An Agent Based Approach to Study Incubation in Innovation Ecosystems

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Abstract. The innovation ecosystems are clusters of economic entities creating high productivity and business diversity based on innovations. The business incubators are among the most well-known approaches to support economic growth in these ecosystems. Although the number of business incubators has increased substantially in the last decade, the absence of efficient assessment techniques for business incubation calls for novel approaches. In this paper, we present an approach for the analysis of innovation ecosystems by using an agent based modeling methodology with a focus on incubation. We model the role of business incubators considering different support methods and show their effects on global economy with our preliminary results.

1 Introduction

Innovation has been recognized as a core component of economic growth, productivity and job creation. Global economies have been trying various methods of investment for successful innovations to improve productivity and create jobs. Business incubation is one of the most well-known approaches to support economic growth. There is a wide range of available techniques for business incubation and it has been considered as an important factor for the survival of start-up companies. Although there is a broad interest in the policies for innovation and business incubation, certain innovation ecosystems become extremely productive with the help of business incubators while other similar systems languish. Therefore, the assessment of business incubation and its effect on global economy remains as a critical challenge.

In order to improve the understanding of innovation ecosystem dynamics and test incubation or policy hypotheses, we use agent based computational economics. We model an innovation ecosystem as a non-linear, complex adaptive network to reflect its characteristics. In an innovation ecosystem, the success of an innovation depends not only on the innovating entities, but also on the

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other factors forming the system such as the suppliers and consumers of those entities [2, 3]. All entities in an ecosystem co-evolve and the technology space of the ecosystem changes in response to the innovations. Therefore, in our model, the economic agents are connected by dynamic networks and cooperate, compete and adapt to each other's needs.

Our preliminary innovation ecosystem model [12,17] is extended in this paper to create a spatially embedded artificial economy. We consider technology as a transformation process and show that the transformation networks can be used to model the structure of technology space in an artificial economy. We model the system of economic agents as an ecological network and embed each agent or Adaptive Resource Transformer (ART) in a spatial environment. This approach provides an artificial economy that can be utilized to investigate the role of innovation on economic growth. Then we use our agent based model to observe the business incubator impact in the innovation ecosystem. For this purpose, we compare several different types of business support techniques in terms of their impact on the macroeconomic growth. The results and implications of our approach are twofold. First, it demonstrates the value of using an emergent agent based model as a simulation environment to experiment with different forms of macroeconomic strategies. Second, the impact of business incubators on global economy is evaluated for a set of support methods.

The remainder of this paper is organized as follows. The general concepts in the related literature is summarized in Section II. The details of our model are explained in Section III. In Section IV, we present our experiments and results on business incubation and its effect on global economy. We finally conclude in Section V.

2 Related Literature

Innovation and technology diffusion are critical components of economic growth [1, 8]. There are various approaches in literature investigating and exploring the nature of innovation, patterns of technology diffusion and the integration of innovation with economic growth models. The goal of the model introduced in this paper is to study the incubation and its effect on economic growth.

The economic growth and its relationship with innovation, have been modeled with neoclassical approaches [8]; evolutionary approaches [9]; econometrics [19] and computational agent based approaches [10]. These approaches differ primarily in the level of nuance allowed to the modeler when representing various economic behaviors and structure. With respect to modeling the role of innovation in economic growth, an agent based approach offers flexibility and it is a natural fit to the stochastic and non-linear nature of innovation [5,11,18]. Agent based modeling also allows the representation of knowledge in ways that are mathematically intractable.

We use an agent base approach to model the economy as an ecosystem and the agents in the model are treated as components in an ecological network [14, 16]. Technology space is represented by a network structure similar to a food web and the resources flow in this network as the energy does in food web. Each agent represents a set of economic entities with a particular technology used for production. Two agents are connected if the output of the first agent's production process is the input to the second agent's production. The resulting overall structure is a directed network similar to the recent results given by Hidalgo and Hausmann [15], where products are associated with countries.

The core component of our model is the "transformation network", where each technology type is considered as a transformation process. Transformation networks summarize the technological structure and production capabilities of an economy. Furthermore, there is a correlation between the structure of a transformation network and the economic performance of the associated economy [21]. Transformation networks can be considered as directed hypergraphs, which can be represented as $H = (V, E)$. V is the set of resources used in the production process and they can be natural, manufactured, or intangible. E is the set of edges connecting these resources. Each edge in a transformation network encodes a specific technology available to the population. Therefore, the transformation network of an economy changes with the production capabilities of the population.

