How to prevent infectious diseases in effective and cost-effective way?

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Motivation

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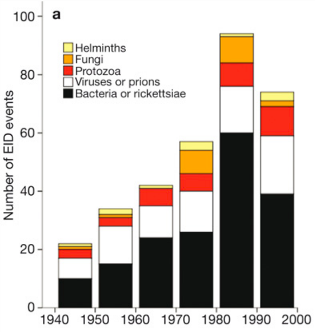
  - Viruses have been present for up to 80 million years. Afflict humans at least since prehistoric times. Early recordings of poliomyelitis in 1400BC Egypt.
  - Since the XXth century, smallpox killed 300 million people, influenza about 100 million, HIV about 30 million, Covid-19 about 2/3 million.
  - New viruses or mutated forms arise frequently (West Nile, Ebola, SARS...).

Trends in Emerging Infectious Diseases



Source: Jones et al (2008), *Nature*

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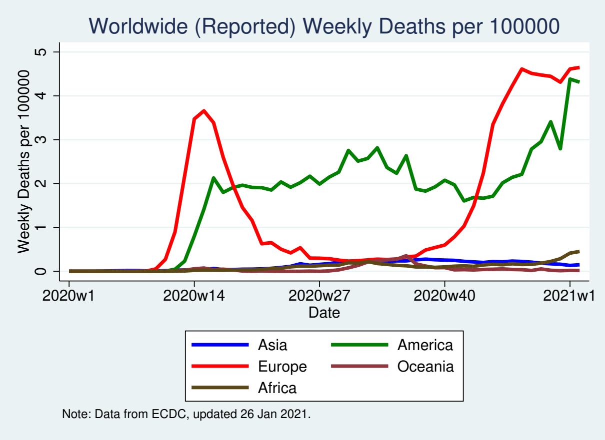

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- Short-run vs long-run measures.

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    - Covid: asymptomatic cases and variation in tests across time, countries, region.
    - Covid: strategic non-disclosures of deaths, different labelling of causes of deaths.

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- Analysis and forecasting are more an art than a science:
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  - especially when the data are scarce.
    - Pre Covid: little data on prevalence of viral diseases at a high frequency.
    - One exception: France since 1985, more below.

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  - little exogenous variation in policy measures.
    - Covid: confinements, school closures imposed when the epidemic is on the increase.
    - Covid: by now, individuals are getting better at anticipating future policy measures.

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  - and when individuals take their own decisions.
    - Respecting social distance is an individual choice. For Covid, a lot of awareness of the disease. Not the case for gastro-enteritis for instance.

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- Can we learn from the pre-COVID past?

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  - J Adda (2016), "Economic Activity and the Spread of Viral Diseases: Evidence from High Frequency Data" *Quarterly Journal of Economics*, 131 (2): 891-941.

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  - J Adda, R Bouccekine, J Thuilliez (2021) "An Economic -Epidemiological Model of Diseases".
  - My own reading of the overwhelming literature on Covid.

Plan of talk

Motivation

Model and Analysis of Diseases
- Standard Epidemiological Model
- Econometric model
- Econometric Issues
- Spatial Effects
- Example

Cost effectiveness

Taking into account Behavior

Conclusion

Standard Inflammatory Response model

- Standard model in epidemiology. Dates back to Kermack and McKendrick (1927). Three types of individuals:
  - Susceptible to contract the disease, S
  - Infected individuals, I
  - Individuals who have recovered and are immune, R

$$S + I + R = 1$$

- Dynamic of infection:

$$\frac{dI}{dt} = \alpha SI - \beta I$$

$$\frac{dR}{dt} = \beta I - \delta R$$

$$\frac{dS}{dt} = -\alpha SI + \delta R$$

- β^{-1} is the average infectious period. Disease specific constant.
- α captures the rate at which individuals become infected. May vary both in short and long run.

Determinants of infection rates

The coefficient α may depend on:

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  - Policy measures preventing contact between individuals (school or firm closures, travel restrictions)
  - Economic fluctuations.
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  - Medical progress (new vaccines).
  - Infrastructure, in particular transportation.
  - Population structure, population density, migration patterns.
  - Economic growth, trade.
  - Changes in work-practices.

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  - Changes in work-practices.
- These effects may differ *within* and *across* regions or countries.

