Modeling the COVID-19 transmission in Italy: The roles of asymptomatic cases, social distancing, and lockdowns

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Abstract

The SEIR model of COVID-19 is developed based on the system dynamics approach. Compared with existing models, the model successfully reproduces similar multiple observed outputs such as infected and recovered patients in Italy by July 2020. In doing so, the system dynamics model captures the roles of undocumented cases on the Italian COVID-19 flow. The model also considers two types of measures including behavioral measures and lockdown measures as they are embedded in the model. It is hoped that the model can enhance our understanding of the roles of undocumented cases, so-called asymptomatic cases, and the efficacy of two different policies on the COVID-19 flow. This study concludes that the first policy is important once the number of infected cases is relatively low. However, once the number of infected cases is very high so the society cannot identify infected and disinfected people, the second policy must be applied soon. It is thus this study suggests that relaxed lockdowns lead the second wave of the COVID-19 around the world.

Keywords: COVID-19; SEIR model; system dynamics, Italy, corona virus model.

I. Introduction

Despite its high quality of the national healthcare program, Italy was the epicenter of the corona virus disease (the COVID-19) during the European first wave. The Italy first closure owing to COVID-19 was on February 22nd, 2020. As COVID-case spiked, the government started the first measure on March 4th by closing public places such as stores, and schools as well as enforcing physical distancing in severely affected areas close to Milan and Venice (Sjödin et al., 2020). This lockdown was lengthened on March 9th, owing to a rise of documented cases and confirmed deaths were about 7,000 people and 400 people respectively.

Some existing studies discussed issues relate to Italian COVID-19 cases such as policy measures (Flaxman et al., 2020; Lavezzo et al., 2020; Sjödin et al., 2020), the dynamics of
high COVID-19 cases (De Natale et al., 2020; Garazzino et al., 2020; Gatto et al., 2020; Goumenou et al., 2020; Grasselli et al., 2020; Grossi et al., 2020), and comparisons of the COVID-19 in Italy and China (Nesteruk, 2020). It appears that existing studies successfully has modelled the COVID-19 cases in Italy and analyzed the main factors of Italian COVID-19. However, at the best author knowledge, no available study have successfully modelled two different notified policies in tackling the COVID-19: the behavior policy and the lockdown policy. This is important as other studies (Carlucci et al., 2020; Graffigna et l., 2020; Meier et al., 2020; Pagnini et al., 2020) highlighted the importance the first and the second policies in minimizing the COVID-19 flow in Italy. Hence, this study compares the efficacy two different measures in the Italian COVID-19 cases.

This study also investigate three important cases simultaneously including recovered, infected, and dead patients, especially during the first wave in Italy. It this thus this study aims to develop a SEIR model that explains dynamics of three important issues: infected, recovered, and dead patients during the first wave of the COVID-19. As previous studies mentioned ((De Natale et al., 2020; Raheem, 2020) possible roles of undocumented cases, this study also investigates the important role of the undocumented cases in Italy. With keep these points in mind, the author believes that modeling the COVID-19 in Italy can give us understanding the dynamics flow of the COVID-19 in terms of behavior, lockdown policies, and undocumented cases. This means this study provides more insights for policymakers in the flow of the COVID-19 in other areas.

In the first section, this study explains existing studies of COVID-19 in Italy. Furthermore, this study explains the system dynamics approach to understand dynamic of susceptible, exposed, infectious and recovered patients in Italy. Thus, this study offers a holistically comprehensive SEIR model than existing studies (e.g. Dehning et al., 2020; Raheem, 2020; Sjödin et al., 2020). This study also offers analysis that is more comprehensive as this study analyses the impacts of undocumented cases than an existing study (De Natale et al., 2020; Flaxman et al., 2020; Gatto et al., 2020; Lavezzo et al., 2020). The latter is important as undocumented cases have an important role in the COVID-19 flow in Italy (De Natale et al., 2020; Raheem, 2020) and in China (Li et al., 2020).

The system dynamics approach has a long tradition to model health issues such as epidemiology, healthcare facilities, and non-communicable diseases (Darabi, N. & Hosseinichimeh, 2020; Homer, & Hirsch, 2006). Because of this, this study develops a SEIR model based on the system dynamics approach to simulate observed deaths, observed recoveries, and observed incidences in Italy.
II. Data and methods

Required data were collected from https://www.worldometers.info/coronavirus/, www.rki.de (Robert Koch Institute) and https://coronavirus.jhu.edu (John Hopkins University). Three data types including active cases (infected people), deaths and recovered people were extracted from aforementioned sources.

