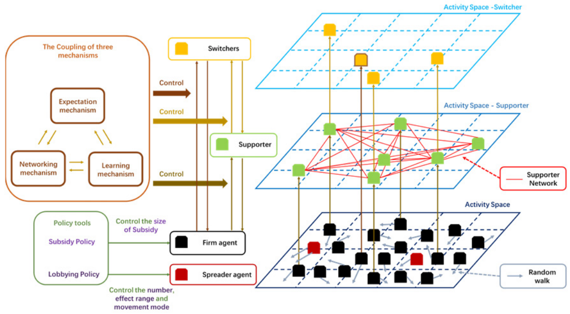

Figure 1: Conceptual framework of the agent-based model for technological transition.

On the other hand, as shown on the right side of Figure 1, we divide the model space into three abstract layers: the primary activity space, the supporter activity space, and the switcher activity space, which correspond to different states of the firm agents.

The bottom left of Figure 1 shows the two policy tools in our model, namely the lobbying policy and the subsidy policy, which affect the firm agents and spreader agents, respectively.

In the following text, we give details of each part of the model.

2.1.1 Basic Assumption

We assume that there are two technologies in the market, the new technology and the old technology, and assume that the market has reached equilibrium when the old technology is used.

We use $\Pi_{i,t}$ and $\Pi^n_{i,t}$ to represent the profit obtained by using the old technology and the new technology, respectively.

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

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

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 use the traditional technology; $\Pi^n_{i,t}$, R^n and $C^n_{i,t}$ represent the profit, revenue and cost associated with the production at time t of firm i which use the new technology.

In addition, for the case that a company choose to use the new technology but leads to failure, we set the profit to be $0.5R^n$. The reason for setting the coefficient 0.5 is that we want to be able to describe the expectation using the success probability p exclusively. Consider that for a new technology with a risk of failure, the net profit deviation from the original technology will not be large when it is first adopted by the company. A setting higher than 0.5 would easily lead to a failure penalty that is too small, corresponding to a situation where the new technology outperforms the old one across the board and all companies would adopt it quickly; a setting less than 0.5 would again lead to a failure penalty that is too severe, thus making it difficult for the new technology to produce a stable state within the time period we set for the experiment, which means that the new technology would develop too slowly. Therefore we set it to 0.5, because too high or too low would lead to trivial dynamics.

The firm agent is mainly controlled by three mechanisms, namely, the expectation mechanism, networking mechanism, and learning mechanism, which work together and maintain the transformation process of the firm agent to supporter and switcher.

2.1.2 Expectation Mechanism

Expectation mechanism mainly controls the parameter $ex_{i,t}$. The parameter $ex_{i,t}$ represents firm i's expectation of the new technology at time t. The Expectation mechanism affects the magnitude of the parameter $ex_{i,t}$ in the following two ways.

1) The parameter $ex_{i,t}$ is positively correlated with the profit generated after using the new technology.

$$ex_{i,t+1} = ex_{i,t} + \Pi^{n}_{i,t}, \quad (3)$$

2) Increase the expectation value of the new technology when the firm agent meets with the spreader agent.

$$ex_{i,t} = ex_{i,t} + \eta, \quad (4)$$

where η means a control parameter the lobbying effect on new technologies when a firm agent encounters a spreader agent.

2.1.3 Networking Mechanism

The Networking mechanism mainly controls the generation of supporter networks and the related parameter changes.

Establishment of Supporter Network

When two firm agents are supporters of a new technology and are close enough to each other, the two firm agents will establish a connection.

It should be noted that since we use the Netlogo platform to run our program, we define "close enough" between the two firm agents as being in the same patch.

Once the connection is established, the firm agent that becomes a supporter can join the supporter network and share the resources in the network.

When a firm agent no longer supports new technology, the agent will quit the supporter network. At this time, all the ties connected to this agent will be broken.

