The Economics of upgrading to innovative treatment technologies in the fight against HIV/AIDS

Patrick L. Leoni

Abstract. We argue that current funding campaigns to fight AIDS in developing countries fail to recognize significant losses associated with the introduction of innovative treatment technologies. For instance, the future albeit uncertain appearance and widespread use of a therapeutic vaccine will trigger significant and unrecoverable losses in current drugs treatment investments. Our objective is then two-fold. We first document losses associated with the transition to better treatment technologies and we show that failure to hedge against such losses leads to sub-optimal policies. Our second objective is to provide policy recommendations to alleviate this problem. We show how to transform some cutting-hedge financial products to generate full insurance coverage against such losses, and in some cases how to achieve full risk-sharing with agencies developing innovative treatments. We recommend that every funding campaign in current AIDS treatments be accompanied with the provision of such insurance against the cost of switching to future albeit uncertain innovative treatments.

1. Introduction

The epidemic of HIV/AIDS has been one of the most significant medical crises worldwide in the last few decades. It turns out that the epidemic has mostly spread in developing countries, for instance in Sub-Saharan Africa where the share of HIV infected individuals represents 5% of the population in 2007 (see UNAIDS 2007). Given the magnitude of the epidemic, both governmental and international interventions are necessary to contain and eradicate the disease. The shocking consequence is that developing countries face not only a medical crisis, but also an economic crisis since a significant fraction of national GDP must be allocated to fighting the disease. For instance, Nigeria has allocated 1.2% of its GDP in 2005 to fight HIV/AIDS only (see Hickey 2005), a colossal amount of national resources that no country can forfeit without severe consequences on its economic development. Moreover, the spread of the disease triggers an increase in AIDS-related spendings over time; for instance, the percentage of health expenditures devoted to HIV/AIDS has switched from 0.8% to 7.8% between 2001 and 2005 in South-Africa (see Hickey 2005).

International agencies such as the United Nations, the GAFTAM and the G7 have provided significant subsidies and expertise to developing countries to help them contain and eradicate the disease. A total of about US$ 8.3 billion have been spent in 2005, about US$ 8.9 billion and US$ 10 billion in 2006 and 2007 respectively (see Leoni and Luchini, 2006). Nevertheless, those subsidies are

nowhere close to being sufficient to meet the medical needs, and a significant part of the economic burden still remains on the developing countries.

In the situation of insufficient resources that developing countries face, the need to prioritize medical interventions and to identify optimal economic policies to fund them becomes critical. So far, economic policies have focused on two distinct objectives. The first objective is to foster investments in current treatment technologies such as field delivery of already-available ARV treatments; the second one is to allocate funds, entirely coming from developed countries, to develop innovative treatment technologies such as therapeutic vaccines (see Klausner et al., 2003).

In this study, we argue that those two policies are antagonistic, and thus inefficient, because they fail to address the severe inefficiencies associated with the transition to future albeit uncertain innovative treatment technologies. In a first step, we show that the development of innovative treatment technologies is a deterrent to current investments in available technologies. The basic idea is that the optimal reaction of developing countries, when facing the risk of forfeiting a significant part of current investments during the transition, is to postpone those investments until more information becomes available about the time of their obsolescence. This finding is consistent with reports of reluctance to invest in current treatment technologies in some African countries (see UNAIDS, 2004, p.11). Second, we show that the availability of insurance contracts allowing developing countries to hedge against the severe losses resulting from the appearance of an innovative treatment (a therapeutic vaccine for instance) must be a full component of every optimal policy in the fight against HIV/AIDS. We also explain why standard insurance contracts cannot be used for this type of risk, and we describe two distinct ways of efficiently replicating the desired hedge using recent financial products such as exotic options.

The deterrence to invest in current treatment technologies is briefly explained as follows. As documented in Section 2, therapeutic vaccines currently developed are more effective both at medical and economic levels. It is commonly agreed that the therapeutic vaccine will eventually become available, although the time of availability is uncertain. Current treatment technologies such as ARV treatments would then become immediately obsolete after the appearance of such vaccines. Moreover, new financial efforts would be needed to implement the innovative technology. The abandonment of the obsolete technology nevertheless implies to forfeit unrecoverable previous investments; those losses are particularly severe and are documented in Section 3. The social cost of those losses triggers severe crowding-out effects on every other public expenditures; that is, those unrecoverable AIDS-related expenditures tend to

decrease public investments in other essential activities of a country life such as schools, roads et.c. (see Harling et al., 2005). It turns out that an insurance contract available at the time decisions to invest in current treatments are made, and allowing to hedge against the losses resulting from the upgrading, is the most efficient way to alleviate those crowding-out effects.

When the development of innovative technologies is accompanied by the issuance of hedging schemes as described in this study, we argue that **optimal delays** in current investments are shortened. The main benefit of shortening those optimal delays is an easier containment of the epidemic, with positive consequences on the morbidity as well as future economic development. Despite the availability of insurance schemes and its influences on current investments, it remains optimal to nevertheless delay because of crowding-out effects linked to the always present losses in unrecoverable investments. Another positive effect of the introduction of those insurance schemes is the increase in optimal provision of current treatments, as argued in the welfare analysis of Leoni and Luchini (2006).