This study develops a mechanistic model as (Holmdahl & Buckee, 2020) explained the mechanistic model such as the Susceptible, Exposed, Infected, and Recovered (SEIR) can capture the impacts of uncertain parameters, capture non-linear feedback, and the efficacy of policies.

Previous studies have successfully simulated infectious, non-infectious diseases, and other healthcare issues (Donsimoni et al., 2020; Darabi & Hosseinichimeh, 2020; Davahli et al., 2020; Homer & Hirsch, 2006). Owing to this, the SEIR model used in this study is developed based on the system dynamics approach. Despite usefulness of the SEIR model, some uncertain parameters have not been defined or unknown. The SEIR model also investigate the efficacy of policies in minimizing the COVID-19 flow and the role of undocumented cases.

To obtain the best parameter values, this study applies the Markov Chain Monte Carlo (MCMC) calibration process owing to unknown parameters using Vensim©. To obtain the best parameter values, the system dynamics model compares three outputs including infected cases, death cases, and cumulative death cases. The three respective observed variables are compared with simulated variables to get the best parameter values in which means that the best parameter values lead to the smallest variances.

The model starts the simulation from January 1st, 2020 and runs in daily terms until by July 2020. Simulated parameters such as an incubation time, Ro, and an infection duration are based on existing studies. It is important to note that the SEIR model will be set in two different first confirmed cases. Previous studies (e.g. Usuelli, 2020) noted that COVID-19 models of Italy should assume that the first confirmed case is infected Chinese tourists who was acknowledged as an imported COVID-19 case on January 31st, 2020. While other studies (De Natale et al., 2020; Gatto et al., 2020; 2020; Sjödin et al., 2020) assumed that the first Italian confirmed case should be the first infected male on February 21st, 2020.

III. Discussion and results

To obtain the best value for each parameter, at the first step, the SDM is embedded by range values stated in table 1 and at second step, we run the Markov Chain Monte Carlo (MCMC) calibration available in Vensim©. To accommodate uncertain parameter values, this study set
range values based on existing studies. For instance, other studies (Lauer et al., 2020; Yu et al., 2020) sets that Ro ranges between 2.4 and 3.7.

| Names                           | Values                      | References                                                                 |
|---------------------------------|-----------------------------|-----------------------------------------------------------------------------|
| The first confirmed case(s)     | February 21st, 2020         | (De Natale et al., 2020; Goumenou et al., 2020; Raheem, 2020)                |
| Ro (basic reproduction number)  | 3.5 (3-4)                   | (Garazzino et al., 2020; ISSc, 2020)                                         |
| Incubation time                 | 4 days (3-5) days           | (Lauer et al., 2020; Sjödin et al., 2020; Yu et al., 2020)                   |
| Infection duration              | 26 (7-45) days              | (ISSc, 2020)                                                                |
| Recovery time                   | 8 (5-12) days               | (Grasselli et al., 2020)                                                    |
| Behavioral reaction time        | 15 days on March 4th (public place closures) and 22nd (the national lockdown) | (Goumenou et al., 2020; ISSc, 2020)                                         |
| Behavioral risk reduction       | This policy is voluntary act without legal enforcement. This is assumed to be between 10% and 50% |                                                                 |
| Lockdown reaction time          | 45 days (after the first case) | (Garazzino et al., 2020; ISSc, 2020)                                         |
| Lockdown risk reduction         | The lockdowns are very strict and enforced by law so the efficacy is high (60%-95%) |                                                                 |
| Fraction of undocumented cases upon documented cases | 55% (46-62)% | Li et al. (2020) Flaxman et al. (2020); Gatto et al. (2020); Lavezzo et al. (2020) |

Table 1. Parameter values of the SDM. Bracketed values are min and max values based on existing studies

The SIER model

The system dynamics model (SDM), so called stock-flow model, for Italian cases can be seen in figure 1. The SDM consists of five stocks such as the susceptible, infected, and recovered cases. The SDM also accommodates the impacts of behavioral measures such as physical distancing, hand washing, and mask covers. For these measures, the SDM applies two variables namely, “behavioral risk reduction” and “behavioral reaction time”. These two variables respectively explain efficacy of and starting time of aforementioned measures in minimizing the flow of COVID-19. The more striking COVID-19 cases, the more critical or
defensive measures are taken such as isolating patients and lockdowns. In considering striking cases, the SDM also captures the impacts of such isolation related measures through two variables: “lockdown risk reduction” and “lockdown reduction time”. Similarly, the two variables respectively explain efficacy and starting time of lockdown policies in minimizing the flow of COVID-19. The SEIR model is sketched as seen in figure 1. Other studies (Grosi et al., 2020; Goumenou et al., 2020) stated that undocumented cases may be responsible of rising cases in Italy and other cities in China (Li et al., 2020). The SDM reveals the roles of undocumented cases through two variables: “undocumented infected cases” and “fraction of undocumented cases”. A fraction of undocumented cases is a portion of undocumented cases compared with documented cases. In this model, documented cases is represented as “infected rates”.