Here we introduce a matrix e_{ij} for the linkage for the network as the following

$$e_{ij} = \begin{cases} 1 & if\ i\ and\ j\ are\ linked \\ 0 & if\ i\ and\ j\ are\ not\ linked \end{cases} . \quad (5)$$

When a connection is generated between firm i and firm j, e_{ij} is equal to 1, otherwise it is 0. And in each turn of the simulations, we update e_{ij} first, then we will calculate the other state variables.

Resource Sharing in Supporter Network

For each firm agent, we define the individual power ($I^{power}_{i,t}$) as all its shareable resources related to the new technology other than knowledge.

We assume that in a supporter network, companies will share not only their knowledge, but also their R&D and production experience. These are essential to reduce the production costs of using new technologies.

Therefore, we update the cost of using new technologies in each round in the following way.

$$C^{n}_{i,t+1} = C^{n}_{i,t} - c \cdot I^{power}_{i,t} - n \cdot \sum_{\substack{i,j \\ i \neq j}} e_{ij} \cdot \left(I^{power}_{i,t} + I^{power}_{j,t}\right) , \quad (6)$$

where *c* and *n* are parameters that adjust the impact of individual and aggregated powers, the latter of which is defined as the sum of the individual power of two endpoint of all ties, as shown in Eq. 6.

2.1.4 Learning Mechanism

We assume that the members of the supporter network will share their knowledge ($K_{i,t}$) about using the new technology with each other and thus reduce the cost of using the new technology.

The learning mechanism mainly affects the success rate of profitability after using the new technology.

$$\begin{aligned} K_{i,t=0} &= random(Evenly\ distributed) \\ K_{i,t+1} &= K_{i,t} + \theta K_{i,t} \end{aligned} , \quad (7)$$

$$Rsk_{t+1} = Rsk_t - \varepsilon \cdot \sum_{\substack{i,j \\ i \neq j}} e_{ij} \cdot \left(K_{i,t} + K_{j,t}\right) , \quad (8)$$

where $K_{i,t}$ represents the knowledge of firm i at time t, Rsk_t represents failure rate of using the new technology to all the firm agents at time t, θ and ε are the parameters that adjust the effect of $K_{i,t}$.

2.1.5 Technological Transition

Finally, we control the transformation of firm agent to supporter and switcher by two conditions.

a) For the condition of whether to become a supporter

$$sup_{i,t} = \begin{cases} 1 & if\ ex_{i,t} > ex^{support} \\ 0 & if\ ex_{i,t} \leq ex^{support} \end{cases}, \quad (9)$$

when $sup_{i,t} = 1$, firm i transformed into supporter.

b) For the judgment condition of whether to become switcher

$$sw_{i,t} = \begin{cases} 1 & if\ E(\Pi^{n}_{i,t}) \leq 0 \\ 0 & if\ E(\Pi^{n}_{i,t}) > 0 \end{cases}, \quad (10)$$

when $sw_{i,t} = 1$, firm i transformed into switcher.

Firm agents are mainly active in 3 abstract spaces.

The first space where firm agents can randomly roam is called activity space. Activity space represents the abstract social network space rather than geographic space.

When a firm agent becomes a supporter, supporters can build a network. The networking mechanism mainly controls this process. We assume that when the distance between two agents satisfies certain conditions, a connection based on social relations of identification with the new technology can be established between each other. This connection allows both endpoints to share part of the knowledge and information about the new technology. At this point, the agents that meet the conditions to join the supporter network enter the second layer of Activity Space - Supporter.

When a firm agent satisfies the condition to become a switcher, it can enter the third activity space - Switcher from the first or second space.

2.1.6 Policy Tools

The policy tools in our model consist of two main components: lobbying policy and subsidy policy.

