Optimal Lockdown as a Real Options Problem under Ambiguity

Elettra Agliardi
Department of Economics, University of Bologna
and
Willem Spanjers
Department of Economics, Kingston University, London

Faculty of Business and Social Sciences
FARO Seminar
Kingston-upon-Thames, UK, 24th February 2022

1. Introduction

Main question:

- Can the real options approach contribute to identifying principles of ***optimal lockdown*** policies to deal with ***Covid19***?

Short answer: Yes.

- The ***real options*** approach combines exponential growth with the randomness of a random walk.
- Incorporating ***ambiguity*** (i.e. incalculable risk) makes it possible to take proper account of its unknown nature.

Key Questions:

- Is it optimal to have one ***single watershed value*** instead of different threshold values for imposing and for lifting local lockdown?
- How can the optimal ***threshold values*** be ***calculated*** on the basis of relevant variables?
- How do the optimal threshold values change if ***ambiguity*** about Covid19 reduces?
- How do the results relate to the ***UK lockdown policy*** in different stages of the pandemic?

Related Literature:

- Dixit, A. (1989), ‘Entry and Exit Decisions under Uncertainty’, *Journal of Political Economy, Vol. 97*, pp. 620-638.
- Kast, R., A. Lapied, and D. Roubaud (2014), ‘Modelling under Ambiguity with dynamically consistent Choquet random walks and Choquet Brownian Motions’, *Economic Modelling*, pp 495-503.
- Gollier, C. (2020), ‘Pandemic Economics: Optimal Dynamic Confinement under Uncertainty and Learning, *Covid Economics, Issue 34*, CEPR Press.
- Pindyck, R. (2020), ‘Covid-19 and the Welfare Effects of Reducing Contagion’, *NBER WP 27121*.

2. A Simple Lockdown Model

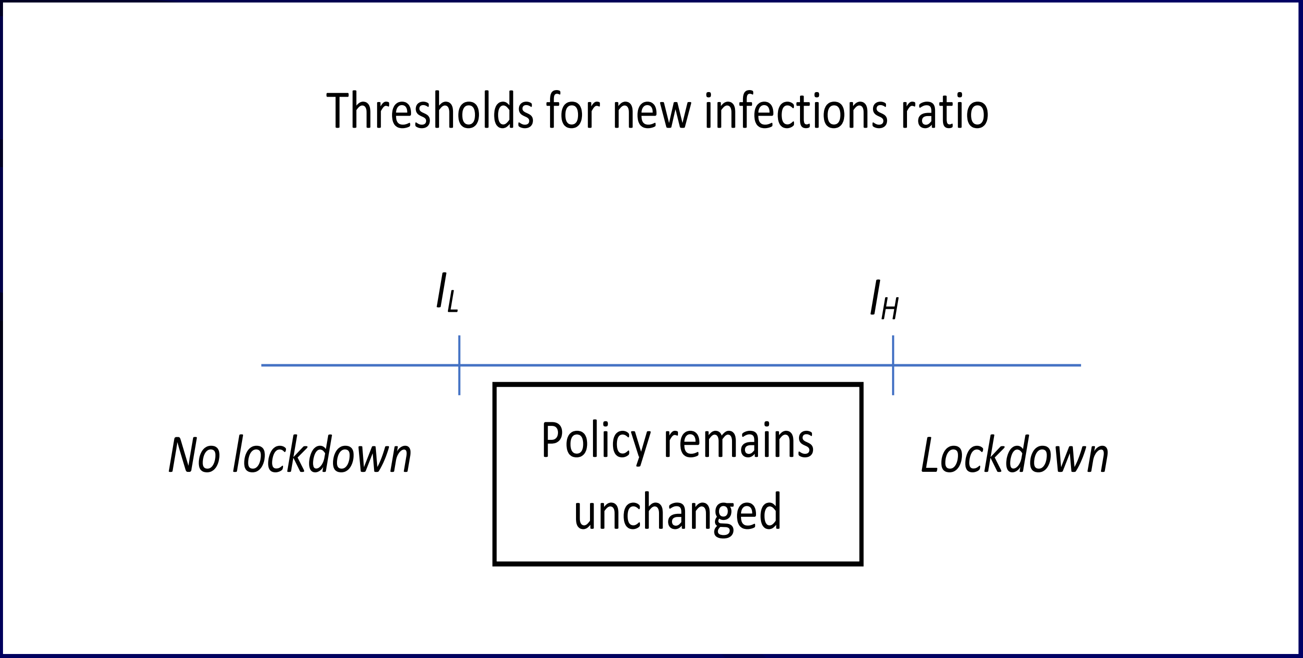
- We apply a Dixit (JPE, 1989)-style ***real options model*** to new infections.
- The Dixit model analyses the ***optimal switching*** on and off ***of production*** when output prices changes follow a random walk.
- In the absence of ambiguity, the lockdown model assumes a ***Brownian motion*** with ***drift*** μ and ***volatility*** σ for the rate of new infections.
- To include ***ambiguity*** we generalize the stochastic process to be a ***Choquet-Brownian motion***.

