The Economics of Natural Disasters

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Introduction

Large-scale disasters regularly affect societies over the globe, causing huge destructions and damages. The 2010 earthquake in Port-au-Prince and the hurricane Katrina in 2005 have shown that poor as well as rich countries are vulnerable to these events, which have long lasting consequences on welfare, and on human and economic development.

After each of these events, media, insurance companies and international institutions publish numerous assessments of the 'cost of the disaster'. However these various assessments are based on different methodologies and approaches, and they often reach quite different results. Beside technical problems, these discrepancies are due to the multi-dimensionality in disaster impacts and their large redistributive effects, which make it unclear what is included or not in disaster cost assessments. But most importantly, the purpose of these assessments is rarely specified, even though different purposes correspond to different perimeter of analysis and different definitions of the 'cost'.

This confusion translates into the multiplicity of words to characterize the cost of a disaster in published assessments: direct losses, asset losses, indirect losses, output losses, intangible losses, market and non-market losses, welfare losses, or any combination of those. It also makes it almost impossible to compare or aggregate published estimates that are based on so many different assumptions and methods.

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This research is supported by the European Community's Seventh Framework Programme (FP7/2007-2013), ConHaz Project, Contract No. 244159.

To clarify the situation, this article proposes a definition of the cost of a disaster, and emphasizes the most important mechanisms that explain this cost. It does so by first explaining why the direct economic cost, i.e. the value of what has been damaged or destroyed by the disaster, is not a good indicator of disaster seriousness and why estimating indirect losses is crucial. Then, it describes the main indirect consequences of a disaster and of the following reconstruction phase, and discusses the methodologies to measure them. Finally, it proposes a review of published assessments of indirect economic consequences, which confirm their importance and the need to take them into account.

What is a disaster? How to define its cost? For which purpose?

There is no single definition of a disaster. From an economic perspective, however, a natural disaster can be defined as a natural event that causes a perturbation to the functioning of the economic system, with a significant negative impact on assets, production factors, output, employment, or consumption. Examples of such natural event are earthquakes, storms, hurricanes, intense precipitations, droughts, heat waves, cold spells, and thunderstorms and lightning.

Disasters affect the economic system in multiple ways and defining the cost of a disaster is tricky. Pelling *et al.* (2002), Lindell and Prater (2003), Cochrane (2004), Rose (2004), among others, discuss typologies of disaster impacts. These typologies usually distinguish between direct and indirect losses.

Direct losses are the immediate consequences of the disaster physical phenomenon: the consequence of high winds, of water inundation, or of ground shaking. Direct losses are often classified into direct market losses and direct non-market losses (also sometimes referred to as intangible losses, even though non-market losses are not necessarily intangible). Market losses are losses to goods and services that are traded on markets, and for which a price can easily be observed. Even though droughts or heat waves affect directly the economic output (especially in the agriculture sector), direct market losses from most disasters (earthquakes, floods, etc.) are losses of assets, i.e. damages to the built environment and manufactured goods. These losses can be estimated as the repairing or replacement cost of the destroyed or damaged assets. Since building and manufactured goods can be bought on existing markets, their price is known. Direct market losses can thus be estimated using observed prices and inventories of physical losses that can be observed (as recorded, e.g. in the EM-DAT database or insurance-industry databases) or modelled (using, e.g. catastrophe models of the insurance industry).

Non-market direct losses include all damages that cannot be repaired or replaced through purchases on a market. For them, there is no easily observed price that can be used to estimate losses. This is the case, among others, for health impacts, loss of lives, natural asset damages and ecosystem losses, and damages to historical and cultural assets. Sometimes, a price for non-market impacts can be built using indirect methods, but these estimates are rarely consensual (e.g. the statistical value of human life always leads to heated controversies).

Indirect losses (also labelled 'higher-order losses' in Rose (2004)) include all losses that are not provoked by the disaster itself, but by its consequences. Often, the term 'indirect losses' is used as a proxy for 'output losses', i.e. the reduction in economic production provoked by the disaster. Output losses include the cost of business interruption caused by disruptions of water or electricity supplies, and longer-term consequences of infrastructure and capital damages. Indirect losses can also have 'negative-cost' components, i.e. gains from additional activity created by the reconstruction. Sometimes, non-monetary indirect consequences of disasters are also included, like the impact on poverty or inequalities, the reduction in collected taxes, or the increase in national debt.

Another difficulty in disaster cost assessment lies in the definition of the baseline scenario. The cost of the disaster has indeed to be calculated by comparing the actual trajectory (with disaster impacts) with a counterfactual baseline trajectory (i.e. a scenario of what would have occurred in absence of disasters). This baseline is not easy to define and several baselines are often possible. Moreover, in cases where recovery and reconstruction does not lead to a return to the baseline scenario, there are permanent (positive or negative) disaster effects that are difficult to compare with a non-disaster scenario.