Lobbying policy mainly controls the number of another type of agent, the spreader agent. The spreader agent is not involved in the production but focuses on the diffusion of new technologies. It represents the government's efforts to diffuse new technologies in real life. When the Spreader agent meets the firm agent, the spreader introduces and promotes the new technology, while the corresponding firm agent increases the understanding and confidence in the new technology. The control of lobbying policy in our model is mainly reflected in the number of spreader agents. Our model's number of spreader agents increases as the government invests more in lobbying policy. In turn, the encounter probability between the firm agent and the spreader agent is increased to achieve the effect of propaganda and lobbying for the new technology.

Subsidy policy mainly controls the size of the subsidy. As we explained in the previous section, a subsidy policy is very important for a technology that is not yet mature. However, the size of the subsidy should be strictly controlled and reviewed. Too few subsidies do little to help develop and sustain new technologies, while too many subsidies can lead to subsidy fraud. Such subsidy fraud consumes social resources and may reduce the public's awareness and enthusiasm for new technologies. Both are heavy blows to the development of new technologies. How to set the size of subsidies reasonably to guide the new technology to maturity is precisely the problem we want to solve.

3 RESULTS

Our main results have three parts. As we have previously described, there is currently no accepted definition of "subsidy" or "subsidy fraud" in the academic community. In our model, we describe subsidy fraud as an observable risk measure. It is mainly described by the number of Supporters and Switchers and their relationship with each other.

Our model theory builds on the multi-level perspective (MLP) framework developed by Geels et al. (2002, 2020).

MLP divides technology development into horizontal directions representing the maturity and diffusion of technology: Emergence stage, Diffusion stage, and Reconfiguration stage, and vertical directions representing the state of access to the public and the degree of impact on social structures: Niche innovations, Social-financial regime, and Landscape development.

Thus, a mature technology should not only be successful in the development and diffusion of the technology itself but also profoundly impact public perception and social structure.

Combined with our model, the number of companies that become supporters and the number of companies that become switchers are both high to be considered a well-developed and booming technology.

Under normal circumstances, a company should first understand and see the new technology and then try to use it for production. However, when a technology has a high number of switchers with a low

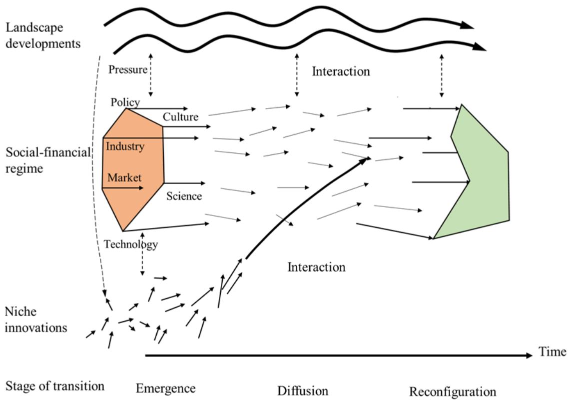

Figure 2: The multi-level perspective on sustainability transitions (Geels et al., 2020).

number of supporters, we consider the model anomalous. In the actual numerical simulation, we found that such anomalies occur steadily when the size of the subsidy is more significant than specific values. Therefore, we classify this situation as a "description of the risk of subsidy fraud." And due to our model setup, the number of supporters and the number of switchers are counted separately and do not affect each other. So, when the number of switchers in the model is steadily higher than the number of supporters, we believe that the probability of subsidy fraud is higher.

The values of all other parameters required in the experiments are given in appendix.

3.1 The Critical Condition

3.1.1 Derive the Critical Value

For a firm who is making decision on the adoption of the new technology, we assume that the higher the expectation of the new technology, the higher expectations of the profit, and the lower expectations of the cost. This assumption means that $E(R^n)$ is proportional to $ex_{i,t}$, and $E\left(C^n_{i,t}\right)$ and $ex_{i,t}$ are inversely related with each other. From the model, it can be seen that the conditions for firms to use the new technology are as follow:

$$E\left(\Pi^n_{i,t}\right) = E(R^n) - E\left(C^n_{i,t}\right) + Subsidy$$
$$= ex_{i,t} \cdot R^n - \frac{1}{ex_{i,t}} \cdot C^n_{i,t} + Subsidy > 0 \quad (11)$$

Therefore:

$$ex_{i,t} > \frac{-Subsidy + \sqrt{(Subsidy)^2 + 4 \cdot R^n \cdot C^n_{i,t}}}{2 \cdot R^n} \stackrel{\text{def}}{=} ex^c \quad (12)$$

We can find three important conditions by changing the size of subsidy (shown as in Table 1).

