Predictability and Prediction for an Experimental Cultural Market

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Abstract. Individuals are often influenced by the behavior of others, for instance because they wish to obtain the benefits of coordinated actions or infer otherwise inaccessible information. In such situations this social influence decreases the ex ante predictability of the ensuing social dynamics. We claim that, interestingly, these same social forces can *increase* the extent to which the outcome of a social process can be predicted very early in the process. This paper explores this claim through a theoretical and empirical analysis of the experimental music market described and analyzed in [1]. We propose a simple model for this music market, assess the predictability of market outcomes through reachability analysis with the model, and use insights derived from this analysis to develop algorithms for predicting market share winners, and their ultimate market shares, in the very early stages of the market. The utility of these predictive algorithms is illustrated through empirical analysis of the music market data sets [2].

Keywords: Social dynamics, prediction, theoretical analysis, empirical analysis.

1 Introduction

Enormous resources are devoted to the task of predicting the outcomes of social processes, in domains such as economics, public policy, popular culture, and national security, but the quality of such predictions is often quite poor. Consider, for instance, the case of cultural markets. Perhaps the two most striking characteristics of these markets are their simultaneous *inequality*, in that hit songs, books, and movies are many times more popular than average, and *unpredictability*, so that well-informed experts routinely fail to identify these hits beforehand. Examination of other domains in which the events of interest are outcomes of social processes reveals a similar pattern – market crashes, regime collapses, fads and fashions, and “emergent” social movements involve significant segments of society but are rarely anticipated.

It is tempting to conclude that the problem is one of insufficient information. Clearly winners are qualitatively different from losers or they wouldn’t be so dominant, the conventional wisdom goes, so in order to make good predictions we should collect more data and identify these crucial differences. Research in the social and behavioral sciences calls into question this conventional wisdom and, indeed, indicates that there may be fundamental limits to what can be predicted about social systems. Consider social processes in which individuals pay attention to what others do. Recent empirical studies offer evidence that the *intrinsic* characteristics of such processes, such as the quality of the various options in a social choice situation, often do not possess much predictive power [3-10].

In order to understand this phenomenon more deeply, Salganik, Dodds, and Watts [1] conducted an elegant experiment in which over 14,000 participants were recruited to participate in an "artificial" music market and the impact of social influence on their choice of songs to download was examined. Briefly, the participants were presented with a web page displaying a selection of 48 songs by unknown bands and were asked to choose songs to listen to and download. As they arrived at the music market site they were randomly assigned to one of two experimental conditions: Independent, in which they saw only the names of bands and songs, and Social Influence, in which they were further divided into distinct "worlds" and could see (in addition to the bands and songs) the number of times each song had been downloaded by previous participants in their respective worlds. There were three main findings: 1.) song "quality" is only weakly related to market share success, 2.) the presence of social influence leads to "herding" behavior regarding song popularity, and 3.) increasing the strength of social influence increases both inequality and unpredictability of market outcomes.

Both the empirical analyses [3-10] and the experimental study [1] offer evidence that, for many social processes, it is not possible to obtain useful predictions using standard methods, which focus almost exclusively on the intrinsic characteristics of the process and its possible outcomes. We propose that useful prediction requires consideration of both intrinsics and the underlying *social dynamics* of a process, and offer in [11] a new approach to predictive analysis which leverages this idea. The present paper applies this analytic framework to the experimental music market described in [1,2] and makes two contributions. First, we develop a simple model for cultural markets (such as the music market [1]) which captures both process intrinsics and social influence dynamics. This model is employed to formally assess the predictability of market outcomes for various sets of candidate measurables and thereby identify those measurables which possess predictive power. Second, using insights derived from this predictability analysis we formulate algorithms for predicting market share winners, and their ultimate market shares, very early in the market's evolution; the performance of these algorithms is illustrated through empirical analysis of the music market data sets [2].

