

Are Losses from Natural Disasters More Than Just Asset Losses?

The Role of Capital Aggregation, Sector Interactions,
and Investment Behaviors

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Abstract

The welfare impact of a natural disaster depends on its effect on consumption, not only on the direct asset losses and human losses that are usually estimated and reported after disasters. This paper proposes a framework to assess disaster-related consumption losses, starting from an estimate of the asset losses, and leading to the following findings. First, output losses after a disaster destroys part of the capital stock are better estimated by using the average—not the marginal—productivity of capital. A model that describes capital in the economy as a single homogeneous stock would systematically underestimate disaster output losses, compared with a model that tracks capital in

different sectors with limited reallocation options. Second, the net present value of disaster-caused consumption losses decreases when reconstruction is accelerated. With standard parameters, discounted consumption losses are only 10 percent larger than asset losses if reconstruction is completed in one year, compared with 80 percent if reconstruction takes 10 years. Third, for disasters of similar magnitude, consumption losses are expected to be lower where the productivity of capital is higher, such as in capital-scarce developing countries. This mechanism may partly compensate for the many other factors that make poor countries and poor people more vulnerable to disasters.

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What is the economic cost of a natural disaster? Events such as floods or earthquakes destroy assets such as roads, plants, or office space, thus leading to losses of economic production over the following months to years or decades. Assessing the value of this lost production is a key component of the assessment of the welfare impact of disasters.

By definition, the economic value of an asset is the net present value of its expected future production, and the output loss caused by a disaster is simply equal to the value of the lost assets. Summing asset and output (or income) losses would thus be double counting.¹ What value should be used to assess asset losses from natural disasters, then? This is no trivial task. Measuring the value of damaged or lost assets through their construction or replacement cost or through their pre-disaster market value can be inaccurate, in particular if the economic conditions when the assets were built differ from the conditions after the disaster hit, or in the presence of externality or distortion.

This issue is reminiscent of the old debate on whether using economic aggregates, and in particular an aggregated capital stock, can provide sufficient insights on the link between existing capital stock and economic production. Stiglitz (1974) summarized one aspect of this debate as follows:

“From a practical point of view, economists are always dealing with aggregates: one person's labor is aggregated with another, one piece of land is aggregated with another, one kind of steel is aggregated with another, even though they all have different properties. The condition under which these aggregates can be formed, that is, under which the aggregates act as if they were homogeneous factors of production, are very restrictive; nonetheless, I believe that, under most circumstances and for most problems, the errors introduced as a consequence of aggregation of the kind involved in standard macro- analysis are not too important; nonetheless, we must always be on our guard for situations in which this is not true. The question is, Do the problems associated with the accumulation of capital in growth processes represent one area in which properly formulated aggregates (e.g., using chain indices) are likely to lead to serious error? This, I suggest, remains a moot question.”

Here, we suggest that the analysis of natural disasters may be one of these cases where aggregation can lead to errors that are too great to ignore. We find that using a traditional production function would lead to a systematic underestimation of disaster output losses, and that immediate output losses after a disaster reduces the capital stock are better estimated by using the average – not the marginal – productivity of capital – leading to up to a factor three difference in estimates. The reason is that the traditional production function implicitly assumes that the capital which has not been destroyed can immediately and freely be relocated to its most productive use. Explicitly modeling several categories of

¹ In many estimates of households' disaster losses, one can find “asset losses” and “income losses” (see for instance (Patankar and Patwardhan, 2014)). However, it is often the case that “asset losses” represent the losses to the assets owned by the considered household and “income losses” represent the loss in income due to damages to other people's (or public) assets. For instance, a household can lose its house (an asset loss) and be unable to work because its firm is damaged (a loss to the firm owner's asset) or because transportation is impossible (a loss of public assets). In that case, no double counting is happening.

putty-clay capital shows that as long as the destroyed capital does not happen to be the least productive in the economy, output losses will be higher than asset losses.

One implication is that the net present value of disaster-caused consumption losses decreases when the reconstruction is accelerated. Discounted consumption losses are only 10 percent larger than asset losses if reconstruction is completed in one year, compared with 50 percent if reconstruction takes 10 years. After a disaster there is an urgency to redirect resources away from new investments to concentrate them on repairs and reconstruction. This fact is consistent with the higher marginal productivity of reconstructed capital (compared to investment in new assets) that is found in the framework proposed here.

Finally, if asset and income losses are to be avoided, it is because they ultimately result in consumption losses. We thus analyze how asset losses due to natural disasters result in consumption losses. We find that for disasters that destroy a similar fraction of built capital, net present consumption losses are expected to be lower where the productivity of capital is higher, such as capital-scarce developing countries. Indeed, in economies where capital has a higher productivity, the ratio of installed capital over consumption is smaller. Thus replacing the same fraction of destroyed capital requires less forgone consumption. This mechanism may partly compensate for the many factors that make poor countries and poor people more vulnerable to disasters, such as the lower quality of their assets, their lack of access to insurance and credit, and their low level of pre-disaster consumption (Hallegatte et al., 2016).

1 Output losses with a classical production function

Production functions relate the inputs and the outputs in the production process. Classically, output can be represented as

$$Y = F(L, K)$$

Where L denotes the amount of labor, K the amount of capital, and Y the output. In this framework, the damage that natural disasters – such as floods, storms, earthquakes – impose on assets can be modeled as an instantaneous decrease in the stock of productive capital ($K_0 \rightarrow K_0 - \Delta K$), where ΔK is the value of the asset losses, measured as the repair or replacement cost at pre-disaster prices (this is the common metric used to measure disaster economic losses).

For small shocks, the impact on production can be estimated using the marginal productivity of capital.

Denoting $r = \frac{dF}{dK}$ the marginal productivity of capital:

$$\Delta Y(t_0) = r\Delta K \tag{1}$$

If there is no reconstruction, the net present value of the constant output losses discounted at an unchanged rate r equals the pre-disaster replacement value of lost assets:

$$\widetilde{\Delta Y} = \Delta K \tag{2}$$

In a more realistic setting, however, this method to assess output losses may lead to significant underestimation. One issue is that asset losses may be too large to be considered marginal. To assess non-marginal shocks on the capital stock, one can use the full production function, and decrease the amount of capital from K_0 to $K_0 - \Delta K$. In that case, output losses are larger than in the idealized (marginal) framework and Equation (1) is replaced by:

$$\Delta Y(t_0) = F(L, K) - F(L, K - \Delta K) \quad (3)$$

This factor alone would make the net present value of the output losses larger than the value of the damages to assets expressed with pre-disaster prices.²

2 Disasters affect the capital structure, not only the capital quantity

Equation (3) assumes that the destruction from the disaster affects only the least productive assets, or that capital consists only in one homogeneous commodity that can be instantaneously reallocated toward its more productive usage. However, this assumption is unlikely to be valid after a disaster, because assets such as roads or offices cannot be transformed into other assets such as bridges or factories at no cost and instantaneously.