In Section 5, we discuss in details why standard insurance contracts are of no help to generate the desired hedge. Basically, the nature of the risk does not allow the issuer to diversify away as it is typically done. This fact alone prevents the issuance of such contracts because of the large amount of money at stake. However, we show how to modify recently commercialised financial products to replicate the desired hedge. We give two distinct methods hinging on different approaches of diversification. The first approach is derived from so-called *Collaterized Debt Obligations*, initially used to hedge the risk of losses on corporate bonds (see Chacko et al. 2006). The second approach uses a set of appropriately designed securities to be purchased both by developing countries and agencies in charge of vaccines R&D. Leoni and Luchini (2006) shows that full risk-sharing between developing countries and R&D agencies can be achieved when those securities are traded.

The paper is organised as follows. In Section 2, we carry out a general economic analysis, presenting all the relevant data relevant and explaining the improvements a therapeutic vaccine brings upon the currently available technologies. In Section 3, we explain why it always remains optimal to postpone current investments. In Section 4, we carry out a standard risk management analysis to show the improvements an insurance contract against a vaccine appearance before a given date brings. In Section 5, we give two distinct ways to generate the desired hedge using exotic options. Finally, Section 6 concludes this work. We have kept our discussion at a conceptual level, always presenting the intuition of the results and purposely avoiding mathematical modelling. The interested reader is invited to check the mathematical soundness

of our results by directly looking at the references therein. Moreover, our analysis is devoted to the important case of HIV/AIDS, although the same analysis extends to similar diseases such as tuberculosis and malaria.

2. General economic analysis

We now discuss two important economic ideas central to the problem of transition to innovative treatment technologies. Those two ideas are crowding-out effects triggered by AIDS-related expenditures, and economic externalities (or future consequences) associated with the spread of the disease. In a first step, we identify why optimal economic policies must prioritize those problems; in subsequent sections we will discuss why the issuance of appropriate insurance schemes must be part of every optimal policy tackling those problems. Even if our focus is on AIDS, our discussion extends to similar diseases such as malaria and tuberculosis.

The first and obvious economic issue in the fight against HIV/AIDS is the funding of current treatments; that is, once an infected population and appropriate treatments strategies are identified the most natural challenge is to optimally allocate funds to implement those strategies (see Jenkins and Robalino, 2003, for an exhaustive list of strategies). This problem is simple albeit already difficult to address, since funds are not available to fully tackle this problem. For instance, the total amount of funds to fight AIDS in 2004 amounted to U.S. $10.8 billion, which resulted only in 12% of the overall HIV-positive population worldwide receiving ARV treatments (see WHO, 2004, this figure includes international subsidies). Moreover, even if governments in developing countries were to allocate enough funds to treat the infected population in its entirety, the diversion of those funds from other necessary public expenditures (such as schools, public infrastructures and else, see Harling et al., 2003) would render this policy inefficient. The idea is that, when treating the whole infected population, the severe reduction in social welfare resulting from all the other forfeited expenditures would offset the benefits of eradicating the disease. The economic situation is thus far more complex than solely funding treatment strategies on a given infected population, and addressing this issue alone without alleviating crowding-out effects necessarily leads to sub-optimal policies.

Another important issue is the future economic consequences of the spread of the epidemic. The most natural consequence of an uncontrolled spread is an increase in future public expenditures that will aggravate crowding-out effects (see Hickey, 2005, for the already-described increase in public expenditures in South-Africa). We next argue that an uncontrolled spread of the epidemic also, and perhaps foremost, leads to a decrease in domestic investments and in turn to a slow-down in the economic growth of developing countries. When a

significant fraction of the population is infected as in Sub-Saharan countries, it becomes difficult to maintain a productive labour force and in turn competitive businesses because of the morbidity associated with AIDS. The prospect that the epidemic spreads, and thus that a larger fraction of the labour force gets infected, makes current investment decisions in labor-intensive businesses riskier and thus less likely. Labour-intensive businesses that are typical in developing countries may indeed find themselves short of workers in the long-run, and thus they may have to slow-down their production plans with a long-term reduction in profitability.

When making investment decisions in labour-intensive businesses, or in other words when evaluating the profitability of such investments, it becomes essential to anticipate the spread of the epidemic and its effect on the labour force. Standard economic theory (Dixit and Pyndick, 1994, Chapters 5-11 for instance) teaches us that the optimal reaction is to postpone investments until better information about the reliability of the labour force becomes available. However, postponing the creation and/or expansion of such businesses is a significant impediment to the economic development of already poor countries. At a micro-economic level, delays in investments affect nearly every aspect of economic life, such as agriculture with possible future famines and private sectors (see Shisana et al., 2004, for an exhaustive list of economic sectors sensitive to AIDS). Young (2007) reaches similar conclusions using a different approach, although the author considers mortality as an economic factor. Therefore, optimal economic policies must address not only the treatment of the currently infected population, but also the containment of the epidemic to reduce future negative effects on the labor force.

It turns out that crowding-out effects and spread externalities are intimately linked to the problem of transition to innovative treatment technologies, for reasons made clear in the next section. In the remainder of this study, we develop in details this issue that has been completely ignored so far, and we also describe some other negative economic consequences associated with switching to innovative treatment technologies. We also provide policy recommendations optimally tackling the pitfalls of upgrading; in particular, we show that those recommended policies alleviate crowding-out effects and spread externalities.

3. Optimal investment delays

We now explain why it is always optimal to delay current investments when facing the risk of upgrading to an innovative treatment technology. The analysis developed here for the therapeutic vaccine extends to any other medical improvement.

