Coordination Games

Complementarities and Macroeconomics

This book studies the implications of macroeconomic complementarities for aggregate behavior. The presentation is intended to introduce Ph.D. students into this subfield of macroeconomics and to serve as a reference for more advanced scholars. The initial sections of the book cover the basic framework of complementarities and provide a discussion of the experimental evidence on the outcome of coordination games. The subsequent sections of the book investigate applications of these ideas for macroeconomics. The topics Professor Cooper explores include economies with production complementarities, search models, imperfectly competitive product markets, models of timing and delay and the role of government in resolving and creating coordination problems. The presentation goes into detail on a few models and uses them as a structure to integrate related literature. The discussion brings together theory and quantitative analysis.

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Coordination Games

Complementarities and Macroeconomics

RUSSELL W. COOPER
Contents

Preface \hspace{1cm} \hspace{1cm} page \hspace{1cm} vii

1 Experimental Evidence and Selection \hspace{1cm} 1
2 A Framework for Analysis \hspace{1cm} 18
3 Technological Complementarities \hspace{1cm} 41
4 Imperfect Competition and Demand Spillovers \hspace{1cm} 61
5 Thick Markets: Search and Matching \hspace{1cm} 84
6 Timing of Discrete Choices \hspace{1cm} 100
7 Government Policy \hspace{1cm} 126
8 Concluding Thoughts \hspace{1cm} 151

References \hspace{1cm} 153
Index \hspace{1cm} 161
Preface

The goal of this book is to provide a synthesis of research on the topic of complementarities in macroeconomics. Its primary goal is to isolate the various sources of complementarity and then to explore their implications for the behavior of macroeconomies. The success of this approach is seen through the numerous theoretical and empirical applications of the basic structure inherent in model economies built upon the macroeconomic complementarities structure.

As this is principally a book about applications in macroeconomics, it has been necessary to leave aside a number of topics that relate to the implications of complementarities for other branches of economics, such as industrial organization. Still, the reader interested in applications outside macroeconomics ideally will find the more general discussion of models of complementarities as well as the presentation of experimental evidence of some value.

The first two chapters as well as the next section of this Preface focus on general issues arising in models of complementarities, thus providing a framework for the more applied analysis that will follow. In particular, the first two chapters discuss experimental evidence on coordination games and theories of selection and put forth a general model of macroeconomic complementarities.

The remaining chapters explore applications of the general structure by investigating particular channels of interactions across agents. This includes the study of economies in which (i) externalities are present in the technology of the individual agent, (ii) markets are imperfectly competitive, (iii) agents come together through a search process and (iv) information
is imperfect. As we shall see, all of these deviations from the standard general equilibrium model of Arrow and Debreu can give rise to macroeconomic complementarities.

The structure of the presentation has two important aspects. First, as much as possible, I have tried to blend theory and quantitative analysis. This is mainly apparent in the more applied chapters, where specific models of complementarity have been “taken to the data.” This blending of theory and quantitative analysis is important since ultimately models are evaluated in terms of their ability to “match” observations. Further, the presentation makes clear that even though a model with complementarities is more complex than, say, a representative agent structure, quantitative analyses are possible. In fact, one might speculate that our ability to deal quantitatively with dynamic strategic interactions between heterogeneous agents will only enrich the set of models with complementarities we can quantitatively investigate.

Second, each chapter is organized around a core model that is analyzed in some detail. In addition, extensions of the basic model are examined, though in less detail. The idea is to provide a sense of the literature through a core model.

WHAT ARE COORDINATION GAMES?

This book studies a very special but rich class of games, called coordination games. These games have a number of distinct characteristics that make them quite interesting in many areas of economic research. As this is essentially a book about macroeconomics, our focus will be mainly on macroeconomic examples and implications of coordination games for the aggregate economy.

In contrast to many strategic situations, coordination games do not rest solely upon conflict between players. Instead, confidence and expectations are critical elements in the types of coordination games that we will study. In particular, the possibility of coordination failures, arising from self-fulfilling pessimistic beliefs, is observed in equilibrium. The resulting inefficiencies are, in turn, quite interesting in a variety of macroeconomic contexts.

To motivate this, we begin purposefully with a game that is outside macroeconomics. Consider the fascinating example discussed by Schelling [1960] in which two individuals must independently decide where to
Preface

locate. Further, to emphasize the gains to coordination, suppose that these players achieve positive utility only if their choices agree. So, the players gain utility if and only if they choose the same location. Clearly, the gains from interaction are derived solely from coordination rather than conflict. In this setting, multiple noncooperative equilibria easily emerge since all that matters is that players make similar choices. Still, there is a nontrivial problem here: where should the players locate given that they must act independently?

These types of situations can be embellished by supposing that certain outcomes, in which players take the same action, bring higher payoffs than others. So, in the location problem, suppose that there are two locations, A and B. Further, assume that players are better off locating at point B than not locating at the same point, but they are even better off if they locate at point A. Thus, there are gains to coordinating at any point and further gains to coordinating at point A instead of point B.