2.1 Accounting for imperfect capital reallocation

Let us use a simple example with an economy where capital consists only of roads that produce “transport services”. Roads are built starting from the most productive, that is the one used by the most people, to less productive ones, used by fewer people. At a given point in time, some roads have a high productivity, and some roads have a low productivity. Only the least productive road has the same marginal productivity as the aggregated capital stock. At equilibrium, and assuming that all roads cost the same, the construction cost of the least productive road is equal to the discounted value of its production. The other roads have a higher productivity, and the value of their production is larger than their construction cost.

If a disaster happens to destroy the segment of the road that was built last, that is the least productive segment, then the value of the destroyed road would happen to be equal to the marginal productivity of roads as an aggregate. As in equation (1), output losses ΔY would thus be the product of the value of the destroyed road (ΔK) times its productivity (r). Discounted production losses would thus equal the construction cost of the road segment, as in equation (2). But if the disaster destroys any other segment, then the productivity of destroyed capital is higher than the marginal productivity of the road network before the disaster hits. The production loss associated with the destruction of an arbitrary road segment is equal the construction cost of that segment times to the productivity of that particular segment, which is higher than the marginal productivity of the aggregated road network. To assume that the destruction of *any* road can be valued at the marginal productivity of the road network would amount to assume

² Note that if the value of asset losses ΔK is defined as the discounted value of the lost production, then by definition the asset losses are equal to lost production. Here, we highlight the difference between the asset losses measured by their pre-disaster value and the lost production.

roads can be instantaneously reallocated to their most productive use, i.e. that roads can be moved where they are the most useful, which is of course impossible.

This example shows that the production loss can be higher than the marginal productivity of capital, and the net present value of the lost production can be larger than the construction or replacement value of the road. The replacement value of lost assets provides an underestimation of the net present value of the loss in output.

If the disaster affects more flexible forms of capital, then capital reallocation is possible. Someone whose car has been damaged could for instance buy the least productive undamaged car to its owner. However, this reallocation is (1) not instantaneous (it takes time for all the transactions to take place); (2) not costless (there are transaction and adjustment costs in capital reallocation); (3) not complete (some capital, like the roads in the previous example, cannot be reallocated, for technical, financial, institutional or behavioral reasons).

This issue links to the possibility to describe the capital stock with a single number in an aggregate production function. The question was core to the Cambridge capital theory controversy and the limits of the one-commodity model (Cohen and Harcourt 2003), and to (Robinson 1974) critics on the problem of path dependence. Indeed, the capital stock can be represented unambiguously through a single number only if this capital stock is the result of a process of optimal capital accumulation, or if capital can be reallocated instantaneously and at no cost toward its optimal use. Only the assumption of optimal capital allocation allows to remove relative prices and interest rate from the valuation of the capital stock and make it possible to measure capital with a single variable K (Cohen 1989).

Even if capital was allocated optimally during its progressive accumulation, a natural disaster destroys a random fraction of this capital, and there are obvious limits to capital reallocation in a disaster aftermath. In what follows, we investigate the impact of capital losses on aggregate output in a model with explicit categories of capital that cannot be relocated across categories. We then use a different approach, using a model with a single stock of productive capital, where two dimensions (total capital and fraction of capital destroyed) are used to describe the stock of capital and the production process.

2.1.1. Modeling disaster impacts on output with layers of capital

Let us first assume that the capital is the aggregation of many “layers” of capital:

$$K = \sum_{i=1 \dots N} k_i$$

Layers can be broad (homes, vehicles, manufacturing equipment, etc.) or narrow (a road going from A to B, the cars in the city C, the houses of the neighborhood D, etc.). Each capital layer i has a uniform productivity π_i , such that:

$$\frac{\partial Y}{\partial k_i} = \pi_i$$

There is also a maximum amount of capital in each capital layer: $k_i \leq \bar{k}_i$. For instance, once all roads in a neighborhood are built, building more roads will not produce more mobility. This can be seen as an extreme version of decreasing returns within categories: the marginal productivity is constant until a given threshold, and then drops to zero when all opportunities for investment within that layer of capital are exhausted.

We rank the layers of capital so that their productivities are decreasing:

$$i < j \rightarrow \pi_i > \pi_j.$$

The production function is given by:

$$Y = \sum_{i=1 \dots N} \pi_i k_i$$

If the aggregated capital stock K is allocated optimally, investment goes first to the highest-productivity layer of capital until all potential is exhausted, then moves to the second-best layer of capital, and so on. Only the last layer used may have unused potential in the sense that:

$$i < i_0, k_i = \bar{k}_i$$

$$k_{i_0} \leq \bar{k}_{i_0}$$

The production function becomes:

$$Y = F(K) = \sum_{i=1 \dots N} \pi_i k_i$$

And the marginal productivity of aggregated capital is given by the productivity of the least productive used layer of capital:

$$F'(K) = \pi_{i_0(K)}$$

The production function meets all of the classical properties. In particular, the marginal productivity of capital is decreasing with K , that is, the production function exhibits decreasing returns.

With such a production function, a destruction of capital ΔK can lead to a loss of production given by the marginal productivity of capital π_{i_0} , but only if the destruction occurs in the last layer of capital (or if capital could be reallocated from the lower- to the higher-productivity capital layers).

A more plausible case is if capital destruction is distributed uniformly over the layers of capital, that is for all i :

$$\frac{\Delta k_i}{k_i} = \frac{\Delta K}{K}$$

Assuming capital reallocation is not possible across capital layers, the impact on production is:

$$\Delta Y = \sum_{i=1 \dots N} \pi_i \Delta k_i = Y \frac{\Delta K}{K}$$

In other words, $\Delta Y / \Delta K$, the productivity of destroyed capital, equals Y/K , the average productivity of capital – not the marginal productivity of capital. In particular, output losses are higher than the construction value of damaged assets.

Importantly, this larger impact of capital losses does not require that reallocation of capital is entirely impossible – the result holds if reallocation of capital is possible within layers (a car or a house can be reallocated to its most efficient use), but not across layers (a house cannot replace a damaged road).

2.1.2. Modeling disaster impacts with categories of fully substitutable capital

Consider now a more generic model, in which capital still consists of a sum of different types of capital:

$$K = \sum_{i=1 \dots N} k_i$$

And that each capital category produces output with the same production function:

$$y_i = f(k_i)$$

where f has all the classical properties, and in particular $f' > 0$ and $f'' < 0$. The total production is simply the sum of the output of all categories:

$$Y(K) = \sum y_i = \sum f(k_i)$$

If capital K is allocated optimally across the capital categories, there is one λ such that for all i :

$$f'(k_i) = \lambda$$

so that all k_i are equal and thus equal to K/N . Under the assumption of perfect capital allocation, we can describe the production process with the following aggregate production function:

$$Y = F(K) = Nf\left(\frac{K}{N}\right)$$

In this case, the marginal productivity of aggregate capital is given by:

$$F'(K) = f'\left(\frac{K}{N}\right)$$

And the second derivative of production is:

$$F''(K) = \frac{1}{N} f''\left(\frac{K}{N}\right)$$

So this aggregate production function meets the classical conditions of a production function.