2 Predictability Assessment

Basic idea. A defining characteristic of cultural markets is that participants are influenced by the behavior of others, for instance because they wish to obtain the benefits of coordinated action (e.g., enjoy the offering with friends) or infer otherwise inaccessible information (e.g., by observing people "in the know"). Processes in which observing a certain behavior increases an individual's probability of adopting that behavior are often referred to as *positive externality processes* (PEP), and we use that term here. One hallmark of PEP is their apparent unpredictability: phenomena from hits in cultural markets to financial markets crashes and political upheavals appear resistant to predictive analysis (although there is no shortage of ex post explanations for their occurrence!).

It is not difficult to gain an intuitive understanding of the basis for this unpredictability. Individual preferences and opinions are mapped to collective outcomes through an intricate, dynamical process in which people react individually to an environment consisting of others who are reacting likewise. Because of this feedback dynamics, collective outcomes can be quite different from those implied by simple aggregations of individual preferences; standard prediction methods, which typically are based (implicitly or explicitly) on aggregation ideas, do not capture these dynamics and therefore are often unsuccessful. Interestingly, the feedback dynamics which reduces PEP predictability based on simple preference aggregation may *increase* the predictive power of very early measurements of these dynamics. Again the intuition is clear: early trends are reinforced through the positive feedbacks of PEP, suggesting the possibility that early rankings of alternatives may be informative concerning the ultimate outcomes. We now explore this intuition more formally

Model. Consider an online market, such as the music market [1], in which individuals visit a web site, browse an assortment of available items, and choose one or more items to download. For simplicity, we focus on a market visited by a sequence of consumers, with each visitor choosing between two items {A, B}; generalizing this simple binary choice setting to any finite number of choices is straightforward [12]. We model this situation by supposing that agent i chooses item A with probability

$$\Sigma_{\text{online}} \qquad P_i(A) = \beta\pi + (1-\beta)\, f$$

where $f \in [0,1]$ is item A's current market share, $(1-\beta)$ quantifies the intensity of social influence (with $\beta \in [0,1]$), and π is the probability of an agent choosing A in the "no social influence" case (i.e., when $\beta=1$). Agent i selects item B with probability $1 - P_i(A)$. In this model, π can be interpreted as a measure of the "appeal" of item A (relative to B), f is the social influence, and β quantifies the relative importance of appeal and social influence in the decision-making process.

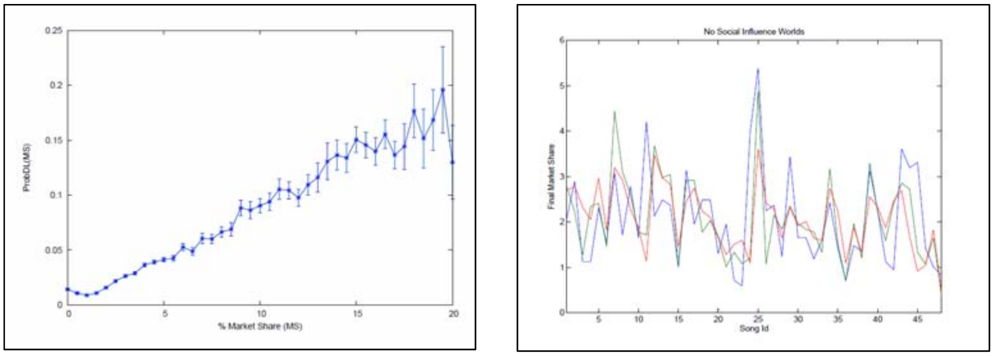

Fig. 1. Some characteristics of the music market dynamics. The plot at left shows that in the Social Influence worlds the market is a PEP, with song download probability increasing with number of previous downloads. The plot at right displays the ultimate market share for all songs in the Independent worlds and indicates that, in the absence of social influence, a few of the songs have intrinsic appeal.