The difficulty with current treatments against HIV/AIDS, such as ARV treatments, is that they are awkwardly expensive and difficult to deliver to patients. Moreover, much better ways to tackle the epidemic, both at medical and economic levels, are being developed and will eventually cause the abandonment of current treatments. The best innovative treatment technology being currently developed is a therapeutic vaccine, capable of both reducing the transmissibility of the virus and treating infected patients by reducing the viral load within a population (see Klausner et al., 2003). With such a vaccine available, one injection only would treat a patient instead of a live-long treatment with ARV; moreover, the cost of production and delivery of one injection is small. Even if such vaccines are typically cheap to produce and easy to deliver to patients, the development is technologically challenging and expensive (see Kremer and Glennester, 2004). We have witnessed many failures in the R&D process, for instance with the Institut Pasteur in 2004 and Merck & Co. in 2007; however, it is commonly agreed that it is just a matter of time before success arises.

The availability of this vaccine could thus appear as good news for developing countries, since cheaper and more effective ways to treat large infected populations would *de facto* become available. Developing countries and subsidizing organisations such as GAFTAM, the G7 and others will find it optimal to adopt this new vaccine technology, both for medical and economic reasons. International subsidies amounting to roughly 75% of the overall budget allocated to fighting AIDS will thus be diverted to vaccine implementation, forcing in turn developing countries to upgrade to this new technology. Nevertheless, irreversible investments in current treatments technologies will be lost.

Those irreversible investments or *sunk-costs* are particularly stringent in the case of ARV treatments for instance; using UNAIDS 2004 data Leoni and Luchini (2006) estimates that, at the very least, they amount to $6 billion for the period 2005-2008. This last figure includes program level costs or managerial costs and related issues, but it does not include the cost of reshuffling/shutting down drugs plants nor inefficiencies linked with the transition period. This amount would represent not only a severe direct loss in case of a switch for developing countries, but also and perhaps foremost the *opportunity cost*[1] of those funds is severe and renders public economic policies inefficient if those losses cannot be compensated.

The general framework is thus as follows. Consider the decision for a developing country of **whether to invest now** in available treatments. Some of

[1] That is, the social value of what is forfeited with those funds.

those investments are irreversible; that is, once the money is spent it cannot be recovered if those treatments are to be abandoned in the future. The risk faced by developing countries is about the date of obsolescence of those investments, or in others words about when a therapeutic vaccine appears. We next see how the **uncertainty about the time those losses occur** distorts optimal decisions to **invest now** in available treatments technologies.

The following figure summarizes the timing of investment decision in current technology and obsolescence of such investments, where the obsolescence corresponds to the random appearance of the vaccine for the reasons previously explained.

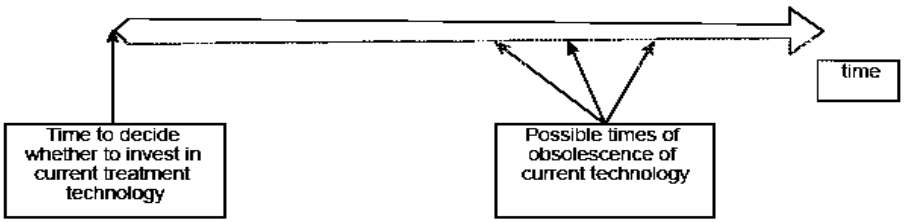

Figure 1 Timing of investment and obsolescence

This abstract situation has been extensively analyzed in economic theory; it is a standard risk management problem with countless applications in Industrial Organisation and Finance for instance. Following an argument similar to that in Dixit and Pyndick (94) Ch. 7 for instance, it can be derived that the optimal investment decision in our setting is… to postpone the investment. The strategic motivation for delaying the investments is to wait until better information about the expected time of a vaccine appearance becomes public; this in turn will provide a better estimate about how long current investments will remain in place and thus about their profitability.

This idea is rather intuitive and easy to explain. The decision of investing now in current treatment technologies is based on the comparison between the return of the investments, not entirely measured in monetary terms in our setting, and the overall social cost of the investments. It is important to notice that the social cost of those investments ought to include the opportunity cost of money; that is, the cost of not using this money for other necessary social needs such as building schools and roads. The decision to invest now is optimal when the

expected social benefits exceed the expected social costs, where the expectation encompasses the random time of obsolescence of current investments. This method is standard in Economics, and it is called a *cost-benefit analysis*. Since the time of appearance is random, it is rational to use the expected time of appearance when making the above comparison.

Standard results in Probability Theory show that, when better information become available over time, the estimator of the expected appearance time becomes more accurate leading in turn to more reliable cost-benefit analysis. The **optimal delay** to invest thus corresponds exactly to the date when this estimator on the time of vaccine appearance becomes accurate enough to make the cost-benefit analysis reliable. Information about the likely time of a vaccine appearance will come naturally over time, for instance through public releases of success probability in the trial period of the vaccine or investment levels from bodies in charge of its pre-trial R&D. The situation is illustrated in the following figure.

