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Equilibrium selection in sequential games with imperfect information [☆]

Jon X. Eguia ^{a,*}, Aniol Llorente-Saguer ^{b,c}, Rebecca Morton ^{d,e}, Antonio Nicolò ^{f,g}^a Michigan State University, United States^b School of Economics and Finance, Queen Mary University London, United Kingdom^c CEPR, United Kingdom^d Department of Politics, NYU–NYC, United States^e NYU–Abu Dhabi, United Arab Emirates^f Department of Economics and Management, Università degli Studi di Padova, Italy^g School of Social Sciences, University of Manchester, United Kingdom

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ABSTRACT

Games with imperfect information often feature multiple equilibria, which depend on beliefs off the equilibrium path. Standard selection criteria such as passive, symmetric or wary beliefs rest on ad hoc restrictions on beliefs. We propose a new selection criterion that imposes no restrictions on beliefs: we select the action profile that is supported in equilibrium by the largest set of beliefs. We conduct an experiment to compare the predictive power of the existing and our novel selection criteria in an application on vertical multi-lateral contracting. We find that our criterion outperforms the other selection criteria.

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* Corresponding author.

E-mail addresses: eguia@msu.edu (J.X. Eguia), a.llorente-saguer@qmul.ac.uk (A. Llorente-Saguer), rebecca.morton@nyu.edu (R. Morton), antonio.nicolo@unipd.it (A. Nicolò).

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1. Introduction

We propose a solution to the problem of multiplicity of equilibria in a class of two-stage games in which players who move at the second stage (receivers) are imperfectly informed about the actions played by those who move at the first stage (proposers). The most prominent application of this class of games is multi-lateral vertical contracting. These are games in which one or more upstream firms make private offers to each of two or more downstream firms. Each contract signed by a downstream firm affects all downstream firms (contracts generate externalities), but at the time a downstream firm decides whether or not to accept the offer, it does not know what offers other firms have received (downstream firms operate under imperfect information).¹

Other applications of this class of games can be found in the literature of consumer search; international trade; markets with network effects; markets with intermediaries; financial and health care markets; and in games of electoral competition.²

These games typically feature multiple Sequential equilibria. Equilibria depend on how, after observing a deviation, the second movers update their beliefs about the first movers' actions. Refinements that are useful for signaling games such as the intuitive criterion (Cho and Kreps, 1987), D1 or universal divinity (Banks and Sobel, 1987) have no bite in this context, because the lack of information is about the first movers' actions, not about their type.

The literature has dealt with this multiplicity of equilibria by imposing particular beliefs off the equilibrium path, selecting equilibria that can be supported by these beliefs, and discarding all other equilibria. In their seminal paper, McAfee and Schwartz (1994) propose three possible beliefs to consider: passive beliefs, symmetric beliefs, and wary beliefs.

Passive beliefs, sometimes called “passive conjectures” (Rey and Tirole, 2007), are such that a downstream firm that receives an out of equilibrium offer does not update its beliefs on the offers received by all other players; rather, it believes that all the other unobserved actions remain as in equilibrium. The selection criterion based on singling out equilibria that can be supported by such passive beliefs is the one most frequently used in the literature.³

However, “in many circumstances the *ad hoc* restriction to passive beliefs may not be compelling” (Segal and Whinston, 2003). Indeed, while defending the assumption of passive beliefs in the particular game in which they use it, Rey and Tirole (2007) concede that assuming passive beliefs “is much less appealing in the case of Bertrand competition, and indeed in many games of contracting with externalities.”

An alternative criterion to solve the multiplicity problem is to select equilibria that can be supported by symmetric beliefs. These beliefs are such that a downstream player who receives an out of equilibrium offer believes that all other downstream players receive this same offer as well. If the equilibrium offer to each downstream player i is x_i , a downstream player who receives an offer of $y \neq x_i$ believes that the offer to every downstream player is also y .⁴

A third suggestion is to consider equilibria supported by wary beliefs. These beliefs are such that a downstream player who observes a deviation believes that the upstream player must have deviated to a strategy that is optimal given the action that the downstream player observes. Despite their greater conceptual merit, unfortunately wary beliefs have had scant following in the literature of vertical contracting (Rey and Vergé, 2004; Avenel, 2012a; Reisinger and Tarantino, 2015). Hagiu and Hałaburda (2014) apply it in a setup with markets with two-sided network effects.⁵

The problem common to all these criteria is the lack of a convincing argument for why only one particular set of beliefs should be admissible off the equilibrium path. The existence of several alternative choices of specific beliefs that have received consideration in the literature underscores that none of these beliefs are an obvious choice for all possible games of imperfect information. Eliminating all equilibria that rest on different beliefs is not warranted. We argue that passive beliefs, wary beliefs, or symmetric beliefs, may be plausible in a given particular application, but not in others. A sharp restriction on the set of admissible beliefs to the exclusion of all others is often inappropriate. Martin et al. (2001) provide evidence of the weakness of this approach. Using a laboratory experiment that mimics a vertical industry structure with an upstream firm and two competing downstream firms, they find that no specific restriction on beliefs (passive or symmetric beliefs) is consistent with the data.⁶

¹ See theories by Hart and Tirole (1990); O'Brien and Shaffer (1992); Segal (1999); de Fontenay and Gans (2005); Caprice (2006); Rey and Tirole (2007); Nocke and Rey (2014); Miklós-Thal and Shaffer (2016), to cite only a few.

² See Bar-Isaac et al. (2012), Buehler and Schuett (2014), or Janssen and Shelegia (2014) on consumer search; Bernard and Dhingra (2015) on trade; de Fontenay and Gans (2014) or Hagiu and Hałaburda (2014) and Mayzlin and Yoganarasimhan (2012) on network effects; Inderst and Ottaviani (2012) on markets with intermediaries; Ho (2009) on medical care markets; Brunnermeier and Oehmke (2013) on financial markets; Gavazza and Lizzeri (2009) on electoral competition.

³ See Hart and Tirole (1990); O'Brien and Shaffer (1992); McAfee and Schwartz (1994); Rey and Tirole (2007); Ho (2009); Arya and Mittendorf (2011); Brunnermeier and Oehmke (2013); Caprice and Rey (2015); Reisinger and Tarantino (2015), among many others.

⁴ Symmetric beliefs are used, among others, by Pagnozzi and Piccolo (2011). However, most of the literature seems to agree with McAfee and Schwartz's (1994): “[Symmetric] beliefs are not very compelling.”

⁵ Passive and wary beliefs are justified by two very different rationales. Passive beliefs consider deviations from the equilibrium strategy as unintended mover's mistakes; therefore, receivers should not revise their beliefs. In contrast, wary beliefs implicitly interpret deviations as mover's intentional attempts to leave the equilibrium path. In that case, receivers should revise their beliefs accordingly. Still, wary beliefs cannot rationalize why in the first instance the mover deviated from the equilibrium strategy.

⁶ See as well the contracting experiments by Boone et al. (2014), and by Möllers et al. (2017).

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