Econometric model

- Let I_{rt} denote the incidence rate of a particular virus in region r, $r = 1, \ldots, R$.
- Let $S_{rt-\tau}$ be the proportion of susceptible individuals
- τ represents the incubation time.

$$I_{rt} = \alpha I_{rt-\tau} S_{rt-\tau} + X_{rt}\delta + \eta_{rt}$$

- The shock η_t is potentially serially and spatially correlated.

Event Analysis

- Event analysis is a popular method for assessing the effect of a policy.
- In the context of infectious diseases, the model is

$$I_{rt} = \lambda_r + \lambda_t + \sum_{k=0} \beta_k IPol_{r,t-k} + \underbrace{(\alpha I_{rt-\tau} S_{rt-\tau} + \eta_{rt})}_{u_{rt}}$$

- Consistency requires that $cov(IPol_{r,t-k}, u_{rt}) = 0$.
- In other words, the policy cannot be initiated because authorities see an unexpected rise in infections. In major epidemics, this assumption is never holding.

Estimated model

- We allow for measurement error: $\tilde{I}_{rt} = I_{rt} + \varepsilon_{rt}$
- Define $L_{rt} = I_{rt} . * S_{rt}$

$$\tilde{I}_{rt} = \alpha \tilde{L}_{rt-1} + X_{rt}\delta + u_{rt}$$

with

$$u_{rt} = \eta_{rt} + \epsilon_{rt} - \alpha\epsilon_{rt-1}(S_{rt-1} + \sum_j \epsilon_{rt-j}) - \beta\varepsilon_{rt-1} + \alpha\tilde{I}_{rt-1}\sum_j \epsilon_{rt-j}$$

- The error term is potentially correlated with the right-hand side variables. $\text{cov}(\tilde{L}_{t-1}, u_t) \neq 0$.
- OLS would yield biased coefficients. Difficult to evaluate policy measures.

Spatial Econometric model

Within and Between Region Spread

- Let I_{rt} denote the incidence rate of a particular virus in region r, $r = 1, \ldots, R$.
- Let $S_{rt-\tau}$ be the proportion of susceptible individuals

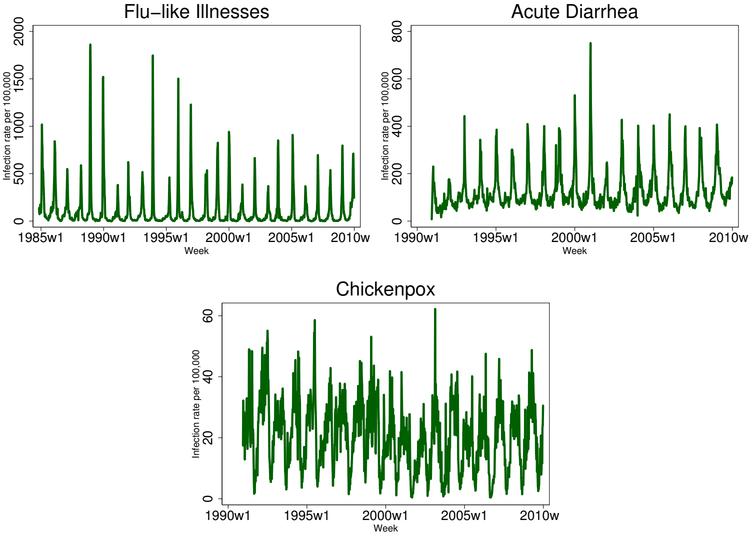
$$I_{rt} = \alpha_{within} I_{rt-\tau} S_{rt-\tau} + \alpha_{between} \sum_{c \in R \setminus r} I_{ct-\tau} S_{rt-\tau} + X_{rt}\delta + \eta_{rt}$$

- The model can be made more complex by allowing different transmissions rate across areas.

Example: Viral Diseases in France

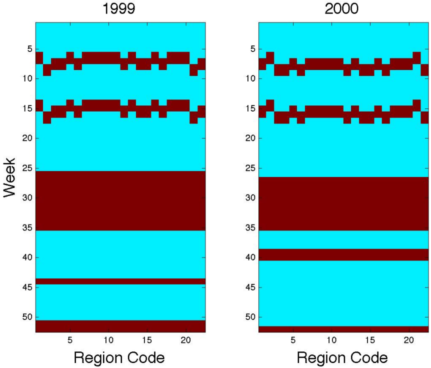
- Weekly infection rates, between 1984 and 2009.
- By age group: children, adults and elderly.
- For all of the 21 regions in France.
- Data on three major viral diseases:
  - Flu-like illnesses (influenza).
  - Acute diarrhea (gastro-enteritis).
  - Chickenpox (varicella).
- Source: "Réseaux Sentinelles", a network of about 1,200 French GPs, gathering data across all of France, based on diagnostic at their surgery or at the patient's home.