The model Σ_{online} is extremely simple, perhaps the simplest possible representation which captures the effects of both social influence and appeal in an online market. Nevertheless, this model reflects key behaviors observed in the music market [1] as well as in other cultural markets [e.g., 9]. For instance, Figure 1 provides a quantitative characterization of the roles of social influence and appeal for the music market [1]. The plot at the left of Figure 1 shows that in the Social Influence worlds the market exhibits positive externalities, with song download probability (vertical axis) increasing with number of previous downloads (horizontal axis); the error bars represent two standard errors. The plot at the right of the figure shows ultimate market share for all songs in the Independent worlds and indicates that, in the absence of social influence, a few of the songs (e.g., song 25) possess intrinsic appeal. Observe that, in particular, the dependence of song download probability on previous downloads is approximately linear, and that capturing intrinsics in terms of download probability in the Independent condition appears reasonable. Moreover, simulations of Σ_{online} show that as social influence (SI) increases (β decreases) both inequality and unpredictability of market shares increase. Thus, despite its simplicity, Σ_{online} provides a useful starting point for studying predictability of online markets. Note that Σ_{online} can be written as a set of stochastic differential equations with state variables x_1 = f and x_2 = 1/(t+1) [12]; this representation enables the system's predictability properties to be evaluated using the methods presented in [11].

Predictability assessment. Consider the predictability of ultimate market share for the system Σ_{online}. We develop in [11] a stochastic reachability-based approach to predictability assessment which is implementable with a broad range of dynamical systems. Here this assessment methodology is applied in an informal, intuitive manner; the reader interested in a more formal treatment is referred to [11, 12]. Our main interest in this study is *eventual state (ES) predictability*. Roughly, a system Σ is ES predictable if qualitatively different outcomes (say hit or flop in a cultural market) have "sufficiently different" probabilities of occurring when Σ is initialized at similar starting configurations (see [11] for a more precise definition). A key aspect of this definition is that it depends upon the specification for the initial configurations, which in turn depends on which system states and parameters are assumed measurable; this dependence permits ES predictability assessment to be used to *identify* measurables with predictive power.

The standard approach to market share prediction is to assume that item appeal is a relevant measurable, estimate appeal in some way, and use this estimate to predict market share. To examine the utility of this approach, we assess ES predictability of market share for items with identical appeal (π=1/2) and identical initial market shares (f(0)=1/2). If it is likely that the market will evolve so one or the other item dominates (f becomes large or small), then market dynamics are not very dependant on item appeal and therefore are unpredictable using standard approaches. In this case we should seek a different prediction method, perhaps based on other measurables. Alternatively, if market dominance by either item is unlikely then the market dynamics depend on item appeal in a more predictable way and standard methods may be useful.

We evaluate ES predictability using the assessment procedure proposed in [11]. Let X_{s1} and X_{s2} be two subsets of the state space of Σ_{online} corresponding to, respectively, f $\approx$ 1/2 (approximately equal market share) and large/small f (market dominance by one or the other item). Define the set of similar initial configurations X_0 to be a small set surrounding f(0) = 1/2, the identical initial market share condition. Then, if both X_{s1} and X_{s2} are likely to be reached from X_0, the problem is ES unpredictable (and also unpredictable in a practical sense). See Figure 1 for a sketch depicting the basic setup.

As an illustration of the insights obtainable with such analysis, consider the high SI case corresponding to small β in Σ_{online}. For a broad range of noise models, the analysis generates fairly high probabilities for reachability of both X_{s1} and X_{s2} from X_0. Thus two qualitatively different outcomes – market share equity (X_{s1}) and market shares dominance (X_{s2}) – are both likely, indicating that the system is ES unpredictable. This result is consistent with empirical findings for cultural markets [e.g., 1] and suggests that standard approaches to market share prediction are not likely to produce reliable forecasts.

Next consider the problem of searching for alternative measurables which provide better predictability properties in the high SI case. For example, it might be supposed that very early market share time series data would be useful for prediction when SI is high. The intuition behind this idea is that the "herding" behavior which can arise from SI, and which makes market prediction hard using standard methods, may lead to a lock-in effect, in which very early market share leaders become difficult to displace. To test this hypothesis, define X_0* to be a small set surrounding f(t*) = 1/2, where t* is a small *but nonzero* time (see Figure 2). This specification for X_0* corresponds to the situation in which market shares for the two items are still approximately equal after the market has had the opportunity to evolve for a short period. Using the ES predictability assessment algorithm given in [11] we compute the probability that Σ_{online} with π=1/2 will evolve from X_0* to X_{s1} and X_{s2}. In this case, the analysis yields a high probability of reaching X_{s1} and low probability of reaching of X_{s2} (typical probabilities are on the order ~0.9 and ~10^{-3}, respectively). Analogous results are obtained when X_0* is defined to reflect situations in which market shares are unequal at small but nonzero "initial" times. Thus using very early time series data produces a more predictable situation, in which indistinguishable market configurations evolve to indistinguishable outcomes.