![Figure 1. The SIER model for Italy](image)

The SEIR model capturing undocumented cases and two different policies is described in figure 1. The SEIR model separates patients into four categories, exposed, infected, dead,
recovered, and undocumented cases. In the model, undocumented cases is represented as a multiplication between a fraction of undocumented cases and infected cases. Time variables such as recovery time is defined the average time between the symptom onset and recovery while infected duration is defined as the average time between the symptom onset and deaths.

The SEIR model calculates the number of infected cases, deaths, and recoveries are based on equations 1-3 as follows:

\[
\text{infected rates} = \frac{\text{cumulative-exposed}}{\text{incubation time}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)
\]

\[
\text{dying rates} = \frac{\text{cumulative-infected1}}{\text{infection duration}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)
\]

\[
\text{recovery rates} = \frac{\text{cumulative-infected1}}{\text{recovery time}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3)
\]

Transmission rate measures the number of exposed people after contacting or stand closes with infected people. Following Fiddaman (2020), transmission rate is calculated based on equation 3. For the first policy, its impact is calculated based on equation 4. Equation 4 means that the first policy of behavioral reduction risk decreases transmission rate based on two factors: “behavioral reduction risk” and “behavioral reduction time”.

\[
\text{Transmission rate} = \left( \frac{\text{Ro}}{\text{recovery time}^2} \right) \times \text{fraction of susceptible} \times (1 - \text{the impacts of behavioral risk reduction}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)
\]

The second policy i.e. lockdowns is calculated similar to equation 4. Equations 5a and 5b show the number of exposed cases decreases after the second policy starts at “lockdown reduction time”.

\[
\text{the expected impacts of lockdown risk reduction} = \text{IF THEN ELSE} (\text{Time} = \text{import time} + \text{"lockdown risk reduction time"}, \text{"lockdown risk reduction"}, 0) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5a)
\]

\[
\text{the actual impacts of lockdown risk reduction} = \text{DELAY3I} (\text{the expected impacts of lockdown risk reduction}, \text{delaytime}, \text{the expected impacts of lockdown risk reduction}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5b)
\]
After running the calibration policy as stated in section Data and Methods, optimized values for each parameter are shown in table 2. The second and third columns represent optimized values if the first case is around January and around February 2020 respectively. As seen in table 2, there no much value differences between the two columns. This implies that the first policy i.e. voluntary acts such as social distancing and handwashing hindered the COVID-19 in early January 2020. In other words, the first policy is helpful once the number of infected cases are relatively low (Piguillem & Shi, 2020). However, that study (Piguillem & Shi, 2020) also claimed that once the COVID-19 cases rise significantly so separating infected and disinfected people owing to is relatively difficult, policymakers must apply the second policy.

| Variables                              | Estimated values #1     | Estimated values #2     |
|----------------------------------------|-------------------------|-------------------------|
| Ro (basic reproduction number)         | 3.68 (3-3.7)            | 3.7 (3-3.7)             |
| Incubation time (days)                 | 3 (3-5) days            | 3 (3-5) days            |
| Infection duration (days)              | 16.5 (7-45) days        | 12.56 (7-45) days       |
| Recovery time (days)                   | 5.7 (3-35) days         | 2.75 (3-35) days        |
| Fraction of undocumented cases         | 73% (46-62)%            | 79% (46-62)%            |
| The behavioral reaction time (days)    | 37.87 days*             | 20.7 days*              |
| The behavioral risk reduction          | 37.33%                  | 31.37%                  |
| The lockdown(s) of risk reduction time | 33 days*                | 18 days*                |
| The lockdown(s) of risk reduction      | 65%                     | 65%                     |
| Delay time (days)                      | 5 days                  | 5.3 days                |
| Import time                            | The first confirmed cases should be a case announced on January 31st, 2020 | 52 days (The first confirmed cases is February 21st or day 52 from January 1st, 2020) |

Table 2. The best parameter values. Variables with asterisk should be quantified from the first confirmed case.