In our model, under normal circumstances, firms go through three states: neutral, supporter, and switcher, depending on their expectations of the new technology and the benefits of using it, which represent, respectively, "neutral attitude toward the new technology". They represent, "supportive attitude towards new technology", "using new technology for production".

From Eq. 11 and Eq. 12, we set the condition of the state variable $ex_{i,t}$ that satisfies the condition of making firm agent a switcher under the corresponding subsidy policy as E^{Nor} ; the condition of the parameter $ex_{i,t}$ that satisfies the condition of making firm agent a supporter as E^{Sup}; the condition of the parameter $ex_{i,t}$ that satisfies the condition of making firm agent a neutral as E^{Neu}.

At this point, we can derive three important boundary conditions based on the size of the subsidy and the relationship between the condition of becoming supporter and the condition of becoming switcher.

At the initial stage, all the firm agents have a neutral rather than supportive attitude to the new technology.

1. when there is no subsidy policy, the boundary condition that ex^c needs to satisfy is set E^{Nor}.
2. when the condition of being switcher is weaker than the condition of being supporter, the boundary condition that ex^c needs to satisfy is set to E^{Sup}.

$$ex^c \le E^{Sup} \quad (13)$$

3. when the condition of becoming switcher is weaker than the condition of becoming neutral, the boundary condition to be satisfied by the ex^c is set to E^{Neu}.

$$ex^c \le E^{Neu} \quad (14)$$

From Eq. 13 and 14, after substituting the numerical calculation, we can get the critical size of the subsidy as 20.8% and 125%, which are derived from Eq. 12.

1. When $Subsidy \le 20.8\%$, 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.
2. But when $Subsidy > 20.8\%$, the situation will change, and the prerequisite is no longer necessary. Because the government subsidies are too solid, many firms are willing to try to use new

technology for production even if they have not yet become supporters of it.

3. When $Subsidy > 125\%$, the condition to become a switcher is more vital than the condition to become neutral. Regardless of the attitude toward the new technology, all firm agents will immediately switch to the new technology because of the excessive subsidy.

In our paper, the subsidy rate is associated with the cost. Therefore, we introduce two parameters β and γ and set them to 20.8% and 125%, respectively. And use a form like $\beta \cdot C_{i,t}^n$ or $\gamma \cdot C_{i,t}^n$ to express the size of the subsidy.

Table 1: Conditions to become a switcher.

Subsidy Size	Critical expectation for a switcher	Condition to become a switcher
0 (No subsidy)	$ex^c \leq E^{Nor}$	Stronger than to become a supporter
$> \beta \cdot C_{i,t}^n$	$ex^c \leq E^{Sup}$	Weaker than to become a supporter
$> \gamma \cdot C_{i,t}^n$	$ex^c \leq E^{Neu}$	No condition to become a switcher

*Condition to become a supporter: $ex_{i,t} > 0.75$

Therefore, we believe that when the size of the subsidy is between 0 and $\beta \cdot C_{i,t}^n$, the subsidy is reasonable and the probability of subsidy fraud is small; however, when the size of the subsidy is between $\beta \cdot C_{i,t}^n$ and $\gamma \cdot C_{i,t}^n$, there is a high risk of subsidy fraud due to unreasonable subsidy setting; when the size of the subsidy is larger than $\gamma \cdot C_{i,t}^n$, the subsidy setting is exceptionally unreasonable, and there is a very high risk of subsidy fraud.

