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Predicting internet commercial connectivity wars: The impact of trust and operators' asymmetry

Alessio D'Ignazio [a], Emanuele Giovannetti [b,c,*]

[a] Bank of Italy, Rome, Italy
[b] Institute for International Management Practice, IIMP, Anglia Ruskin University, Cambridge, UK
[c] DSE, University of Verona, Verona, Italy

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ABSTRACT

Early studies on forecasting the growth of the Internet suggested that its evolution could not be predicted as being simply the result of a random network formation process. Recent evidence has shown that commercial connectivity goes through cycles, due to providers regularly disconnecting their customers. We model these cycles as being a result of the providers' limited ability to monitor their customers' contractual compliance. Based on twelve years of quarterly observations, we estimate the impacts of key covariates on the probability of starting a *connectivity war*. Following a choice model approach, we use different econometric specifications to test the model implications. Our results predict that the asymmetry between *customers* and *providers*, which increases the incentives to abuse connectivity, and the history of past connections, which affects mutual trust and information asymmetries, are the main factors in determining the probability of providers starting a *connectivity war*, thus helping to explain the cycles that are observed in Internet connectivity.

1. Introduction

Early studies that tried to forecast the growth of the Internet focussed on the choice of the most appropriate metrics for representing this *network of networks*, and suggested that its evolution could not be predicted by a simple *random network formation* process (Pastor-Satorras & Vespignani, 2004). Instead, these findings advocated the necessity of addressing relevant economic questions, since, rather than being generated randomly, bilateral Internet links are the expression of micro-business decisions as to whether or not to establish bilateral interconnections between independent providers.

Our paper models the incentives that underlie these connectivity decisions, with a focus on the roles of asymmetric information and strategic interaction. Under this approach, interconnection choices are the outcome of inter-temporal equilibrium strategies, based on individual incentive compatibility.

We provide estimates of the key parameters that drive the evolution of Internet commercial connectivity, based on a dataset of twelve years of quarterly observations on micro-decisions, constructed by Dhamdhere and Dovrolis (2011). These authors estimated that the total number of connections supplied by upstream *providers* of Internet connectivity to their downstream *customers* was described best by an exponential growth rate that slowed down

* Correspondence to: Anglia Ruskin University, Institute for International Management Practice, East Road, CB1 1PT, Cambridge, UK.
E-mail address: emanuele.giovannetti@anglia.ac.uk (E. Giovannetti).

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considerably after the *dot-com* bubble in 2001.[1] They also focussed on "removed" connections, finding that, by 2011, around 86% of them were due to *providers* removing the connectivity that they had previously supplied to their *customers*, a phenomenon that they defined as *dewiring*. Hence, the temporal profile of commercial upstream Internet *connectivity* seems to follow cycles around its exponential growth trend.

Our paper has two main objectives: first, to provide an incentive compatibility model for interpreting these cycles as the outcome of strategic interactions under asymmetric information; and, second, to identify and estimate the key variables that significantly affect the probability of a *connectivity war* starting.

The driving feature in our model is the presence of asymmetric information, between upstream transit *providers* and their *customers*, about the use, or abuse, of the contractually agreed capacity to route traffic to the rest of the Internet. This informational asymmetry is attributed to the instantaneous nature of traffic exchanges and their dynamic routing features, as a perfect monitoring of the connectivity contracts between Internet Service Providers (ISPs) can be particularly difficult and costly to achieve.

1.1. Related literature

The early literature on forecasting the evolution of the Internet emphasized the limited applicability of traditional telephony forecasting techniques, given the different, packet-based, non-dedicated, nature of Internet traffic exchanges (Papagiannaki, Taft, Zhang, & Diot, 2003). Along these lines, Madden and Coble-Neal (2004) showed that Internet traffic dynamic data appear to be considerably more heterogeneous and less predictable than traditional telecommunications data, as analysed by Fildes, Hibon, Makridakis, and Meade (1998). Our paper's main objective is aligned with their conclusion that "for more insightful analysis, it is necessary to develop structural economic models" for their "ability to anticipate cyclical fluctuations" (Madden & Coble-Neal, 2004, p. 176).

While a large body of empirical literature has focussed on studies of penetration and the final demand for access (see the extensive survey by Fildes & Kumar, 2002, on the forecasting of telecommunications demand), we concentrate on *Business to Business* agreements, where larger ISPs (the *providers*) decide whether to supply commercial connectivity to smaller ISPs (the *customers*), who need these upstream links in order to, eventually, provide *end to end connectivity* to their own final customers.

Our econometric specification is based on nonlinear panel data models, and aims to capture the effects of key covariates that reflect the levels of trust, asymmetry and information noise on the probability of starting a *connectivity war*. The different probit specifications analysed reflect a choice model approach that is typical of micro-market analyses (see Fildes & Kumar, 2002), while their panel data structure is essential for the study of the inter-temporal features of these effects, as was discussed by Islam, Fiebig, and Meade (2002).

More recently, Fushing, Jordà, Beisner, and McCowan (2014) focussed on forecasting network connectivity in order to provide an early warning system for impending systemic crises. In their paper, both network evolution and connectivity structures are driven by the assumption that nodes have heterogeneous information processing capabilities. Our paper shares the same objective, namely identifying the key parameters that affect the probability of a connectivity break-down, but we assume asymmetric information between the players. Interestingly, we find that, in our approach, temporary instabilities in links, such as are observed during connectivity wars, are a necessary part of a dynamic strategy that otherwise guarantees overall network connectivity.

In a seminal contribution, Gao (2000) provided criteria for interpreting observed bilateral Internet connections in terms of their commercial nature. The main idea is that, as ISPs' commercial bilateral relationships determine their traffic routing instructions, these business relationships can also be inferred back from publicly observable data on the advertised connections.[2] D'Ignazio and Giovannetti (2006, 2009) used these inferred relationships to measure the extent of the market power in the European Internet, and focussed on whether or not asymmetries between providers' market shares would affect their interconnection choices.

A large body of economic literature (Economides, 2006, chap. 9; Laffont, Marcus, Rey, & Tirole, 2003; Lippert & Spagnolo, 2008; Shrimali, 2010) has produced increasingly sophisticated game theoretic models focussing on the incentives to interconnect in the Internet. This research usually analyses the interconnection regime as being the outcome of a strategic game capturing a relationship of both complementarity (each network must be able to access the others in order to assure universal connectivity of the Internet) and competitiveness (they compete over downstream customers).

Our paper models connectivity choices from a *repeated games* perspective. In particular, we build upon models that were developed initially for explaining the emergence and cycles of *price wars*, as per Green and Porter (1984) and Porter (1983). These contributions show how alternating cycles of *cooperation* and *punishment* may sustain cooperation among competitors when their actions are private information. According to this body of literature, intermittent price wars emerge as the equilibrium outcome of strategy profiles, explicitly including temporary punishments in order to deter deviations from an otherwise cooperative strategy.[3]

[1] They showed that the evolution of the number of providers until 2001 can be modelled as $y = (5462 \pm 434)e^{(0.102\pm0.006)t}$, but that after 2001, this changed to $y = (15260 \pm 550)e^{(0.034\pm0.001)x}$.

[2] Gao (2000) classified four types of business relationships: *customer–provider, provider–customer, peer–peer*, and *sibling*.

[3] For example, collusion may break down under Cournot competition and demand uncertainty, as firms are unable to differentiate between the effects of a rival's deviation and those of an exogenous shock that acts to lower industry demand. Temporary price wars deter deviations from collusive behaviour, as, without them, unmonitored deviations remain unpunished and may become profitable (Abreu, Pearce, & Stacchetti, 1990).