Infection rates over time



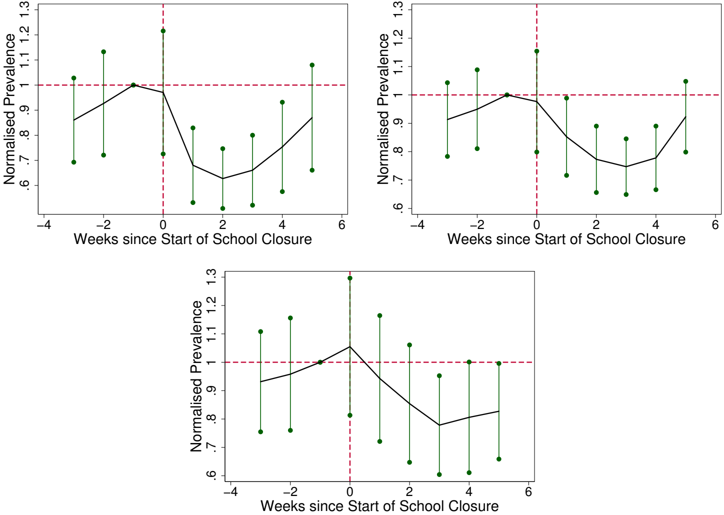
School holidays

- School holidays, by region, 1984-2009:
- Set nationally, for all schools.
- Usually 4 two-week holidays per year, and one summer break (about 8 weeks).
- Exact timing varies across years and regions, especially for winter and spring breaks.
- Independent variation, conditional on year, week and region dummies.



Event Analysis: Flu-like Illnesses, School Closure

Children, Adults and Elderly



Event Analysis: Acute Diarrhea, School Closure

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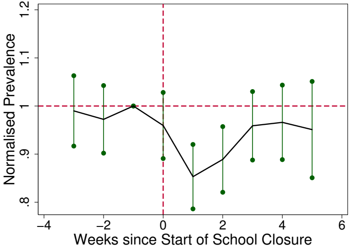
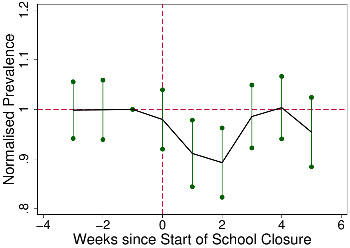
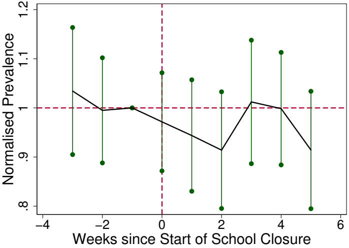
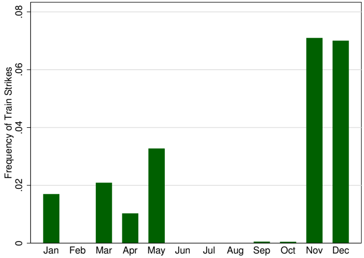


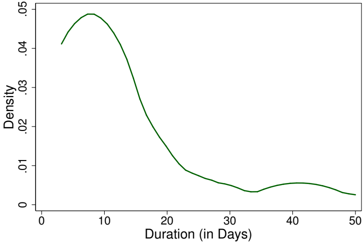




Transportation strikes

- Record of all transportation strikes over the period 1984-2009.
- Collected from the main press.
- National and local strikes, which lasts for more than 2 days.
- Over the period, between 18-28 weeks of strikes per region (out of 1280 weeks).





Average Duration: 12.3 days; Median duration 8 days.

Event Analysis: Flu-like Illnesses, Transportation Strikes

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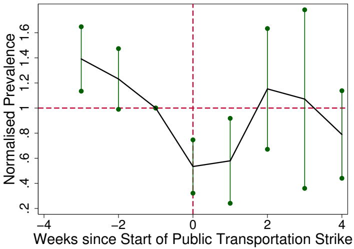

