A high frequency model of the COVID-19 pandemic

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Figures

Abstract

The COVID-19 pandemic represents a complex challenge to policymakers from both a public health and economic perspective. It has caused a severe economic shock to both the Irish and global economy with shutdown measures in Ireland and its trading partners. This paper describes a high frequency database and model developed from both the econometric and medical literature to provide a relative measure of the path of the pandemic in Ireland and across the globe with the aim of adding to the real time evidence for policy makers. Model estimates are reported for the critical early and peak stages of the pandemic.

The model is complementary to those used for public health policy as while it cannot estimate the rate of transmission that is critical for policy decisions is has the flexibility to provide daily estimates and relative metrics for a large set of countries. In the early stages of the pandemic the model estimated a high value of steepness of the curve for Spain and Italy and a low level for Korea. Ireland's measure showed a trend decline, in line with countries such as Denmark and Austria. In the early stages of the pandemic as the situation improved in some of Ireland's continental trading partners there was deterioration in the UK and US, indicating the potential for a more prolonged economic impact. Illustrative calculations reveal that if Ireland's pandemic curve been on average as steep as in Spain, 1,000 fatalities would have been reached 2.4 weeks earlier than observed.

1. Introduction[1]

The outbreak of coronavirus disease (COVID-19), first identified in China in December 2019, has now become a global pandemic. At the time of writing, approximately sixteen million cases of the disease have been confirmed affecting almost all countries and territories, leading to over 600,000 deaths.[2] Aside from the health impact, this has also brought the world economy to a near standstill as governments introduce measures in an effort to contain the spread.

For Ireland, COVID-19 poses the single largest challenge to the economy since the financial crisis (2007-08), and is likely to have an even larger impact in the short term. The highly contagious nature of the disease has meant that the stringency of the containment measures imposed have been unprecedented in nature even compared to the previous literature on the economic impact of pandemics, (Keogh-Brown, 2010; Jonung and Roeger, 2006). Economic activity in some sectors has completely ceased, while the labour market has also been transformed from one of full employment in late-2019, to one in which unemployment reached its highest level on record (Central Statistics Office, 2020). A number of domestic institutions have estimated a severe impact on the Irish economy, ESRI (March 2020), Central Bank (April 2020) and Department of Finance (April 2020). The estimated impacts on GDP for the year range from a -7.1 to -10.5 per cent decline depending on the type of recovery scenario assumed.[3] Ultimately an exit from the containment measures will be determined by the path of the virus. This underscores the importance of real time quantification of the dynamics of the virus.

In addition to the direct impact of measures on the domestic economy, part of the estimated downturn for Ireland captures the weakening of the global economy as the COVID-19 pandemic has also led to lockdown measures across a substantial number of Ireland's trading partners. In their broader contagion scenario, the OECD forecast global growth to fall to 1.5 per cent in 2020, half the rate that was predicted before the pandemic. The IMF forecasts are even more pessimistic, projecting the global economy to contract sharply by 3 per cent in 2020, worse than the fall observed during the 2008–09 financial crisis. This worsening of the external environment will weigh on demand for Irish exports and so economic activity within Ireland. For the year as a whole, GDP will likely decline significantly in the euro area, UK and US (IMF, 2020) – with these destinations accounting for two-thirds of Irish exports. Ireland's vulnerability as a small, open economy to such shocks in the global environment is well documented, with its reliance on markets such as the UK already highlighted in a number of studies focusing on the economic impact to Ireland following Brexit (Department of Finance 2016). It is thus important to not only track the path of the pandemic in Ireland but also in Irelands key trading partners and globally.

With the rapid changes in the dynamics of the pandemic the prospects of economies exiting lockdown measures can change on a daily basis. Of critical importance is the

[2] Source: European Centre for Disease Control (ECDC). https://www.ecdc.europa.eu/en
[3] Box 5 of the Department of Finance Stability Programme provides an overview of the different recovery scenarios.

steepness/flatness of the pandemic curve as this is related to the severity of the pandemic and so to the use lockdown measures and their associate economic implications. The need for daily tracking across a large number of countries motivates development of the model in this paper. In estimating the steepness/flatness daily fatalities data are used as opposed to cases. Cases would give more of a leading indicator of potential future pressures on the health services. However fatalities data are likely to be more consistent across countries than cases data and the aim is to provide relative estimates on the path of countries throughout the pandemic due to its economic implications and not to provide a predictive, medical scenarios type model as is done with SEIR models from the epidemiological literature.