3.2 Scenarios

It should be noted that for the development of the technology, there are two important state variable in our model, one is the number of supporter and the other is the number of switcher. We describe development of the technology diffusion by comparing these two quantities. The development rate of new technologies can be interpret as the rate of which the number of supporter and switcher approaches 100%. It is worth mentioning that the same firm agent can be identified of both supporter and switcher.

We believe that normally a company should understand a technology and become a proponent of the new technology before it may decide to use it. Therefore for the case of skipping the supporter stage and becoming a direct switcher, we believe that the risk of subsidy fraud would be high. We will define the following three scenarios for development of technology diffusion in order to discuss the risk of the subsidy fraud respectively.

3.2.1 Success Diffusion (SD) Scenario

When the number of supporter is more than the number of switcher, both of them increase rapidly. This means that the development of the new technology is good. Eventually both are close to 100%, then it means that the development of the new technology is successful. This development pattern is the best quality pattern. Therefore, we define this scenario as SD Scenario, which means the success diffusion scenario.

3.2.2 Failure Diffusion & Low Risk (FDLR) Scenario

When the number of supporter is more than the number of switcher, both of them increase rapidly. But eventually both are less than 100%, or the number of switcher is less than 100%, then it means that the development of new technology is not very successful. Improved policies are needed to stimulate the proliferation and development of new technologies. However, the probability of subsidy fraud in this development model is low, because most firm agents become supporter first and then switcher. Therefore, we define this scenario as FDLR Scenario, which means the failure diffusion and low subsidy fraud risk scenario.

3.2.3 Failure Diffusion & High Risk (FDHR) Scenario

In some cases, when the number of switcher is significantly more than the number of supporter, it is thought that the way of development is not very healthy. There are a large number of companies that do not understand the new technology that are using it in exchange for subsidies, and at this point we believe that there is a higher risk of subsidy fraud. Therefore, we define this scenario as FDHR Scenario, which means the failure diffusion and high subsidy fraud risk scenario.

3.3 Numerical Experiments

In this subsection, we conduct numerical experiments for the critical values derived in the previous subsection. Our model is based on the Netlogo platform, and each experiment is generated by running a population of N = 100 firms located on a 32

× 32 grid. Each experiment will consist of 2600 time-steps to simulate the evolution of a company that makes technology decisions once a week for approximately 50 years. Because even based on the same parameter settings, the model is still affected by random factors. As a result, we plot the average of 100 experiments under the same initial conditions. In this way, we can eliminate the influence of random factors as much as possible and further ensure the stability of our results. The following is an analysis of the figure results.

3.3.1 No Subsidy Policy

In the first scenario, the government adopts a policy of no subsidy rates, which is equal to 0 (Subsidy = 0%).

As shown in Fig 3, we can see that the technology diffusion development is very smooth, and the number of supporters is going up until it is smooth. However, technology development only takes off because of the lack of policy support. Finally, the number of switchers is low.

This is a typical FDLR scenario. We name this scenario the FDLR scenario I

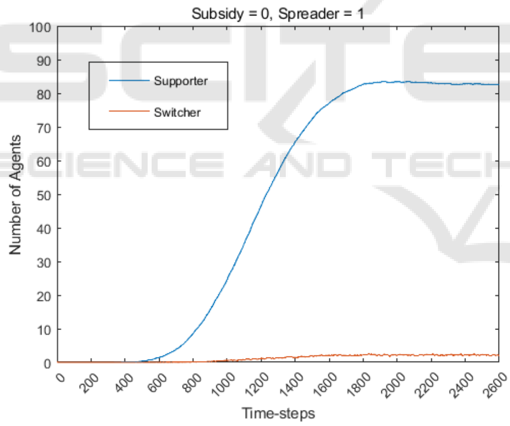

Figure 3: The numerical experiment of FDLR scenario I 0 - 2600 time-steps: Subsidy = 0 , Spreader = 1.

