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The Avian Flu Disease: A Case of Precautionary Failure

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Abstract -The Precautionary Principle has been proposed as the proper behaviour to adopt in the face of the new catastrophic risks that have made their appearance in the last decades. We advance a workable definition of the Precautionary Principle and apply it to the possible outbreak among humans of the avian flu disease. We make use of a Principle-Agent model and show in which sense such outbreak can be considered a "Precautionary failure".

JEL classification: D81, I18, K32

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Introduction

In September 2004, Thai and senior officials of the World Health Organization (WHO) announced the first documented case of human-to-human transmission of the A(H5N1) virus, more widely known as the *avian flu,* in a family cluster of cases. In Bangkok a 26-year-old woman died of avian flu after having contracted the disease from her daughter. The avian flu has been known for more than a century now and its victims have been until very recently only birds.

The extremely worrying news of September 2004 marks a new era and opens before us terrifying scenarios with lethal forms of avian flu readily transmissible among humans. According to scientists and health authorities, we are facing the possibility of a global pandemic that could cause millions of deaths among humans, principally children. This nightmare, that recalls the Spanish flu, might have been avoided. In due time it was possible to develop a vaccine against human avian flu, and to produce a sufficient quantity of specific antiviral to reduce side effects of the disease. Why this has not happened? Would a rational decision rule have led to a different course of action?

The Precaution Principle (PP, henceforth) - which has become worldwide known after the Rio Conference in 1992 - has been advocated as the right response to a whole series of new catastrophic risks (global warming, genetically modified food, unknown diseases such as AIDS) to which the avian flu disease can now be added. Crucially, our knowledge in these areas is very limited so that most of the rational decision models are inapplicable. This partly explains why there has been such an intense debate about the proper interpretation of the PP, its consequences and limits of application.

In this paper our aim is twofold. On the one hand, we want to give a precise interpretation of the PP as a guide to rational behaviour in the presence of uncertainty on the occurrence of catastrophic events. On the other, we want to show that a timely application of the principle might have avoided the nightmare of a global pandemic that now looms before us. To clarify the latter point we will make use of a Principal-Agent model, where the Principal abides by the PP but has to motivate the Agent – who will not bear the likely negative consequences of his choices - to carry out the best action.

The paper is organized as follows. A description of the origin and diffusion of the avian flu and its economic and social consequences are in Sections 2 and 3. Section 4 clarifies our interpretation of the PP. The Principal-Agent model is presented in Section 5. The paper ends with some concluding remarks.

2. The Avian Flu: Origin and Diffusion

The avian influenza was first identified in Italy more than a century ago. It is an infectious disease of birds and is by now spread worldwide. There are three types of avian influenza virus called A, B and C. Types B and C are less aggressive. Virus B can cause human epidemics, but does not cause pandemics while virus C causes mild illness in humans but not epidemics or pandemics. Virus A can infect humans and animals.

Wild birds are the most prone hosts for this virus and domestic poultry, such as turkeys and chickens, can get very sick and die from type A flu.[1] Among the avian influenza virus subtypes, H5N1 is the worst: it mutates rapidly and acquires genes from viruses infecting other animal species. The virus H5N1 not only affects the respiratory tract but damages liver and kidney of infected humans and hurts central nervous systems in ferrets and some birds. Illness is characterized by fever, myalgia, severe malaise, rhinitis, otis, nausea and vomiting.

Despite its seriousness, the avian flu did not raise alarm until there was no doubt or proof that the virus could be contracted by human beings and, more worryingly, be transmitted from human to human.

Until 1997 scientists believed that the avian flu virus could not be directly transmitted to humans. The mediation of mammals such as pigs was considered necessary.[2] It has been documented that bird flu had jumped onto pigs in Vietnam in 2004. Indeed since as early as 1997 many signs have been accumulated that human beings are exposed to this terrible virus.