For this game, there are again multiple noncooperative equilibria. In one both players go to A and in the other both go to location B. In this situation, the multiple equilibria are Pareto-ranked. Still, a coordination failure can easily arise: in the equilibrium in which all players locate at point B, all players would be better off if they could coordinate their choices and thus go to location A. Despite this, the outcome when both go to location B seems to qualify as a legitimate noncooperative outcome since both players are best responding to the (anticipated) action of the other.

This book is devoted to the study of environments where coordination games naturally emerge. Our focus is on the theoretical basis for these coordination problems and the likely outcome in these strategic situations. These games have a number of properties that make them particularly applicable to macroeconomics and of special interest to game theorists as well.

First, as in the preceding location example, coordination games may exhibit multiple Pareto-ranked equilibria. This gives some content to the theme, often expressed in macroeconomics, that an economy may be “stuck” at an inefficient equilibrium. While all agents in the economy understand that the outcome is inefficient, each, acting independently, is powerless to coordinate the activities of other agents to reach a Pareto-preferred equilibrium. So, from this perspective, a depression in aggregate economic activity arises when the economy falls into the trap of a low activity level Nash equilibrium. In addition, all of the equilibria may
be Pareto-dominated by some other feasible outcome, as in the familiar prisoner’s dilemma game. To this degree, externalities are not internalized by individual agents.

Second, the nature of the strategic interactions underlying the multiple equilibria of the game has implications for the behavior of economies built around the repeated play of coordination games. In particular, the actions of players in coordination games are strategic complements, implying that increases in the level of activity of other agents create an incentive for increased activity by the remaining agent. These interactions may exist both intra- and intertemporally and are interesting for macroeconomics as they generate the positive correlation in activity levels across agents and persistence over time which are characteristic of macroeconomic time series.

Third, these games have captured the attention of game theorists, leading to powerful results on the nature of equilibria for coordination games and the process of attaining an equilibrium outcome. Developing these more game theoretic topics requires us to explore a class of games, termed supermodular games, into which the coordination games emphasized in macroeconomics neatly fit. This is taken up in Chapter 2, while subsequent chapters investigate these themes by analyzing macroeconomic applications in detail.

This overview introduces coordination games through a simple example. We use this example to be more specific about the themes of this book. Moreover, before delving into the details of conditions under which multiple equilibria and thus coordination failures can occur, it is useful to address a prior concern about evidence on outcomes of coordination games. Thus, Chapter 1 builds upon the simple example to provide a discussion of experimental evidence on coordination games and theories of selection that have been proposed for this type of strategic interaction.

AN EXAMPLE

Consider a game between two players, A and B, both of whom provide effort in a production process.\(^1\) Assume that player \(i\) receives a payoff of \(2c_i - e_i\) from consumption \((c_i)\) and effort \((e_i)\), \(i = 1, 2\). Further suppose that

\(^1\)This is motivated by the discussion in Bryant [1983], which we return to in some detail in Chapter 2.
per capita consumption equals min(e₁, e₂) and that only two effort levels are feasible, i.e., eᵢ ∈ {1, 2}. The payoff matrix for this coordination game is given by

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
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</thead>
<tbody>
<tr>
<td><strong>B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1,1</td>
<td>1,0</td>
</tr>
<tr>
<td><strong>A</strong></td>
<td>0,1</td>
<td>2,2</td>
</tr>
</tbody>
</table>

Coordination game

There are two pure strategy Nash equilibria in this simultaneous move game, the strategy profiles {1, 1} and {2, 2}, as well as a mixed strategy equilibrium in which each player selects action 1 with probability 1/2. These are Nash equilibria because each agent is acting optimally given the choice of the other. Note, though, that the {2, 2} equilibrium Pareto-dominates both the {1, 1} equilibrium and the mixed strategy equilibrium. In this sense, neither the pure strategy equilibrium at {1, 1} nor the mixed strategy equilibrium is socially optimal.

The multiplicity of Nash equilibria here has nothing to do with the large number of equilibria that emerge in games of incomplete information. That is, the various equilibria are not a consequence of assumptions regarding the structure of beliefs off an equilibrium path since the coordination game assumes complete information. Further, the equilibria of this coordination game are regular (strict) in that under small perturbations of the payoffs, the set of pure strategy equilibria does not change.²

Instead, the multiplicity of equilibria, and thus the possibility of a Pareto-inferior equilibrium, derives from agents’ inability to coordinate their choices in this strategic environment. As a consequence, realized equilibrium outcomes that are Pareto-suboptimal relative to other equilibria, such as {1, 1}, are often termed coordination failures.

A key element in the structure of this game concerns the extra payoff a player receives from taking a “high” action (strategy 2 in the game) as a function of the action chosen by the other player. In the preceding coordination game, the increased payoff for player A to switching from

² That is, smaller variations in the payoffs of the game do not result in large changes in the number of equilibria. This contrasts to the sensitivity of equilibria in the normal form representations of signaling games.
Preface

action 1 to action 2 is −1 when B chooses 1 but is 1 when B chooses 2. Thus, higher action by player B increases the marginal return to higher action by player A. This property of positive feedback, often termed strategic complementarity, is central to the characterization of coordination games and will form the centerpiece of the analysis that follows.

