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Productivity dispersion and output fluctuations: An evolutionary model☆

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ABSTRACT

We develop a model of technology choice with search costs. Innovators develop technology of varying quality or productivity. Firms acquire technology after paying a search cost to find high productivity technology. The resulting model has mixed equilibria with productivity dispersion. However, such mixed equilibria are unstable under the logit dynamic from evolutionary game theory. Instead, the economy converges to limit cycles, whose existence we verify numerically. We conclude, therefore, that mixed equilibria is not a robust explanation of productivity dispersion in our model. Instead, such productivity dispersion is a cyclical phenomenon. An additional implication is that cyclical productivity dispersion contributes to endogenous fluctuations in aggregate output.

1. Introduction

Productivity dispersion has been a topic of significant interest in the economics literature. For example, Baily et al. (1992) and Syverson (2004) show the presence of significant productivity dispersion among firms in the US. In a more recent paper, Kehrig (2015) empirically establishes not just the presence of productivity dispersion among manufacturing firms in the US, but also that the dispersion is cyclical. Thus, according to that paper, different firms exhibit different levels of total factor productivity at a given time. Furthermore, the proportion of firms exhibiting a certain level of productivity does not remain constant over time but changes cyclically. These empirical findings provide the motivation to develop a theoretical model that explains the existence of productivity dispersion and, moreover, allows us to assess whether such dispersion is stable or cyclical. This paper develops such a theory by building an evolutionary model of productivity dispersion in the presence of search costs.

The theoretical literature on this topic has focused on characterizing productivity dispersion as an equilibrium phenomenon. Acemoglu and Shimer (2000), for example, extend the Burdett and Judd (1983) model of price dispersion into a two-sided search model involving firms and workers in a general equilibrium framework. Their model implies that in equilibrium, both the technology choice of firms as well as the wages of workers are dispersed. Dispersion in technology choice

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by firms, in turn, translates into dispersion in productivity of workers employed in the firms. Another paper in this direction is Syverson (2004), which focuses on the effect of imperfect product substitutability on the dispersion of productivity. Due to imperfect product substitutability, not all consumers move to high productivity (or low cost) firms, allowing inefficient firms to survive in the market. This results in productivity dispersion as an equilibrium phenomenon. We note, however, that while these papers do establish the persistence of productivity dispersion, they do not consider whether the pattern of dispersion is stable over time, or cyclical, as documented by Kehrig (2015). The contribution of our theoretical model is that it will show the presence of such dispersion as well as establish its cyclical nature.

As with Acemoglu and Shimer (2000), the basis of our paper is the canonical model of price dispersion by Burdett and Judd (1983). We extend that model to the context of technology choice by innovators and firms. Innovators choose the quality of technology they produce, higher quality technology involving higher cost of production. Firms search for the highest quality technology to produce output, but may find it optimal to settle for a lower quality due to the presence of search costs. Innovators, therefore, lack the incentive to race each other towards producing the highest quality of technology. This results in mixed equilibria with dispersion in the quality of technology. In this model, the technology adopted by a firm is the productivity of that firm. Therefore, co-existence of different qualities of technology generates a non-degenerate distribution of productivity among firms. We interpret this distribution as the dispersion of productivity in the economy.

The application of the Burdett and Judd (1983) model, therefore, provides an explanation of productivity dispersion as an equilibrium phenomenon. To assess the robustness of this explanation, we extend our analysis into a dynamic framework. Since our main objective is to ascertain whether productivity dispersion exhibits a cyclical pattern over time, evolutionary game theory is a natural choice of technique for our dynamic analysis. This is because unlike conventional equilibrium focused game theory, evolutionary game theory can readily explain persistent fluctuations in an economic phenomenon by using the notion of the limit cycle. If an evolutionary dynamic converges to a limit cycle instead of to an equilibrium, then that explains the cyclical behavior of a variable over time. The use of evolutionary game theory, however, requires agents to by myopic. In our context, we may justify this assumption on the grounds that in the dynamic environment of an economy characterized by the interaction of a large number of agents, it may be prohibitively expensive for agents to acquire information required for the use of more sophisticated forward looking strategies.

Lahkar (2011) applies evolutionary game theory to account for the cyclical nature of price dispersion in the Burdett and Judd (1983) model. Following a similar approach, we construct a finite analogue of our technology choice model.[1] As in Lahkar (2011), we apply the logit dynamic (Fudenberg and Levine, 1998) for our evolutionary analysis.[2] The logit dynamic is one of canonical models of evolutionary game theory. Using a technical condition called positive definiteness, we show that all mixed equilibria of this model are unstable under the logit dynamic. It is, therefore, reasonable to expect that the social state (the distribution of strategies among innovators and firms) converges to more complex attractors like limit cycles. It is not feasible to prove the existence of limit cycles. Instead we rely on numerical simulations to reveal their existence.[3]

Convergence of the social state to a limit cycle has two implications on the nature of productivity dispersion among firms. First, multiple qualities of technology do co-exist at a limit cycle. Hence, the distribution of qualities (or productivity levels) among firms is non-degenerate at a limit cycle. Therefore, dispersion of productivity is a persistent phenomenon in our model. Second, and more significantly, due to the instability of mixed equilibria, such dispersion is not an equilibrium phenomenon. Hence, the distribution of productivity does not remain stable over time. Instead, it shows cyclical variations. This is a conclusion that is consistent with the empirical findings of Kehrig (2015).

This explanation we provide for the nature of productivity dispersion is the primary contribution of this paper. Another contribution is that the model also explains how the cyclical dispersion of productivity contributes to fluctuations in the aggregate level of output produced by the firms. When there are more high productivity firms, aggregate output is also high whereas, when more firms exhibit low productivity, aggregate output is low. This conclusion is of significance from the point of view of the business cycle literature as these fluctuations in aggregate output in our model arise entirely endogenously. This is different from the more usual way to generate fluctuations in aggregate output through the introduction of exogenous shocks (see e.g. McCandless, 2008). Of course, the methodology that generates these aggregate output fluctuations in our model is very different from the usual techniques in macroeconomic theory. Evolutionary game theory relies on myopic behavior by agents whereas conventional business cycle theories postulate agents who are infinite horizon optimizers. Nevertheless, such fluctuations in aggregate output as a consequence of productivity dispersion is an interesting implication of our model, which may be amenable to experimental tests in the manner of the testing of the Burdett and Judd (1983) model by Cason et al. (2005).[4]

We have already noted the similarities in the modelling approach of this paper and those in Burdett and Judd (1983) and Lahkar (2011). This approach allows us to characterize equilibrium in the present model from results in these earlier

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[1] The finite approximation is to avoid technical complications involved in applying evolutionary game theory to a model with continuous strategy sets.

[2] The original application of evolutionary game theory to the problem of price dispersion is by Hopkins and Seymour (2002). That paper uses the replicator dynamic to conclude that mixed equilibria in the price dispersion models of Varian (1980) and Burdett and Judd (1983) are unstable. Lahkar (2011) adapts the approach of Hopkins and Seymour (2002) to the logit dynamic to show the cyclical nature of price dispersion.

[3] As a technical point, we note that stability results under the logit dynamic relate to logit equilibria, which are approximations of Nash equilibria. However, the approximation becomes increasingly accurate as the perturbation factor becomes small. Our instability results are valid for arbitrarily small perturbation and hence, are sufficient to rule out mixed Nash equilibria as a robust prediction.

[4] Also see Cason et al. (2013) for tests on cyclical behavior in rock-paper-scissor games.