For instance, a disaster can lead to a permanent extinction of vulnerable economic activities in a region, because these activities are already threatened and cannot recover, or because they can move to less risky locations. In that case, the disaster is not a temporary event, but a permanent negative shock for a region and it is more difficult to define the disaster cost. Also, reconstruction can be used to develop new economic sectors, with larger productivity, and lead to a final situation that can be considered more desirable than the baseline scenario. This improvement can be seen as a benefit of the disaster. It is however difficult to attribute unambiguously this benefit to the disaster, because the same economic shift would have been possible in absence of disaster, making it possible to get the benefits without suffering from the disaster-related human and welfare losses.

Most importantly, defining the cost of a disaster cannot be done independently of the purpose of the assessment. Different economic agents, indeed, are interested in different types of cost. Insurers, for instance, are mainly interested in consequences that can be insured. Practically, this encompasses mainly the cost of damages to insurable assets (e.g. damaged houses and factories), and short-term business interruption caused by the disaster (e.g. the impossibility to produce until electricity is restored).

For affected households, insurable assets are also a major component, but other cost categories are as important. Primarily, loss of lives, health impacts and perturbation to their daily life are crucial. But in addition, households are concerned about their assets but also about their income, which can be reduced by business interruption or by loss of jobs, and about their ability to consume, i.e. the availability of goods and services.

At the society scale, all these aspects are important, but local authorities, governments and international institutions are also interested in other points. First, to manage the recovery and reconstruction period and to scale the necessary amount of international aid, they need information on the aggregated impact on economic production, on unemployment and jobs, on the impact of inequality and poverty, on local-businesses market-shares, on commercial balance, on collected taxes, etc. Second, to assess whether investment in prevention measures are desirable, they need the broadest possible assessments of the total disaster cost to the population, i.e. an estimate of welfare losses.

Moreover, disaster impacts can have positive or negative ripple-effects at the global scale, as shown by hurricane Katrina, which led to a significant rise in world oil prices. Depending on the purpose and of the decision-making spatial scale, the perimeter of the cost analysis will be different. For instance, a country may want to assess the losses in the affected region, disregarding all out-of-the-region impacts, to calibrate the financial support it wants to provide to the victims. But it may also want to assess total losses on its territory, including gains and losses outside the affected region, for example to assess the impact on its public finance.

Clearly, depending on the purpose of the assessment, some of the cost components have to be included or not in the analysis. In the following, we focus on the economic cost for the affected region, with the aim of informing decision-makers on post-disaster financial aid and prevention measure desirability. To do so, it is obvious that the direct cost is an insufficient measure, and that the loss of welfare is much more relevant. Assessing a loss of welfare is complicated, as it includes many economic and non-economic components. Here, we focus on the economic component of welfare losses, and we define the economic cost of disaster as the lost consumption, considered as an important component and a good proxy of economic-related welfare losses.[1] Of course, this article does not try to be comprehensive, and major cost components are left out of the analysis, like loss of lives, health consequences and loss of jobs. These additional component are important for the population welfare and therefore for prevention measure assessments.

Consumption losses and output losses

This section explains how to assess consumption losses from asset and output losses. More precisely, it explains why the sum of asset losses and output losses is a good proxy for the loss of consumption. To do so, Figure 1 (a), (b) and (c) show simplified representations of a post-disaster situation. Figure 1(a) depicts the situation in which only output losses are estimated: in this situation the disaster leads to a temporary reduction in output during the reconstruction phase. We assume here that reconstruction is a return to the baseline scenario (i.e. a no-disaster counterfactual scenario). As already stated, this is not always the case, but making an assumption on the final state is necessary to define the cost of the disaster, and the assumption of a return to the non-disaster baseline scenario is likely to be the most neutral one for this type of assessment.