The first time avian influenza A(H5N1) infected both humans and poultry and transmitted itself from the latter to the former in Hong Kong in 1997. About one and half million chickens were killed, eighteen persons were infected and six of them died. The destruction of almost the entire poultry population in Hong Kong is believed to have prevented the risk of a pandemic. In 1999, again in Hong Kong two cases of avian influenza A(H9N2) were found in humans. In that same country similar cases where detected in February 2003 when one person died of A(H5N1) after a travel to southern China. In 2003 avian flu A(H7N7) infected poultry workers and their relatives (80 persons) and killed a person in the Netherlands. In mid-December 2003 epidemic flu A(H5N1) started from the Republic of Korea and spread to other Asian countries, infecting humans in January

[1] Influenza type A viruses are classified into two main classes on the basis of the proteins on the surface of the virus (HA- hem agglutinin and NA-neuraminidase). Fifteen subtypes of influenza virus are known to infect birds, but all outbreaks of the highly pathogenic form have been caused by influenza A viruses of subtypes H5 and H7. Influenza viruses can change by antigenic drift (continuous small changes over time) or by antigenic shift (combination of one or both proteins in a form that has not been detected in humans).

[2] The great influenza pandemic known as Spanish flu, which occurred between 1918 and 1920 and caused around 50 million deaths, was so lethal because after the jump from birds to pigs both human and avian viruses swapped genes as the viruses reproduced.

2004 in Vietnam. The virus affected 10 countries in Asia and has infected humans in Vietnam and Thailand. By the end of January 2004 more than 100 million birds had been culled and 108 human cases, 54 of which were fatal, of the avian flu were recorded.[3]

The United Nations defined the epidemic of avian flu among poultry in Asia a crisis of global importance and the U.S. Department of Agricultural banned the import of all birds (class aves) from: Cambodia, Indonesia, Vietnam, Thailand, Japan, Malaysia, People's Republic of China, Hong Kong SAR, South Korea.

Several suspect cases were reported but there was no evidence of human-to-human transmission of the virus. For instance, two sisters in Vietnam who died of the disease probably infected by their brother and similar cases are believed to have taken place in Hong Kong. Indeed, until summer in 2004, scientists did not believe the A(N5H1) virus could spread from one person to another even if they feared that it could mutate into a subtype form readily transmissible to humans.[4]

Unfortunately, in September 2004, the first documented case of transmission of the virus A(H5N1) from humans-to-humans was announced and the consequences of this event may be terrifying.[5]

3. Terrible Risks and Inadequate Precautions

Looking at historical evidence, scientists warn that during each century influenza pandemics may happen three or four times. In the last hundred years there have been three cases of varying seriousness: the Spanish flu of 1918-1919, the Asian flu of 1957-1958 and the Hong Kong flu of 1968-1969. The chances that the avian flu may spur the fourth pandemic in a century are not nil.

There are no reliable estimates of the cost of a possible pandemic A(H5N1) flu among humans, but if public health systems around the world warn about high morbidity and the severe rate of decease, we can assume that they could be catastrophic, beyond any conceivable nightmare. Even if there is no evidence of the virus spreading outside the family cluster to other humans, the WHO warned of a potential pandemic should the A(H5N1) strain of avian flu mutate and increase

[3] "That includes 17 cases with 12 deaths in Thailand, 87 cases with 38 deaths in Vietnam and 4 cases all of them fatal in Cambodia (June 2005). The majority of these cases involved individuals who had direct contact with sick or dead poultry. The majority of H5N1 cases involved children or young adults. The H5N1 viruses isolated from both poultry as well as humans are resistant to the antiviral drugs amantadine and rimantadine, but they are susceptible to oseltamivir.

[4] In April 2004, the Health Service reported that a man, who had never been in direct contact with poultry, in Westchester County (NY) contracted the A(H5N1) virus during the autumn.

[5] Pranee Korngkaew, a 26-year-old woman died on September 20. Thailand's Disease Control Department confirmed that the young woman had the A(H5N1) virus, but said that she was not known to have come into contact with suspicious birds. What is known is that this month she went to see her 12-year-old daughter, Sankuntala, who died in hospital on September 12 in the northern Kamphaengphet province. Both Sakuntala and her 32-year-old aunt, with whom she had been staying, had contact with dead chickens, the WHO reported. Sakuntala's mother, her aunt, and her 6-year-old cousin had the A(H5NI) virus.

its ease of transmission, as in the case of Severe Acute Respiratory Syndrome[6] (SARS). Now the WHO is more concerned about the chance that the A(H5N1) influenza virus develops the ability to spread easily among people, and whether it will remain extremely lethal. If the virus A(H5N1) acquires the ability to increase its rate of infection it will have the potential to kill more humans world-wide than AIDS has killed in the last 25 years. According to conservative estimates by the WHO, there could be from two to seven million human deaths, but no one can say what could be the real effects of the outbreak of a highly infective avian influenza virus subtype.[7]

As far as birds are concerned we have some rough estimates of the costs involved and in particular of the market impact of the recent spread of avian flu in the Asian region, which hosts 40% of the world's chicken population. The principal measure to control an outbreak of A(H5Nl) in birds is the culling of sick and exposed birds. To date many countries have banned imports of poultry from risky countries, like Thailand and China. This makes for an increasing demand for the poultry of other producers (USA, Brazil and EU) and inevitably leads to higher international prices with sensible effects on the welfare of consumers.