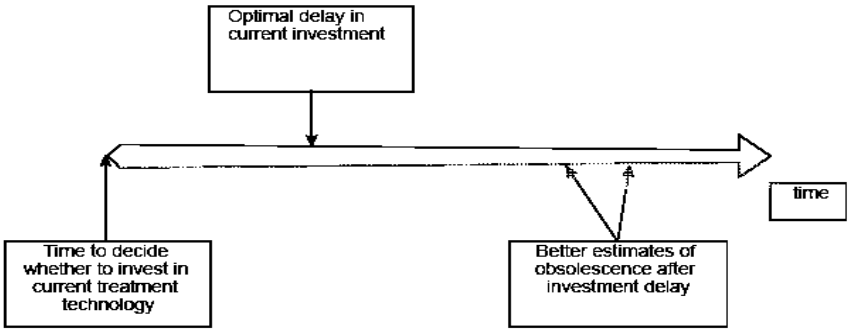

Figure 2. Optimal delay in current investments

We still need to incorporate the externality of the epidemic spread in our analysis. The apparent difficulty is that any optimal decision to invest now must encompass this issue, and at the same time an investment delay (proven to be optimal in the previous case) worsens the spread. It turns out that it still remains optimal to delay current investments in the presence of an epidemic spread; however the presence of this negative externality shortens the optimal delay of the previous case. The intuition is similar to the previous cost-benefit analysis,

the only difference is that the benefits of current investments are now increased because they slow down the spread. The soundness of this new cost-benefit analysis still and nevertheless depends on the accuracy of the estimator of the time of vaccine appearance, and as argued earlier delays to sharpen this estimator still remain optimal. Following this reasoning, it is also easy to see that the stronger the externality of the spread, the shorter the delay.

The optimal reaction of developing countries is rather problematic because it forces to delay current investments when we would ideally like immediate intervention. This is a typical situation of an uninsurable risk; in the next section, we show that the creation of financial products allowing to hedge against the risk of a vaccine appearance before a given date optimally tackles this problem.

4. Risk management

We now analyze how to optimally manage the risk of vaccine appearance from the viewpoint of developing countries. In particular, we explain why optimal delays are shortened and the provision of AIDS-related expenditures is increased with the availability of insurance schemes. We also argue that standard insurance contracts cannot be used in this case. However, the design of such insurance schemes is postponed until the next section.

The most obvious motivation for purchasing an insurance against a vaccine appearance before a given date is to compensate for the loss of sunk costs. The financial compensation allows future insurance payments to be allocated to the implementation of the new technology. That is, sunk costs are not recovered *per se* but the compensation to developing countries makes more funds available during the transition to the new technology. This lagging effect on investment compensations, and consequently crowding-out effects on current public expenditures, is unavoidable; however, future insurance payments have a direct and positive influence on current investment decisions at every macro-economic level.

Leoni and Luchini (2006) carries out a welfare analysis to identify the effects of the availability of this insurance opportunity not only on AIDS spendings but also on other macro-economic variables such as public goods (like roads, schools et.c.). The point is to see whether the introduction of this insurance fosters investments in current treatment technologies as well as reduces the crowding-out effect on public expenditure described earlier. The main finding is that the optimal reaction from developing countries, when having this insurance available, is to increase the level of investments in current treatment technologies. Moreover, it is shown that the **optimal** redistribution of insurance payments in case of a vaccine appearance also increases other current public

expenditures. The study thus shows that crowding-out effects of AIDS spendings are significantly reduced when insurance schemes are available.

The intuition of the results in Leoni and Luchini (2006) is well beyond the scope of this study, but the idea can be roughly summarized as follows. The introduction of this hedging tool *completes the market*; that is, it allows to switch from a situation of fully uninsurable risk to another one where every hedging need can be met. Standard economic theory teaches us that social welfare, which encompasses provision of public goods as well as AIDS spendings, is maximised when markets are complete. This increase in social welfare directly stems in our case from an increase in both the provision of AIDS spendings and public goods; the proportion of the increases and thus the reduction of crowding-out effects depend on the substitution effects across those goods.

Another effect of the introduction of this insurance is the reduction of the optimal delay in current investments. Going back to our cost-benefit analysis from the previous section, we have seen that the optimal decision to invest in current treatment technologies occurs when the benefits of current investments are greater than their overall social costs. Those social costs must include the opportunity cost of unrecoverable funds in current investments. The necessity to consider those opportunity costs as social costs is that **unrecoverable** funds are invested in AIDS-related expenditures and not in other **necessary** public goods; this diversion of funds is economically detrimental because of the scarcity of resources (this issue is particularly stringent in developing countries). The value is what is currently forfeited, and permanently lost if no compensation is made, has a direct decreasing effect on overall social welfare encompassing every aspect of the social life of a country.

One of the consequences of the welfare analysis in Leoni and Luchini (2006), described above, is that the opportunity cost of sunk costs can be partially compensated by the benefits of future insurance payments in case of an upgrading. The introduction of our insurance schemes therefore reduces the overall social cost of current investments in available technologies, since provision of public goods is shown to increase in this case. The optimal delay to evaluate whether the benefits of current investments are profitable enough is necessarily shortened as a consequence, by argument similar to the cost-benefit analysis of the previous section. However, since the uncertainty about the time of the vaccine appearance can only be reduced by delaying the investment, delaying still remains optimal. The following figure illustrates this situation.

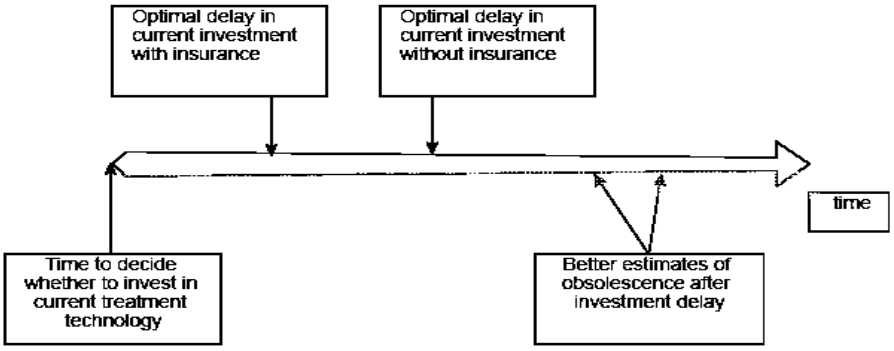

Figure 3. Optimal investment delay with insurance

After having described the benefits of this hypothetical insurance scheme, we are now left with designing its implementation. It turns out that standard insurance contracts are not applicable in this setting, for reasons explained next, and we must rely on recent financial products such as *derivatives* and in particular *exotic options* to meet this hedging need (see Hull, 2006, for a complete introduction to those products).