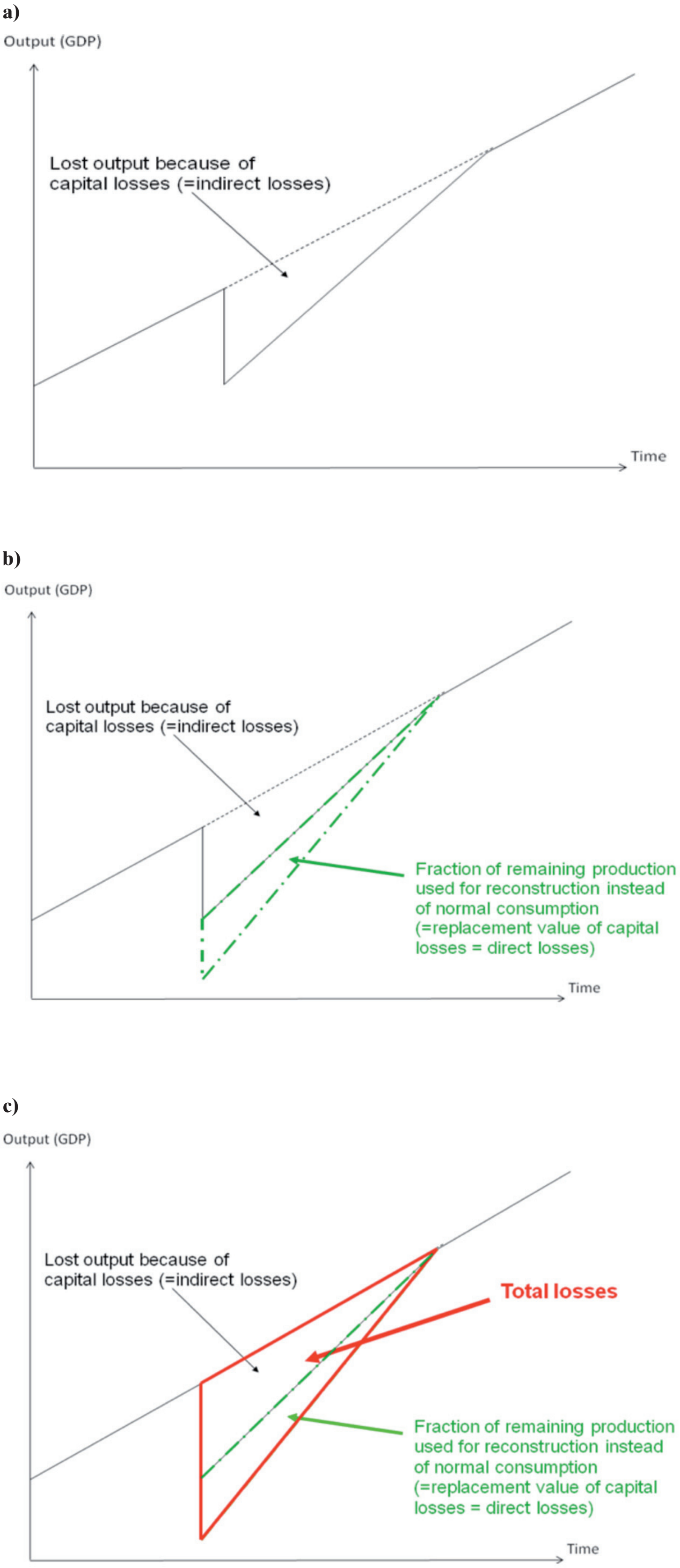
The sum of instantaneous output loss is what is often referred to as the indirect loss. But reconstruction needs in the disaster aftermath means that a significant share of the remaining production will have to be devoted to reconstruction, as shown in Figure 1(b). In other terms, the resources used to rebuild damaged houses cannot be used to build new houses, or to maintain existing ones. This reconstruction output is included in total output, and is not a loss of output. But it is a 'forced' investment, in addition to the normal-time investment – consumption trade-off. It causes, therefore, a loss of welfare. The value of this forced investment is the replacement value of damaged asset, which is referred to as the direct losses. This is what is represented in Figure 1(c): the sum of the output loss and of the reconstruction output is the amount that cannot be used for consumption and non-reconstruction investment. This is referred to here as 'total losses'.

In this framework, total costs are the sum of the indirect cost (i.e. the reduction of the total value added by the economy due to the disaster) and the direct cost (i.e. the portion of the remaining value added that has to be dedicated to reconstruction instead of normal consumption). Capital and output losses can therefore be simply added to estimate consumption losses.

Of course, Figure 1 shows a simplified situation in which production has no flexibility. In this case, reconstruction needs cannot be satisfied through increased production and it has to crowd out other consumptions and investments. Figure 2 depicts a different case, in which there is a limited flexibility in the production process: capital destruction leads to a reduction in output; but unaffected capital can increase its own production to compensate this reduction, for instance through an increase in work

[1] In an utilitarist framework, what matters is not output and production, but consumption.

Figure 1
Direct Losses, Indirect Losses and Total Losses When There Is No Flexibility in the Production Process



Source: Authors' conception.

hours by workers at unaffected factories and businesses. In practice, there are gross indirect losses, and gross indirect gains (due to the stimulus effect of the reconstruction). But there is still a fraction of the remaining production that is used for reconstruction instead of normal consumption, even though this share is smaller than in absence of production flexibility.