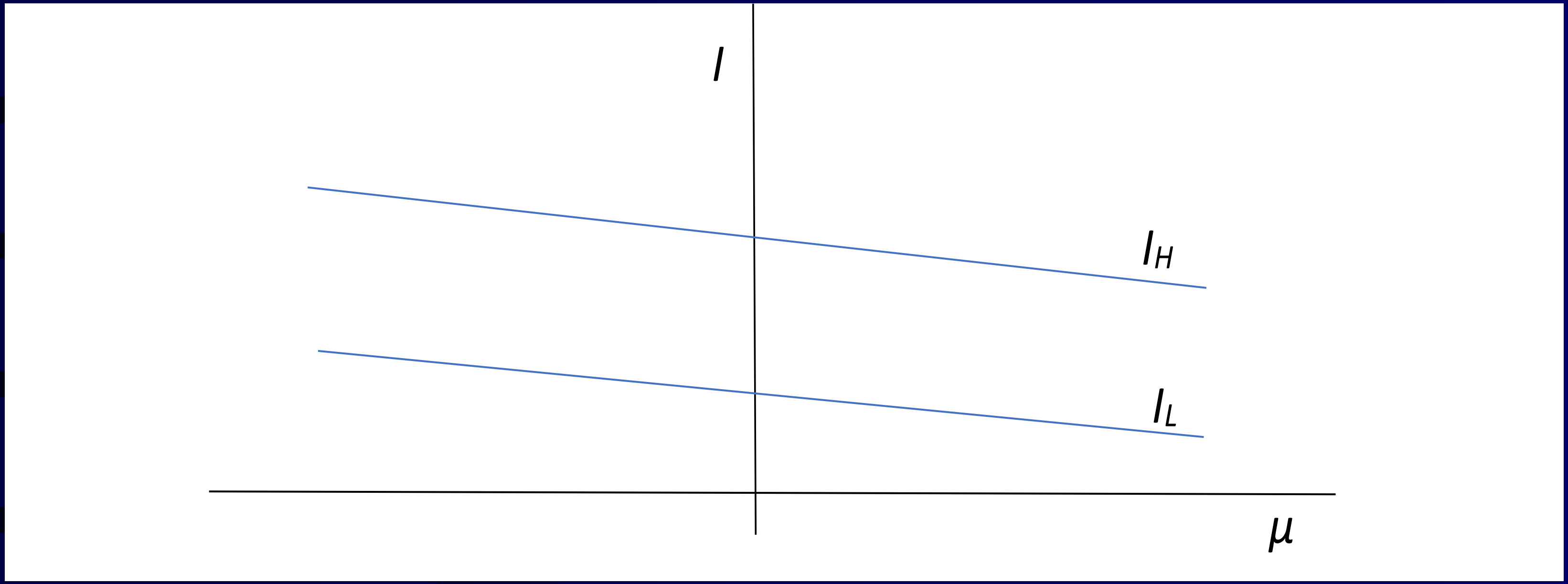
- The lockdown model ***minimizes*** the discounted expected loss to society.
- It ***balances*** the cost of ***forgone output*** under lockdown with the benefit of ***reducing infections.***
- We identify two ***threshold values of the new infections ratio***, one for ***entering lockdown*** and another for ***lifting lockdown***.