Thai poultry exports are estimated at US $1 billion and Chinese poultry exports are around 500,000 tonnes for a total value of US $900 million. The epidemic cost Vietnam's poultry industry about US $192 million and 5,000,000 chickens have been culled in Korea. In Taiwan and Japan 1 million chickens were culled. It is necessary also to consider that the estimates of the Food and Agriculture Organization (FAO) about the effects for global animal feed markets are close to those of the mad cow disease.

There are other relevant economic effects of the avian flu outbreak: it could affect services-related businesses, such as tourism, and the domestic demand for restaurants and other outlets, with an economic damage of tens of billions of US$. A conservative estimate of the general economic damage induced by a pandemic of avian flu disease only in Asia set the total cost at US $130 billion (New York Times November 30, 2004).

In this scenario, health services recommended as a precautionary measure huge stockpiling of vaccines and, as a second best line of defence, of antiviral medicines. Indeed, in the case of the A(H5N1) virus the two main antagonists to its pandemic are vaccine and antiviral medicines. Conventional flu vaccines are not believed to act against avian flu. Only a few biotechnology firms have the skills and advanced genetic technology to develop proper vaccines; among them Aventis

[6] Severe acute respiratory syndrome (SARS) is a viral respiratory illness caused by a corona-virus. SARS was first reported in Asia. According to the WHO, 8098 people worldwide became sick during the 2003 and 774 of them died.
[7] A human flu pandemic could cause 20% of the world population to become ill and within a few months close to 30 million of people would need to be hospitalized, a quarter of whom would die (Stahr and Esveld 2004).

Pasteur Inc. of Swift Water, Pennsylvania, the Chiron Corporation of Emeryville, California and Sinovac Biotech Ltd. of Beijing, China.

Unfortunately only one antiviral medicine, Tamiflu (i.e. oseltamivir phosphate), works against the flu. It is effective only if it administrated within 36 hours from the symptoms of contagion. Tamiflu is a product of the Roche Group, Switzerland, which holds exclusive manufacturing rights. Its retail price is $ 106/112 for a 10-capsule (75 mg) treatment course for one adult.

The WHO and other national health institutes report an extremely short supply of Tamiflu. In fact, it will be very hard to face a possible pandemic of avian flu, since no country has a stockpile adequate for treating human-to-human transmission of avian flu. The steps taken so far have been untimely and inadequate. Given this scenario, the spectrum of the terrible plagues of the three others pandemics in the last hundred years, which caused a lot of dead among humans, has begun to materialize.

The crucial question is: why are antidotes in such short supply?

Senior WHO officials have strongly criticized vaccine manufacturers,[8] because they decided to develop vaccines against A(H5N1) only after receiving contracts from the U.S. National Institute of Health.[9] Aventis and Chiron are scheduled to deliver (probably) the first experimental vaccines during 2005 but have no plans for mass producing the vaccine, while Sinovac Biotech signed an avian flu vaccine co-development agreement with the China Centers of Disease Control and Prevention only on 16 December 2004. Similarly, Roche seems not to have invested heavily to expand the production of Tamiflu. To the best of our knowledge, Tamiflu is made only at a small factory in Europe, but plans have been made for another plant in the U.S.A.. Roche answered its critics saying that Tamiflu has been produced in the quantities demanded by the market. Indeed stockpiling costs and uncertain demand have kept production in check. A further obstacle is represented in both cases by the sunk cost implicit in specific research. Moreover, national authorities planned to stockpile only a modest quantity of effective drugs, also because they did not want to run the risk of over-reaction, as in 1976, when 45 million Americans were vaccinated against a specific subtype of flu that did not occur.[10]

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[8] Reported by the International Herald Tribune September 30, 2004.