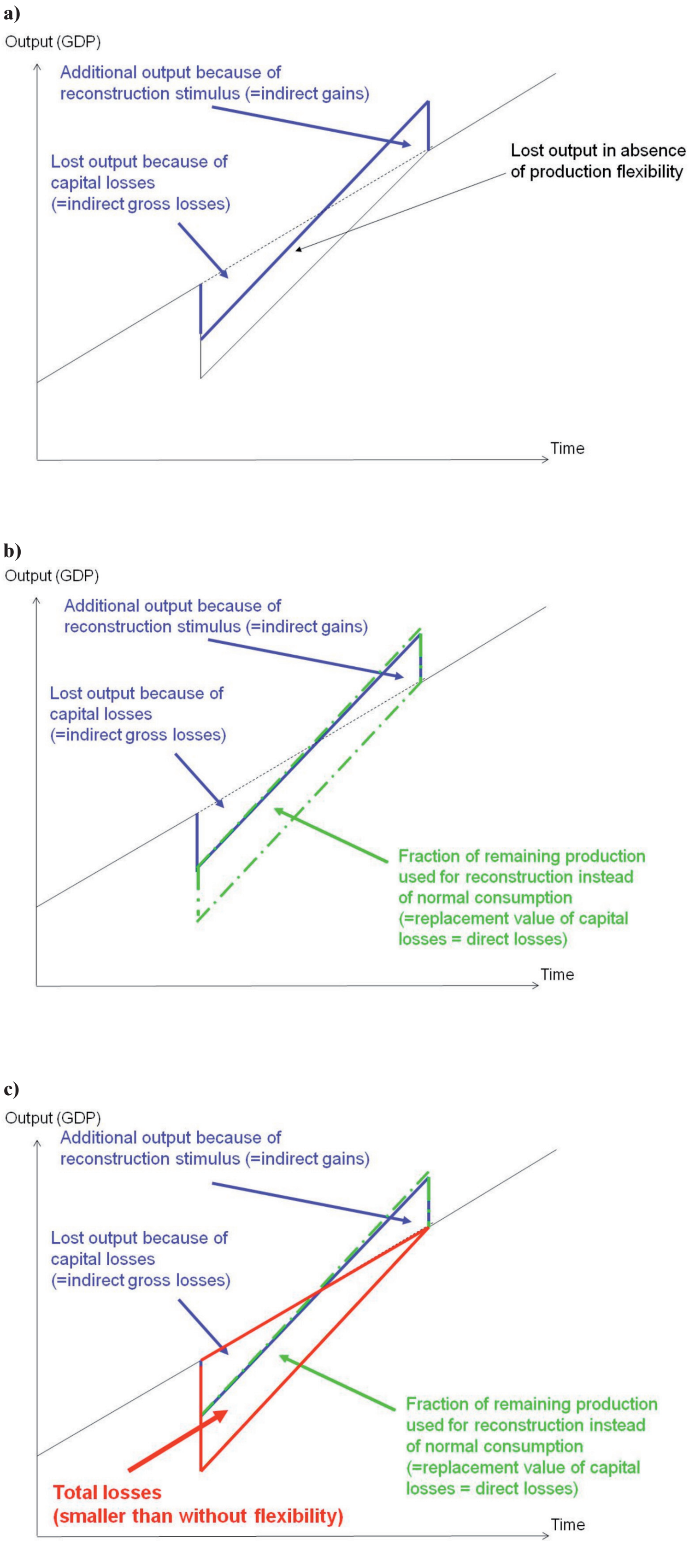
In this situation also, the consumption loss is still the sum of direct (asset) and indirect (output) losses (see Figure 2(c)), making it necessary to estimate output losses. But output losses are not only the lost production from the affected capital, but also the output gains and losses from unaffected capital in the rest of the economy. It makes the assessment of output losses more complicated, since it depends on complex economic mechanisms and trade-offs.

In practice, moreover, the reduction in consumption can be mitigated or amplified by (i) changes in prices; (ii) flexibility in the production process; (iii) changes in the saving-consumption trade-off for the remaining production; and (iv) the fact that the rebuilt capital will be more recent than before the disaster, with potential benefits (Hallegatte and Dumas 2009). The following section will describe methodologies to assess output losses and highlight the most important processes to take into account.

How to assess output losses?

If output losses represent an important component of total losses, it becomes essential to develop methodologies to assess them. To do so, we propose to

Figure 2
Direct Losses, Indirect Losses and Total Losses When There Is a Limited Flexibility in the Production Process



Source: Authors' conception.

start by assessing the lost output from the directly affected capital. In the second subsection, we investigate the systemic impacts of disasters, including the effect on the capital that is not directly affected by the disaster.

From asset losses to output losses

The first step in an assessment of output losses is to estimate how much output is lost because of direct asset losses. Economic theory states that, at the economic equilibrium and under certain conditions, the value of an asset is its expected future production, and this equality has been widely used to assess disaster output losses. Assuming this equality is always verified, the output loss caused by capital loss is simply equal to the value of the damages, capital losses and output losses are simply equal, and the sum of asset and output losses is the double of asset losses.

The assumption that output losses are equal to capital losses is however based on strong assumptions, which are not always verified. In estimates of disaster consequences, 'asset loss' is the replacement value of the capital. To have the equality of asset loss and output loss, a double equality needs to be verified: replacement value has to be equal to market value; and market value has to be equal to the net present value of expected output. In an optimal economy at equilibrium, these two equalities are valid: first, the market value of an asset is by definition the net value of its output; second, if market value were higher (lower) than replacement value, then investors would increase (decrease) the amount of capital to restore the equilibrium.