Assume now that a shock destroys a non-marginal quantity ΔK of capital. If capital remains optimally allocated, then the impact can be approximated by:

$$\Delta Y_{opt} = \Delta K f' \left(\frac{K}{N} \right) + (\Delta K)^2 \frac{1}{N} f'' \left(\frac{K}{N} \right) = \Delta K F'(K) + (\Delta K)^2 F''(K)$$

If capital losses occur only in one (say, the first) category of capital, and assuming perfect reallocation within categories but not across categories, the result is:

$$\Delta Y_1 = \Delta K f' \left(\frac{K}{N} \right) + (\Delta K)^2 f'' \left(\frac{K}{N} \right) = \Delta K F'(K) + N(\Delta K)^2 F''(K)$$

So that:

$$\Delta Y_1 - \Delta Y_{opt} = (N - 1)(\Delta K)^2 F''(K)$$

For marginal shocks, if $(N - 1)(\Delta K)^2 F''(K)$ is negligible, representing capital and production as aggregates only does not lead to a significant underestimation of capital losses. But if losses are large or concentrated on a few sectors, if the number of layers across which capital cannot be reallocated is large, or if the second derivative of the production function is large in absolute value, the difference can be substantial. In this case, representing the production process with an aggregate capital stock would lead to underestimating the effect of asset losses on production. And this aggregation error increases with the size and concentration of the shock: as the disaster becomes more serious, or if losses are concentrated spatially or sectorally, then the aggregated production function leads to a larger underestimation of the losses.

In such a model, whether a shock is small or marginal cannot be decided by comparing the total amount of losses ΔK to the total amount of capital K . One has to consider each category of capital (within the N categories) and compare the losses within that category to the amount of capital in that category, as well as the curvature of the production function, to compare $\Delta K F'(K)$ and $N(\Delta K)^2 F''(K)$.

For instance, if a disaster destroys an entire category of capital, total capital losses are $\Delta K = K/N$, and output losses equal :

$$\Delta Y = f \left(\frac{K}{N} \right) = \frac{F(K)}{N} = \frac{F(K)}{K} \Delta K$$

Here again, the loss in output is equal to the loss in assets multiplied by the average – not the marginal – productivity of capital, even if the total amount of capital destroyed is very small. In particular, if the economy is partitioned in a very large set of categories N , and disasters tend to destroy entire categories of capital at once (for instance a bridge is usable or not), then output losses depend on the average productivity of capital. (On the other hand, if categories are only partially damaged, then losses are lower – if a bridge is only partially damaged and can accommodate 50% of peak traffic, it is likely that the service it produces is reduced by less than 50%.)

2.1.3. Modeling aggregate capital with two variables

Two distinct representations of the capital as the aggregation of many categories of capital lead us to conclude that output losses from natural disasters can be directly proportional to asset losses, that is depend on the average, not the marginal productive of capital. Echoing the remark by Stiglitz in the introduction, these models use several variables, not just one aggregate, to track capital. In this section, we propose an alternative model that implements as simply as possible this idea that several variables are needed to track capital: using two variables to track it.

The first variable is the total amount of capital in the absence of disaster damages K and the second variable is the amount of damaged capital K_d . We assume that in the absence of damages, the output is given by the usual production function $F(L, K)$. When a fraction of the capital is damaged, output is simply reduced proportionally to the loss in capital: if 10% of the capital stock is lost, then 10% of the instantaneous output is lost:

$$Y(K, K_d) = \left(1 - \frac{K_d}{K}\right)F(L, K) \quad (4)$$

In this model, asset losses ΔK add to destroyed capital, K_d instead of reducing constructed capital K . With these assumptions, lost capital has a productivity equal to the average productivity of the capital in the economy, and

$$\Delta Y(t_0) = \mu \Delta K \quad (5)$$

with μ equal to the average productivity of capital $F(L, K)/K$. Assuming no reconstruction, output reduction is permanent, and the net present value of output losses is:

$$\widetilde{\Delta Y} = \frac{\mu}{r} \Delta K \quad (6)$$

With these assumptions, the net present value of the loss in output is larger than the value of lost assets expressed as replacement value at pre-disaster prices (since average productivity is higher than marginal productivity). Assuming a Cobb-Douglas production function and using a share of capital income of 1/3, as is observed in most economies, discounted output losses are three times larger than what an estimation with a traditional production function would suggest.

This idea can be expanded to accommodate for labor. Indeed, after a disaster, either labor (through causalities and fatalities, for instance) or capital can be the binding constraint. Denoting L_d the part of labor that becomes unusable after the disaster, this model can be generalized as:

$$Y(K, L, K_d, L_d) = \overbrace{F(L, K)}^{\text{Long-term production function}} \overbrace{\min \left[1 - \frac{L_d}{L}, 1 - \frac{K_d}{K} \right]}^{\text{Short-term production constraint}} \quad (6)$$

Note that this writing also allows capturing the fact that the malleability of the production system depends on the timescale. Traditional production functions, such as Cobb-Douglas depending on labor and capital, are good representations of long-term factor allocations, when capital reallocation and technology adjustments to substitute capital and labor are possible. $F(L, K)$ can be a traditional production function. Over the short term, however, factor allocation is less flexible. The Leontief-style additional factor on the right represents that. Equation (6) is an example of production function that can be used to capture both the urgency to reconstruct and recover from an event, and the choice between investing in capital or labor over the long term.

2.2 Interactions between damaged and undamaged assets

The previous section suggests that the productivity of the lost capital may be larger than the marginal productivity of capital, but still assumed that the assets that have not been directly affected by the disaster can continue producing with an unchanged productivity.

But we also need to take into account the spill-over effects of asset losses: when assets are imperfectly substitutable, the loss of one asset affects the productivity of other assets. Output losses are not only due to forgone production from the assets that have been destroyed or damaged by the event. Assets that have not been affected by the disaster can also become unable to produce at the pre-event level because of indirect impacts. For instance, most economic activity cannot take place during a power outage, because electricity is an essential (and often non-substitutable) input in the production process.

2.2.1. Anecdotal evidence

(McCarty and Smith 2005) investigated the impact of the 2004 hurricane season on households in Florida, and find that among the 21% of the households who were forced to move after the disaster, 50% had to do so because of the loss of utilities (e.g., they had no running water). Only 37% of them had to move because of structural damages to the house. In most cases, the loss in the housing services produced by a house is not due to an impact on the house itself, but to impacts to complementary assets (e.g., water pipes).

(Tierney 1997) and (Gordon, Richardson, and Davis 1998) investigate the impact of the Northridge earthquake in 1994 in Los Angeles; they find also that loss of utility services and transport played a key role. Tierney surveys the reasons why small businesses had to close after the earthquake. The first reason, invoked by 65% of the respondents (several answers were possible), is the need for clean-up. After that, the five most important reasons are loss of electricity, employees unable to get to work, loss of telephones, damages to owner's or manager's home, and few or no customers, with percentages ranging from 59% to 40%. These reasons are not related to structural damages to the business itself, but to offsite impacts. (Gordon, Richardson, and Davis 1998) ask businesses to assess the earthquake loss due to transportation perturbations, and find that this loss amounts to 39% of total losses. (Kroll et al. 1991) find comparable results for the Loma Prieta earthquake in San Francisco in 1989: the major problems for small businesses were customer access, employee access, and shipping delays, not structural damages. Utilities (electricity, communication, etc.) caused problems, but only over the short term, since these services were restored rapidly; only transportation issues led to long lasting consequences. (Rose and Wei 2013)

investigate the impact of a 90-day disruption at the twin seaports of Beaumont and Port Arthur, Texas, and find that – even in the absence of other losses – regional gross output could decline by as much as \$13 billion at the port region level (and that specific actions to cope with the shock can reduce these impacts by nearly 70%).