The fatalities from the virus have displayed a very different dynamic across countries (Figures 1, 2 & 3). These figures show the comparative measures for the early phase of the pandemic, up to early June. From Figures 1-3 is can be seen that the pandemic changes rapidly over time. The figures presented give a sample of the daily summary statistics produced throughout the pandemic, currently containing 43,091 data points. The growth rate and levels of the data are aligned to give countries a common starting point, e.g. greater than 1 or 10 fatalities recorded and converted to fatalities per 100,000 of population to facilitate cross country comparison as countries entered the pandemic at different points in time.

As will be discussed in the subsequent section a range of modelling approaches have been used to track the pandemic and provide evidence for policy makers. These include large simulation models from the epidemiological literature but also econometric approaches. Econometric approaches are particularly applicable as the topics of economics and finance have always been to the forefront of high frequency and big data modelling problems (Dunbar, 2019). In this paper a logistic model is used due to its flexibility in quickly estimating a high volume of daily data across a large number of countries allowing an insight into countries relative dynamics. This approach complementary to SEIR models. SEIR models are used for medically motivated precise interventions such as, the lifting of restriction and counterfactual estimation of the impact of these policies on the rate of transmission, hospital admissions and intensive care unit (ICU) admissions. This involves detailed estimates for a particular country. The logistic approach complements this by providing a high-frequency cross country comparison.

In reporting estimated results, although figures can be reported to the current date, the focus in this paper is on estimates produced at the early stages and peak of the pandemic when the figures were of most value to policy makers dealing with a very new challenge.[4] The model estimates that in the early stages of the pandemic steepness of the curve was low in Korea and high in Spain and Italy, in line with observed developments. There was a trend flattening of the curve in Ireland relative to other countries bringing the estimates closer to those of Denmark and Austria. An illustrative scenario shows that fatalities in Ireland would have reached 1,000 seventeen days earlier if the dynamics of curve flattening had followed the pattern in Spain rather than what did occur in Ireland. The model also provided an early indication of a deteriorating situation in some of Ireland's main trading partners indicating a more prolonged economic impact. The paper will be organised as follows Section 2 reviews the literature. Section 3 presents the model used. Sections 4 presents the results and Section 5 concludes.

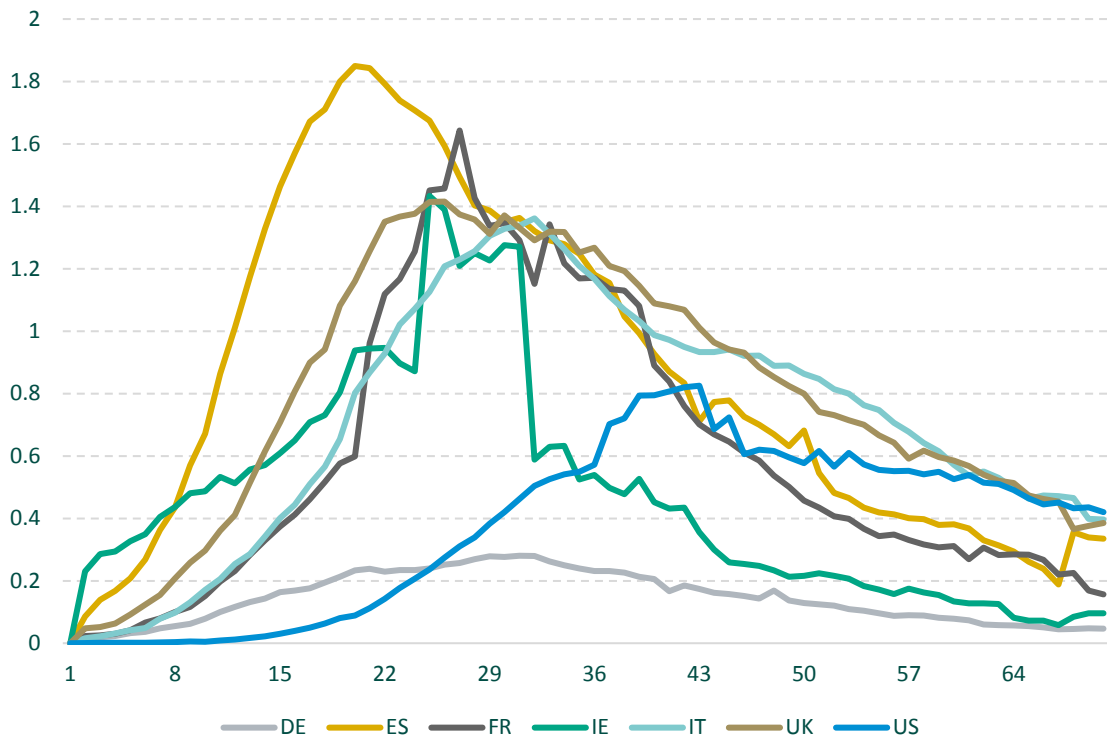[4] Estimates in this paper are correct as of early June.