Therefore, in theory, there is no difference between capital losses and the reduction in output from this capital. But the assumption of the economics being optimal and at equilibrium is questionable. First, for the replacement value and the market value to be equal, the economy needs to be at its optimum, i.e. the amount of capital is such that its return is equal to the (unique) interest rate. This is unlikely for the capital that is affected by natural disasters, especially as infrastructure and public assets are heavily affected. Since these assets are not exchanged on markets, they have no market prices. Moreover, they are not financed by private investors, but decided about through a political process under the consideration of multiple criteria (e.g. land-use planning objectives), and there is no reason for their purely-financial return to be equal to the (private) interest rate. Practically, some assets may have an output value lower than their replacement value (e.g. a secondary road that is redundant and does not provide a significant gain of time or distance), while some may have an output value much larger than their replacement value (e.g. a bridge that cannot be closed without large consequences for users).

Second, for market values to be equal to net present value of expected output, expectations have to be unbiased and markets need to be perfect. This is not always the case especially in sectors affected by disasters, where expectations can be heavily biased (e.g. in housing market).

Also, output losses are most of the time estimated from a social point of view. The equality between market value (for the owner) and expected output (for the society) is valid only in absence of externalities. Some assets that are destroyed by disasters may exhibit positive externality. It means that their value to the society is larger than the value of the owner's expected output. Public goods have this characteristic, among which most infrastructures.

An example is provided by the San Francisco Oakland Bay Bridge, which is essential to the economic activity in San Francisco and had to be closed for one month after the Loma Prieta earthquake in 1989. Its replacement value has no reason to be equal to the loss in activity caused by the bridge closure, because the bridge production is not sold on a market, the bridge has no market value, and the social return on capital of the bridge is unlikely to exhibit decreasing returns and is likely to be much higher than the interest rate.

Another example is the health care system in New Orleans. Beyond the immediate economic value of the service it provided, a functioning health care is necessary for a region to attract workers. After Katrina landfall on the city, the absence of health care services made it more difficult to reconstruct, and the cost for the region was much larger than the economic direct value of this service.

The systemic impact of natural disasters

The equality between output losses and asset losses is questionable for any economic shock, small or large. The most important issues appear when considering very large shocks, or *systemic events*, which are the events that perturb the functioning of the entire economic system and affect relative prices. In this case, output losses may be damped or amplified by several mechanisms.

(a) Changes in prices

Figures 1 and 2 show output in real terms, i.e. with no monetary effects. But output losses can be estimated assuming unchanged (pre-disaster) prices or con-sidering the impact of the disaster on prices. Both assumptions lead to the same result if the disaster has only a marginal impact on the economy, with little impact of prices, but can be very different in the opposite situation. In other terms, one can assume that if a house is destroyed, the family who owns the house will just have to rent another house at the pre-disaster price. But this assumption is unrealistic if the disaster causes more than a marginal shock. In post-disaster situations, indeed, a significant fraction of houses may be destroyed, leading to changes in the relative price structure. In this case, the price of alternative housing can be much higher than the pre-di-saster price, as a consequence of the disaster-related scarcity in the housing market. Estimating the value of lost housing service should then be done using this higher cost instead of the pre-disaster one, which can lead to a significant increase in the assessed disaster cost. Unfortunately, it is difficult to predict ex ante the change in prices that would be caused by a disaster, making loss assessment more complicated.

The same reasoning is possible in all other sectors, including transportation, energy, water, health, etc. In extreme cases, reconstruction may even be impossible, at all prices. This is because markets are not at equilibrium in disaster aftermath (i.e. price is not such that demand equals production). The 'if I can pay it, I can get it' assumption is not valid in post-disaster situations. In these situations, therefore, the value of lost production cannot always be estimated as the product of lost produced quantity and pre-disaster prices. Providing an unbiased estimate requires an assessment of the disaster impact on prices.

Often considered as resulting from unethical behavior from businesses, which are thought to benefit from the disaster, post-disaster price inflation can also have positive consequences. This inflation, indeed, helps attract qualified workers where they are most needed and creates an incentive for all workers to work longer hours, therefore compensating for damaged assets and accelerating reconstruction. It is likely, for instance, that higher prices after hurricane landfalls are useful to make roofers from neighboring unaffected regions move to the landfall region, therefore increasing the local production capacity and reducing the reconstruction duration. Demand surge, as a consequence, may also reduce the total economic cost of a disaster, even though it increases its burden on house owners.

(b) Length of the reconstruction phase

Importantly, there is a large difference between losing a home for one day (in this case the total loss is the reconstruction value, i.e. the direct loss) and losing a home for one year (in this case the total loss is the reconstruction value, i.e. the direct loss, plus the value of one year of housing services, i.e. the output loss). Of course, the longer the reconstruction period, the larger the total cost of the disaster.