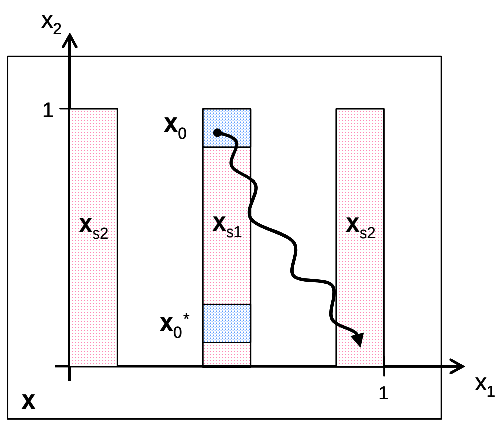

Fig. 2. Setup for online market predictability assessment.

3 Prediction

Introduction. The insights obtained through the predictability assessment procedure summarized above can be used to derive methods for predicting outcomes of the evolution of the music market [1]. We are interested in two problems: 1.) identifying market share winners very early in the market's evolution and 2.) predicting ultimate market shares for these successful songs.

Identifying market share winners. The objective here is to identify a practically measurable "indicator" condition which enables successful songs to be recognized early in the music market's evolution. We focus on the ten high SI markets in the experiments [2], as these are the most unpredictable using standard methods [1]. Our method is simple and natural. The distribution of downloads in high SI markets is right-skewed, reflecting the PEP nature of these markets and hinting at the tendency for market share "lock in" to occur early in the process. This observation suggests that when a market first exhibits signs of this right-skew, a good prediction for the song that will ultimately win the largest market share is the one with leading market share at that point.

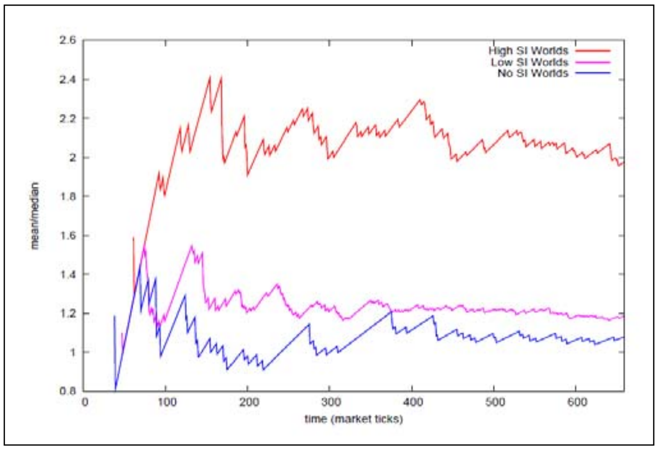

Fig. 3. Dynamics of $MM_i(t)$. The plot shows average $MM_i(t)$ for the high SI (red), low SI (magenta), and no SI (blue) music markets.

Consider the simple measure of right-skew $MM_i(t) = mean_i(t)/median_i(t)$, where $mean_i(t)$ is market share mean for the 48 songs in (high SI) world i at time t and $median_i(t)$ is the analogous median (time t is measured in market "ticks" [2]). The plot in Figure 3 shows that the dynamics of $MM_i(t)$ provides a reliable early means of distinguishing high SI markets from the low and no SI markets. Moreover, these data indicate that high SI markets reach $MM_i(t) \geq 1.1$ very early (i.e., at ~5% of the total market trajectory). Thus we propose the following method for identifying market share winners: for a given market i, predict as the ultimate market share winner the song with leading market share when $MM_i(t) \geq 1.1$ for the first time. Implementing this strategy with the music market data [2] yields the following results: 1.) the winning song is correctly identified in 90% of the high SI markets and 2.) this identification is made within the first ~5% of the market trajectory.