There are many reasons why standard insurance contracts, like an individual car insurance contract, would be of no help in the fight against AIDS. Let us focus on car insurances to illustrate this idea, and let us take the standpoint of the insurer. Let us assume that this insurer knows somehow that her average customer has a car accident with a probability of, say, 10%, and that an accident triggers an average payment of $5,000 from the insurer. A naïve and inefficient way to manage this risk for the insurer would be to set an insurance premium so that she would break even ex-ante; here, the premium P to be charged should be such that P-5,000*0.1=0 corresponding to the *fair price* of the contract.

The way this risk is managed in practice is very different from that, and it relies on more sophisticated statistical ideas. The problem of issuing one contract only is that the insurer faces a huge volatility on her cash flow, and therefore the issued contract would simply come down to transferring the risk of

a car accident from the driver to her. Standard risk management techniques rely on the fact that this volatility is significantly reduced by issuing a large number of similar contracts; the idea is that the realised uncertainty of a large group of comparable individuals is a lot more predictable that the realised uncertainty of a single individual. The Central Limit Theorem for instance, when applied in this setting, asserts that percentage of the insured population that will **actually** have a car accident converges to 10% (this corresponds to the probability of an accident) as the insured population increases. With this fact in mind, it becomes straightforward for the insurer to manage the cash flow and the risk of accident.

From the previous example, we can readily see why such contracts are of no use to hedge against a vaccine appearance. A potential insurer cannot issue many such contracts in the case of vaccine appearance, and all the customers are simultaneously affected by the same event (in contrast, it is fair to assume that the occurrence of an accident for a single driver cannot affect the odds of accident of a large population). As argued earlier, the insurance contract described in this section would thus represent a net risk transfer to the issuer, and this issuer would find it nearly impossible to diversify away this risk. In the unlikely event that an insurer accepts to issue such a contract, any financial regulator following the Basel II agreement would prevent its issuance because of too high the risk taken by the insurer. It turns out that modern financial products such as derivatives and exotic options allow to replicate the desired hedge against a vaccine appearance while avoiding all the previous flaws. Those products are described in the next section.

5. Health derivatives

We now describe some financial products capable of replicating the desired hedge against the risk of upgrading before a given date, while avoiding the pitfalls of standard insurance contracts. As we have seen in the previous section, the main problem with standard insurance contracts is that the risk of vaccine appearance is nearly impossible to diversify away. We next describe two ‘exotic options’ making this diversification natural, even if they rely on two very different approaches of risk management. We first give a brief overview of these products, and we describe them in details later in this section.

The first exotic option that we give is inspired from a class of *credit derivatives* (see Hull, 2006, Ch. 21 and Chacko, 2006) called *Collaterized Debt Obligation*, or CDO forthwith. Diversification is obtained by pooling parts of a broad insurance against vaccine appearance with many other risky assets in order to form a new financial asset. The point of adding parts only of the broad insurance against vaccine appearance, instead of the broad contract, is to allow an easier diversification through many CDOs. Once this large structured product

is formed, the insurer or issuer of the CDO sells separate pieces or *tranches* of this body to investors, each tranche does not specify which assets are at risk but rather the overall risk of potential losses of the structured product. This construction is called a CDO, or also a *structured product,* even if they may take different shapes in practice. CDOs have largely grown in popularities to become one of the largest financial markets nowadays. To illustrate their importance, the aggregate global CDO issuance worldwide was U.S.$ 249 billion in 2005 and U.S.$ 489 billion in 2006.[2] Finance professionals have found ways to incorporate various forms of financial assets into those structured products. For instance, the risk of default on individual home loans has been hedged with CDOs, even if they have caused the famous credit crunch of 2007 in the U.S.

The second exotic option presented here is taken from Leoni and Luchini (2006). The way to diversify the risk of vaccine appearance in this case is based on the observation that developing countries and bodies in charge of the vaccine R&D face *negatively correlated risks*; that is, success in developing a vaccine negatively affects developing countries whereas failure maintains current investments in place longer and thus it positively affects those countries. In this situation, it should be possible to exchange the risk between those two parties by issuing well-designed securities, and it turns out that the securities described later achieve full risk-sharing between developing countries and agencies in charge of vaccine R&D.

The financial products introduced here are regarded as the latest generation of financial products due to the originality in their diversification techniques. Structured products have been developed sometimes in the mid-90s to hedge against losses on corporate bonds in case of bankruptcy of the issuing sides. The securities described in Leoni and Luchini (2006) are more difficult to trace in practice because of some potential problems of moral hazard; in the case of a vaccine development it is possible to fully eliminate this problem as explained later. The origin of those securities is more theoretical and is due to K. Arrow and his early works on complete markets, thus the name of *Arrow securities* used throughout. Exotic options such as CAT bonds, introduced in the late 90s to provide compensations if a pre-determined catastrophic event occurs (or not), are somewhat similar to the Arrow securities designed here.