Incubation can greatly improve the chances of survival of small businesses in an innovation ecosystem. Al-Mubaraki and Busler [4] identify that one of the major obstacles faced during incubation is the underestimation of financial resource requirements of small businesses. Incubators face the challenge of selecting weak yet capable start-ups that will maximize on the infrastructure and resources provided [6], making the selection of incubatees a major component of incubation. Hackett and Dilts [13] define three phases of incubation, stating that proper selection, resource provision and business assistance define the performance of incubation. Once the incubatees are selected, the incubator must optimize resource provision and business support/mediation for these start-ups [6]. It has been shown that firms on incubation have almost twice the probability of forming external technological agreements and are much more likely to gain financial support through public subsidies [7].

3 The Innovation Ecosystem Model

We constructed an agent based model of innovation ecosystems using MASON [20]. The agents of the model reside in a spatial environment and they are driven by economic behaviors. The model is created to explore the relationship between microeconomic activity and macroeconomic phenomenon. Therefore, the emergent results of this model are macroeconomic markers such as GDP, resource consumption, resource production, trade activity, resource prices, wealth distribution and frequency distribution of transformation rules.

An Adaptive Resource Transformer agent (ART) represents the basic economic entity in the model. It has state variables that represent its economic state, spatial information, production rules, monetary wealth and resources. An ART has the ability to take a set of resources as input, transform them into some output. When there is a demand for the produced output, it is sold to other agents in the system. This behavior is intended to embody the primal concepts from standard economic theory.

Environment The model includes an ecosystem environment to conduct the money and resource dissipation from ARTs as experienced by firms in the real world (for example, losses due to taxation). The environment is also used for the injection of money and resources into ARTs. In the model, ARTs perceive the environment as the initial source of resources and money. Additionally, as the environment is aware of the fitness of all ARTs, the environment also triggers the reproduction of agents. Finally, the environment is responsible for the incubation of selected agents. Incubation is considered as a two-step process and it is described in further detail in Section 4.

Adaptive Resource Transformers The ARTs are production driven objects of the ecosystem, which represent economic entities in a real world economy. Within a transformation network formed between several interacting ARTs, two resources are connected by a technology if one resource can be transformed into another through a technological process. Therefore, the network among resources encodes the resource and technology space of the economy. The transformation network can be used to identify the critical resources and the transformation cycles in the ecosystem.

An ART displays a set of common behaviors during its life time: 1) Harvesting, 2) Production, 3) Trading, 4) Resource/Product Pricing, 5)Reproduction, and 6)Death.

Harvesting: At initialization, ARTs are set up with an initial amount of money and input resources. During the simulation, ARTs harvest money and resources from the environment. Harvesting is a stochastic process governed by the ART's injection probability. For an ART to acquire resources from the environment during a simulation step, it must have the necessary fitness in relation to other agents.

Production: Each ART contains a single transformation rule which is either randomly assigned to it at initialization or inherited from its parent during reproduction. Production is defined by an ART's transformation rule and denoted as $R \to P$, which represents the technology required to transform a *resource type*, R, into a *product type*, P. Thus, an agent's input may be used as another's output, or vice versa. In our model, ARTs convert their available input into output during each simulation step.

Trading: Input *resources* are also obtained by trading with other ARTs. Agents move spatially, throughout the ecosystem searching for viable trade partners to purchase resources from. Once discovered, production converts input resources to output *products*. These products are then traded off to other ARTs in exchange for money. Money enters and leaves an ART as another characteristic effect of trading. However, resources and money can also leave an ART through the stochastic processes of dissipation, harvesting and incubation. In economic terms, the dissipation can be interpreted as the indirect costs of production, sales and resource decay.

Resource/Product Pricing: ARTs are able to decide the current demand of the product they are selling through the number of recent sales of their product. If the agent experiences a number of successful consecutive sales, then the product price is incremented. If the agent consecutively fails to sell, then the product price is decremented until it reaches a predefined minimum price.