Figure 1: Fatalities per 100,000 in days after 10 fatalities recorded in each country
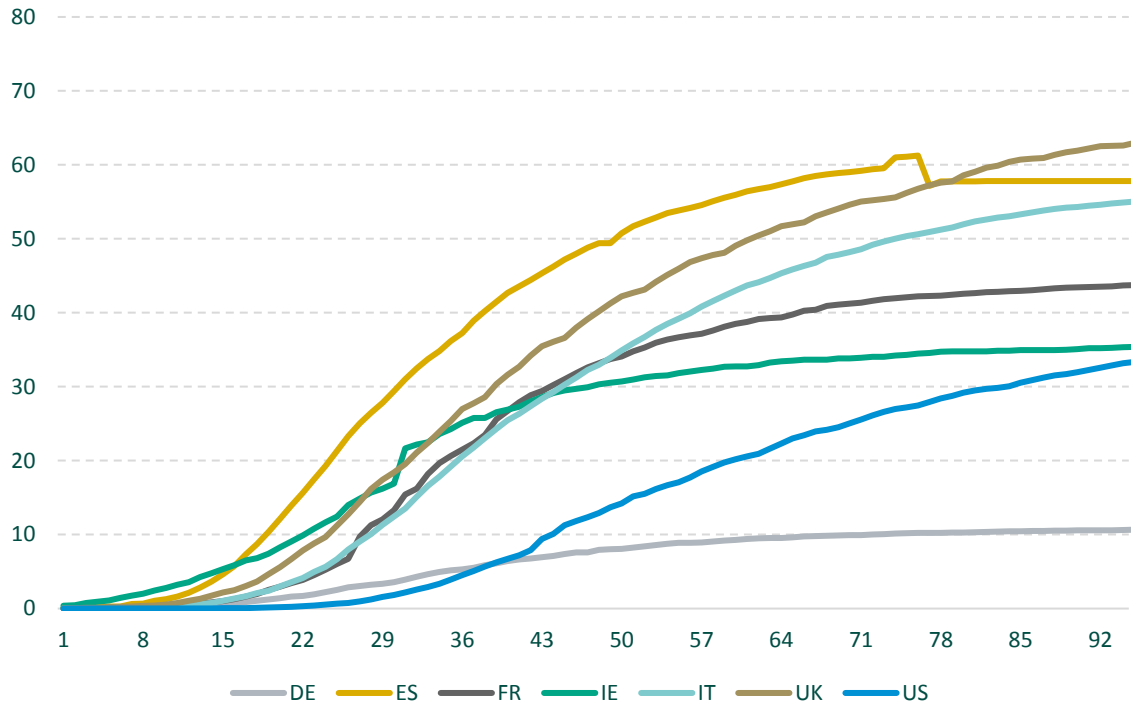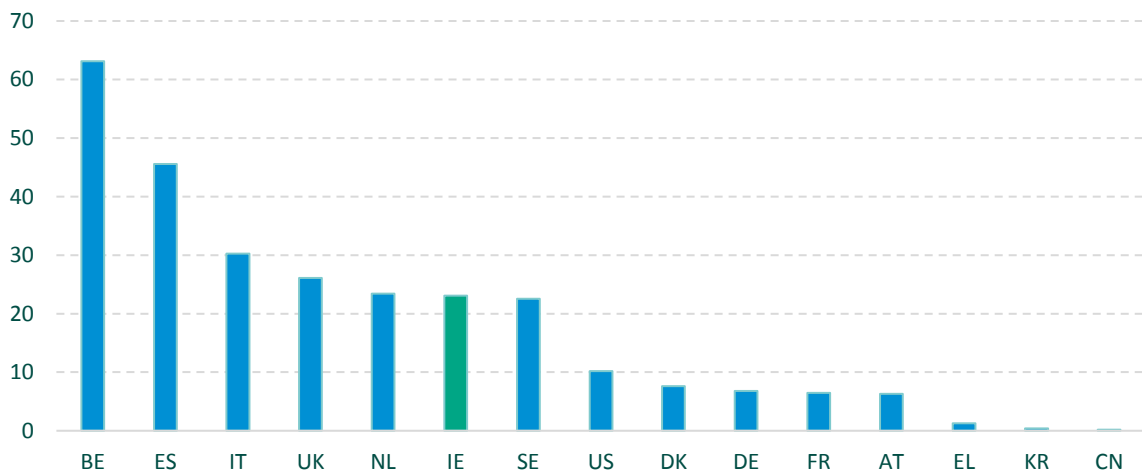