[9] The National Institutes of Health awarded Chiron Corporation a $1.194 million contract to develop up to 40,000 doses of vaccine against the H9N2 avian influenza (August 17, 2004) and HHS announced the awarding of a contract to Aventis Pasteur Inc. to manufacture and store 2 million doses of the avian influenza H5N1 vaccine. The amount of the contract is nearly $13 million (September 21, 2004).

[10] The Centers of Disease Control and Prevention (CDC) of the Department of Health and Human Services (HHS), one of the main government agencies, has created an initial stockpile of 2.3 million treatment courses of oseltamivir to which more doses will be added.

As a result, despite its technical superiority even "the US faces a major shortfall in manufacturing the right vaccine and in stockpiling anti-influenza drugs. An estimated 89.000 to 207.000 Americans will die in the next pandemic" (D. Ho 2005, 422). This scenario induces to think in term of the failure in the application of the PP, which may be imputed to the whole set of institutions - public and private – in charge of human welfare at large. Several questions arise in this respect: which would have been an ex ante rational course of action? Which role should the several institutional actors have played in this rational action? Which specific features of the avian flu make a precautionary policy particularly difficult to define and implement?

In the following sections we take up these issues and provide a general framework where they can be treated analytically. Such framework is characterized by lack of certainty on several crucial aspects of the phenomenon, which makes it appropriate to base the analysis on the notion of ambiguity. As we have already seen in the avian flu case there was ambiguity about the possibility of human-to-human transmission of the avian flu, about the morbidity of the A(H5N1) virus, about the subtype of influenza[11] and, finally, about the A(H5N1) ability to spread among people. Our problem is, first of all, to define a rational decision-making process in the presence of ambiguity and to single out, within the set of rational decisions, those which embody a precautionary attitude.

Another crucial feature of our framework is the presence of agency problems. As we have seen, market signals are unreliable as a precautionary guide. Therefore, it is necessary to set up an institutional system whereby the Principal (represented by the government) enters into a contractual relation (broadly defined) with the Agent (pharmaceutical industry) in order to make the latter's behaviour with respect to the production of vaccines consistent with the requirements of a truly precautionary course of action. Our first step is to clarify some important aspects of the precautionary principle itself.

4. The Precautionary Principle: A Suggested Interpretation

The PP has been the subject of intense discussion among scholars in different fields and policy makers. As a consequence, opinions about its relevance in policy-making vary markedly. Some people think that the PP is a misguided concept for regulating human activities, since it induces innovation and technology-development aversion among human beings. On the other hand, many environmentalists and politicians see the PP as the only protection against the many human activities that may endanger public health and the environment. Such conflicting views are due, at

[11] There are two subtypes of avian flu: Highly Pathogenic (HPAI), associated with high mortality in poultry (kills 90 to 100% infected chickens), and Low Pathogenic (LPAI), less severe or no illness in poultry.

least to some extent, to the lack of a well-defined and widely-agreed definition of the principle itself.[12]

To put some order in such a messy field it has been suggested that a distinction should be made between a strong and a weak version of the PP. Unfortunately, neither version is fully satisfactory, mainly because they both fail to take seriously the issue of what rationality implies in the presence of uncertainty and irreversibility.

The distinguishing element of the strong version is the reversed burden of proof (Morris 2000, Sunstein 2003, Löfstedt 2004): in practice, no action should be taken unless the actor – usually a firm – has demonstrated beyond any reasonable doubt that no harm will result. A margin of safety should be guaranteed in any decision: "better safe than sorry", as Sunstein (2003, p. 9) puts it.[13]

However, the logical consequence of imposing a condition (certainty that no harms will follow) that in the given conditions (lack of full certainty) can never be fulfilled is to block almost any activity. In particular, human beings should refrain from using new technologies (no new technology is completely safe), giving up the benefits that such technology may bring about. As Wildasky (2000) has stated, the search for trials without errors, which the strong PP seems to encourage, may lead economic progress to a complete standstill.

The weak PP basically states that lack of full certainty is not a justification for preventing an action that might be harmful. On the other hand regulation can be justified even if we cannot establish a definite connection between, for example, low-level exposure to certain carcinogens and adverse effects on human health (Morris 2000, p. 8). It would be rather disappointing to interpret the weak PP in terms of placing the burden of proving harm on the regulator, for we would reach an equally unrealistic conclusion as in the case of the strong version: since it is impossible to achieve certainty on harmful effects, any action shall be tolerated. A more convincing interpretation of the weak version is that regulation is admissible also when negative effects are uncertain. Unfortunately, it is not clear on the basis of which elements such decision should be taken. The conclusion to be drawn seems to be that everything is possible - uncertainty is neither necessary nor sufficient for regulation or *laissez faire.*

To make the PP a reliable guide to policy making, two problems should be addressed – both of which have received only limited attention.

