Commentaries: The Bass model: a parsimonious and accurate approach to forecasting mortality caused by COVID-19

The dynamics of the COVID-19 is difficult to model because so much is unknown about it. Government interventions to flatten the curve have successfully slowed the spread of the virus in the USA, but challenges in predicting the future rate of infection are owing to not knowing the true mechanisms of transmission, infection and recovery and not having accurate data on who has actually been exposed to the virus and have tested positive to its antibodies. This paper illustrates that simple models can predict well in these instances.

The Bass model does not incorporate interventions such as stay-at-home orders, the availability of hospitals and ventilators and population variables such as age distributions and density. The model, however, also does not require these data to make forecasts. When the true generative mechanism is unknown and when data quality is poor, simple models can be useful and should be included in the array of forecasting tools used to predict future cases.

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As a practitioner and consultant to pharmaceutical firms, and as a student of Frank Bass, I find this manuscript to be very interesting in its application and insights.

The theoretical underpinning of the Bass model (1969), as the authors have noted, is epidemiology – how virus spreads in a society. So, the application of the Bass Model to study the diffusion of COVID-19 is sound – and the empirical results demonstrate this. The model fits very well and provides as good a forecast of mortality as some of the other rich models.

The extraordinary parsimony has made the Bass model a very useful decision tool for practitioners, who are interested in forecasting sales of a new product. I have used the model and its variants to forecast the demand/sales of several pharmaceutical drugs. This paper now demonstrates that the model can be a handy tool for pharmaceutical and health-care practitioners and policymakers, who are interested in forecasting the diffusion of a virus such as COVID-19.

If managers can forecast the mortality/hospitalization for an infection, they can use these forecasts as inputs into their decision-making to improve the quality of decisions. The Bass model, supported by judicious assumptions influencing the parameters, makes this possible. Not only because it is very simple and direct but also it can conveniently be estimated in Excel.

The exact underlying mechanisms may not be explicit in the Bass model but that is not very material because we know that the model is derived from epidemiological assumptions and has demonstrated its accuracy over the past five decades.

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As we are in a global market, it would be very instructive to examine how the Bass model applies to Asia, China, Europe and India and more.

Thanks to Professors Kalyanaram and Mukherjee for demonstrating the applicability of the Bass Model in understanding the diffusion of COVID-19 (and other infectious diseases) and making very encouraging forecasts.

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The COVID-19 pandemic caused severe disruption to human lives and businesses worldwide. It has also spawned a large number of published studies modeling various aspects of the growth and impact of the pandemic. The authors identify some of the popular models and propose the implementation of Bass model as an alternative model owing to its simplicity and parsimoniousness. There are numerous strengths of the paper and some areas for future research.

First, the authors introduce the Bass model as an additional approach to study the spread of COVID-19. The Bass model is a very flexible model with a strong theoretical foundation in epidemiology. The coefficient of innovation represents the impact of spontaneous adoption of new products by consumers. In the present context, the estimates of the coefficient of innovation reflect the number of new infections caused owing to travelers from outside a region. Similarly, the estimates of the coefficient of imitation reflect the number of new infection caused owing to transmission across people within a region. Future researchers may quantify the levels of risk of disease spread from one region to another using these estimates. Moreover, there are several extensions that can be explored further. For example, how do the coefficients of innovation and imitation relate to the epidemiological constructs of susceptible, exposed, infectious and Recovered in the SEIR model? In the context of COVID-19, once a patient dies or is cured of the disease, there is no subsequent transmission of the disease; this is not the case when we apply the model to the adoption of new products in consumer markets. Consumers who have bought a certain new product can still influence others. Thus, the standard interpretations of the Bass model parameters need to be reinterpreted to enhance the underlying intuition.