Reproduction: Reproduction is triggered by the environment within the most fit ARTs selected out of the current population. Reproduction involves the mutation of the parent ART to create a new child ART. Essentially, the transformation rule, which defines the functionality of a single agent, is subjected to mutation. Both the input and output of the transformation network are mutated according to a uniform distribution. The rate of mutation in reproducing agents is controlled stochastically by the mutation probability.

The child agents also receive a percentage of its parent's money and resources determined by the child contribution parameter.

Death: Every ART maintains a level of energy (E) which is the sum of its monetary wealth (M_q), its input resource quantity (R_q) and its product quantity (P_q). Thus, the level of energy for an ART i at time step t is calculated as follows:

$$E_i(t) = M_{qi}(t) + R_{qi}(t) + P_{qi}(t)$$

If an ART's energy drops to zero (or in other words if it ever runs out of all its money, resources and products), it "dies" and it is removed from the ecosystem. This process is countered by reproduction in the system.

3.1 Preliminary Validation

Our model produces output data about the GDP, distribution of wealth, population, production level, product prices, distribution of technology, and structure of the transformation network.

We conducted a preliminary validation of our model against a small set of basic stylized facts from economics. The ages of ARTs at an arbitrary time step is exponentially distributed, and follows a power-law. The value of the combined money and resources for ARTs is also power-law distributed. We also observe the process of creative destruction as a shift into dominant technologies. When we define the ART types according to their technologies and investigate their distribution, we observe a cyclic behavior in the macroeconomic output variables.

We also repeated two experiments conducted on the preliminary version of our model. As with the initial work by Hollander and Garibay [17], we investigated the relationship between the GDP of the underlying economy associated with an innovation ecosystem and the structure of its transformation network. Our results showed a positive correlation between the density of the transformation network and the GDP. Additionally, this correlation holds also when money or resources are exogenously injected into the economy.

4 Incubation Analysis and Results

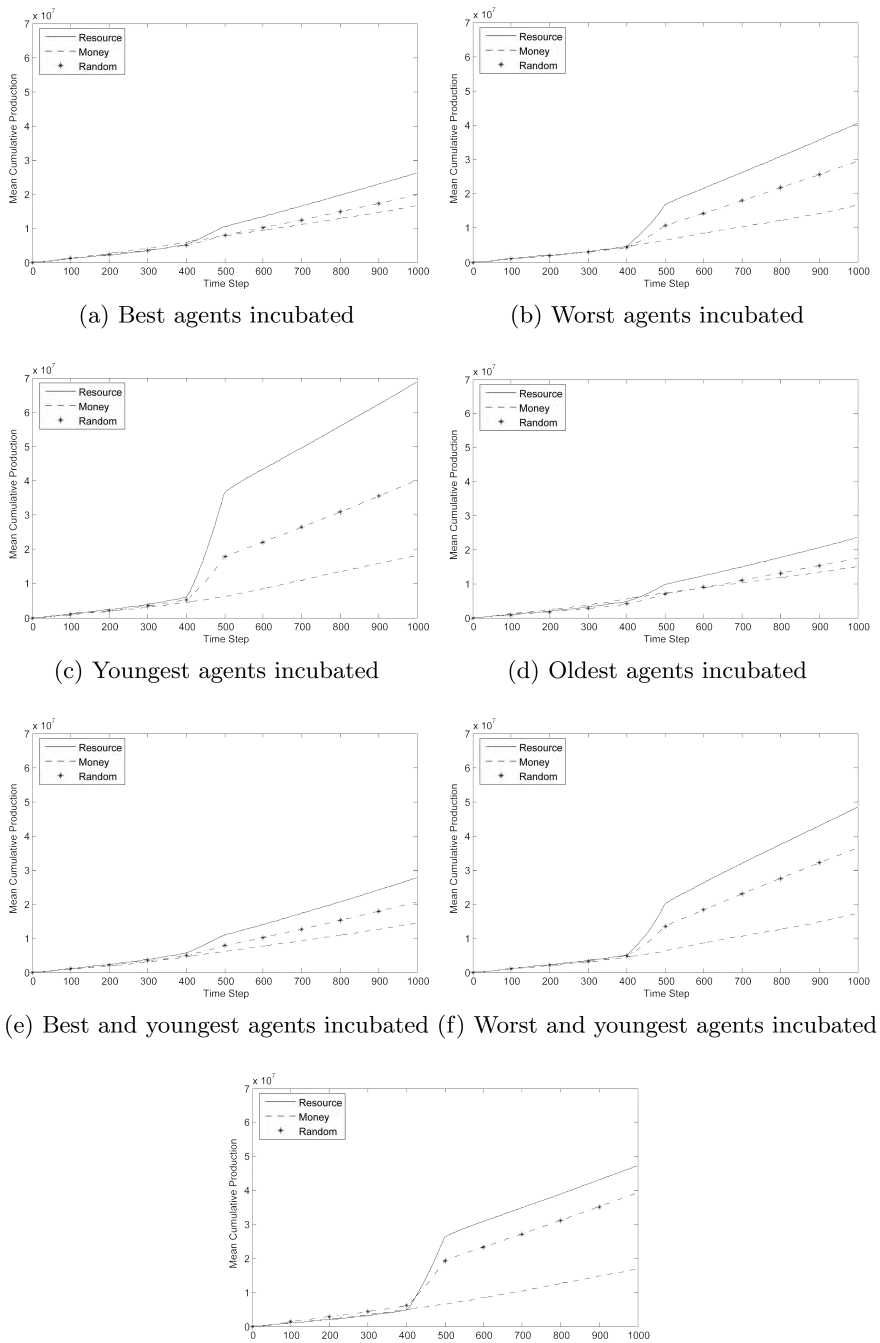
There are several different approaches towards the incubation of firms in an innovation ecosystem. For the purpose of this paper, incubation consists of two main phases: 1) *selection* of firms to be incubated; and 2) *provision* of one of the various forms of business assistance. Our model iss used to study the possible variation in macroeconomic measures when applying different approaches towards achieving these two phases of incubation. This can be considered as a preliminary step in discovering the effective incubation techniques through agent based modeling methodology.