Output losses due to a disaster depend not only on interactions across sectors but also on interactions across firms (Henriet, Hallegatte, and Tabourier 2012). Business perturbations may indeed also arise from production bottlenecks through supply-chains of suppliers and producers.³ Modern economies, with global supply chains, limited number of suppliers and small stocks, may be more vulnerable to natural disasters than traditional, close economies. The impacts of disasters on supply chains are illustrated by the large 2011 floods in Thailand. Car manufacturing in Thailand dropped by 50% to 80%, and Toyota was the company hit the hardest in terms of production loss, even though none of its plants got inundated: A critical supplier in the manufacturers' supply chains was affected by the floods (Haraguchi & Lall, 2015). Similarly, the global production of hard drive disks (HDD) decreased by 30% in the 6 months after the floods, causing a price spike between 50% and 100% (Haraguchi & Lall, 2015; Japanese Ministry of Economy, 2011). This production loss was not only caused by the disruption of production facilities in Thailand, but also further HDD manufacturers outside Thailand were affected by missing parts from suppliers in flooded areas (Wai & Wongsurawat, 2013).

These effects are measurable. (Barrot and Sauvagnat 2016) explore the impact of natural disasters in the US on firms' sales, but also on their suppliers. They find that – unsurprisingly – the occurrence of a natural disasters decreases affected firms' sales (by about 5 percent), but also the sales of the affected firm's customers (by about 3 percent, four months after the disasters). They also show that this effect is not due to geographic proximity between affected firms and their customers, suggesting that the effect propagates through supplies' scarcity, and that the effect is magnified when the suppliers is "specific," i.e. when the supply is not generic and is therefore more difficult to replace. Similar effects have been observed after the 2011 earthquake in Japan, with propagation beyond Japanese borders (Boehm, Flaaen, and Pandalai-Nayar 2015). Todo, Nakajima, and Matous (2015) shows that network firms have not only an impact on disaster impacts, but also on "firm resilience," defined as the ability of the firm to recover from the shock: among firms that were affected by the 2011 earthquake in Japan, those with suppliers and customers outside the affected areas recovered more quickly than the others.

While these effects are now well documented, they remain challenging to model and quantify. Here, we explore two specific models of firm-to-firm or sector-to-sector propagation, based on Cobb-Douglas and Leontief production functions.

2.2.2. The case with Cobb-Douglas production functions

The framework used in Acemoglu et al (2012) allows investigating propagation effects with Cobb-Douglas production functions. Let us assume that the production technology in sector i is described by a Cobb-Douglas function:

³ These ripple effects can even take place within a factory, if one segment of the production process is impossible and therefore interrupts the entire production.

$$x_i = k_i^\alpha \prod_{j=1 \dots n} x_{ij}^{(1-\alpha)w_{ij}}$$

where k_i is the capital stock in sector i , $\alpha \in (0, 1)$ is the share of capital income, and x_{ij} is the amount of commodity j used in the production of good i , and w_{ij} represent the share of different intermediate consumption in the production process. (This is the model from the original paper, where labor has been replaced by the capital stock; an alternative representation would be to represent capital as one intermediate consumption.)

Acemoglu et al (2012) show that with Cobb-Douglas functions, there are no propagations of a productivity shock upstream, because price and quantity effects cancel out.

Assume that a disaster reduced each sector's capital by a fraction d_i , the production function becomes:

$$x_i = ((1 - d_i)k_i)^\alpha \prod_{j=1 \dots n} x_{ij}^{(1-\alpha)w_{ij}}$$

Here, the relationship between production and capital losses is given by the Cobb-Douglas function, so that the loss of consumption is worth a fraction $(1 - d_i)^\alpha$ of pre-disaster capital – the losses depend on marginal productivity, like in section 2.1.2, because it is implicitly assumed that reallocation is possible at no cost within each sector i .

Acemoglu et al (2012) show the output in the competitive equilibrium is given by:

$$\log(Y) = v'(1 - d)$$

where d is the vector of $\{d_i\}$ and v is given by:

$$v = \frac{\alpha}{n} [I - (1 - \alpha)W']^{-1} \mathbf{1}$$

Where W is the input-output matrix of w_{ij} . At equilibrium, the vector v is also the “sale vector”:

$$v_i = \frac{p_i x_i}{\sum_j p_j x_j}$$

where p_i is the pre-disaster competitive equilibrium price of good i . (This is consistent with Hulten's theorem linking sector-level productivity shocks to macro-level output; Hulten 1978.) If a sector that represents 2% of the total sales in the economy loses 10% of its production, the loss in output is 0.2%. Note that v is the sale vector, not the value-added vector. It gives more importance to sectors with large intermediate consumption (since intermediate consumption is the wedge between value added and sales). In this context, an economy with large intermediate consumptions will experience larger macroeconomic losses from the level sector-level shock.

2.2.2. Illustrative modeling with Leontief functions

Spill-overs across sectors can also be represented through non-homogeneous capital: capital components are not perfectly substitutable within a network of economic activities, and the relative price of different types of capital depends on the relative quantity. If the stock of capital consists of an ensemble of capital categories that have some complementarity, then the destruction of one component may reduce the productivity of other components and thus have an impact that is larger than what could be expected from the analysis of one component only. (On the other hand, if different types of capital are substitutable, the destruction of one type of capital can be compensated partially with the utilization of another type of capital. For instance one road from A to B can become more productive, that is be used by more passengers, if an alternative route from A to B is destroyed.)

One extreme example is the case of a road that is built out of a series of segments between two points: if one segment is destroyed, then the road is not usable and the other segments become useless. The output loss due to the destruction of one segment cannot be estimated based on the construction value of that segment alone, but requires an analysis of the entire system (the road). The same is true – at various degrees – of the entire economic system: the loss of one component can affect the other components and lead to losses that are higher (or lower) than the value of the asset loss suggests depending on the substitutability. This problem is disregarded if one assumes that the capital stock is always (both before and after an event) optimally allocated (in that case, road segments can be moved to their most efficient uses).

This problem can be illustrated by replacing the classical production function $f(L,K)$ by a function with two types of capital $f(L,K_1,K_2)$. If there are decreasing returns in K_1 and K_2 , the impact of a given loss $\Delta K = \Delta K_1 + \Delta K_2$ depends on how losses are distributed across the two capitals. The loss in output is larger if all losses affect only one type of capital, compared with a scenario where the two capitals are equally affected.