3.3.2 Low Risk Range of Subsidy Fraud

In the second scenario, the government adopts a policy of low subsidy rates, which is between 0 and $\beta \cdot C_{i,t}^{n}$ (Subsidy = 10%).

As shown in Fig 4, we can see that the technology is developing more rapidly than in the first case; the number of supporters is increasing until it plateaus. The number of final switchers has increased because of sufficient policy support. This also means that the risk of subsidy fraud is low at this scenario.

This is also a kind of FDLR scenario. We name this scenario the FDLR scenario II

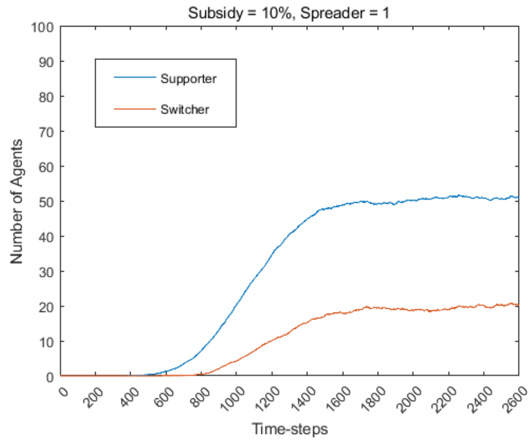

Figure 4: The numerical experiment of FDLR scenario II 0 - 2600 time-steps: Subsidy = 10% , Spreader = 1.

3.3.3 Middle Risk Range of Subsidy Fraud

In the third scenario, the government adopts a policy of high subsidy rates, which is between $\beta \cdot C_{i,t}^{n}$ and $\gamma \cdot C_{i,t}^{n}$ (Subsidy = 21%).

This case has been described in detail in our previous study (Yang et al., 2021). When the subsidy rate is set between Critical value II and Critical value III, As shown in Fig 5, the number of supporters and switchers increases rapidly to 100%. However, this situation holds only when the subsidy policy is maintained. If we remove the subsidy policy, the number of switchers immediately returns to the state when it is not subsidized. This represents a complete policy failure, consuming a large amount of revenue without really generating the goal of promoting the diffusion and development of new technologies.

At this point we consider the risk of subsidy fraud to be slightly higher. The reason is that after the subsidy is removed, the firm agent abandons the new technology in large numbers. The utilization rate of the new technology has dropped to almost single digits. So this development model we think is an unhealthy way of development.

This is also a kind of FDHR scenario. We name this scenario the FDHR scenario I

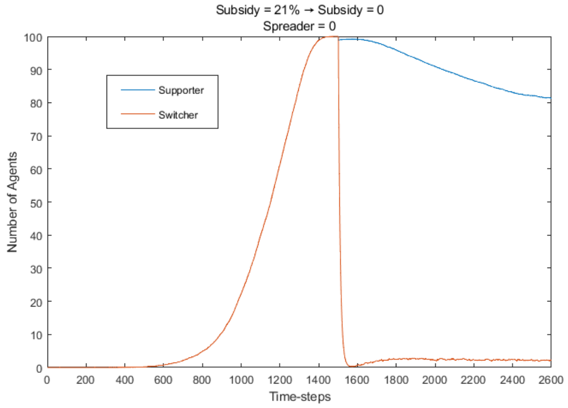

Figure 5: The numerical experiment of FDHR scenario I 0 - 1500 time-steps: Subsidy = 21% , Spreader = 1 ; 1500 - 2600 time-steps: Subsidy = 0 , Spreader = 1.