One can easily imagine other ways to generate the desired hedge while avoiding diversification problems; however the central problem of pricing those products is a significant challenge that is not yet fully understood, and it thus can prevent their implementation.

[2] In contrast, the Gross Domestic Product of Benin in 2006 was U.S.$ 4,749 million.

5.1 Structured product

We now describe in details the first class of exotic options generating the desired hedge. The structured product presented next is derived from a standard CDO in which we can easily diversify any insurance contract against a vaccine appearance. Before showing how to diversify away our desired hedge with such a product, we first describe the basic organisation of an abstract CDO.

Consider an arbitrary number of tradable assets, every asset has a reselling price and carries the risk that its price may decrease in the future. The point is to hedge against the risk of loss in the reselling value. Those assets can be assembled into one single financial product, whose value (or price) is the sum of the prices of all pooled assets. This structured product is also risky, since a loss on any constituting asset will directly translate into a loss on the pool. However, standard results in Probability Theory show that the variance of the structured product is smaller than the sum of all individual variances, and thus the structured product is less risky than individual assets alone. It turns out that the smaller the correlation across constituting assets, the less risky the structured product.

The most standard way to diversify away the risk of the structured product is to cut it into pieces or tranches and to sell the tranches to outside investors, who would accept the risk of losses in return for a pre-agreed yield depending on the risk of the tranche. Tranches can be designed as follows, even if other combinations are possible and commonly seen. The first tranche **amounts to, say, 15% of the overall initial value of the CDO** and it absorbs the first 15% losses of this initial value. That is, if the CDO has lost more than 15% of its initial value during the lifetime of the tranche then the first tranche will become worthless. If now the overall loss on the CDO is less than 15% at the end of the lifetime, then the owner of the tranche will receive from the issuer of the CDO a pre-determined yield on the remaining value of the tranche on top of the remaining value. The second tranche amounts to 25% of the value of the CDO, and it absorbs losses within the range of 15-25% of the overall CDO during its lifetime. Payments to the owner of the second tranche work exactly as for the first tranche, with a different pre-determined yield though. The third tranche then absorbs losses within the range 25-35%, and works exactly as the previous ones. The process is repeated until every possible risk level is allocated to a tranche.

The next question is how to attract outside investors in buying such tranches. Clearly, the first tranche is much riskier than the second tranche; the second tranche is much riskier than the third and so on. Therefore, the issuer must provide a greater yield to the owner of the first tranche to compensate for the

greater risk, then a lower yield for the owner of the second tranche and so on. Typically, high yields on the riskiest tranches have attracted aggressive investors such as hedge funds, whereas less risky tranches have attracted conservative investors seeking assets with low risk and yields greater than those of riskless Treasury bonds for instance. The structure of this CDO is described in the following figure.

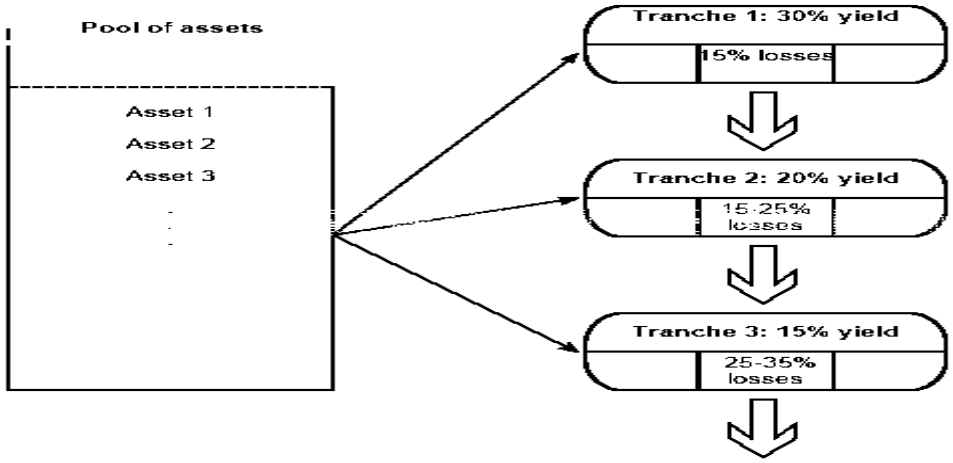

Figure 4. Basic structure of a Collaterized Debt Obligation

We now describe how to add the hedge against vaccine appearance into an abstract CDO as above. Consider a contract stipulating a pre-determined payment if a therapeutic vaccine becomes available before a given date and nothing otherwise; such payment need not cover all the losses incurred by developing countries so as to break down in smaller pieces the broad hedging scheme. The risk of loss in **issuing** this contract occurs in case of a vaccine appearance during the life of the contract, and in this case the loss to the issuer is the value of payment to developing countries less the selling price of the insurance. The only potential problem in adding this contract to an already existing CDO is that it would make the tranches riskier. That is, the potential pitfall is that the probability that any tranche becomes less profitable or even worthless increases by adding insurance schemes against the risk of a vaccine appearance. It turns out that the overall risk of having any tranche riskier is **unaffected** by adding this insurance contract to the CDO. This can be shown by observing that the risk of vaccine appearance is uncorrelated with the risk of losses of any other already-pooled asset, since the event of a vaccine appearance

(or not) is independent of the performances of most of the financial assets traded such as stocks and corporate bonds. Even if the variance of the CDO will be affected, the overall risk of the structured product remains the same after adding this new insurance contract, and the attractiveness of the CDO also remains unchanged.