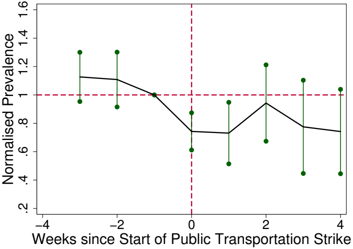

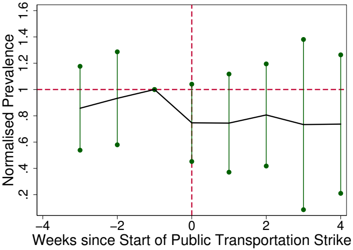

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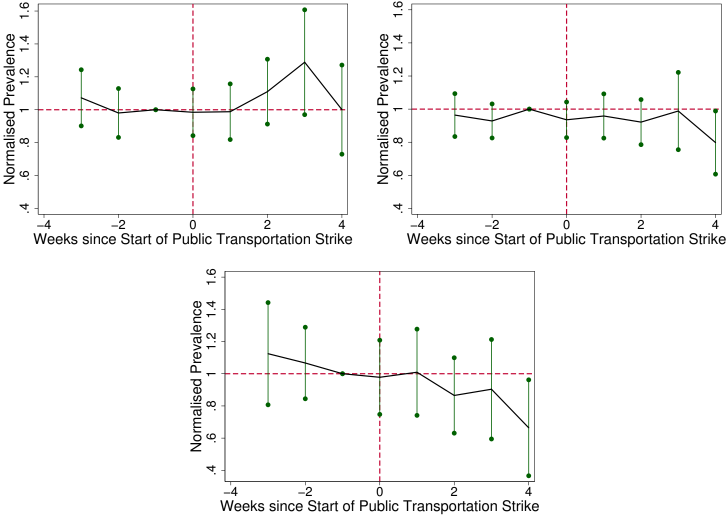

Baseline results: OLS and IV

	Flu-like illness		
	Children	Adults	Elderly
	(1)	(2)	(3)
	Panel A: OLS estimates, within region transmission only		
Within region (α_{within})	0.280***	0.455***	0.120***
	Panel B: OLS estimates, within and between region transmission		
Within region (α_{within})	0.243***	0.412***	0.103***
	(0.008)	(0.008)	(0.004)
Between region ($\alpha_{between}$)	0.005***	0.006***	0.003***
	(0.001)	(0.001)	(0.000)
	Panel C: IV estimates, within and between region transmission		
Within region (α_{within})	0.205**	0.290***	0.111***
Between region ($\alpha_{between}$)	0.012***	0.016***	0.005***
Observations	25,005	25,005	25,005
Autocorrelation (AR1)	0.34	0.17	0.37
F test (endogeneity)	4.430	10.730	9.690
P-value	0.109	0.005	0.008

Note: ***, ** and * denotes significance at 1%, 5%, and 10% level. All regressions include region, year and week fixed effects. Time is expressed in years minus 1984. IV regressions using lagged temperature and precipitation as instruments. Standard errors are corrected for serial and spatial correlation, using a a Prais-Winsten regression, where a region specific AR(1) process is assumed.

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Spatial Econometric model

Within and Between Region Spread with social determinants

- Complete model where the transmission rate is time-varying and region-specific.
- Within regions: we denote a set of K region-specific variables W_{rt}^{k}.
- Includes school closure and transportation closures indicators, the effect of temperature and weather, population density, measures of economic activity...
- Between regions: we denote a set of K region-specific variables $\tilde{W}_{rct}^{k}$. inter-regional trade, distance between regions (defined as the distance between the most populous cities in each region), population ratios, log regional GDP ratios, and temperature differences.

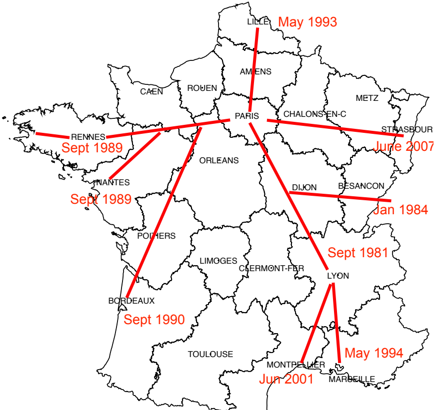
$$\begin{aligned} I_{rt} &= I_{rt-\tau} S_{rt-\tau} \sum_{k=1}^{K} \alpha_{within}^{k} W_{rt-\tau}^{k} \\ &+ \sum_{c \in R \backslash r} I_{ct-\tau} S_{rt-\tau} \sum_{k=1}^{\tilde{K}} \alpha_{between}^{k} \tilde{W}_{rct-\tau}^{k} + X_{rt}\delta + \eta_{rt} \end{aligned}$$

Determinants of spread

- We collect data on a number of potential additional determinants:
  - Weather (temperature and rainfall), by region and week. (European Climate Assessment & Dataset)
  - Large popular gatherings.
  - Expansion of the high-speed rail network.
  - Regional trade patterns. (INSEE).
  - Regional GDP and unemployment rates (INSEE).
  - Population density by region and year (INSEE).

