Behavioural models of technological change

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Chapter 6

Conclusions

6.1 Summary

This thesis deals with technology competition as an emergent phenomenon of decision making by economic agents. Broadly speaking, this thesis addresses the question of how and to what extent behavioural issues can explain the pattern of technological change. The main focus is on agency and dynamics, and in particular on the endogenous mechanisms leading to decision feedback loops, such as network externalities, social interactions, market dynamics, and environmental policy. In each chapter a model is proposed, addressing a specific aspect of technology competition, based on a specific agents' decision problem concerning technology. The present chapter provides a summary of these models and of the main results obtained in this thesis, including suggestions for innovation and environmental policies. In addition, ideas for further research are outlined.

Chapter 2 starts off with a cost-benefit analysis of the trade-off between diversity and specialization, associated with increasing returns to scale, in technology investment. One motivation for a model of diversity in technology investments is the actual debate on diversity in renewable energy (van den Heuvel and van den Bergh, 2008). Instead of the more traditional view which emphasizes the advantages of diversity as stemming from a reduction of uncertainty, the model in this chapter focuses on the benefits of recombinant innovation. Such innovation is assumed to occur with a probability that is proportional to the diversity of the technology investment. A perfectly symmetric technology portfolio may represent either a maximum or a minimum value of total benefits though, depending on the returns to scale. There is a threshold value of returns to scale below which diversity is a global maximum. This threshold changes with the time horizon of the problem, because the probability of recombinant innovation depends positively on the total size of cumulative investments in the two technologies, beside the relative size: when the time horizon is beyond a critical value, the best choice becomes diversity. This threshold time will be larger, the higher are the returns to scale. Introducing initial values of parent options breaks the symmetry of the problem: in cases where diversity is to be preferred, the optimal solution has different shares of the two technologies. This is also the case when returns to scale differ (i.e. are heterogeneous) among different technologies. Nevertheless, in the long-run, the effect of initial conditions vanishes, while the effect of heterogeneous returns to scale increases.

The model in Chapter 3 extends the study of recombinant innovation to the dynamic setting of sequential decisions. Every time period a new firm has to make the decision about how much financial capital to allocate to each of two available technologies. Consequently this chapter studies theoretically the dynamics of competing recombinant technologies. The model is constructed in a way that is consistent with the so-called "urn schemes", or Polya processes, following Arthur et al. (1987). With recombinant innovation and an environmental policy, the model of Chapter 3 extends the path-dependence framework of the urn scheme model to technological innovation and environmental economics. The diversification incentive of a hybrid technology contrasts the specialization tendency due to the positive feedback of increasing returns. The chapter considers the case of technologies which differ in terms of pollution emission intensities, creating an asymmetric system. An environmental policy internalizes the pollution externality and introduces a negative feedback on decisions. The focus of the analysis is on the role of recombinant innovation and environmental policy in abating pollution. This is addressed by simulating the model with a Monte Carlo approach. It is found that the expectation of a recombinant technology helps to escape from a lock-in of the dirty technology, notably if the stringency of the environmental policy is low. On the other hand, if environmental policy is stringent, recombinant innovation limits the abatement of pollution - even though it reduces the uncertainty of the outcome - as the system will not entirely move away from the dirty technology. Nevertheless, the abatement of pollution due to the expectation of a recombinant technology is substantial, and recombinant innovation may in fact be seen as an effective strategy to realize a substitution of a dirty by a clean technology.

Chapters 4 and 5 propose a discrete choice approach to modelling technological competition. Differently from the sequential decision setting of Chapter 3, the discrete choice setting uses a "mean-field" model scheme, where all agents decide about their strategy (technology choice) in every period, while interaction between agents is modelled as an average interaction force (mean-field). In Chapter 4 there is competition between a superior costly technology (innovation) and an inferior technology (imitation): these two market strategies affect total factor productivity in a perfectly competitive market. The endogenous dynamics of this heterogeneous supply and a homogeneous demand results in an evolutionary environment with negative feedback: innovators drive down the market price because of cost reduction, but they profit more from a high price. Such opposite incentives may end up offsetting each other in a stable equilibrium where both strategies coexist in some proportion. Alternatively, cycles of period 2 occur. Two extensions of this basic model are studied, namely asynchronous updating of strategies and technological progress. The main result for asynchronous updating is that period 2 cycles may turn into chaotic dynamics of agents' choices and market price. Although qualitatively destabilizing, asynchronous updating is quantitatively stabilizing, because it reduces the amplitude of possibly chaotic market oscillations. Technological progress is modelled endogenously with a technological frontier which builds up as the cumulation of innovators' actions in each period: agents choices dictate the evolution of the technological frontier, and such technological change feeds back into agents choice. This extension of the model reproduces a number of different stylised facts of industrial dynamics, such as path-dependence and technology learning curves.