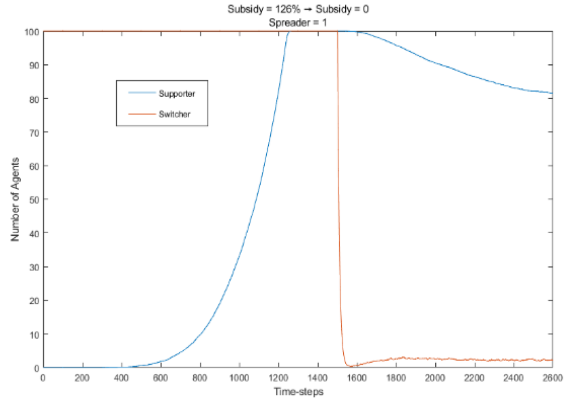

Figure 6: The numerical experiment of FDHR scenario II 0 - 1500 time-steps: Subsidy = 126% , Spreader = 1 ; 1500 - 2600 time-steps: Subsidy = 0 , Spreader = 1.

3.3.4 High Risk Range of Subsidy Fraud

In the fourth scenario, the government adopts a policy of super high subsidy rates, which is bigger than $\gamma \cdot C_{i,t}^{n}$ (Subsidy = 126%).

In another numerical experiment, we find that if the subsidy amount exceeds 125%, all firms will instantly become switchers. Then, as time increases, every firm will gradually become a supporter, and the market becomes steady. However, after it, if we cancel the subsidy, we can find that the proportion of switchers has decreased to single digits in a short period, and the proportion of supporters has continued to decrease until it stabilizes at around 80%, see the details in Fig. 6.

In the end, it is consistent with the previous case and returns to the steady state under the same parameter setting. This also means the complete failure of the policy.

At this point we believe that almost all the firm agents in the market are using new technologies for the sake of subsidies. Too strong subsidy policy, so that those who were in a neutral attitude, but also directly began to use the new technology. It is a very unhealthy way of development.

This is a typical FDHR scenario. We name this scenario the FDHR scenario II.

3.4 Mechanism and Principal Analysis

We have organized the mechanism of the model and obtained the following mechanism diagram of the model. As shown in Fig 7.

Regarding how the firm agent converts to supporter or switcher, it is mainly influenced by the parameters $ex_{i,t}$ and $E\left(\Pi_{i,t}^{n}\right)$, respectively. And the subsidy fraud risk of the firm agent in the model system is mainly controlled by the magnitude of the variable ex^{c}.

According to our previous conclusion, the risk of subsidy fraud can be minimized at the source when the following conditions are satisfied.

$$E^{Sup} < ex^{c} < E^{Nor} \quad (5)$$

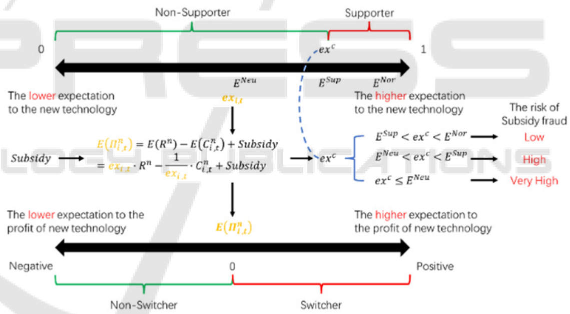

Figure 7: Mechanism diagram of the model.

Moreover, this leads to another question: why are subsidies less likely to be fraudulent when they are in this range?

In conjunction with Fig 7. we try to shed light on the fundamental mechanisms of subsidies. As shown in Fig 8., we illustrate the principles and linkages of the actions of the designed stakeholders in the subsidy policy.

The government's main objective is to solve a problem, which may be developing a specific industry or technology. The solution to this problem requires the assistance of a firm in the relevant industry. On the other hand, for a firm, the only concern is profit, so in order to attract the firm to solve the problem, the essence of the government's subsidy policy is to create a related subsidiary for the problem and subsidize all the firms that try to solve the problem.