The reconstruction phase, and the economic recovery pace, will ultimately determine the final cost of the natural disasters. The reconstruction pace is linked to the constraints to the reconstruction phase, which are of two types. First, they can be financial. This concerns situations in which households and businesses can simply not finance the reconstruction. This is of particular importance in countries with limited resources (Freeman *et al.* 2002; Mechler *et al.* 2006).

Constraints are also technical. Technical limits to the ability to increase production are obvious in the construction sector, which experience a dramatic increase in demand after the disaster. In spite of this demand, production does not follow, because there are strong constraints on reconstruction. Many households are able to pay for reconstruction, but cannot find workers and contractors to carry out the work. The same is true for businesses and factories. This explains why reconstruction often takes several years, even for limited damages (e.g. the 2004 hurricane season in Florida – see McCarty and Smith 2005). Examples of constraint include the availability of equipment and qualified workers. For instance, the limited availability of glaziers increased the cost of reconstruction and lowered the reconstruction pace after the 2001 chemical explosion in Toulouse (France), despite glaziers coming from all the country to carry out the work.

(c) Output gains and losses from the non-affected capital

Damages in crucial intermediate sectors may lead to negative 'network effects' in the economy, leading to production losses even for businesses that are not directly affected by the disaster. Water, electricity, gas and transportation are the most critical sectors, and their production interruption has immediate consequences on the entire economic system. In past cases, it has been shown that the indirect consequences of utility services had larger consequences than direct asset losses, both on households (McCarty and Smith 2005) and on business (Tierney 1997). Of course, when capital cannot produce because of a lack of input (e.g. electricity, water), input substitution, production rescheduling, and longer work hours can compensate for a significant fraction of the losses (see Rose *et al.* 2007). These mechanisms can damp the output losses, and can especially reduce the crowding-out effects of reconstruction on normal consumption and investment (see Figure 2). But their ability to do so is limited, especially when losses are large.

There are many sources of flexibility in the economic system. First, production capacity is not fully used in normal times and idle production capacity can be mobilized in disaster aftermath to compensate for lost production from lost assets. Second, behaviors can change in disaster aftermath and workers can increase their work hours in unaffected businesses to help society cope with disaster consequences (and sometimes benefit from increased prices). As a consequence, unaffected capital can often increase production to compensate for output loss from affected capital. After mild disasters, net output gains can even be observed, explained by the non-zero price elasticity of production, and by the under-optimality of the pre-disaster situation that leaves some room for increased production. In an economy that fully uses all resources and cannot increase its production over the short-term (whatever the price level), such a gain would be impossible. In a more realistic economy that does not use efficiently all resources (with underemployment, and imperfect allocation of capital), additional demand does not lead only to inflation, but also to increased output.

The 'adaptability' and 'flexibility' of the production system and its ability to compensate for unavailable inputs is largely unknown and largely depend on the considered timescale. Over the very short term, the production system is largely fixed and the lack of one input can make it impossible to produce. Moreover, over short timescales, local production capacity is likely to be highly constrained by existing capacities, equipments and infrastructure. Only imports from outside the affected region and postponement of some non-urgent tasks (e.g. maintenance) can create a limited flexibility over the short-term. This is what is represented in economic Input-Output model (e.g. Okuyama 2004), in which producing one unit of output requires a fixed amount of all input categories.

Over the longer term and the entire reconstruction period which can stretch over years for large-scale events, the flexibility is much higher: relative prices change, incentivizing production in scarce sectors; equipments and qualified workers move into the affected region, accelerating reconstruction and replacing lost capacities; and different technologies and production strategies can be implemented to cope with long-lasting scarcities. The production system organization can also be adjusted to the new situation: one supplier that cannot produce or cannot deliver its production (because of transportation issues, for instance) can be replaced by another suppliers; new clients can be found to replace bankrupt ones; slightly different processes can be introduced to reduce the need for scarce inputs (e.g. oil-running backup generator can be installed if electricity availability remains problematic). These types of substitution are represented in Calculable General Equilibrium models (e.g. Rose *et al.* 2007), in which the scarcity of one input translates into higher price, and reduced consumption of this input, compensated by larger consumption of other inputs.

IO models are often considered too pessimistic, since they assume that prices are fixed and that no substitution can take place in the production system. On the opposite CGE models are considered as too optimistic, since they assume that markets function perfectly (even in post-disaster situations), and that optimal prices balance production and demand and, act as signals to incentivize production of the most needed goods and services. The reality probably lies somewhere in between these two extremes, prompting the work on intermediate models. These intermediate models are either IO models with flexibility like those in Hallegatte (2008) or CGE models with reduced substitution elasticity like those in Rose *et al.* (2007).