The age and performance of agents were used as incubation selection criteria. Thus, seven selection types were chosen to experiment with: 1) the best performing agents, 2) the worst performing agents 3) the youngest agents, 4) the oldest agents, 5) the youngest agents with the worst performance, 6) the youngest agents with the best performance, and 7) random selection. During the selection process, agents that better fit the criteria being used for selection were given a higher probability of selection. Secondly, three business assistance types were selected to experiment with: 1) provision of resources 2) provision of money and 3) randomly iterating between providing resources or money per simulation step. Thus, an incubation technique refers to the application of one of the above mentioned selection methods followed by one of the mentioned business assistance approaches.

4.1 Results

The experiments were carried out in order to explore how different modes for selection and different modes of assistance effected the performance of the innovation ecosystem. Performance was measured using rate of production and the value of production (or GDP).

Result 1 When the ARTs were deployed in the environment, they were initialized with no money or resources. However they were allowed to harvest a constant amount of money or resource every step from the environment. The reproduction parameters of ARTs, mutation probability and child contribution, were set to 0.1 and 0.5, respectively.Incubation was set to happen from step 400 to 500 and each experiment was sampled for 1000 steps. Agents trade in this scenario with the neighboring agents, which are in their vision ranges. The cumulative quantity of products produced by all agents for each step is the first performance measure we selected. The obtained results are show in Fig. 1.



(a) Best agents incubated (b) Worst agents incubated

(c) Youngest agents incubated (d) Oldest agents incubated

(e) Best and youngest agents incubated (f) Worst and youngest agents incubated

(g) Agents randomly incubated

Fig. 1. Mean Cumulative Production over Time

The results in Fig. 1 show that the most significant rise in production was brought by the provision of resources for all employed selection types. This can be attributed to the fact that an ART can directly convert the input resources obtained through incubation into products, in comparison to using money (obtained through incubation) to buy these resources first and then perform production. Provision of money by incubation had relatively smaller improvement to cumulative production.

The results also show that when using selection of younger agents for incubation, a much higher spike in production is observed when using resource incubation. This leaves firms in an ecosystem with a more product rich environment when the incubation is stopped, which explains the much higher end cumulative production count for younger agent selection with resource provision.

The selection of the worst performing agents in the ecosystem and the worst and youngest also showed a comparatively strong improvement in production. However, these selection types were quite similar to random selection. Other selection types: selection of best, selection of oldest and selection of best and youngest selection showed poorer cumulative production compared to the random selection.