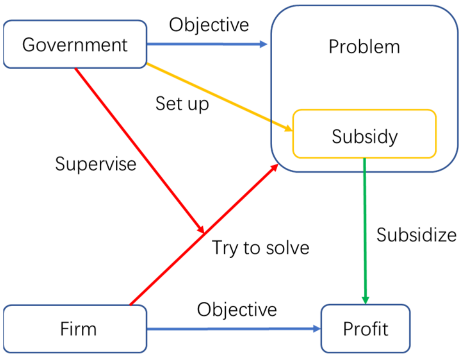

Figure 8: Principles of action and linkages of designed stakeholders in the subsidy policy.

The two parties' actions were divergent from the beginning. On the one hand, the company must try to show the government that it is solving the problem in order to get the subsidy in order to deal with government regulation; on the other hand, the objective of the firm has always been to get more subsidies rather than to help the government solve the problem, so the company side is always motivated to cheat the policy regulation.

When subsidies are small relative to production or R&D costs, the firm is more inclined to obtain subsidies through formal channels than to be punished if it is found to be a subsidy fraud. Although the purpose of the firm attracted at this point is often more in line with the government's aspirations, it is relatively less attractive to the firm as a whole.

The cost of concealing government regulation can be covered by the number of subsidies obtained when the amount of subsidies assumed is more significant than a particular threshold value. At this point, the subsidy policy will be more attractive for many companies. Moreover, when subsidies increase further, the incentive to commit subsidy fraud will be more than sufficient. This can lead to tragedy, as in the case of the 2004 subsidy fraud by a Norwegian ferry operator (J⊘rgensen F et al., 2010) and the 2016 subsidy fraud by 20 new energy vehicle companies in China (Wang et al., 2022).

4 CONCLUSIONS

Subsidy policy, the central policy used by governments to support innovative industries in modern society, is a critical factor in promoting innovation in a country. It stimulates the diffusion and development of new technologies by providing tangible financial support to companies that adopt them. However, often the objectives of firms and governments do not precisely coincide. When governments use subsidy policies as a stimulus, firms that engage in fraud targeting specifically for subsidies can also arise. As Goodhart's law says, "When a measure becomes a target, it ceases to be a good measure." When companies make access to subsidies their target, the subsidy policy is no longer as perfect as it was designed.

Although subsidy fraud may be unavoidable, we can still design subsidy policies to reduce the risk of subsidy fraud. Based on such a viewpoint, this paper attempts to present a quantitative approach to assess the risk of subsidy policies.

In this study, firstly, we review the literature on subsidy and subsidy fraud concepts and define these two concepts in a clearer manner. After that, we analyze the agent-based model designed on the basis of MLP mathematically, from which we find the three critical values of subsidy rates in the theoretical model. Lastly, four different scenarios designated by different ranges of subsidy rate, that are separated the three critical points, are simulated numerically. From the numerical experiments, we do find a specific range of subsidy rates, that the size of the subsidy should be less than 20.8% of the cost in our model, relative to the production cost which can effectively reduce the risk of criminal behaviours.

Also, we analysed the mechanism behind different behaviours of the model. We identified in the diagram showing the work of various factors (Fig. 8), the most related stakeholders in the subsidy policy. Indeed we find that subsidy fraud is almost unavoidable in emerging technology fields where subsidy policies exist. In the meantime, we believe that we can continue to explore the causes of subsidy fraud based on the diagram in the future, which may bring about a breaking through in the field.

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APPENDIX

Table 1: Parameter setting.

Type	Denotation	Valuation	Type	Denotation	Valuation
$Global$	NE	0.75	$Global$	$p_{t=0}$	0.5
	η	0.02		Rsk_t	$1 - p_t$
	π	0.001		$Cex_{t=0}$	0.5
	n	0.01			
	c	0.01			
	θ	0.025	$Firm\ i$	$ex_{i,t}$	0.5
	υ	2		$I_{i,t=0}^{power}$	[0, 0.3]
	$Subsidy$	0		$K_{i,t=0}$	[0, 0.01]
	R_n	1.5		$Cn_{i,t=0}$	0.5