These two issues can be illustrated with a simple example. Assume that there are two categories of capital, K_1 and K_2 , that are not substitutable. The production function is a nested Cobb-Douglas between capital services and labor, and capital services are produced using the two capital categories, through a Leontief function:

$$Y = f(L, K_1, K_2) = [\text{Min}(c_1 K_1, c_2 K_2)]^\alpha L^\beta$$

K_1 and K_2 could be interpreted as two segments of a road with different construction costs, for instance: if one segment is completely destroyed, the second segment's productivity falls to zero, and the total capacity of the road is given by its segment with the lowest capacity. If one segment is damaged so that only half of the traffic can go through, then the second segment also sees half of the traffic and its productivity is also halved.

Total capital is $K = K_1 + K_2$. At the optimum, the quantities of each type of capital adjust such that $c_1 K_1 = c_2 K_2$. If we assume that capital K is always distributed optimally across K_1 and K_2 , the production function becomes:

$$Y = F(K, L) = \left[\frac{c_1 c_2}{c_1 + c_2} K \right]^\alpha L^\beta$$

This production function is a classical Cobb-Douglas function, and it can be used to estimate changes in production resulting from investments or divestment, provided that the capital is optimally distributed across categories of capital (i.e. across sectors, technologies, localization, etc.), at the marginal productivity of aggregate capital:

$$\frac{\partial F(K, L)}{\partial K} = \alpha \frac{c_1 c_2}{c_1 + c_2} \left[\frac{c_1 c_2}{c_1 + c_2} K \right]^{\alpha-1} L^\beta$$

If a disaster hits this economy and destroys capital K_1 and K_2 proportionally, or if the residual capital in the two categories can be reallocated, then the immediate loss of output will be given by the product of the marginal productivity of capital by the value of the damages, and the net present value of capital losses will be equal to the value of the damages, as expected.

But if only one category of capital is affected – say K_1 – then $c_1 K_1 < c_2 K_2$, and if there is no possible reallocation of capital,⁴ then the production becomes driven by K_1 over the short term, and the loss in output from a marginal loss of K_1 is:

$$\frac{\partial Y}{\partial K_1} = \alpha c_1^\alpha K_1^{\alpha-1} L^\beta$$

Replacing K_i with $F'(K)$ and generalizing to n categories of capital, we get:

$$\frac{\partial Y}{\partial K_i} = \left(\frac{\sum c_j}{\sum c_j - c_i} \right) F'(K)$$

In that case, the destruction by a disaster of a (marginal) amount ΔK_i of one type of capital would lead to a loss of output with a net present value equal to:

$$\widetilde{\Delta Y} = \left(\frac{\sum c_j}{\sum c_j - c_i} \right) \Delta K_i$$

If c_i is small, the net present value of output losses can be much larger than ΔK_i . This case is extreme because the different categories of capital are assumed non-substitutable. But recent evidence suggests that at least over the short-term, elasticities in the production system are close to zero (Boehm, Flaaen, and Pandalai-Nayar 2015; Farhi and Baqaee 2017). Typically, it is the case that if all electricity generation is impossible, most other production processes are interrupted. Even though electricity generation represents a small share of GDP, the impact of such an event on total output can be very large (Rose, Oladosu, and Liao 2007; Farhi and Baqaee 2017).

The qualitative result remains valid with higher substitutability: considering disaggregated capital categories with imperfect substitutability, a disaster would break the assumption that the total amount

⁴ In growth models, the impossibility to relocate capital can be represented by a non-negativity constraint on investments: investments in capital K_1 cannot be negative, with the divestment used to consume or invest in K_2 ; see an example in Rozenberg et al. (2014).

of capital is optimally distributed across these categories, increasing the marginal productivity of destroyed capital and the value of output losses (and as a result, the marginal productivity of reconstruction).

Recent papers have explored the impact of microeconomic shocks on aggregate consumption of GDP, using production function with constant elasticity of substitution (Farhi and Baqaee 2017; Baqaee 2016; Taschereau-Dumouchel 2017). Unsurprisingly, they find that smaller elasticity in the production function tends to increase the aggregate losses due to a negative shock, and that a large shock to a small sector can have a large impact on macroeconomic aggregates.

2.3 Externalities

Output losses need to be estimated from a social point of view. The equality between market value (for the owner) and expected output (for society) is valid only in the absence of externalities. Some assets that are destroyed by disasters may exhibit positive externality. It means that their value to society is larger than the value of the owner's expected output. Public goods have this characteristic, among which include infrastructure projects, health services, and education services.⁵

One example is the health care system in New Orleans. Beyond the immediate economic value of the service it provides, a functioning health care system is necessary for a region to attract workers (in other terms, it creates a positive externality). After Katrina's landfall on the city in 2005, the lack of health care services made it more difficult to attract construction workers to the region, and thus slowed down the reconstruction; as a result, the cost for the region of the loss in health care services was larger than the direct value of this service.

To account for these effects, lost assets (ΔK) should be valued taking into account externalities. Below, we explore two particular cases: the stimulus effect of reconstruction; and productivity spill-overs from reconstruction.

2.3.1. The stimulus effect

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. For instance, (Albala-Bertrand 2013) assumes that reconstruction spending has a Keynesian multiplier equal to two (each dollar spent in reconstruction increases GDP by two dollars). However, as for any stimulus, its consequences depend on the pre-existing economic situation, such as the phase of the business cycle and the existence of distortions that lead to under-utilization of production capacities ((S. Hallegatte and Ghil 2008). If the economy is efficient and 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. For instance, the 1999 earthquake in Turkey caused direct destruction amounting to 1.5 to 3% of Turkey's GDP,

⁵ Other assets may exhibit negative externality, e.g. air pollution from a coal power plant.

but consequences on growth remained limited, probably because the economy had significant unused resources at that time (the Turkish GDP contracted by 7% in the year preceding the earthquake). In this case, therefore, the earthquake may have acted as a stimulus and increased economic activity in spite of its human consequences. In 1992, the economy in Florida was depressed and only 50% of the construction workers were employed (West and Lenze 1994) when Hurricane Andrew made landfall on south Florida. Reconstruction had a stimulus effect on the construction sector, which would have been impossible in a better economic situation (e.g., in 2004 when four hurricanes hit Florida during a housing construction boom).

2.3.2. Productivity spill-overs

Disasters damage old and low-quality capital, and the reconstruction may allow to “build back better” and to reach an endpoint that is superior in some aspects to the pre-disaster situation. For instance, an earthquake may destroy old, low-quality, buildings, making it possible to rebuild with improved building norms (and higher energy efficiency leading to better comfort and lower energy bills); this possibility has been mentioned for the Christchurch earthquake in New Zealand in 2011. And (Hornbeck and Keniston 2014) show that the Great Fire in Boston in 1872 led to a large increase in land values, suggesting that reconstruction created positive local externalities that were difficult to capture through normal building turnover. More general exploration of this effect, hereafter referred to as the “productivity effect” (closely linked to the “Schumpeterian creative destruction effect”), can be found in Albala-Bertrand (1993), Stewart and Fitzgerald (2001), Okuyama (2003) and Benson and Clay (2004).