(d) The stimulus effect of disasters

Disasters lead to a reduction of production capacity, but also to an increase in the demand for the reconstruction sector and goods. Thus, the reconstruction acts in theory as a stimulus. However, as any stimulus, its consequences depend on the pre-existing economic situation, or the phase of the business cycles. If the economy is in a phase of high growth, in which all resources are fully used, the net effect of a stimulus on the economy will be negative, for instance through diverted resources, production capacity scarcity and accelerated inflation. If the pre-disaster economy is depressed, on the other hand, the stimulus effect can yield benefits to the economy by mobilizing idle capacities. This complex interplay between business cycles and natural disasters economics is analyzed in detail in Hallegatte and Ghil (2008), who support the counter-intuitive result that economies in recession are more resilient to the effect of natural disasters. This result appears to be consistent with empirical evidence. For instance, the 1999 earthquake in Turkey caused destructions amounting to 1.5 to 3 percent of Turkey's GDP, but consequences on growth remained limited, probably because the economy had significant unused resources at that time (the Turkish GDP contracted by 7 percent in the year preceding the earthquake). In this case, therefore, the earthquake may have acted as a stimulus, and have increased economic activities in spite of its terrible human consequences. In 1992 also, when hurricane Andrew made landfall on southern Florida, the economy was depressed and only 50 percent of the construction workers were employed (West and Lenze 1994). The reconstruction needs had stimulus effects on the construction sectors, which would have been impossible in a better economic situation.

(e) The productivity effect

When a disaster occurs, it has been suggested that destructions can foster a more rapid turn-over of capital, which could yield positive outcomes through the more rapid embodiment of new technologies. This effect, hereafter referred to as the 'productivity effect', has been mentioned, for instance, by Albala-Bertrand (1993), Stewart and Fitzgerald (2001), Okuyama (2004), and Benson and Clay (2004). Indeed, when a natural disaster damages productive capital (e.g. production plants, houses, bridges), the destroyed capital can be replaced using the most recent technologies, which have higher productivities. Examples of such upgrading of capital are: (i) for households, the reconstruction of houses with better insulation technologies and better heating systems, allowing for energy conservation and savings; (ii) for companies, the replacement of old production technologies by new ones, like the replacement of paper-based management files by computer-based systems; and (iii) for government and public agencies, the adaptation of public infrastructure to new needs, like the reconstruction of larger or smaller schools when demographic evolutions justify it. Capital losses can, therefore, be compensated by a higher productivity of the economy in the event aftermath, with associated welfare benefits that could compensate for the disaster direct consequences. This process, if present, could increase the pace of technical change and accelerate economic growth, and could therefore represent a positive consequence of disasters.

As an empirical support for this idea, Albala-Bertrand (1993) examined the consequences of 28 natural disasters on 26 countries between 1960 and 1979 and found that, in most cases, GDP growth increases after a disaster and he attributed this observation, at least partly, to the replacement of the destroyed capital by more efficient one.

However, the productivity effect is probably not fully effective, for several reasons. First, when a disaster occurs, producers have to restore their production as soon as possible. This is especially true for small businesses, which cannot afford long production interruptions (see Kroll *et al.* 1991; Tierney 1997), and in poor countries where people have no mean of subsistence while production is interrupted. Replacing the destroyed capital by the most recent type of capital implies in most cases to adapt company organization and worker training which takes time. Producers have thus a strong incentive to replace the destroyed capital by the same capital, in order to restore production as quickly as possible, even at the price of a lower productivity. In extreme case, one may even imagine that reconstruction is carried out with lower productivity, to make reconstruction as fast as possible, with a negative impact on total productivity. Second, even when destructions are quite extensive, they are never complete. Some part of the capital can, in most cases, still be used, or repaired at lower costs than replacement cost. In such a situation, it is possible to save a part of the capital if, and only if, the production system is reconstructed identical to what it was before the disaster. This technological 'inheritance' acts as a major constraint to prevent a reconstruction based on the most recent technologies and needs, especially in the infrastructure sector.

This effect is investigated in Hallegatte and Dumas (2008) using a model with embodied technical change. In this framework, disasters are found to influence the production level but cannot influence the economic growth rate, in the same way as the saving ratio in a Solow-like model. Depending on how reconstruction is carried out (with more or less improvement in technologies and capital), indeed, accounting for the productivity effect can either decrease or increase disaster costs, but is never able to turn disasters into positive events.

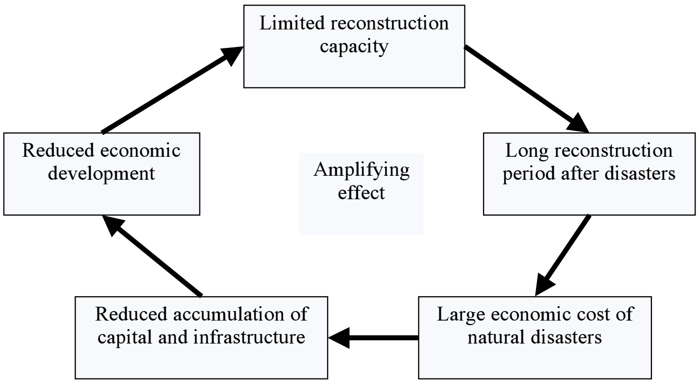
(f) Poverty traps

It is crucial to also take into account the possibility that natural disasters increase poverty. In particular, because they destroy assets and wipe out savings, they can throw households into 'poverty traps', i.e. situation in which their productivity is reduced, making it impossible for them to rebuild their savings and assets. These micro-level poverty traps can also be created by health and social impacts of natural disasters: it has been shown that disasters can have long-lasting consequences on psychological health (Norris 2005), and on children development (from reducing in schooling and diminished cognitive abilities – see, for instance, Santos (2007); Alderman *et al.* (2006)).