Source: ECDC

Figure 2: Seven day average change in fatalities per 100,000 in days after 10 fatalities recorded in each country

Source: ECDC

Figure 3: Five day average of fatalities per 100,000 – 50 days from first fatality

Source: ECDC

2. Literature Review

COVID-19 forecasts have largely been based on mathematical models that capture the probability of moving between states from susceptible to infected, before either a recovered state or a fatality (SIR models). How an epidemic plays out over time is determined by the transition rates between these three states.[5] In general, these models assume random mixing between all individuals in a given population. SIR models can account for a range of alternative estimates of key parameters and be used for counterfactual scenario analysis.

A more aggregate strategy is to focus on modelling the empirically observed COVID-19 population infection or death rate curves, the latter of which directly reflect both the transmission of the virus and the case-fatality rates in each community. Indeed, daily deaths are likely more accurately reported than cases in settings with limited testing capacity. Logistic models can be used to provide a simple representation of the evolution of infection numbers, hospital admissions and deaths from a pandemic by fitting a curve to the available series. These have been commonly used to model outbreaks as they are able to capture the initial slow growth of a pandemic, followed by a period of rapid growth, followed by a tapering off (Baldwin, 2020).

Early results using these types of models have shown a high degree of accuracy in predicting the evolution of the COVID-19 outbreak in Wuhan (Batista, 2020). This was also the case when applied to other regions in China, while outperforming the use of other mathematical models in its fit for cases and deaths (Jia et al, 2020).Logistic models have also been used with empirical data from Costa Rica, Italy, Spain and the US (Villalobos-Arias, 2020), obtaining a high degree of fit in each. In an attempt to forecast extreme scenarios model parameters were obtained from South Korea and Italy, two developed countries which have had very different experiences in dealing with the spread, in order to generate a range of forecasts for daily infections in the state of Utah (Queadan et al, 2020).

Logistic-type models have the benefit of being relatively simple, flexible and can be updated quickly to follow data released on a daily basis. They can also be used to predict the point of inflection in the curve, or turning point, which is when the number of daily observations in cases or deaths will have peaked and thereafter start to decrease. This approach has been taken to track the progression of the COVID-19 outbreak in the UK in terms of daily cases and deaths announced, and had enough data as of 15 April 2020 to estimate that a corner had been turned (Golinski and Spencer, 2020a & 2020b). We follow the same curve fitting approach in this paper.[6] It is important to note that model takes an econometric approach and does not estimate the rate of transmission which is a key variable from a public health policy perspective.

3. Model data and estimation

The data used is taken from the European Centre for Disease Prevention and Control (ECDC). This comprises daily data on cases and fatalities covering 184 countries beginning on the 31/12/2019. Fatalities data is selected for estimation as there are considerable cross country differences is testing coverage and guidelines (Irish Times, 2020). Even though the fatalities

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[5] Atkeson (2020) introduces a simple SIR model of the progression of COVID-19 in the US.
[6] A Gompertz curve or other functional form specifications can provide a better fit to the data for some countries however in the early and peak stages of the pandemic, which is the focus of this paper, there is not a substantial improvement over the logistic model.

data may be more consistent it should be noted that this is still not directly comparable as countries have differed thus far in the reporting of COVID-19 fatalities.[7]