Lockdown Thresholds

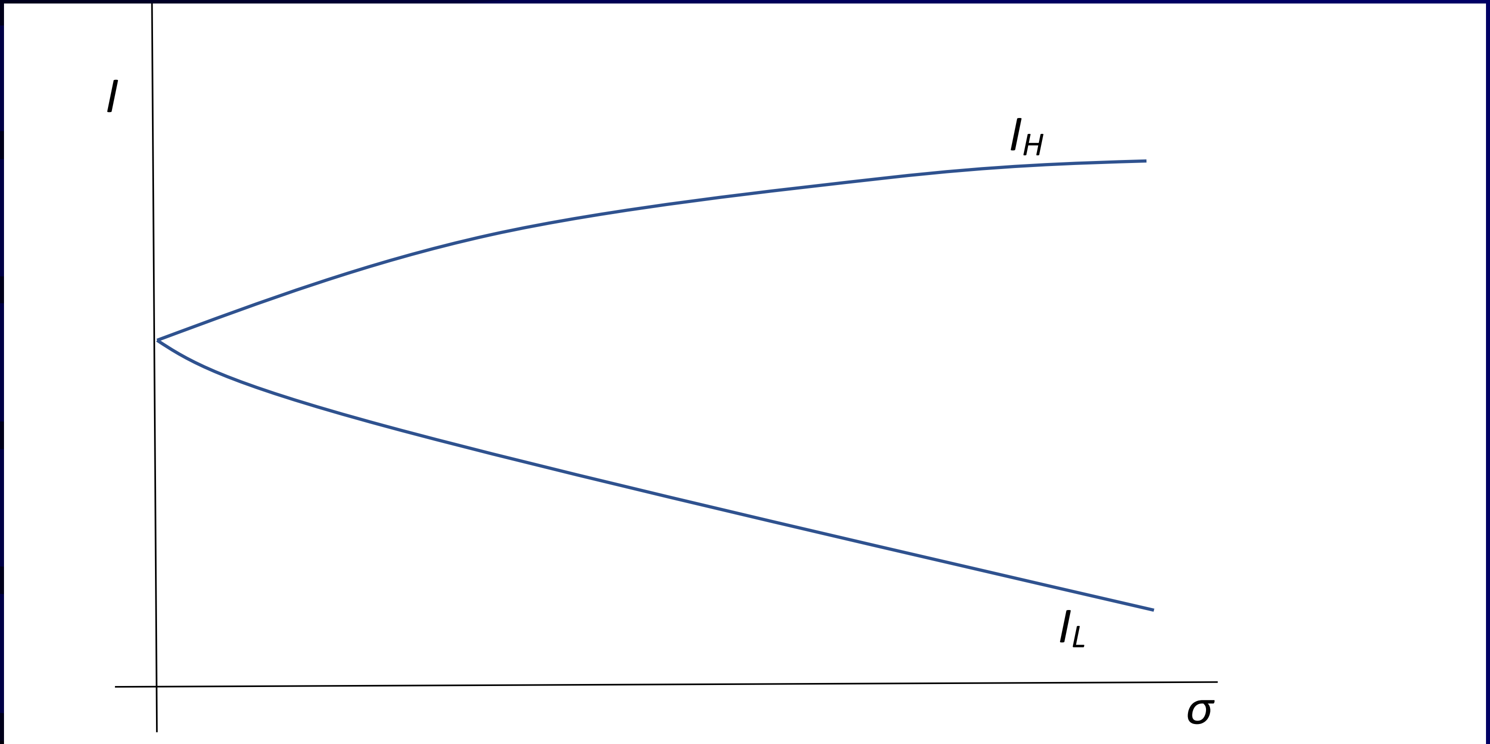
The threshold of the new infections ratio for:

- ***entering lockdown*** is denoted by I_H,
- ***lifting lockdown*** is denoted by I_L.