Looking back at table 2, it appears that voluntary acts such as handwashing and social distancing, despite their importance in hindering the COVID-19 flow, have the relatively lower effect than the lockdown policy (31%-37% vs 65%). However, this does not mean that voluntary acts are not needed. The first policy such as handwashing and social distancing could hinder the flow of COVID-19 in the first wave despite its relatively low effects. This study also highlights that the important roles of undocumented cases, so-called asymptomatic cases, during the first wave of COVID-19 in Italy. This study finds that undocumented case was about 70% of the confirmed cases in Italy. A possible reason of this is a fraction of symptomatic patients is not treated in hospitals as usual but at home (Long et al., 2020).
The SEIR model can reproduce similar outputs compared to respective observed outputs as seen in figure 1. The SD model performance shows that the SD model has symmetric Mean Percentage Errors (sMAPE) less than 10%.

| Variables       | sMAPE |
|-----------------|-------|
| Infected cases  | <10%  |
| Death cases     | <10%  |
| Recovered cases | <10%  |

Table 3. sMAPE for the SEIR model

IV. Concluding remarks

Using the system dynamics approach, Italian COVID-19 is successfully modelled. Differing from other studies, this study aims to model dynamics of infected, recovered, and dead cases incorporating undocumented cases. Moreover, the SDM captures the positive effects of policy measures including behavioral policies (masks, handwashing, and social distancing) and lockdowns or isolations.

Once optimized values for each parameter are obtained through the MCMC calibration process, the SEIR successfully reproduces similar outputs as observed outputs. The SEIR model provides evidence that the first policy has relative lower impacts than the second policy. Nevertheless, the first policy is important once the number of infected cases are relatively low. Once the number of infected cases are high, the second policy shows relatively higher impacts in minimizing the flow of COVID-19. The higher impacts of the second policy than the first policy may be a clue to the second wave of the COVID-19 around the world.

*The SEIR model is available online at: https://osf.io/vuypf*
References

Carlucci, L., D’Ambrosio, I., & Balsamo, M. (2020). Demographic and attitudinal factors of adherence to quarantine guidelines during COVID-19: The Italian Model. *Frontiers in Psychology, 11*, 2702.

Darabi, N., & Hosseinichimeh, N. (2020). System Dynamics Modeling in Health and Medicine: A Systematic Literature Review. *System Dynamics Review*.

Dehning, J., Zierenberg, J., Spitzner, F. P., Wirbals, M., Neto, J. P., Wilczek, M., & Priesemann, V. (2020). Inferring change points in the spread of COVID-19 reveals the effectiveness of interventions. *Science*.

De Natale, G., Ricciardi, V., De Luca, G., De Natale, D., Di Meglio, G., Ferragamo, A., ... & Spina, E. (2020). The COVID-19 infection in Italy: a statistical study of an abnormally severe disease. *Journal of Clinical Medicine, 9*(5), 1564.

Fiddaman, T. (2020). ‘A Community Coronavirus Model for Bozeman’. *MetaSD* (blog). 11 July 2020. https://metasd.com/2020/03/community-coronavirus-model-bozeman/.

Flaxman, S., Mishra, S., Gandy, A., Unwin, H., Coupland, H., Mellan, T., ... & Schmit, N. (2020). Report 13: Estimating the number of infections and the impact of non-pharmaceutical interventions on COVID-19 in 11 European countries.

Garazzino, Silvia, Carlotta Montagnani, Daniele Donà, Antonella Meini, Enrico Felici, Gianluca Vergine, Stefania Bernardi et al. "Multicentre Italian study of SARS-CoV-2 infection in children and adolescents, preliminary data as at 10 April 2020." *Eurosurveillance 25*, no. 18 (2020): 2000600.

Gatto, M., Bertuzzo, E., Mari, L., Miccoli, S., Carraro, L., Casagrandi, R., & Rinaldo, A. (2020). Spread and dynamics of the COVID-19 pandemic in Italy: Effects of emergency containment measures. *Proceedings of the National Academy of Sciences, 117*(19), 10484-10491.

Goumenou, M., Sarigiannis, D., Tsatsakis, A., Anesti, O., Docea, A. O., Petrakis, D., ... & Aschner, M. (2020). COVID-19 in Northern Italy: An integrative overview of factors possibly influencing the sharp increase of the outbreak. *Molecular Medicine Reports*, 22(1), 20-32.

Grasselli, G., Zangrillo, A., Zanella, A., Antonelli, M., Cabrini, L., Castelli, A., ... & Iotti, G. (2020). Baseline characteristics and outcomes of 1591 patients infected with SARS-CoV-2 admitted to ICUs of the Lombardy Region, Italy. *Jama*, 323(16), 1574-1581.