The dynamics of fatalities across countries are modelled by a general logistic function:

$$F(t) = \frac{\beta_1}{1 + e^{(\beta_2 - \beta_3 * t)}} \quad (1)$$

Time is given by t and β are the parameters estimating key features of the curve; level, intercept and slope. The model is flexible enough to fit the distribution at both the early and late stages of the pandemic. To fit the daily fatality data for estimation the model is discretized and an error term, $\epsilon_t \sim N(0,1)$, added:

$$F'(t) = \beta_1 (1 + e^{(\beta_2 - \beta_3 * t)})^{-2} (\beta_3 e^{(\beta_2 - \beta_3 * t)}) + \epsilon_t \quad (2)$$

Estimation is in differences given the issues of estimation on levels data (Sims, 1980). The model is applied to a rolling sample of daily data from 15 observation up to the end of the sample for each country. Throughout the pandemic the data program allowed this model to be run for 184 countries and provided summary statistics and estimates on a daily basis. The first observation is taken as when a country recorded at least 5 fatalities. While not a causal analysis, and relying on distributional assumptions, this data driven model can give some indication of countries relative position in moving through the pandemic. The cumulative distribution function of the logistic function provides a close description of the pandemics dynamics. The fitted and actual values from the estimation of equation 2 for China, Ireland Italy and Spain are shown in Figure 4 for the early stages of the pandemic.

The model can be used to estimate the steepness/flatness of the curves across countries and to construct an indicator of turning points. As a robustness check on the results we also employ techniques from the finance literature as discussed in Golinski and Spencer (2020a & 2020b). We estimate equation two with a square root volatility specification as used for bounded processes in Cox, Ingersoll, and Ross (1985). We find that for the sample of countries used this does not radically change the estimate of the steepness parameter which is of primary interest in this paper. Thus for computational ease with high frequency data equation 2 is used.

The estimation of the turning point in each country is based on the rolling estimation of model parameters. Point estimates of parameters yield a turning point estimate at that point in time. As the sample increases this rolling estimate will converge to the actual inflection point. To approximate this end point, a function is fit to a convergent sequence of parameter estimates from the model and forecast forward. Forecasted numbers are subject to more uncertainty than estimates on observed data, however the method employed here is less reliant on restrictive assumptions than other approaches which employ an estimated common fatality rate across countries (IHME, 2020).
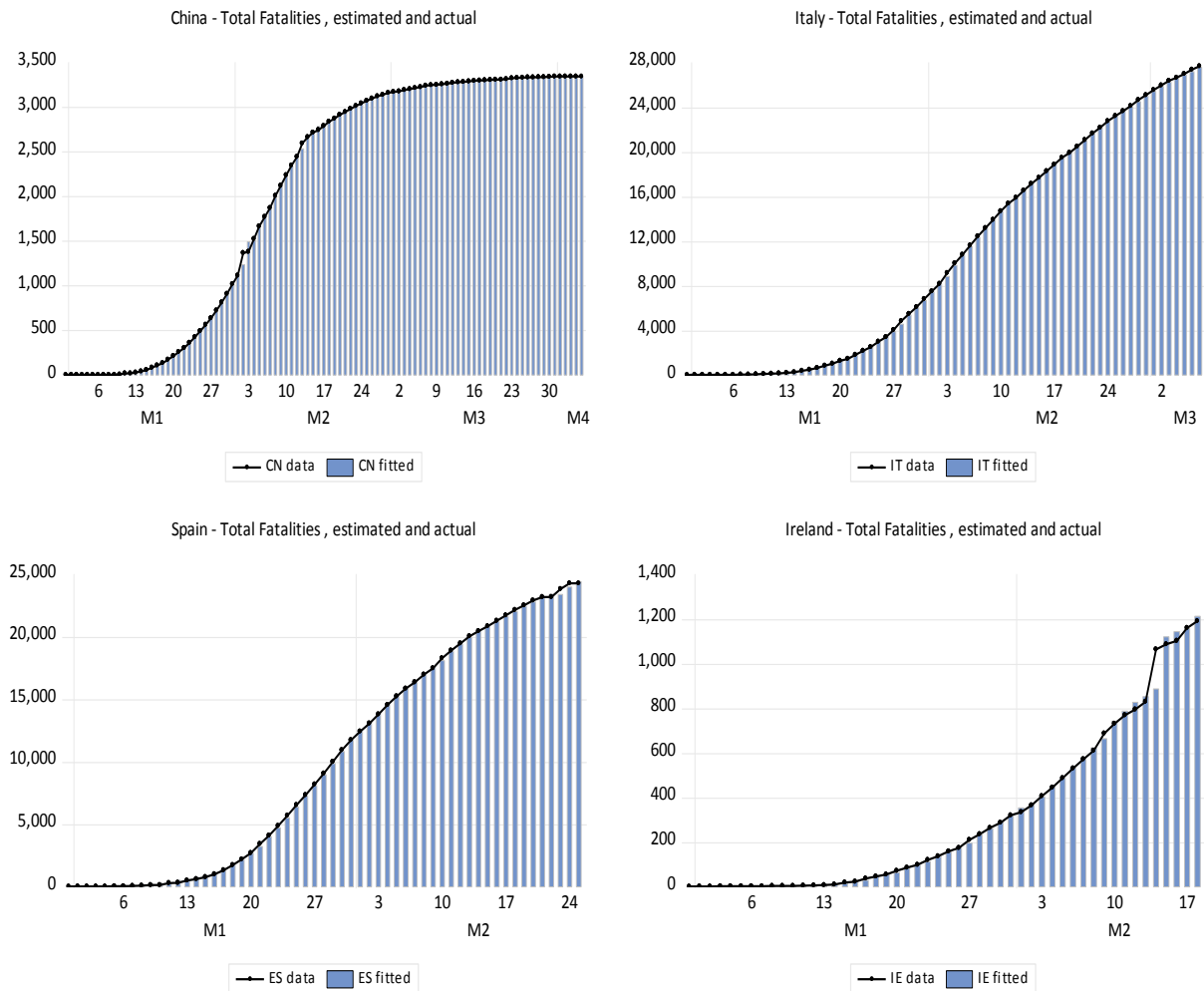
4. Results