As to the first problem we should make it crystal clear that the PP refers to situations characterized by uncertainty (more precisely: scientific uncertainty), irreversibility and catastrophic

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[12] According to Sandin 1999 (quoted by Löfstedt 2004, p. 10) there are at least 19 definitions of the PP. Majone (2002, p. 93) reminds us that also for the original German principle there are no less than eleven interpretations.
[13] See also European Commission (2001).

events. Therefore it is necessary to clarify what rationality entails in such situations and to suggest an interpretation of the PP as a specific rational behaviour. We have analyzed this problem in full detail elsewhere (Basili and Franzini 2005). Here we recall the main points of our interpretation.

Rationality requires making use of all available information, but when uncertainty prevails the available information is basically of the type Ellsberg pointed out with his paradox (Ellsberg 1961). In particular people attach different weights to various probability distributions. Under such conditions subjectivity is all too important and rationality is compatible with a broad range of decisions. As a consequence the PP can be seen as a criterion for selecting one of them. Interpreted in this way the PP is neither coincident with rationality nor in conflict with it. Rather it complements rationality as a normative criterion.

In our interpretation to behave "precautionally" means acting on the basis of a large weight given to the worst probability distribution one can be aware of, given the available information. The quasi-option value can be a good measure of precaution so defined and may help us to understand what its "cost" is. Attaching a positive value to quasi-options is a sign of cautious behaviour and of confidence that scientific progress and accumulation of knowledge make postponing decisions worthwhile.

In a nutshell, precaution implies that dangers are taken as seriously as possible into account or we could also say that "early warnings" are given utmost attention.[14] Despite this, catastrophes are nonetheless possible in the future and a reason is that individual preferences may lead to a not-too-cautious behaviour in the present.

There are good reasons to believe that the terrible risks associated with the avian flu are the result of a failure in the application of the precautionary principle so defined. In the next section we set up a model which helps to understand what precaution would have suggested in particular with respect to the production of vaccines.

5. Incentive Contracts, Agency Problems and the Precautionary Principle: An Application to the Avian Flu

At the origin of this very critical and dangerous situation there is a series of mistakes and bad judgment on the part of the agents who are in charge of social safety and the pharmaceutical firms. In fact, national governments did not introduce "financial and economic incentives – including fair pricing, guaranteed purchase of unsold supplies, tax incentives …… [and] pharmaceutical companies are reluctant to enter or remain in the business of manufacturing

[14] The importance of "early warnings" is stressed in the volume by Harremoës and Gee (2002). To behave as an ambiguous adverse agent is, in our view, the best (or, probably, the only) manner for giving proper consideration to those pieces of information which are "early warnings".

vaccines – unpredictable consumer demands and lack of financial incentives make vaccine manufacture a risky business" (Fauci 2005, 424).

In our view the avian flu disease is an evident and seminal case in which the PP had to be applied. The production a specific vaccine against the A(H5N1) is to be analyzed in the context of an agency contract under ambiguity, where the WHO and National Health Services are the Principal and pharmaceutical industry is the agent. On the other hand, the production of a sufficient quantity of antiviral drug Tamiflu can be considered as a problem of minimum cost implicit in the option value of avoiding the side effect of an outbreak of the disease.

We will analyze in depth the first problem, while only a few comments on the second are in order.

Tamiflu is a drug that ex-ante everyone knows to be effective and efficient against the side effects of the disease. Roche produces Tamiflu at $ 106/112 a course. Public Authorities (PAs) have a dual choice: buy a sufficient quantity of drug or wait for the *animal spirits* action to define an efficient market equilibrium for Tamiflu. PAs face ambiguity, about the possible outbreak of avian flu, and irreversibility, about the possibility to have a stockpile adequate for treating a human-to-human transmission of avian flu. If PAs only consider their attitude toward risk, the PP would imply a larger demand of Tamiflu if and only if their maximum possible consumer surplus is at least equal to $106/112 a course. PAs implement the notion of the PP related to the plain option value[15] and abstain from buying. If PAs had applied the notion of the PP related to ambiguity, they would have acted considering their ambiguity attitude. Under this scenario, PAs cannot replace ambiguous random variable by their certainty equivalent expected values[16], on the contrary PAs[17] would have considered the quasi-option value involved in the production of a large stockpile of Tamiflu. The quasi-option value determined in light of the economic cost of the avian flu outbreak would have been larger than the retail cost of Tamiflu, resulting in a large stockpile of antiviral drug.