Changes in μ (Dixit, JPE 1989, Figure 4, adapted)



Changes in σ (Dixit, JPE 1989, Figure 3, adapted)

3. Incorporating Ambiguity

- We incorporate ***ambiguity*** by considering a Choquet-Brownian motion.
- When ***minimizing costs*** under ambiguity aversion (i.e. under ***pessimism***) an ***increase in ambiguity*** or a more pronounced ambiguity attitude affects the underlying Brownian motion by:
  - ***increasing*** the ***drift*** term and
  - ***reducing*** the ***volatility***.
- But for ambiguity seekers (i.e. under ***optimism***) by
  - decreasing the drift term (opposite) and
  - reducing the variance (the same).

The Effects of Ambiguity on the Thresholds

Under ambiguity aversion, the consequences of a ***reduction*** in the level of ***ambiguity*** or the intensity of the ambiguity attitude are:

- the threshold I_H for entering lockdown ***increases*** due to a decrease in drift and an increase in volatility.
- the threshold I_L for lifting lockdown ***can go either way*** increases due to the decrease in drift but decreases due to the increase volatility.
- ***the gap*** between I_H and I_L ***increases*** $I_H - I_L$ increases due to the increase in volatility.

The Effect of Objective Volatility

The consequences of a ***reduction*** in the level of ***objective volatility*** are:

- the threshold I_H for imposing lockdown ***decreases***.
- the threshold I_L for lifting lockdown ***increases.***
- ***the gap*** between I_H and I_L ***decreases***
  $I_H - I_L$ decreases due to the decrease in volatility.

These effects are the same as in the absence of ambiguity for a Brownian motion.

The ***effects of*** a reduction of ***objective volatility*** are ***different from*** the effects of a reduction in ***ambiguity***!

The Effects of the Objective Drift Parameter

The consequences of a ***reduction*** in the level of the ***objective drift*** parameter are:

- the threshold I_H for imposing lockdown ***increases*** due to the decrease in drift and increase in volatility.
- the threshold I_L for lifting lockdown ***increases***.

These effects are the same as in the absence of ambiguity for a Brownian motion.

The Effects of Further Parameters

We also consider the consequences of a ***reduction*** in the following parameters of our model:

- the ***lockdown impact on infections***
  I_H for entering lockdown ***tends to increase*** but can go either way
  I_L for lifting lockdown ***increases.***
- the ***fraction of severe cases***
  I_H for entering lockdown ***increases***
  I_L for lifting lockdown ***increases***.

The consequences of a ***reduction*** in:

- the ***cost of forgone production due to infection*** (per infected)
  I_H for entering lockdown ***increases***
  I_L for lifting lockdown ***increases.***
- the ***cost treatment and human suffering*** (per infected)
  I_H for entering lockdown ***increases***
  I_L for lifting lockdown ***increases***.

The consequences of a ***reduction*** in:

- the ***one-off cost of entering lockdown***
  I_H for entering lockdown ***decreases***
  I_L for lifting lockdown ***no impact.***
- the ***one-off cost of lifting lockdown***
  I_H for entering lockdown ***no impact***
  I_L for lifting lockdown ***increases***.
- the ***discount rate*** ('caring about the future')
  I_H for entering lockdown ***decreases***
  I_L for lifting lockdown ***increases***.

4. Lockdown Policy

- We outline the policy recommendations that follow from its ***inner logic***.
- Actual policy decisions clearly ***also*** involve a ***trade-off*** of the ***intensity of lockdown against*** the level of the ***threshold values*** I_H and I_L.
- We consider the ***four phases*** of pandemic linked to the three virus variations in the UK:
  - the ***initial outbreak***, Spring and Summer 2020
  - the ***α-variation***, Autumn 2020 and Winter 2020/21
  - the ***δ-variation***, Spring and Summer 2021
  - the ***o-variation***, Autumn 2021 and Winter 2021/22.

Phase 1: Spring and Summer 2020

This phase was approximately characterized by:

Ambiguity bias	high
Objective drift	moderate
Lockdown impact on infections	high
Fraction of severe cases	huge
Cost of forgone production (p. inf.)	huge
Cost of human suffering (p. inf.)	huge
Cost of entering lockdown	huge
Cost of lifting lockdown	moderate

- Initially, policy makers were considering different ways to deal with the pandemic.
- After a relatively short period of time, they started considering a ***hammer and dance***-like approach.
- This approach was soon refined to a combined ***national*** and ***local*** approach with a small number of ***lockdown intensities***.
- The decisions were driven by ***new infections rates***.
- We use the assumed threshold values I_H and I_L as ***benchmarks*** for the α-variation phase.