Second, the authors recommend the extension of the Bass model to investigate the disease spread across countries with differing geographic, demographic, political and other characteristics. Numerous extensions to the Bass model are possible given the substantial levels of drug development and innovation being conducted in the current context. Governments across countries are collaborating with others in developing tests, treatments and solutions to COVID-19. Considerable disparities across rich and poor countries hurt the diffusion of ideas, treatments and best practices (Sood and Van den Bulte, 2016). The importance of resource allocation to maximize the rate of diffusion of good treatment plans and best practices in preventing infections cannot be understated (Golder and Tellis, 1997, 1998). The Bass model can be extended to incorporate these cross-national socioeconomic and cultural differences (Stremersch and Tellis, 2003; Sood and Kumar, 2018; Tellis *et al.*, 2003).

Third, the authors aggregate several mathematical models proposed by extant researchers in medical, economic, computer science, public policy and business fields to forecast the transmission of COVID-19 in the USA and worldwide. Some models focus on the number of infections or mortality. Others focus on the medical supply needs, hospital capacity, or timing of patient surges. Some are based on real data and offer predictions of future disease spread (Tellis *et al.*, 2020b). Other models use machine learning and artificial intelligence techniques to assess hypothetical scenarios and are based on multiple assumptions. The proposed typology based on theory/data based versus parsimonious/intricate approach can act as a reference for classifying these models. Future research can categorize the models in more intuitive manner to enhance comparison and guide selection based on research objectives.

Fourth, the results on the application of the model to incidences in three states (New York, California and West Virginia) suggest that the Bass model has better predictive ability than the IHME model. Future research can extend the analyses to all 50 states and examine the differences in diffusion patterns across states. It would be interesting and informative to examine how the spread of infection across the 50 states in the US mirrors diffusion across multiple countries (Chandrasekaran and Tellis, 2007, 2008; Stremersch and Tellis, 2004; Sood and Kumar, 2017; Tellis *et al.*, 2020a, 2020b). Future research can also extend the analyses to examine the superiority of the Bass model over alternate approaches. For example, future research may examine whether the Bass model provides reliable estimates with limited data, or whether the knowledge of the model parameters from one country can be used to improve the prediction in other countries, thereby enhancing the efficacy of implementation in other countries.

Finally, a key benefit of a good model is its ability to offer unique insights into the phenomenon. The Bass model can be used to test various kinds of interventions to help reduce this number of new incidences. Given the large variation across states in the timing and extent of intervention, the Bass model may allow insights into the efficacy of various interventions to explain the differences in COVID outcomes across the 50 states. One approach might be use the time-series on the incidences of new cases, deaths or recoveries and use functional data analysis to explore similarities and differences across states and countries (Sood *et al.*, 2009).

In summary, the current paper introduces a powerful, parsimonious and flexible approach to forecasting disease spread caused by COVID-19. The application of the Bass model to investigate the spread of COVID-19 can uncover many fascinating insights about the phenomenon.

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Further reading

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Thank you to Professors Kalyanaram and Mukherjee for their excellent explication of the extant approaches to modeling the rate of infection of COVID-19 and their application of the well-known Bass model of diffusion to the pandemic. As the authors note, the model has epidemiological roots and is, therefore, well suited for modeling the spread of the virus. In addition, it has the virtue of being simple to both estimate the parameters and use for forecasting. The forecasts of deaths from the virus are also very good and are particularly remarkable given the relatively simplicity of the model formulation.

I suggest a couple of additional analyses that could further exploit the state-level data. First, the Bass model has been augmented numerous times to incorporate marketing decision variables (see, for example, Bass *et al.*, 1994). For example, in a traditional marketing setting, the coefficient of innovation, p, can be set to be affected by advertising in that more early adopters will be determined by how much money is spent promoting the product. In the current context, the imitation parameter, q, would be driven at least partially by the amount of personal protection equipment available, respirators in hospitals, hospital beds and other variables.

Another analysis could examine the residuals at the state level. This is another way to better understand heterogeneity. It would be interesting to understand what factors are related to over- versus under-forecasting and to understand if there are certain areas of the USA that are susceptible to the different errors.

Again, thanks to the authors for demonstrating the power and general applicability of the Bass model to this critically important problem.

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