Chapter 5 combines elements of Chapter 3 and Chapter 4, namely modelling the competition between two different technological solutions with a discrete choice approach. This framework allows to model explicitly the positive feedback of network externalities and social interactions. The equilibria structure of the model is studied, together with bifurcations, i.e. qualitative changes in dynamics, that follow from a change in one or more of the parameters. An extension of the model introduces competing technologies causing pollution and an environmental policy. The environmental policy may have the desired effect of increasing the share of the clean technology, but also the undesired effect of triggering cyclical dynamics of technology shares. If compared to the model of competing technologies with environmental policy in Chapter 3, the corresponding model of Chapter 5 gives similar results regarding the multiple equilibria structure, but on top of this it allows for cases with a unique stable equilibrium where two competing technologies coexist, as well as for cyclical dynamics. A different extension of the model of Chapter 5 considers technological progress, which amounts to model together technology competition and growth. The main focal points of this section are the effects of social interactions and network externalities on technological progress. There are cases where stronger network externalities lower technological progress. Environmental policy and technological progress are brought together finally, with the following results: in order to unlock the market from a lock-in into the dirty technology, an environmental policy is not sufficient. The clean technology must also have a higher rate of progress. Moreover, the stronger social interactions and network externalities are, the tougher a policy is to be enforced. The final message is that in order to tackle the environmental problem of polluting technologies, a government policy should work at different levels, by combining an environmental policy, an innovation policy, and by easing network externalities, for instance, with more flexible technology standards and infrastructure.

6.2 Future research

Various directions for future research can be identified. Table 1.1 in the Introduction chapter indicates that horizontal and vertical innovation are addressed separately by the models proposed in this thesis. A natural extension of these models is to address them together in a single model of technology competition and horizontal as well as vertical innovation. This can be done by introducing the concept of recombinant innovation of chapters 2 and 3 in the discrete choice models of chapters 4 and 5. An empirical follow up of this model is the analysis of patent data. This would allow one to study recombinant innovation through citation patterns (Fleming, 2001). In order to test a model of recombinant innovation on patent data, the analysis of chapters 2 and 3 may need to be extended to more than two recombining technologies.

The model of technological growth of Chapter 3 also would allow for empirical analysis. Here the simulated learning curve can be fit to data from one or several industries. By using data from different industries for which learning curves are available, the estimation of the model would allow to see in which cases behavioural effects have a stronger impact on the rate of technological progress.

The model of technology competition of Chapter 5 can be extended to have two different decision rules, one related to social interactions and one to network externalities. The first are assumed to occur before the decision is made, through contagion channels such as word-of-mouth, recruitment and peers effect. Network externalities instead deploy their effect only after the decision is made, that is, when a technology is used. A model that attempts to enter more deeply into the effect of network externalities in technology decisions needs to be equipped with some form of forward-looking expectations about technology shares. The perfect foresight of rational expectations is the opposite case of reference with respect to the decision rule adopted in the models of chapters 4 and 5, which is based on past experience. In between these extremes there is adaptive learning, which can be of an individual or social nature. In particular, due to the positive externalities of technology choices, there is a positive effect of coordination of predictions, which means that it pays off for agents to have similar expectations. This more structured mechanism of agents' decisions would allow to disentangle social interactions from technology network externalities, and to identify the possible effect of social interactions in technology competition.

Finally, another line of research goes in the direction of environmental economics. Chapters 3 and 5 already introduce this dimension, with polluting technologies and environmental policies. In the case of Chapter 5 a more systematic analysis of different scenarios should be made, searching the parameter space in order to understand thoroughly the combined effect of network externalities, technological progress and environmental policy. Regarding Chapter 3, an extension of the model to include recombination of more than two technologies, and more recombination events, would allow to study technological transitions, and consequently to address the issue of sustainability in terms of their environmental impact.