Phase 2: Autumn 2020 and Winter 2020/21

This phase was characterized by:

Ambiguity bias	moderate ↓
Objective drift	high ↑
Lockdown impact on infections	moderate ↓
Fraction of severe cases	high ↓
Cost of forgone production (p. inf)	high ↓
Cost of human suffering (p. inf.)	high ↓
Cost of entering lockdown	high ↓
Cost of lifting lockdown	moderate →

- Compared to the first phase, we have ***less ambiguity*** ($I_H \uparrow, I_L$?) but a ***higher drift*** term ($I_H \downarrow, I_L \downarrow$).
- The measures were more balanced, ***with less impact*** ($I_H \uparrow$?, $I_L \uparrow$), but also much less intrusive.
- Due to fine tuning, ***costs*** both foregone production and human suffering per infection ***fell*** ($I_H \uparrow, I_L \uparrow$) and the ***fraction of severe cases*** ($I_H \uparrow, I_L \uparrow$) ***fell***.
- The cost of entering lockdown fell ($I_H \downarrow, I_L \rightarrow$) , whereas the cost of lifting lockdown remained similar ($I_H \rightarrow, I_L \rightarrow$).
- On balance one would expect the ***threshold values*** I_H and I_L ***broadly remain as before***.

Phase 3: Spring and Summer 2021

This phase was characterized by:

Ambiguity bias	moderate →
Objective drift	huge ↑
Lockdown impact on infections	high ↑
Fraction of severe cases	moderate ↓
Cost of forgone production (p. inf.)	moderate ↓
Cost of human suffering (p. inf.)	moderate ↓
Cost of entering lockdown	low ↓
Cost of lifting lockdown	low ↓

- Compared to the second phase, we face ***comparable ambiguity*** ($I_H \rightarrow, I_L \rightarrow$) but a ***higher drift*** ($I_H \downarrow, I_L \downarrow$).
- The measures are similar but due to vaccination had ***more impact on infections*** ($I_H \downarrow ?, I_L \downarrow$).
- Due to fine tuning, ***costs*** both foregone production and human suffering per infection ***fell*** ($I_H \uparrow, I_L \uparrow$) and the ***fraction of severe cases*** ($I_H \uparrow, I_L \uparrow$) ***fell*** due to vaccinations.
- The cost of entering ($I_H \downarrow, I_L \rightarrow$) and lifting lockdown fell ($I_H \rightarrow, I_L \uparrow$).
- On balance one would, again, expect the ***threshold values*** I_H and I_L to ***broadly remain as before***.

Phase 4: Autumn 2021 and Winter 2021/22

This phase was characterized by:

Ambiguity bias	low $\downarrow$
Objective drift	huge $\uparrow$
Lockdown impact on infections	low $\downarrow$
Fraction of severe cases	low $\downarrow$
Cost of forgone production (p. inf.)	low $\downarrow$
Cost of human suffering (p. inf.)	low $\downarrow$
Cost of entering lockdown	low $\rightarrow$
Cost of lifting lockdown	low $\rightarrow$

- Compared to the third phase, we face ***less ambiguity*** ($I_H \uparrow$, I_L ?) but a ***higher drift*** ($I_H \downarrow$, $I_L \downarrow$).
- The measures and vaccinations had ***less impact on infections*** ($I_H \uparrow$? , $I_L \uparrow$).
- ***Costs*** of both foregone production and of human suffering per infection ***fell*** ($I_H \uparrow$, $I_L \uparrow$) and the ***fraction of severe cases*** ($I_H \uparrow$, $I_L \uparrow$) ***fell***.
- The cost of entering and lifting lockdown remained similar ($I_H \rightarrow$, $I_L \rightarrow$).
- On balance one would now expect the ***threshold values*** I_H and I_L to ***both increase***.