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. 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’s 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. This effect is often cited to explain why some studies find a positive impact of disasters (Skidmore and Toya, 2002, 2007). 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, in which people have no means of subsistence while production is interrupted. 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 (2009) using a simple economic 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 growth model. Depending on how reconstruction is carried out (with more or less improvement in technologies and capital), moreover,

accounting for the productivity effect can either decrease or increase disaster costs, but this effect is never able to turn disasters into positive events.

3 Reconstruction dynamics and consumption impacts

In the previous section, it was assumed that the output losses were permanent, i.e. that there is no investment or reconstruction taking place. In practice, of course, damaged assets are replaced or repaired, often as fast as possible. And if the lost capital has a productivity that is higher than the pre-disaster marginal productivity of capital, the rationale to reconstruct and repair is stronger than the pre-disaster rationale to invest, possibly leading to higher investments. This section investigates these dynamics.

3.1 Modeling the reconstruction phase

Consider the production function proposed in section 2.1.3, where capital is described by two variables; total amount of capital, and amount of capital destroyed. In this model, investment needs to be described by two variables too: investment towards reconstruction of damaged capital (i_R); and the investment into new capital, which is not linked to reconstruction (i_N):

$$\frac{dK_d}{dt} = -i_R$$

$$\frac{dK}{dt} = i_N$$

The marginal return on expanding the total capital stock I_N is $(1 - \frac{K_d}{K})\partial_K F(K, L) + \frac{K_d}{K}F(K, L)$ while the marginal return on reconstruction I_R is $F(K, L)/K$. With decreasing return, marginal productivity is lower than average productivity of capital, and the return on I_N is lower than the return on I_R .⁶

In this theoretical setting, with perfect capital markets, all post-disaster investments should be dedicated toward the reconstruction instead of damages. For instance, construction of any new house would be postponed to focus efforts toward rebuilding and repairing damaged houses. Similarly, construction of new roads and bridges should be delayed to focus on repairing damaged roads and bridges.

If that was the case, if output could be entirely directed toward reconstruction, damages from disasters would be repaired extremely rapidly. Damages from hurricane Katrina represented less than one month of US investments, so the return to the pre-disaster situation could have happened in a matter of months.

⁶ One limitation of using only two variables is that we have to assume that the return on reconstruction is constant, which is obviously an oversimplification. One way to include priorities for reconstruction (more productive destroyed assets can be rebuilt before less productive destroyed assets), is to keep a disaggregated production function.

But investment in reconstruction is limited by financial and technical constraints. First, the people who lost their assets may not have access to savings or borrowing to pay for reconstruction and repair, and may not be insured, so that they cannot make corresponding investments in spite of their large returns. Second, the economic sectors that are involved in the reconstruction have limited production capacity. For instance, the construction sector usually struggles to cope with the surge in demand seen after disasters, which leads to rationing and increased prices (see the Appendix). These constraints mean that I_R cannot usually represent more than a limited share of total investment (and total output), leading to reconstruction periods that are much longer than what the amount of losses would suggest.

The length of the reconstruction period depends on many characteristics of the affected economy, including (1) the capacity of the sectors involved in the reconstruction process (especially the construction sector); (2) the flexibility of the economy and its ability to mobilize resources for reconstruction (e.g., the ability of workers to move to the construction sector, see (Stéphane Hallegatte 2008)); (3) the openness of the economy and its ability to access resources (e.g., skilled workers and materials for reconstruction); (4) the financial strength of private actors, households and firms, and their ability to access financial resources for reconstruction, through savings, insurance claims, or credit; and (5) the financial strength of the public sector and its ability to access financial resources to reconstruct (see the very thorough analysis of financing options in developing countries in (Mechler 2004)).⁷

As shown in the appendix, one consequence of the limited capacity of the reconstruction sector is that the price of reconstruction services hikes in the aftermath of a disaster.

3.2 Consequence on consumption

Assuming that output losses are reduced to zero exponentially with a characteristic time T , output losses after t_0 are given by:⁸

$$\Delta Y(t) = \mu \Delta K e^{-\frac{t-t_0}{T}}$$

⁷ Specific instruments such as contingent credit lines help with reconstruction financing. See for instance on the World Bank's Cat-DDO, http://treasury.worldbank.org/bdm/pdf/Handouts_Finance/CatDDO_Product_Note.pdf.

⁸ One difficulty is the fact that an economy affected by a disaster may never return to its initial situation: some activities may disappear permanently, while new sectors may appear. Hurricanes in La Réunion, a French island off the coast of Madagascar, in 1806 and 1807 led to a shift from coffee to sugar cane production, for instance. Also, "good" reconstruction may improve the quality and resilience of infrastructure and productive capital (Benson and Clay 2004; Skidmore and Toya 2002). In this rule of thumb, however, we assess the cost of the disaster as the losses that occur if the economy returns to its initial state, leaving economic growth aside. A modeling exercise with an endogenous growth model ((S. Hallegatte and Dumas 2009) suggests that introducing even an optimistic version of this effect would not change results dramatically. Moreover, even if there is no "return to the initial situation," defining the "cost" as "the cost to return to the initial situation" provides a useful (and comparable) benchmark.

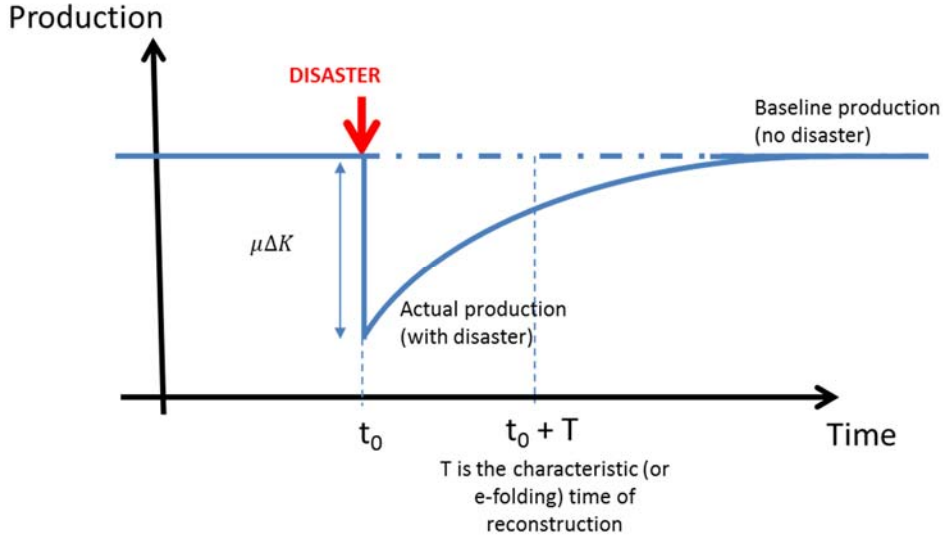


Figure 1: Simplified representation of the return to “initial state” after a disaster. This figure assumes a stable (no-growth) baseline.