High-speed rail transportation

- France has one of the most developed rail system.
- Starting in the early 1980s many high-speed routes were built.
- Usually cuts down journey times by about a factor 3.



Propagation rate of viruses: Fully interacted model

	Flu-like illness			Acute diarrhea			Chickenpox
	Children	Adults	Elderly	Children	Adults	Elderly	Children
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Interpersonal contacts							
School holiday, within	-.145*** (0.019)	-.101*** (0.019)	-.006 (0.008)	-.071*** (0.009)	0.014 (0.013)	0.01*** (0.004)	-.197** (0.078)
School holiday, between	-.003*** (0.0007)	-.0009 (0.0008)	0.0001 (0.0003)	0.003*** (0.0007)	-.004*** (0.0008)	-.0007*** (0.0003)	0.005 (0.004)
Transportation strike, within	-.002 (0.026)	-.056** (0.024)	-.036*** (0.011)	0.038 (0.026)	0.016 (0.039)	0.017 (0.012)	-.060 (0.154)
Transportation strike, between	-.008** (0.004)	-.010*** (0.004)	-.004* (0.002)	-.002 (0.003)	-.003 (0.003)	-.001 (0.001)	0.009 (0.013)
High-speed train	0.005** (0.003)	0.014*** (0.002)	0.007*** (0.001)	0.01*** (0.002)	0.006*** (0.002)	0.0008 (0.0006)	0.001 (0.016)
Adverse weather, within	-.050*** (0.015)	-.035** (0.016)	0.008 (0.006)	-.033*** (0.008)	-.006 (0.01)	-.0002 (0.003)	-.019 (0.087)
Panel B: Trade							
Within region	0.078 (0.088)	-.092 (0.075)	0.008 (0.036)	-1.669 (4.315)	-1.381* (0.714)	-.159 (0.81)	
Between regions	0.035*** (0.008)	0.049*** (0.007)	0.009** (0.004)	0.018*** (0.006)	0.029*** (0.007)	0.002 (0.002)	0.026 (0.029)
Panel C: Unemployment							
Within region	-.012** (0.005)	-.008 (0.005)	0.002 (0.003)	0.005 (0.003)	-.014*** (0.004)	-.001 (0.001)	0.004 (0.02)
Between regions	-.014*** (0.003)	0.006* (0.003)	0.009*** (0.002)	0.01*** (0.003)	0.005 (0.004)	-.002** (0.001)	0.018 (0.02)

Table continued on next page.

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Panel D. Within region characteristics							
Temperature (in C)	-.016***	-.027***	-.004***	-.005***	-.005***	-.0004	-.004
	(0.002)	(0.002)	(0.0009)	(0.0009)	(0.001)	(0.0003)	(0.006)
Population density	1.173***	0.701***	-.252**	0.407***	-.164	-.170***	4.440**
	(0.176)	(0.178)	(0.123)	(0.118)	(0.157)	(0.055)	(1.762)
Panel E. Between region characteristics							
Distance (1000km)	0.0008	0.005	0.004*	-.004	-.011***	-.005***	0.019
	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.001)	(0.09)
Population ratio	0.002**	-.0002	0.0009**	0.005***	0.01***	0.002***	0.025***
	(0.001)	(0.001)	(0.0004)	(0.001)	(0.001)	(0.0004)	(0.006)
Log GDP ratio	-.009	0.018**	-.0007	-.0001	0.066***	0.018***	-.051
	(0.01)	(0.009)	(0.004)	(0.008)	(0.009)	(0.003)	(0.042)
Temperature Difference (in C)	0.0002*	0.0009***	0.0002***	0.0001	0.0006***	0.0002***	0.002**
	(0.0001)	(0.0001)	(0.00006)	(0.0001)	(0.0001)	(0.00003)	(0.0007)
Prevalence in Paris	0.046***	0.043***	0.011***	-.007**	-.003	0.003**	0.023
	(0.006)	(0.006)	(0.003)	(0.003)	(0.004)	(0.001)	(0.016)
Observations	24,407	24,407	24,407	18,537	18,537	18,537	17,602
R-squared	0.57	0.73	0.37	0.54	0.67	0.27	0.24

Note: ***, ** and * denotes significance at 1%, 5%, and 10% level. All regressions include region, year and week fixed effects. IV regressions using lagged temperature and precipitation as instruments. Standard errors are corrected for serial and spatial correlation, using a a Prais-Winsten regression, where a region specific AR(1) process is assumed. The model also includes school holidays, transportation strikes, popular gatherings, quarterly dummies and linear trend interacted with the transmission rates, which are not displayed.