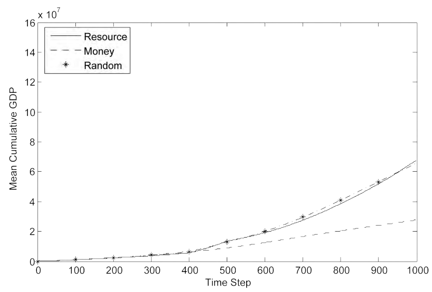
Result 2 In addition to measuring the collective production rate of the ecosystem, we also aimed to capture the success of sales and the demand of transformed products. Therefore, a further investigation into the effect of incubation technique on the ecosystem was performed through GDP analysis. The performance was measured as the cumulative sum of the quantity of products produced by all firms, P_i, t, multiplied by the value of each individual product at the current time step, V_i, t. This measure represented a simplified version of the ecosystems cumulative GDP, given as follows:

$$CumulativeGDP = \sum_{time=0}^{n} (\sum_{i=0}^{N_p - 1} (P_{i,t} * V_{i,t}))$$

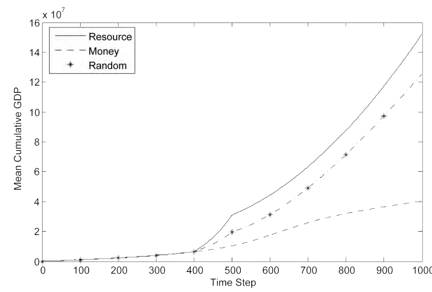
where N_p is the population size of ART i. There were slight differences in the results obtained using this measure as shown in Fig. 2.

The second set of results shows an increased in gradient of cumulative GDP over time for several resource provision and random provision techniques after incubation. This implies that the contribution to cumulative GDP per unit time kept improving even after the incubation period has ended. Further, younger agent selection and random agent selection using provision of money also shows an improvement in cumulative GDP. However, this improvement occurs only around 100 steps after the incubation has ended. This suggests that the improvement in the cumulative GDP due to incubation when using monetary assistance is not immediate but requires additional time for the injected money to liquidate into the ecosystem and be used for purchasing.

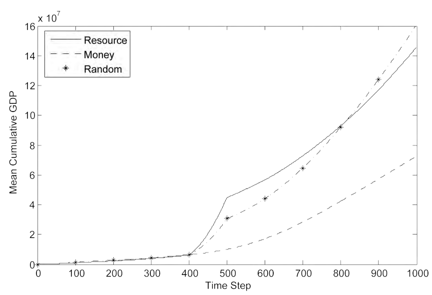
As with cumulative production rate, selection of younger agents for incubation shows the largest improvement in performance. Despite the large differences