These poverty traps at the micro-level (i.e. the household level) could even lead to macro-level poverty traps, in which entire regions could be stuck. Such poverty traps could be explained by the amplifying effect reproduced in Figure 3. Poor regions have a limited capacity to rebuild after disasters: if they are regularly affected by disasters, they do not

Figure 3

Amplifying Effect Illustrating How Natural Disasters Could Become Responsible for Macro-Level Poverty Traps



Source: Authors' conception.

have enough time to rebuild between two events, and they end up into a state of permanent reconstruction, with all resources devoted to repairs instead of addition of new infrastructure and equipments. These obstacles to capital accumulation and infrastructure development lead to a permanent disaster-related under-development. This effect has been analyzed by Hallegatte *et al.* (2007) with a reduced-form model showing that the average GDP impact of natural disasters can be either close to zero if reconstruction capacity is large enough, or very large if reconstruction capacity is too limited (which may be the case in less developed countries).

This type of feedback can be amplified by other long-term mechanisms, like changes in risk perception that reduces investments in the affected regions or reduced services that make qualified workers leave the regions. Because of these mechanisms, the consequences of a disaster can last much longer than what is normally considered to be the recovery and reconstruction period.

An example of assessment on Katrina in New Orleans

For the landfall of Katrina on New Orleans, the availability of a large amount of data allowed many modelling analyses. Hallegatte (2008), for instance, estimated using a regional input-output model that indirect economic losses in Louisiana after Katrina amounted to 42 billion US dollars compared to 107 billion US dollars of direct economic losses. More generally, this analysis concludes that regional indirect losses increase nonlinearly with direct losses, suggesting the existence of threshold in the coping capacity of economic systems. In this analysis of Louisiana, indirect losses remain negligible (or even negative) for direct losses below 50 billion US dollars, and then increase nonlinearly to reach 200 billion US dollars for direct losses of the same amount (see Figure 4). Also, indirect losses decrease rapidly if it is possible to 'import' reconstruction means (workers, equipment, finance) from outside the affected region. This result highlights the importance of considering the interregional interactions.

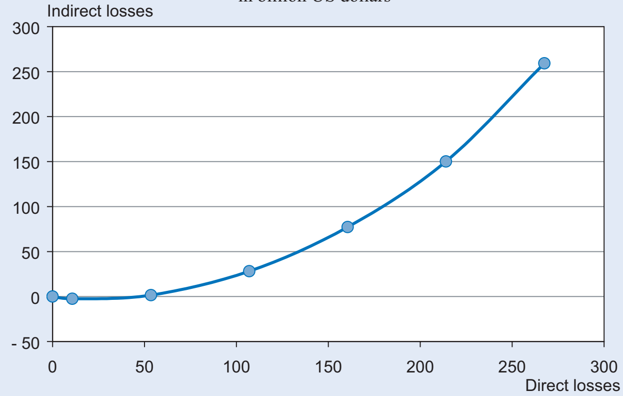
Conclusions

This article highlights the main difficulties in defining, measuring and predicting the total cost of disasters. It focuses on indirect (or output) losses, considered as a major component of the total loss of population welfare. There are several methodologies to assess these indirect losses, but they are all based on questionable assumptions and modelling choices,

Figure 4

Indirect (Output) Losses as a Function of Direct (Asset) Losses in Louisiana for Katrina-like Disasters

in billion US dollars



Source: Hallegatte (2008).

and they can lead to very different results. The main conclusion is of this article twofold.

First, it is impossible to define 'the cost' of a disaster, as the relevant cost depends largely on the purpose of the assessment. The best definition and method obviously depend on whether the assessment is supposed to inform insurers, prevention measure cost-benefit analyses, or international aid providers. A first lesson from this article is that any disaster cost assessment should start by stating clearly the purpose of the assessment and the cost definition that is used. Following this recommendation would avoid misleading use of assessments, and improper comparison and aggregation of results.

Second, there are large uncertainties on indirect disaster costs, and these uncertainties arise both from insufficient data and inadequate methodologies. Considering the importance of unbiased estimates of disaster cost, for instance to assess the desirability of prevention measures, progress in this domain would be welcome and useful. To do so, much more research should be devoted to this underworked problem.

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