Let us now analyze the vaccine problem. Unlike the standard framework (Grossmann and Hart 1983; Hart and Moore 1988, 1999; Maskin and Tirole 1999) of incentive contracts in an agency setting, where individuals have a complete and fully reliable description of all future possible states of nature, the avian flu case is characterized by ambiguity. Knowledge of the A(H5N1) virus is ambiguous and there are no reliable measures of the probability of the magnitude of its diffusion among humans. There is ambiguity because the individuals have a perception of

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[15] Plain option value is the maximum consumer surplus and it depends on attitude toward risk and irreversibility.

[16] In a two-stage (present and future) model the certainty equivalents are the Choquet expected value of the net benefit of not acquiring Tamiflu now and the net conditional expected benefit of not acquiring Tamiflu in the future. For detail see Basili1998.

[17] Pessimism is referred to the possibility of the avian flu outbreak, i.e. the pandemic.

incompleteness, i.e. they are aware that there could be unforeseen contingencies.[18] As a result, incentive contracts have to include such unforeseen contingent events. A generalized principal-agent model is set up to this end.

5.2. *A principal-agent model under ambiguity*

Imagine that the government (Principal) has to maximize its utility, which depends on the quantity or quality (broadly defined) of a vaccine produced by the pharmaceutical industry (Agent)

Let $u(\phi) = \phi$ be the Principal utility (risk neutrality), with $\phi \in [\phi°, \phi^*]$ a low and high quantity of vaccine, respectively, that is $\phi°$ can be considered at most a very low quantity of vaccine or an improper vaccine and ϕ^* at least a very high quantity of proper vaccine. Let e be the Agent's effort level which can take two values only: e^* (high effort) or $e°$ (low effort), with e^* resulting in a higher quantity of vaccine for the principal than $e°$ (low effort). For the sake of simplicity, e° is normalized as zero and e* as a positive effort of one, that is $e = \{0,1\}$. Since the effort is not observable, the relationship between the Principal's utility and the Agent's effort level is described by the conditional density function $f(\phi|e)$, with $f(\phi|e) \geq 0$ for all e and $\phi \in [\phi°, \phi^*]$, all of which are information consistent. It is assumed that the cumulative distribution function $F(\phi|e^*) \leq F(\phi|e°)$, for all $\phi \in [\phi°, \phi^*]$, with strict inequality for some ϕ, this implies that the expected utility of the Principal given e^* is larger than $e°$.[19] The Agent is risk-averse, with a utility function u(π) where $\pi(s,e) = v(s) - \gamma(e)$, such that $v(s)$ is the revenue and $\gamma(e)$ represents the effort cost and $\gamma(e^*) > \gamma(e°)$, in this case $\gamma(e°) = \gamma_0 = 0$ and $\gamma(e^*) = \gamma_1 = \gamma$. The Agent's utility increases with s and decreases with e, at a decreasing rate; moreover $\pi(s,e°) > \pi(s,e^*)$ for all s.

For the sake of simplicity we assume that there is a National Health Service that offers the vaccine to all the citizens and $s(\phi) = v(s)$.

There is a conflict between the target of the Principal and the purpose of the Agent. Given unobservable effort and ambiguity attitude (aversion or seeking) because of partial knowledge of the avian flu disease[20], the Principal's optimal contract solves the following problem:

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[18] See Henry and Henry 2002.

[19] $F(\phi|e^*) \leq F(\phi|e°)$ implies first order stochastic dominance.