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[7] The prime aspect here was some countries were not reporting COVID-19 deaths that occurred outside of hospitals (i.e. nursing homes and long term care facilities).

A key element leading to the shutdown measures is the risk of pressure being placed on medical services by a rapid increase in the spread of the virus. Rolling estimation of the flatness or steepness of the underlying density function can provide an indicator over time across countries of entering a lockdown scenario (Figure 5). The models estimates show that in the early stages of the pandemic Korea, which has managed to avoid severe lockdown measures, has a low number and is well below the estimate for Italy, Spain the UK and US. The situation in important trading partners the UK and US was seen to deteriorate at points over time indicating the potential for a more prolonged economic impact. Ireland's number has shown a trend decline and is closer to the estimates seen in Denmark and Austria than severely impacted countries like Spain and Italy. Denmark and Austria were among the first European countries to lift lockdown measures.

The flattening of the curve estimated in Ireland highlights the value of the model based estimated as this can be seen at a time when fatalities were increasing. The cross country estimates can be used to construct and illustrative scenario such as a comparison of a situation where Irelands curve had not flattened to this extent and had instead evolved in line with that of Spain. An illustrative comparison shows that if the steepness of the curve in Ireland had been at the same average level as Spain 1,000 fatalities may have been reached 17 days earlier than actually observed. This would have implications for pressures on the medical service and would likely have prolonged the period proposed to relax shutdown measures.

The turning point can be approximated by forecasting of model parameters. The results for the turning point estimates are: Ireland - last week of May; UK - Last week of April; Spain - 2nd week of April. These forecast numbers should be interpreted in the context of the caveats outlined.

Figure 4: Estimated and actual fatalities in days after first 5 fatalities recorded in each country.