Graffigna, G., Bosio, C., Savarese, M., Barello, M., & Barello, S. (2020). “# I-Am-Engaged”: Conceptualization and First Implementation of a Multi-Actor Participatory, Co-designed Social Media Campaign to Raise Italians Citizens’ Engagement in Preventing the Spread of COVID-19 Virus. *Frontiers in psychology, 11*, 2428.

Grossi, U., Zanus, G., & Felice, C. (2020). Coronavirus Disease 2019 in Italy: The Veneto Model. *Infection Control & Hospital Epidemiology*, 1-5.

Holmdahl, I., & Buckee, C. (2020). Wrong but useful—what covid-19 epidemiologic models can and cannot tell us. *New England Journal of Medicine*. 
Homer, J. B., & Hirsch, G. B. (2006). System dynamics modeling for public health: background and opportunities. *American journal of public health, 96*(3), 452-458.

ISSc. (Istituto Superiore di Sanità). (2020). Characteristics of SARS-CoV-2 Patients Dying in Italy. Available online: [https://www.epicentro.iss.it/en/coronavirus/bollettino/Report-COVID-2019_20_april_2020.pdf](https://www.epicentro.iss.it/en/coronavirus/bollettino/Report-COVID-2019_20_april_2020.pdf) (accessed on 9 August 2020).

Lauer, S. A., Grantz, K. H., Bi, Q., Jones, F. K., Zheng, Q., Meredith, H. R., ... & Lessler, J. (2020). The incubation period of coronavirus disease 2019 (COVID-19) from publically reported confirmed cases: estimation and application. *Annals of internal medicine, 172*(9), 577-582.

Lavezzo, E., Franchin, E., Ciavarella, C., Cuomo-Dannenburg, G., Barzon, L., Del Vecchio, C., ... & Abate, D. (2020). Suppression of COVID-19 outbreak in the municipality of Vo, Italy. *medRxiv*.

Li, R., Pei, S., Chen, B., Song, Y., Zhang, T., Yang, W., & Shaman, J. (2020). Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). *Science*, 368(6490), 489-493.

Long, Y. S., Zhai, Z. M., Han, L. L., Kang, J., Li, Y. L., Lin, Z. H., ... & Liu, Z. (2020). Quantitative assessment of the role of undocumented infection in the 2019 novel coronavirus (COVID-19) pandemic. *arXiv preprint arXiv:2003.12028*.

Meier, K., Glatz, T., Guijt, M. C., Piccininni, M., Van Der Meulen, M., Atmar, K., ... & COVID-19 Survey Study group. (2020). Public perspectives on protective measures during the COVID-19 pandemic in the Netherlands, Germany and Italy: A survey study. *PloS one, 15*(8), e0236917.

Nesteruk, I. (2020). Comparison of the coronavirus epidemic dynamics in Italy and mainland China. *Preprint| ResearchGate*.

Onder, G., Rezza, G., & Brusaferro, S. (2020). Case-fatality rate and characteristics of patients dying in relation to COVID-19 in Italy. *Jama, 323*(18), 1775-1776.

Pagnini, F., Bonanomi, A., Tagliaabue, S., Balconi, M., Bertolotti, M., Confalonieri, E., ... & Saita, E. (2020). Knowledge, concerns, and behaviors of individuals during the first week of the coronavirus disease 2019 pandemic in Italy. *JAMA network open, 3*(7), e2015821-e2015821.

Raheem, A. (2020). Estimating cases of COVID-19 from Daily Death Data in Italy. *medRxiv*. SDS (Sytem Dynamics Society). (2020). COVID-19 Resource Page. Available at. [https://www.systemdynamics.org/covid-19](https://www.systemdynamics.org/covid-19).

Rovetta, A., & Bhagavathula, A. S. (2020). Covid-19-related web search behaviors and infodemic attitudes in italy: Infodemiological study. *JMIR public health and surveillance, 6*(2), e19374.

Sjödin, H., Wilder-Smith, A., Osman, S., Farooq, Z., & Rocklöv, J. (2020). Only strict quarantine measures can curb the coronavirus disease (COVID-19) outbreak in Italy, 2020. *Eurosurveillance, 25*(13), 2000280.
Usuelli, M. (2020). The Lombardy region of Italy launches the first investigative COVID-19 commission. *The Lancet, 396*(10262), e86-e87.

Yu, P., Zhu, J., Zhang, Z., & Han, Y. (2020). A familial cluster of infection associated with the 2019 novel coronavirus indicating possible person-to-person transmission during the incubation period. *The Journal of infectious diseases, 221*(11), 1757-1761.