Are these policies worth it?

- We evaluate the potential benefits of closing down schools and public transportation.
- We take from the literature accepted costs of sickness. These include:
  - cost of treatment and GP visit.
  - cost of complications and hospitalization.
  - cost of early death.
  - loss of human capital away from school.
  - loss of productivity.
- We simulate the policy for every possible week during the year.

Costs of disease (influenza)

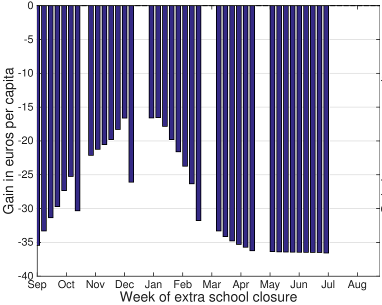
Children	
GP visit (32% chance)	6.68 €
Otitis media (0.28% chance)	17.38 €
Pneumonia (12% chance)	16.45 €
Hospitalisation (0.07% chance)	2.45 €
Hospitalisation (sequelae pneumonia 0.7 per 100,000)	3.61 €
Loss of human capital (3 days off school, 5% return)	99 €
Parent stays home (50% of time, labor market particip. 0.65)	102 €
Value of statistical life	1.3-6 million €
Probability of death	0.7 per 100,000
Cost of death	9-42 €
Adults	
Absent from work (2 days of work at average wage)	78.90€
Reduced productivity (0.7 days at 50%)	13.80 €
GP visit (45% chance)	9.45 €
Hospitalisation (0.04% chance)	1.80 €
Probability of death	4 per 100,000
Cost of death	52-240 €
Elderly	
Outpatient visit	217 €
Hospital	476 €
Probability of death	102 per 100,000
Cost of death	1326-6120 €

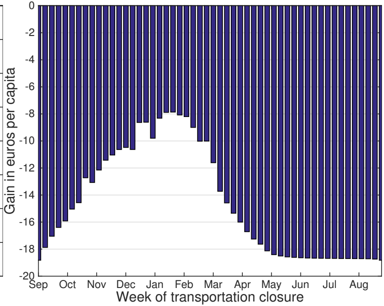
Costs of policy

School closure	
10 days off school, 5% return	350 €
Parent stays home (50% of time, labor market particip. 0.65)	150 €
Public transportation closure	
€400 million per day for 7 days	19 €

Overall cost of Policy

Flu-like Illness. Euros pc





An Economic-Epidemiological Model of Diseases

Joint with Raouf Boucekkine and Josselin Thuilliez

- The SIR model ignores how individuals react to policies and disease prevalence.
- In fact, individual decision plays a crucial role: how much to distance socially.
- Decisions may depend:
    - on beliefs about the effectiveness of measures.
    - on how much time the measures are supposed to last.
    - on how long they have been in place.
    - on severity of enforcement of policies.

An Economic-Epidemiological Model of Diseases

Joint with Raouf Boucekkine and Josselin Thuilliez

- We develop a model where
  - Population is heterogenous
  - Individuals learn about the epidemic and update their beliefs.
  - Individuals decide about how much to move around and mingle with others.
  - Choices are made conditional on their beliefs and policies in place.
  - Policies consist of
    - distance limits
    - duration of lockdown
    - economic compensations
    - fines if policies are not respected.
  - Individual behavioural mobility responses are incorporated into a SIR model with endogenous contact rates.

An Economic-Epidemiological Model of Diseases

Joint with Raouf Boucekkine and Josselin Thuilliez

- Model is calibrated on French data using:
  - Infection and hospitalisation rates,
  - Mobility data at a local level from mobile phone positions,
  - Data on anti-depressant drugs.
  - Changes in policies.
- Allow to better take into account the epidemic, and in particular its long-run effect.
- More complex setting for the evaluation of cost-effective measures.

Conclusion and further research

- Many pitfalls in evaluating policy measures in the context of epidemics. Difficult exercise.
- Cross-disciplinary issue.
- Given the urgency, immediate focus is on short-term measures.
- Scope for longer term considerations as well: role of infrastructures, role for health related human capital.
- How to make our societies more resilient to diseases?