China - Total Fatalities , estimated and actual

Italy - Total Fatalities , estimated and actual

Spain - Total Fatalities , estimated and actual

Ireland - Total Fatalities , estimated and actual

Source: ECDC

Figure 5: Three day average of the measure of steepness/flatness over time. Rolling estimation for all countries beginning for N=15 after at least 5 fatalities were recorded[8].
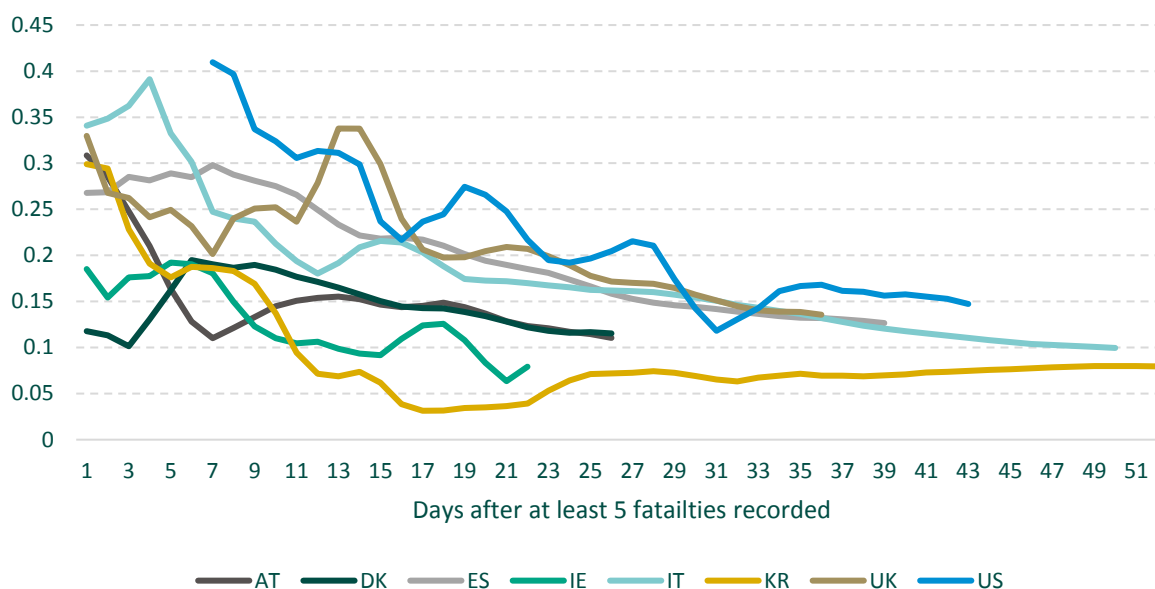
Source: ECDC

5. Conclusions

The COVID-19 pandemic has spread rapidly across the globe and caused considerable challenges for policy makers. A key component in determining the economic impact is the path of the pandemic in Ireland and its trading partners. In quantifying this there are a wide range of modelling approaches available from the medical and economic literatures which can be used to provide insights on the spread and of the pandemic. In this paper we present an econometric approach. This approach is taken as data modelling methodologies employed in economics and finance are well suited to handling high frequency and large datasets.

Using these methodologies we construct a daily data set of corona fatalities of 184 countries and apply an econometric model to track the relative evolution of the flatness/steepness of the pandemic curve in a subset of countries. In the paper the summary statistics and estimates are presented for the early stages and peak of the pandemic as this is when this information was most critical for policymakers. The summary statistic indicators revealed a wide divergence in the dynamic of the pandemic among Ireland and its key trading partners. The rapidly evolving nature of the pandemic necessitated the use of high frequency data techniques. The model is complementary to those used for public health policy as while it does not estimate the rate of transmission it can provide relative measures across a large set of countries.

The flatness/steepness of the pandemic curve is a key feature as a steep curve, although not an exact measure, provides some indication of the risk of a situation where there may be an

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[8] Date from which at least 5 fatalities were recorded: Austria - 20th March, Denmark – 20th March, Spain – 7th March, Ireland – 24th March, Italy – 25th February, Korea – 23rd February, UK – 11th March, US – 3rd March.

excessive strain on the health service and so a motivating for the continuation of lockdown measures. Estimates of this flatness/steepness parameter are provided for a number of countries. The results show consistent low estimates for Korea and high values for Spain and Italy that reduce over time. The model estimates that there has been a flattening of the curve in Ireland over time, relative to other countries. This trend emerged even as the number of fatalities was increasing. This estimate showed that Ireland was moving into line with countries such as Denmark and Austria which had avoided the very sharp rise to peak fatalities seen in other countries. Early in the pandemic as the situation in some of Irelands continental trading partners appeared to be improving the situation in the US and UK began to deteriorate with implications for external demand, suggesting a more prolonged economic impact. An illustrative comparison shows that if the steepens of the curve in Ireland had been at the same average level as Spain 1,000 fatalities may have been reached 2.4 weeks earlier.

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