[20] Ambiguity attitude is expressed by the so-called *α-maxmin* form (*α*-MEU) that has been axiomatized in Ghirardato Maccheroni and Marinacci (2004). It can be represented as:

$V(f) = \alpha \max_{\pi\in\Pi} E_\pi(u \circ f) + (1-\alpha)\min_{\pi\in\Pi} E_\pi(u \circ f)$ where f is an act, Π is a set of additive probability distributions and ambiguity attitude may be varied parametrically with α. The *α*-MEU approach generalizes the E-capacity approach of decision-making under ambiguity.

$$Max_{s(\phi)}\{\rho\int_{\phi^\circ}^{\phi^*}(\phi-s(\phi))f(\phi|e)d\phi+(1-\rho)\min_{s(\phi),f(\phi|e)}\int_{\phi^\circ}^{\phi^*}(\phi-s(\phi))f(\phi|e)d\phi\} \quad [1]$$

such that

$$(i)\int_{\phi^\circ}^{\phi^*}\psi(s(\phi))f(\phi|e)d\phi-\gamma(e)\geq\bar{u}$$

$$(ii)Max_{\bar{e}}\int_{\phi^\circ}^{\phi^*}\psi(s(\phi))f(\phi|\bar{e})d\phi-\gamma(\bar{e})$$

The condition (*i*) is a *participation constraint*, which exhibits the Agent's expected utility to be at least equal to his reservation utility level $\bar{u}$, while the condition (*ii*) is an *incentive constraint*, which assures the Agent's optimal effort level *e*, under the compensation scheme $s(\phi)$.

Since the contract specifies effort level *e*, choosing ϕ to maximize [1], it is assumed that the Principal has to minimize the expected value of Agent's payment, that is

$$Max_{s(\phi)}\{\rho\int_{\phi^\circ}^{\phi^*}-s(\phi)f(\phi|e)d\phi+(1-\rho)\min_{s(\phi),f(\phi|e)}\int_{\phi^\circ}^{\phi^*}-s(\phi)f(\phi|e)d\phi\} \quad [2]$$

or

$$Min_{s(\phi)}\{\rho\int_{\phi^\circ}^{\phi^*}s(\phi)f(\phi|e)d\phi+(1-\rho)\max_{s(\phi),f(\phi|e)}\int_{\phi^\circ}^{\phi^*}s(\phi)f(\phi|e)d\phi\} \quad [3]$$

such that

$$(i)\int_{\phi^\circ}^{\phi^*}\psi(s(\phi))f(\phi|e)d\phi-\gamma(e)\geq\bar{u}$$

$$(ii)Max_{\bar{e}}\int_{\phi^\circ}^{\phi^*}\psi(s(\phi))f(\phi|\bar{e})d\phi-\gamma(\bar{e})$$

Let us consider the case in which the Principal wants to induce effort level *e**. The constraint (*ii*) can be written as:

$$(iii)\int_{\phi^\circ}^{\phi^*}\psi(s(\phi))f(\phi|e^*)d\phi-\gamma(e^*)\geq\int_{\phi^\circ}^{\phi^*}\psi(s(\phi))f(\phi|e^\circ)d\phi-\gamma(e^\circ) \quad [4]$$

Consider the problem [2] and assuming that the co-state variables are strictly positive[21], $s(\phi)$ must to satisfy the first order condition

$$\rho\{-1)f(\phi|e^*)+(1-\rho)(-1)f\hat{}(\phi|e^*)+\lambda\psi'(s(\phi))f(\phi|e^*)+\mu\psi'(s(\phi))[f(\phi|e^*)-f(\phi|e^\circ)]=0$$

Where $f\hat{}(\phi|e^*)$ is the minimum conditional density function with respect to e* in the information consistent set.[22] Dividing by $f(\phi|e)\Psi(s(\phi))$, the first order condition becomes

[21] Co-state variables equal to zero are either impossible or induce the violation of the constraints.

$$\rho(-\frac{1}{\psi'(s(\phi))}) + (1-\rho)(-\frac{1}{\psi'(s(\phi))}\frac{f^{\wedge}(\phi|e^*)}{f(\phi|e^*)}) + \lambda + \mu[1-\frac{f(\phi|e^\circ)}{f(\phi|e^*)}] = 0 \qquad [5] \qquad \text{or}$$

$$\frac{1}{\psi'(s(\phi))}[\rho + (1-\rho)\frac{f^{\wedge}(\phi|e^*)}{f(\phi|e^*)}] = \lambda + \mu[1-\frac{f(\phi|e^\circ)}{f(\phi|e^*)}] \qquad [6]$$