Predicting ultimate market shares. Consider next the problem of predicting the market shares for successful songs early in the market's evolution. More specifically, we wish predict the ultimate market share for each of the top five songs in a given market. Again the focus is on high SI markets, as these are unpredictable using standard methods [1]. We propose the following simple prediction model:

$$\Sigma_{ms} \qquad ms_i(T) = \kappa + \alpha\, ms_{i,\,noSI} + \beta_1\, ms_i(\tau) + \beta_2\, ms_i(k\tau) + \beta_3\, ms_{i,\,mw}(\tau, k\tau),$$

where $ms_i(t)$ is the market share of song i at time t, T is the "closing time" for the market under study, $m_{i,\,noSI}$ is the mean ultimate market share for song i in the no SI markets, τ is the time at which this market first reaches $MM(t) \geq 1.1$, $ms_{i,\,mw}(t_1, t_2)$ is the mean market share for song i over the "moving window" $[t_1, t_2]$, $k \geq 1$ reflects how much early market share time series is available to the prediction model, and $\{\kappa, \alpha, \beta_1, \beta_2, \beta_3\}$ are model parameters learned via regression on a "training set" of songs [13] (see below for additional details). Clearly more sophisticated prediction models could be used; our goal is to demonstrate that useful performance is achievable with a basic linear predictor.

We now summarize some results of applying Σ_{ms} to the task of predicting the ultimate market share of the 50 successful songs in the high SI worlds (top five songs in each of ten high SI markets). First, for a broad range of early time series availability (i.e., k specified so that ≥5% of market time series is used for prediction), all the coefficients of Σ_{ms} (except κ) are statistically significant predictors of final market share ($p<0.05$) when the model is regressed on the entire data set. Next, consider the extent to which final market share can be predicted using only the intrinsic appeal of the songs, as measured by $\alpha\, ms_{i,\,noSI}$. Figure 4 (left plot) shows this quantity has limited predictive power, explaining less than 50% of the variance of final market share over the 50 successful songs. In contrast, the most predictive dynamics term $\beta_2\, ms_i(k\tau)$ can provide useful predictions even if only a small amount of early time series is available (e.g., this term explains ~80% of final market share variance if 15% of early time series is available); see Figure 4. As expected, the predictive power of Σ_{ms} increases rapidly as a function of amount of early market share time series available to the model; this dependence is shown in Figure 4 (right plot). Finally, we investigate the prediction performance of Σ_{ms} through a tenfold cross validation study (a standard method for specifying training and testing sets and evaluating out-of-sample prediction capability [13]). This study shows that the simple linear model Σ_{ms} provides good out-of-sample prediction performance, for instance yielding prediction accuracy of ~82% when given access to the first 15% of market share time series.

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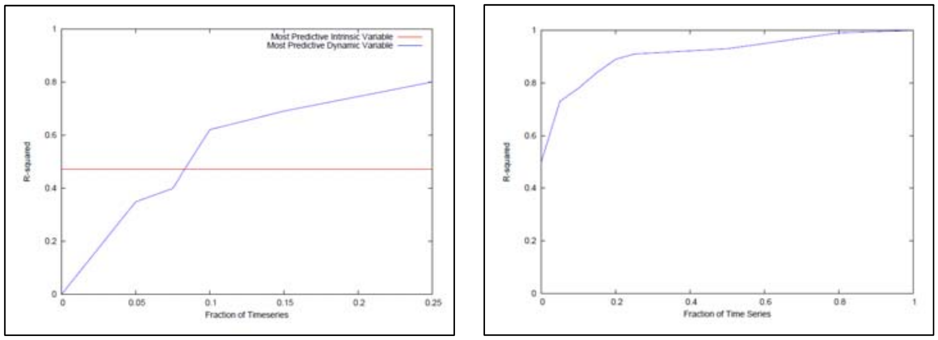

Fig. 4. Sample music market prediction results. The plot at left shows the fraction of final market share variance explained by the most predictive intrinsic alone (α $ms_{i,\ noSI}$, red) and most predictive dynamics variable alone (β_2 $ms_i(k\tau)$, blue), as a function of the fraction of early time series available. The plot at right depicts the fraction of final market share variance explained by Σ_{ms} as a function of the fraction of early time series available.

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