CHAPTER 7

SUMMARY AND CONCLUSIONS

This doctoral thesis combines methods from several scientific disciplines in order to allow for an evolutionary agent-based policy analysis in dynamic environments. We started with a fundamental study on how to build a simple and robust model of economic evolution. We evaluated an array of conventional evolutionary algorithms for their simplicity and robustness and proceeded to build a simple evolutionary mechanism where economic behavior evolves by imitation in a social network. We then used such a model in numeric agent-based simulations to investigate the evolutionary process under different environmental dynamics. Finally, we have formulated and evaluated environmental policies that explicitly take the evolution of economic behavior into account.

In order to build an objectively simple evolutionary mechanism, we introduced and evaluated a numerical method, Relevance Estimation and Value Calibration. It measures the minimum amount of information that is needed to tune an evolutionary algorithm such that it reaches a desired level of performance, and how this performance depends on the correct tuning of individual algorithm parameters. In order to do so it uses probability distributions over parameter values during the tuning process. Probability distributions are well suited to measure information. The method can in principle be applied to fields other than evolutionary computing.

We applied the method to an array of conventional evolutionary algorithms, and found that the need for tuning is distributed in a highly skewed way over the different algorithm components. Typically the tuning of the mutation operators—which maintain diversity—has the highest impact on algorithm performance. This general result was confirmed for models of economic evolution, in simulations where the agents have to adapt under the complex dynamics of climatic and technological change. The same simulations also revealed that when extra detail is added to an evolutionary model, tuning of the model becomes less effective, and the capability of the agents to adapt is re-

duced. This is a further argument to keep the model of imitation as simple as possible.

We proceeded to build a simple evolutionary mechanism with only one free parameter for the diversity of strategies, and studied the welfare effect of changing this parameter under different environmental dynamics. The dynamics were defined with regard to two widely recognized and easily measurable aspects of environmental change, namely how gradual and how frequent it occurs. Extensive numeric simulations identified the level of diversity that leads to a welfare distribution which is socially optimal in terms of constant relative risk aversion. This optimum level is different for different environmental dynamics, and based on our simulations we formulated policy advise on the socially optimal level of diversity when the environmental dynamics are unknown. It emerged that in general, a higher degree of risk aversion calls for a higher degree of diversity. When the precise nature of the environmental dynamics is known, optimizing the diversity to the particular dynamics allows for a significant increase in social welfare. This possibility to improve social welfare by optimizing social imitation to a particular environmental dynamics or to a particular degree of risk aversion constitutes a new opportunity for public intervention that has not previously been recognized.

Finally we applied our methods to a simple model of global warming where the policy maker wants to encourage the agents to replace fossil energy, which has a negative environmental impact, by renewable energy, which is environmentally neutral yet less cost-efficient. Numerical evaluation of a regulatory tax on investments in fossil energy revealed that due to lock in, the tax level for which the evolutionary agents are indifferent between the two technologies differs significantly from what can be concluded from a model with rational and representative agents. As a consequence, the level of such a regulatory tax has to be significantly higher if agents are to be convinced to abandon fossil fuels for good. We designed and evaluated two novel public policies—*prizes* and *advertisement*—that selectively increase the probability of environmentally friendly strategies to be imitated. Both policies are easier to enforce than a regulatory tax, which depends on whether the worst offenders can be persuaded to comply—a difficult task if they have to pay the highest tax. With *prizes*, policy enforcement has shifted to finding enough donors that finance a prize for the best behaving agent. Numerical evaluation showed that the effect of *prizes* on welfare and global warming is similar to that of a regulatory tax. *Advertisement* proved to work well only when the cost difference between fossil and renewable energy is small, but has the unique advantage that it does not depend on a central authority to enforce it.

We conclude that a model of economic evolution can be designed that is simple and robust in an objective way, and that the simple evolutionary mechanism of such a model is sufficient to allow a community of agents to adapt well to different environmental dynamics, even when their rational capabilities are bounded and their information is limited. Despite the inherent randomness of a simulated evolutionary process, robust results can be obtained that are valid over a large number of different environmental and social conditions, pointing to their general validity outside the tested conditions.

Such models do not only lead to different predictions with regard to established policy tools like a regulatory tax, but they open the door for new policy instruments that regulate the selective advantage of economic behavior.