With discounting at a rate ρ , the net present value of output losses is:

$$\widetilde{\Delta Y} = \int_{t_0}^{+\infty} \mu \Delta K e^{-\frac{t-t_0}{T}} e^{-\rho(t-t_0)} dt = \frac{\mu \Delta K}{\rho + \frac{1}{T}}$$

Consider first a case where all losses are repaired instantaneously by reducing consumption and directing all the goods and services that are not consumed toward reconstruction investments (this is a scenario where reconstruction capacity is infinite, and T is equal to zero). In this limit case, there is no output loss since all asset damages are instantaneously repaired. There are however consumption losses, since consumption has to be reduced to reconstruct, and this reduction is equal to the reconstruction value (i.e. the replacement cost of damaged capital). In that case, the net present value of consumption losses ($\widetilde{\Delta C}$) is simply equal to the reconstruction cost. With unchanged prices, this is equal to the pre-disaster value of damaged assets ΔK . (If the prices of goods and services needed for the reconstruction change, as discussed in Appendix A, then the reduction in consumption can be larger than the initial assessment of asset losses, a mechanism known as “demand surge” in the insurance industry.)

Consider now another case with no reconstruction, in which output losses are permanent and all losses in output are absorbed by a reduction in consumption (but no share of income is used for reconstruction). In that case, consumption losses are equal to output losses (with no reconstruction), and T is equal to infinity. The loss in consumption at t_0 is thus equal to $\mu \Delta K$, and the net present value (discounted at the rate ρ) of consumption losses is $(\mu/\rho)\Delta K$, as in the previous section. Consumption losses and welfare losses are thus larger than the value of lost assets in a no-reconstruction case.

In the instantaneous reconstruction scenario, consumption losses are equal to the share of consumption needed to repair and rebuild, i.e. to asset losses ΔK . In the no-reconstruction scenario, consumption losses are equal to output losses $(\mu/\rho)\Delta K$, i.e. larger than direct losses ΔK .⁹ As a result, consumption (and welfare) losses are magnified when reconstruction is delayed or slowed down. And in all realistic scenarios where reconstruction takes some time (from months for small events to years for large-scale disasters), consumption losses are larger than direct losses.

For intermediate scenarios, with reconstruction over a given period, the duration of the reconstruction phase determines the welfare cost of natural disasters. The net present value of consumption losses is equal to:

$$\widetilde{\Delta C} = \int_{t_0}^{+\infty} \left(\mu \Delta K e^{-\frac{t-t_0}{T}} + \Delta K e^{-\frac{t-t_0}{T}} \frac{1}{T} \right) e^{-\rho(t-t_0)} dt = \Delta K \frac{\mu + 1/T}{\rho + 1/T}$$

This result depends crucially on the fact that the productivity of destroyed capital is equal to the average pre-disaster productivity of capital. If the productivity of the lost capital was assumed equal to the marginal productivity of capital, i.e. if μ is replaced by r in the equation, then the loss of consumption is simply equal to the loss of capital and is thus independent of the reconstruction duration. There would be no urgency in reconstructing, and accelerating the reconstruction process would not bring any benefit. With the framework proposed here, consumption losses are increasing with the duration of the reconstruction period, a finding that is consistent with the urgency to reconstruct that is easily observable after a disaster.

⁹ The reality is more complex than what has been described here because not all output losses are translated into consumption losses. In practice, the loss in output changes the terms of the inter-temporal investment-consumption trade-off and translates into ambiguous instantaneous changes in consumption and investment. But the main conclusions of the analysis are not affected by this complexity.

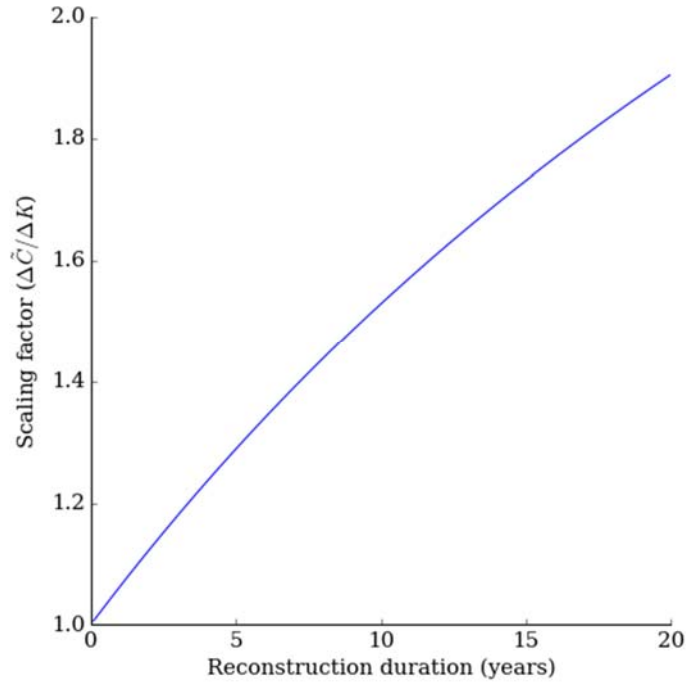


Figure 2: The scaling factor between consumption and asset losses ($\Delta\tilde{C}/\Delta K$) as a function of the reconstruction duration (defined as the time needed to repair 95% of the losses).

The framework also suggests that the relative impact on consumption of a disaster is smaller in developing countries than in developed countries. Express annual consumption as the product of propensity to consume ($1-s$), average capital productivity, and aggregate capital ($C = s\mu K$). Then, the ratio of the net present value of consumption losses to the annual consumption is:

$$\frac{\Delta\tilde{C}}{C} = \frac{\Delta K}{K} \frac{1}{1-s} \frac{1 + 1/\mu T}{\rho + 1/T}$$

If a disaster destroys 15% of the capital in an economy, the relative loss in consumption $\frac{\Delta\tilde{C}}{C}$ decreases with μ : it tends to infinity for $\mu = 0$, and decreases to zero as μ tends to infinity. Since the average productivity of capital μ is expected to decrease as countries develop and accumulate capital (Lucas 1990), rich countries will tend to suffer larger relative consumption losses than poor countries with higher productivity of capital. Where capital has a higher productivity, replacing destroyed capital requires a lower share of consumption.

This effect contribute to the resilience of poor countries (compared with higher income ones): low-income countries can reconstruct without giving up a large share of their consumption, because the amount at stake is lower, even relative to their income. This factor partly rebalances the many other

factors that make poor countries and poor people more vulnerable to natural disaster, such as the higher vulnerability of their capital stock (leading to higher $\Delta K/K$) and the high impact on welfare of the same relative loss in consumption (for a full analysis of the multiple determinants of resilience, see Hallegatte et al., 2016).

This result also suggests that the consumption and welfare impact of natural disasters can be reduced by accelerating reconstruction, for instance by removing some of the financial or technical constraints discussed earlier. Higher penetration of market insurance or better access to borrowing can make reconstruction easier for all economic actors. Higher trade openness helps bring the equipment and materials needed for the reconstruction. Higher openness to workers also helps accelerate reconstruction and reduce the reconstruction cost. For instance, using classical calibration for parameters, reducing a reconstruction period from 5 to 2 years reduces consumption losses by 20 percent (Figure 2).