We have thus seen that breaking down the large insurance contract against vaccine appearance and adding the smaller contracts to many CDOs is a natural and effective way to diversify away the risk. The inherent difficulty with this method is to find the optimal yield assigned to every class; this problem is however common to every CDO. Theoretical methods to find those yields are still in their infancy (see Hull, 2006, Ch. 21), despite the large volume of trades of those products. However, there exists a market price, instead of a theoretical price, for similar tranches characterized by their risk level. In practice, every tranche is assigned a risk level or *credit rating* by specialized agencies such as Moody's. Once the credit rating of a given tranche is assigned, market indices such as iTraxx and CDX IG NA provide the current market price of the tranche. Since adding the insurance contract on AIDS to any CDO does not change the risk of the tranche, the pricing of the CDO is standard and thus this method of diversification can be regarded as feasible and efficient.

5.2 Arrow securities

We now describe our second class of financial products generating the desired hedge against the vaccine appearance. The approach to diversify away the risk here is significantly different from CDOs and other structured products; the idea is now to design securities allowing to share the risk of vaccine appearance/failure before a given date between bodies in charge of the vaccine R&D and developing countries. What follows is derived from Leoni and Luchini (2006); interested readers are referred to this reference for more details, in particular for the pricing of those securities.

In our setting, we are dealing with two parties facing negatively correlated risk as explained earlier. On the one hand, developing countries face the risk of a loss of at least $6 billion in case of a vaccine appearance, and on the other hand vaccine development agencies have invested $500-600 million until 2006 in the R&D and they face the risk of loosing a significant part of this investment in case of failure (Leoni and Luchini, 2006, documents those losses). Many studies such as Arrow (71) show that it is never optimal for risk-averse agents to fully insure against all possible losses; however, it always remains optimal for risk-averse agents to insure against a significant part of those losses. The point is now to design a set of securities allowing both parties to share the risk, by exploiting the negative correlation of the events triggering losses.

Consider a financial asset available when decisions to invest in current treatment technologies are made, with a fixed maturity (or expiration) date and the following payoff structure: a pre-determined small payment is made to the owner of the asset if a successful vaccine is released before maturity and no payment is made otherwise. We call this asset an *Arrow security*. Developing countries can purchase this asset to hedge against the risk of vaccine appearance, and the small payment makes the diversification easier for the issuer.

The way to achieve risk-sharing is obtained by issuing another security, which will call a *complementary security*. Consider a security similar to an Arrow security, different only in the payoff structure: the same payment is made to the owner if the vaccine is **not** released before maturity and no payment is made otherwise. Agencies in charge of the vaccine R&D are in demand for this complementary security, since they can compensate this way for losses resulting from failure in development. However, one must be very carefully when issuing complementary securities because the event triggering their payment is controllable by the party owning those securities. Indeed, a simple way to make profits for those agencies is to purchase those securities in large amount, and to collude for not making any R&D at all. No vaccine will ever appear before maturity, and payments will be received in return for no effort.

We must therefore refine our notion of complementary security to remove this moral hazard. The last problem can be simply tackled in the case of medical innovations as follows. The first observation is that every medical innovation must pass an official trial (for instance, the F.D.A. is in charge of organising those trials in the U.S.) before being approved and then released. A therapeutic vaccine against AIDS is no exception, and moreover there exist reliable tests capable of deciding whether a typically costly trial is worth undertaking (see Leoni and Luchini, 2006, and Klausner et al., 2003, for more details). We can therefore remove the moral hazard described above by making payment of the complementary security contingent on two events: 1- at least one therapeutic vaccine has passed the pre-trial test before maturity, and 2- no therapeutic vaccine is released before maturity. Condition 1 ensures that enough investments in R&D have been made by at least one development agency to have a reliable vaccine; the remaining uncertainty about the official approval depends on the F.D.A. for instance and it is beyond the agency control.

There is yet another moral hazard linked to the nature of the trial. Indeed, medical trials are carried out by national agencies but are paid for by submitting companies. The typical cost of a trial amounts to 1/3 of the overall R&D budget. A natural strategy for a vaccine agency is thus to buy a large amount of

complementary securities, to make enough R&D investments to pass the pre-trial test and to immediately withdraw from the trial. A vaccine agency using this strategy can save 1/3 of its initial budget and receive the payment from the complementary securities, thus making a substantial profit. This moral hazard can simply be removed by adding a third clause to the contract stating that, in order to receive payment from complementary securities, no medical trial can be stopped without the approval of the official agency in charge of carrying it out.

With those two securities, it is relatively easy to see that the risk of vaccine appearance and development failure can entirely be removed. Consider the viewpoint of an insurer having issued an insurance contract against vaccine appearance to a developing country. This contract can be entirely replicated by issuing a given number *N* of Arrow securities (the number needed to be issued depends on the amount of money payable on each security). A natural way to diversify away the risk incurred after this issuance is to issue exactly *N* complementary securities, in which the insurer is taking no risk at all and can make some profits through commission fees. This situation is described in the following figure.