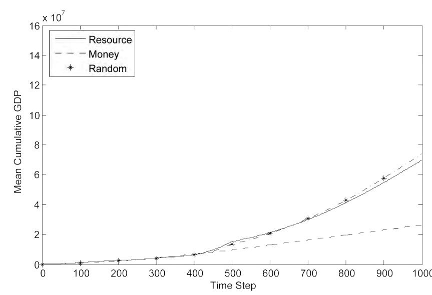
(a) Best agents incubated



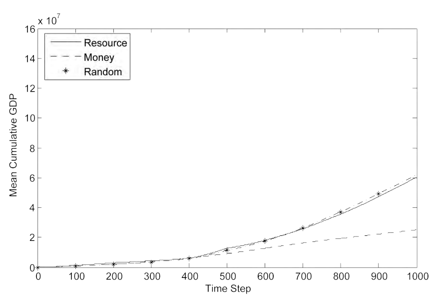
(b) Worst agents incubated



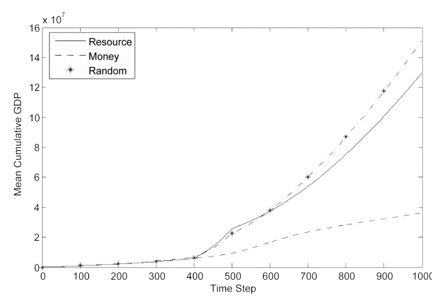
(c) Youngest agents incubated



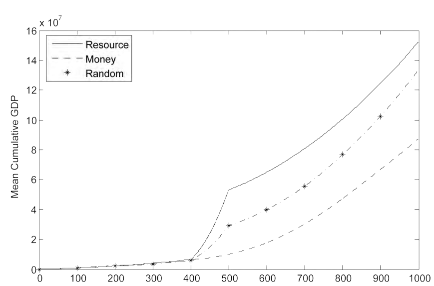
(d) Oldest agents incubated



(e) Best and Youngest agents incubated



(f) Worst and Youngest agents incubated



(g) Agents randomly incubated

Fig. 2. Mean Cumulative GDP over Time

in cumulative production with selection of worst, worst and youngest, and random agents, cumulative GDP in these cases are comparably similar. In both results, we see that the selection of the youngest ARTs for incubation ended up with highest cumulative performances due to the large production and GDP spikes during the incubation period, identified by the sharp increase in gradient during the incubation period. These results imply that the selection of younger agents for incubation helped optimize the incubation process.

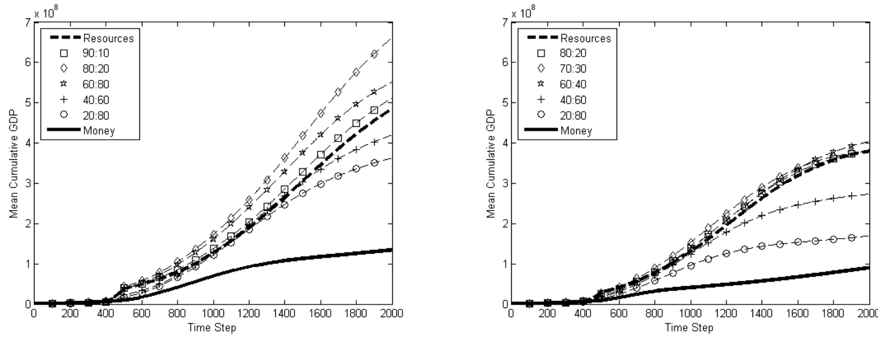
It is also important to note that although resource provision always caused much higher cumulative production, random provision improved cumulative GDP as much as and eventually even better than resource provision, in 5 out of the 7 incubation techniques tested. A probable explanation for this behavior is that the money injected into the agents during random provision started being exchanged for sales later on, which in turn resulted in increase in demand and resultantly increased the value of products. In other words, resource provision improves production after which provision of money would further improve the sales of the generated products, as agents discover trade partners, further strengthening the innovation network.

Result 3 From the results given in Fig. 1, it can be deduced that the provision of money along with resources during incubation yields a stronger economy in the long run in comparison to providing assistance solely through resources. This prompts the question: how much of a monetary contribution would prove optimal for GDP improvement? This was explored by comparing cumulative GDP over time for different proportions of resource and monetary assistance. The same simulation parameters were used as before and selection types *youngest* and *worst* were used as these proved to be the strongest selection techniques in the previous results. The ratio of resource provision to monetary provision during incubation was varied from 0:100 to 100:0, while keeping the total value of resource and monetary assistance constant for each case. The results are presented in Fig. 3.

Fig. 3 shows that there is an optimal proportion of resource and monetary assistance that would optimize GDP improvement in the created ecosystem. For selection type *youngest*, this proved to be around 80:20 (resource contribution: monetary contribution) and 70:30 for selection type *worst*. In other words, when the youngest agents are selected for incubation, an 80% resource provision and 20% monetary assistance out of the total value of assistance give the best result for the global economy. For worst selection, these percentages are 70% and 30%, respectively.

5 Conclusion

Business incubators are among the important components of innovation ecosystems. However, it is challenging to determine the actual effectiveness of incubators or the methods for effective incubation. In this paper, we introduced an



(a) Youngest agents incubated

(b) Worst agents incubated

Fig. 3. Mean Cumulative GDP over Time for Proportionate Assistance

approach for modeling innovation ecosystems, which provides methods to analyze the impact of local interactions and policy decisions on the global system and the economic growth. We then utilized the created model to investigate the global impact of business incubators on the entire regional economy in which the incubated agents exist. Our initial results show that the incubation enhances a regional economy in terms of the number of products and the cumulative GDP. The results also suggest that the selection criteria and type of incubation affect the impact on the economy. Resource provision during the incubation period yields a faster growth in both the production rate and GDP compared to money provision. Selecting youngest firms out of the population for incubation also proved to yield the best results compared to the other selection types investigated. In our future work, we will implement other dimensions of incubation such as networking support and analyze their effects on the economy in combination with the existing capabilities of the model.

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