Further, the game exhibits positive spillovers in that the payoffs of one player increase as the action chosen by the other increases. In particular, if player A chooses 2, then A’s payoff is higher when B selects strategy 2 than if B selects strategy 1. Note that this property of a positive spillover measures the effect of B’s action on A’s payoff given A’s action, in contrast to the concept of strategic complementarity, which is informative about the payoff consequences of changes in A’s action as a function of B’s action.

An important issue in this and other coordination games is the selection of an equilibrium outcome. For this coordination game, what outcome will arise? One might argue that the Pareto-dominant Nash equilibrium in which both players select 2 is a natural focal point.3 Alternatively, the choice of strategy 2 is, for both players, “risky” in that if their opponent does not also select action 2, the payoff loss is 1, while there is no uncertainty from choosing strategy 1.4 From this perspective, the likely outcome might be {1, 1} since this leaves players exposed to no risk whatsoever. To pursue these themes in more detail, Chapter 1 summarizes experimental evidence on coordination games and some theories of equilibrium selection.

For macroeconomics, when the strategy, i.e., effort levels, are ordered, the coordination game is a framework in which equilibria with low levels of economic activity can arise. To provide this macroeconomic perspective, we will discuss a number of economic examples that can be represented as coordination games in subsequent chapters.

These economies, of course, must deviate from the Arrow–Debreu model of perfect competition with complete contingent markets. In that model, the choices of individual agents are completely coordinated through the market mechanism: there are no missing markets. Further, traders are costlessly matched by the auctioneer. Finally, in the spirit of perfect competition, no traders have any influence on prices. The examples that

3. This point appears most recently in Harsanyi and Selten [1988, p. 356], who stress the role of payoff dominance in selecting an equilibrium outcome. In this game, Harsanyi and Selten would then argue that the {2, 2} outcome was focal as a result of its payoff dominance.
4. Harsanyi and Selten provide a formal treatment of strategic uncertainty, which they term risk dominance and apply to games with multiple Nash equilibria which are not Pareto-ordered. Their concepts and arguments are presented later.
Preface

we explore provide insights into the roles of externalities in the production process, matching and imperfect competition as important sources of distortions leading to coordination failures.

As described in the next chapters, one can associate levels of economic activity with the strategies of the coordination game and discover that the multiple equilibria correspond to high and low activity levels in which equilibria with high levels of activity Pareto-dominate. Still, the economy can become stuck in a low level, Pareto-inferior equilibrium, since each agent, acting alone, cannot coordinate the activities of all agents.

Besides the multiplicity of equilibria, coordination games provide insights into other macroeconomic phenomena. In particular, as a result of the nature of the strategic interaction across agents, there is a natural propagation mechanism inherent in these games. Changes in the underlying parameters describing the payoffs to one agent (i.e., shocks to one player) lead to similar responses in the behavior of all agents. In particular, if a shock to one agent leads that agent to choose a higher level of activity, then other agents will also choose higher levels of activity. In this case, a shock that is not common to all agents will lead to positive comovement in activity levels economywide, a feature that is important in business cycles. Further, in dynamic versions of these models, these shocks can be propagated over time as well.

PROGRAMS AND RESEARCH UPDATES

Research is an ongoing process. By the time this book is published, a number of new advances will undoubtedly have been made. It is useful then to have a source of information on research in this area.

Further, the discussion in this book often rests upon numerical results, in the form of either simulated games or simulations of simple aggregate economies. The interested reader might benefit from access to these programs. To facilitate that access, I have created a Website which will contain research updates as well as relevant computer programs. The address is http://econ.bu.edu/faculty/cooper/macrocomp.
xiv  Preface

THANKS

A special debt is owed to Douglas Gale, whose initiatives got this project started. Discussions with Douglas on the nature of the material and the structure of its presentation immensely improved the product.

As the reader will notice, this book draws heavily upon my joint work in the area of complementarities. Whatever the value of these contributions, I am certainly indebted to the long list of coauthors, critics and discussants who, over the years, have enriched my understanding of these issues including Andrew John, Thomas Ross, John Haltiwanger, Douglas Gale, Robert Forsythe, Douglas DeJong, Satyajit Chatterjee, B. Ravikumar, Alok Johri, Joao Ejarque, Dean Corbae, Jess Benhabib, Costas Azariadis, Roger Farmer, Jang-Ting Guo, Christophe Chamley, Jon Eaton, Nobuhiro Kiyotaki, Randall Wright, Peter Howitt, Peter Diamond, Robert Hall, Olivier Blanchard, Hubert Kempf, Pierre Cahuc, John Bryant, Walter Heller and John van Huyck. A special thanks to Joyce Cooper and Jon Willis for their careful reading of this manuscript.

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