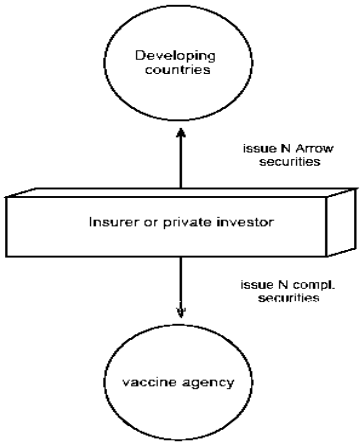

Figure 5. Risk-sharing between parties

The last point to observe in the previous construction is that the risk of vaccine appearance has not fully been eliminated. Given the relative amounts of money needed to be insured by both parties, it appears that insurers following a N-for-N issuance scheme above cannot fully insure developing countries (recall that at least $6 billion are at risk in developing countries, whereas in contrast $500-600 million have been invested in vaccine R&D until 2006). The excess risk in developing can be **optimally covered by international bodies**, such as

the GAFTAM, the G7 and else, subsidizing those countries in their fight against AIDS. Indeed, subsidies are entirely devoted to current treatments whereas throughout this study we have shown that this policy is inefficient. Diverting part of those subsidies to hedging against the pitfalls of a vaccine appearance would render those policies more efficient, and this would allow for a complete risk-sharing between parties involved in the therapeutic vaccine. Moreover, a combination of securities issuance and structured products (as in Section 5.1) to diversify away the resulting excess risk on developing countries is feasible, efficient and easy to implement.

6. Conclusion

We have analysed, from the viewpoint of developing countries, the economic consequences of upgrading to innovative treatment technologies in the case of HIV/AIDS, with a particular focus on therapeutic vaccines. The basic risk for developing countries is that the future albeit uncertainty appearance of a therapeutic vaccine, or any other innovative treatment technology, would trigger significant losses in investments on current treatment technologies.

In a first step, we have seen that the optimal reaction of a developing country, when facing the uncertainty about the time of availability of a vaccine appearance, is to delay investments in current treatment technologies despite the negative externalities this brings. This finding is consistent with reports of reluctance to invest in current treatment technologies in some African countries (see UNAIDS, 2004, p.11). We have also seen that the availability of an insurance allowing to hedge against this risk significantly shortens the optimal delay in current investments, and other studies such as Leoni and Luchini (2006) show that the optimal investment level is increased with the availability of such an insurance scheme. However, standard insurance contracts are useless in this situation and we must rely on modern financial products to effectively replicate the desired hedge.

In a second step, we have given two ways to replicate the desired hedge, one using structured products to diversify away the risk, the second one based on the issuance of Arrow securities allowing to achieve full risk-sharing with vaccine development agencies. We can imagine other financial products for this purpose; however their pricing always remains an important concern and a severe impediment to their practical implementation.

This work has thus addressed the important problem of upgrading to innovative treatment technologies, an issue systematically ignored in the design of economic policies to fight HIV/AIDS. We argue that every optimal policy to fight this epidemic must go beyond the optimal funding of treatments with

current technologies and the R&D in innovative medical products; it must also encompass the transition to those future albeit uncertain innovative technologies.

In this respect, we recommend that funds allocation to current treatment technologies and/or R&D in innovative treatment technologies be accompanied with the issuance of financial products as described here. The point is that, when providing decision-makers with such hedging schemes, the present and future welfare gains largely offset the diversion of funds to immediate treatments and R&D. Those insurance products are thus a full component of every optimal economic policy in the fight against AIDS.

References

Arrow, K. J. (1971), *Essays in the Theory of Risk Bearing*, Chicago: Markham Publishing Co.

Chacko, G., A. Sjoman, H. Motohashi, and V. Dessain (2006), *Credit Derivatives: A Primer on Credit Risk, Modeling, and Instruments*, Wharton School Publishing.

Dixit, A. and R. Pindyck (1994), *Investment under Uncertainty*, Princeton University Press.

Harling, G., R. Wood, and E. Beck (2005), Efficiency of interventions in HIV infection 1994-2003, Symposium of the IAEN Meetings in Cape Town.

Hickey A (2004). *New allocations for ARV treatment: an analysis of 2004/5 national budget from an HIV/AIDS perspective*, The Institute for Democracy in South Africa, AIDS Budget Unit.

Hull, J.C. (2006), *Options, Futures and Other Derivatives* (6th edition), Prentice Hall International Editions.

Jenkins, C. and D. Robalino (2003*), HIV/AIDS in the Middle East and North Africa: The Costs of Inaction*, Washington, DC: World Bank.

Klausner, R.D., A. S. Fauci, L. Corey, G.J. Nabel, H. Gayle, S. Berkley, B. F. Haynes, D. Baltimore, C. Collins, R. G. Douglas, S. Esparza, D. P. Francis, N. K. Ganguly, J. L. Gerberding, M. W. Makgoba, G. Pantaleo, P. Piot, Y. Shao, E. Tramont, H. Varmus, and J.N. Wasserheit (2003), The need for a global HIV vaccine enterprise. *Science*, 300, 2036–2039.

Kremer, M. and R. Glennerster (2004), *Strong Medicine: Creating Incentives For Pharmaceutical Research On Neglected Diseases*, Princeton University Press.

Leoni, P. and S. Luchini (2006), Designing the financial tools to promote universal access to AIDS care, NUIM Working Paper.

Shisana, O., Letlape, L., Social Aspects of HIV/AIDS and Health Human Sciences Research Council (2004), The impact of HIV/AIDS on the sub-Saharan African economy, Report to the Commission for Africa.

UNAIDS (2006), Report on the Global AIDS Epidemics 2006.

---------- (2007), 2007 AIDS Epidemic Update.

WHO (2004), *"3 by 5" progress report*, World Health Organization and Joint United Program on HIV/Aids, Technical report. NLM : WC 503.2.

Young, A. (2005), The gift of the dying: The tragedy of AIDS and the welfare of future African Generations, *Quarterly Journal of Economics*, 120(2), 423-466.