As a consequence, the wage varies with ρ and it can decrease or increase when ρ increases. Consider the case in which ρ=1, then

$$\frac{1}{\psi'(s(\phi))} = \lambda + \mu[1-\frac{f(\phi|e^\circ)}{f(\phi|e^*)}] \qquad [7]$$

When ρ=0, then

$$\frac{1}{\psi'(s(\phi))}\frac{f^{\wedge}(\phi|e^*)}{f(\phi|e^*)} = \lambda + \mu[1-\frac{f(\phi|e^\circ)}{f(\phi|e^*)}] \text{ or } \frac{1}{\psi'(s(\phi))} = \frac{f(\phi|e^*)}{f^{\wedge}(\phi|e^*)}\{\lambda + \mu[1-\frac{f(\phi|e^\circ)}{f(\phi|e^*)}]\} \qquad [8]$$

The above results show that the optimal wage depends on the Principal's ambiguity aversion. In order to grasp the meaning of this result one should bear in mind that, on the basis of our assumptions, the higher effort e^* is optimal also when the Principal ignores ambiguity or has a less pessimistic attitude. Therefore, the change in the wage function does not have the goal of inducing effort e^* whereas the lower effort e° would be chosen with less pessimistic probabilities or disregarding ambiguity.

Due to ambiguity, it may very well happen that the more pessimistic probabilities alter the expected utilities attached by the Principal to different ϕ. This in turn implies that in order to maximize her utility the Principal will associate higher or lower wages to the various observed results.

Comparing equations [6] and [8] it comes out that when the Principal is ambiguity-averse (ρ=0), the optimal wage is lower (respectively higher) than the compensation paid when the Principal ignores ambiguity if $f^{\wedge}(\phi|e^*) > f(\phi|e^*)$, (respectively $f^{\wedge}(\phi|e^*) < f(\phi|e^*)$). Roughly speaking, under ambiguity aversion the Principal will pay less for 'bad outcomes', which are more likely given $f^{\wedge}(\phi|e^*)$ than given $f(\phi|e^*)$. Instead, she will pay more for 'good outcomes', which are more likely given $f(\phi|e^*)$ than given $f^{\wedge}(\phi|e^*)$.

[22] If the set of possible probabilities only includes singleton there is no ambiguity and the degree of confidence does not matter.

6. Concluding Remarks: The Agency Costs of Precaution

As other authors too have stressed (Gollier and Treich 2003), there are very good reasons for believing that the market will never be the right institution for carrying out a precautionary course of action. In this paper we have shown that in the avian flu case, as in many similar cases, the Government should sensibly apply the PP and should also bear the costs of inducing private Agents to behave in accordance with the principle. In particular it should negotiate with a self-committed industry whose actions are, however, of decisive importance for the actual implementation of the PP. As we have already noticed, leaving it up to the market would not work.

That said we should ask why it is so difficult both to build up an institutional setting more suitable to precaution and to make it work according to the basic recommendations of the principle itself. Regardless of the awareness of the various actors, the cost issue is to be seriously considered. Our model cannot rule out the possibility that in some specific circumstances the cost to be borne in order to motivate the Agent to choose the high effort is so high as to discourage also the most precaution-oriented Principal. Several elements may combine in this result, especially those that determine the way in which the immediate benefits of a less than precautionary behaviour are shared among the different subjects. In this light precaution is also a distributive issue. However, leaving this problem aside, we can draw from our model some important implications as to the costs of the incentive scheme. In particular we can go into the issue whether being averse to ambiguity implies necessarily higher agency costs.

Unlike Grossman and Hart (1983), who prove that the incentive scheme is not monotonic with more than two outcomes, our model shows that, even if there are only two outcomes, higher profits for the Principal will not imply higher payments to the agent.

This means that ambiguity aversion does not systematically cause a higher amount of agency costs, by a non-monotonic incentive scheme. What is crucial is how the probability of good and bad outcomes changes when it is evaluated on the basis of the worst distribution.

Therefore behaving in a more precautionary way does not systematically implies higher costs. This rather counterintuitive result may help to give wider currency to precautionary behaviour. Its main thrust is that what matters most is how the incentive scheme is designed: a good design can guarantee low agency costs. This means that a possible obstacle to a more cautious attitude is not necessarily difficult to surmount. What really matters is to implement a set of institutions which are aware that behaving precautionally means giving the highest weight to the worst knowable probabilities and are able to have societies pay the costs implied by such behaviour.

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