4 Conclusion

The modeling of the macroeconomic impacts of natural disasters that is proposed here is extremely simple. It is not meant to replace more sophisticated representations of the impacts of natural disasters, such as those based on input-output models (Okuyama et al., 2004; Hallegatte, 2008, 2014) or calculable general equilibrium models (Rose et al., 2007; Rose and Wei, 2013.). It is meant to highlight the risk of underestimating the cost of natural disasters (and the value of rapid reconstruction) in simple models used for the cost-benefit analysis of disaster risk management investments or for climate change analyses.

First, it shows that using an aggregate production function may lead to underestimating the immediate impact of asset losses due to disasters on the economic output flow. It also proposes an alternative modeling to avoid this bias, by using the average – and not the marginal – productivity of capital to estimate the effect of asset losses on output. This results in an immediate reduction in output flow that is about three times larger than estimates based on the value of asset losses (and an aggregated capital stock). A better estimate of the impact on output is a critical input into the assessment of the benefits of risk reduction measures.

Second, this paper highlights the critical role of the reconstruction capacity and speed in the consumption (and welfare) impact of disasters. Again, the bias created when using only one aggregated capital stock in the production function leads to underestimating the output impact of natural disaster, and to disregard the importance of reconstruction capacity as a critical determinant of welfare losses. This paper provides a simple way to estimate total consumption losses due to a disaster. It suggests that the (discounted) consumption losses due to a disaster are 10 percent larger than asset losses if reconstruction takes place in one year, and up to 50 percent if reconstruction takes place in 10 years. This provides the required inputs to estimate the economic benefits from improved reconstruction capacity (e.g., thanks to insurance or rainy-day funds).

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Appendix A: Price impacts and the cost of reconstruction

The equality of asset value and output is valid only for marginal changes, i.e. for small shocks that do not affect the structure of the economy and the relative prices of different goods and services. The impact is different for large shocks. Such non-marginal shocks affect prices, while asset and output losses are often estimated assuming unchanged (pre-disaster) prices (e.g., assuming that if a house is destroyed, the family who owns the house can rent another house at the pre-disaster price). But this assumption is unrealistic if the disaster causes more than a small 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-disaster price, as a consequence of the disaster-related scarcity in the housing market.¹⁰

¹⁰ Conversely, if a disaster makes a large fraction of the population leave the city (such as Katrina in New Orleans) or if many jobs disappear as a result, then the cost of housing may decrease because of the shock. Changes in risk perceptions could also lead to a decrease in home values, as illustrated in (Bin and Polasky 2004).

For large shocks, estimating the value of lost output service should take into account the price change. Compared with an assessment based on the pre-disaster prices, it can lead to a significant increase in the assessed disaster cost.

Post-disaster price is especially sensible in the construction sector, which sees final demand soar after a disaster. For instance, Figure 3 shows the large increase in wages for roofers and carpenters in two areas heavily affected by hurricane losses in Florida in 2004. This inflation affects the replacement cost of capital and is referred to as “demand surge” in the insurance industry.

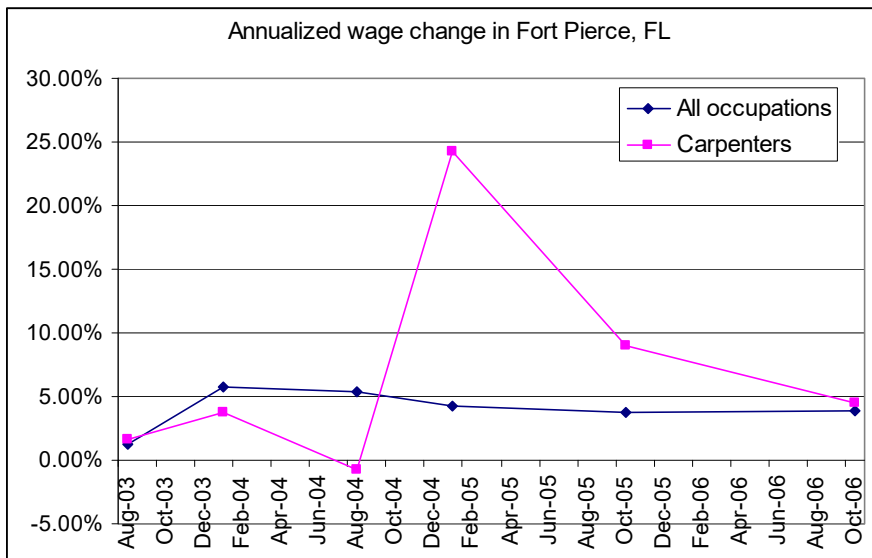
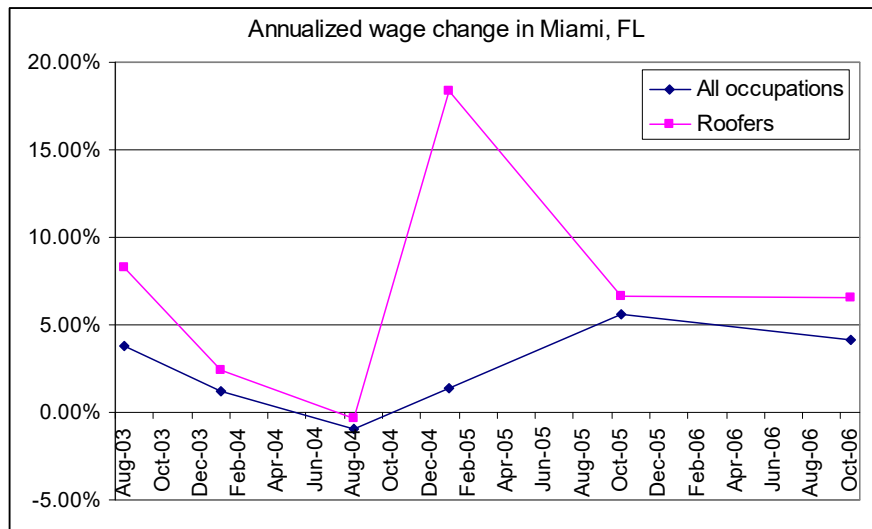


Figure 3: Wages for qualified workers involved in the reconstruction process (roofer and carpenter), in two areas where losses have been significant after the 2004 hurricane season in Florida. Data from the Bureau of Labor Statistics, Occupational Employment Surveys in May 03, Nov 03, May 04, Nov 04, May 05, May 06, May 07.

Post-disaster price inflation is often considered as resulting from unethical behavior from businesses, justifying anti-gouging legislation (e.g., Rapp, 2006). But it also has positive consequences by supporting the optimal allocation of the remaining capital (e.g., housing) and by incentivizing quick reconstruction. 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 financial burden on the affected population.

In extreme cases, or where price adjustment is constrained by ethical considerations or anti-gouging regulations, there may be rationing, i.e. the price cannot clear the market and supply is not equal to demand: there is no available house for rent at any price, there is no qualified worker to repair a roof. In these situations, even using the post-disaster price underestimates the losses.