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Tradable earthquake certificates

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ABSTRACT

This article presents a market-based idea to compensate for earthquake damage caused by the extraction of natural gas and applies it to the case of Groningen in the Netherlands. Earthquake certificates give homeowners a right to yearly compensation for both property damage and degradation of living space. The level of compensation is a percentage of the joint annual gas revenues of the Dutch government, Shell and ExxonMobil and may vary based on the intensity of earthquakes in the previous year. These certificates are tradable within the Netherlands to stimulate the illiquid housing market in the province of Groningen. Although frequent earthquakes have decreased property values in this province, a seller will still receive an efficient price for his house because he can also sell his earthquake certificate. A buyer of this certificate receives an annual stream of income and may use these revenues, for instance, to repay his mortgage or to maintain his house at reduced tax levels. However, multiple implementation problems make the viability of this market-based instrument difficult if not questionable, such as the political decision on the aforementioned level of revenue sharing and the behavioral complexity of the options that tradable earthquake certificates offer to homeowners.

1. Introduction

In 1959 the biggest onshore gas field in the world was discovered in the province of Groningen in the Netherlands. Since 1991 this province suffers from earthquakes caused by the extraction of natural gas by the *Nederlandse Aardolie Maatschappij* (NAM), a joint venture of Shell and ExxonMobil. More than one thousand earthquakes have been registered in this region since the nineties, thus far with a maximum magnitude of 3.6 on the Richter scale reached in 2012 but with a relatively strong impact due to the shallow geological location of the field (Van Thienen-Visser and Breunese, 2015). While the city of Groningen has not been much affected, there has been a significant impact on the many small villages that surround this city. The earthquakes not only cause damage to homes but also lead to reduced enjoyment of the environment and create a conflict of interests between the inhabitants of Groningen, NAM and the rest of the Netherlands. NAM and the remainder of the inhabitants of the Netherlands benefit from gas extraction, while the inhabitants of the province of Groningen bear the burden of the damage, in the form of cracks in the walls of their houses, perceived unsafety due to the risk that buildings may collapse and a faltering regional housing market (Van der Voort and Vanclay, 2015).

Earthquakes caused by natural gas extraction can be seen as externalities: damage to third parties without or with incomplete compensation (e.g. Koster and Van Ommeren, 2015; Couwenberg, O, 2015). According to economic theory (e.g. Pigou, 1920; Coase, 1960), externalities should be fully internalized by those who cause them, which in this case would be NAM. However, on October 5, 2016, the Groningen District Court ruled that NAM shares this liability with state-owned company *Energiebeheer Nederland* (EBN), which implies that the Dutch government is also indirectly responsible for the earthquake damage. If complete internalization does not occur, the welfare of people in Groningen decreases as a result of a commercial activity with harmful side effects. This decrease in welfare should be prevented or repaired. The question is how.

This article adds to the sparse legal and economic literature on gas-induced seismicity (e.g. Ehrman, 2017; Holz et al., 2017) by constructing a market-based policy innovation. It first explains that the current set of policy instruments does not fully cover the earthquake damage and that it also entails significant transaction costs: after each earthquake the inhabitants of Groningen have to ask loss adjusters to prepare a damage report before they receive compensation (Section 2). Building upon and expanding Dulleman and Woerdman (2017), the

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[1] Both authors own a house in the province of Groningen, the Netherlands, where earthquakes occur due to the extraction of natural gas.

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article then considers a market-based alternative: tradable earthquake certificates (Section 3).[2] These certificates give homeowners in the earthquake area of Groningen a (yearly) entitlement to a share of the joint annual gas revenues of the Dutch government and NAM plus a variable payment based on the intensity of the earthquakes in the previous year. This entitlement can also be sold, for example to people who decide to move to Groningen, which stimulates the housing market. Because people have different attitudes to risk, they will respond differently to the options that the tradable earthquake certificates provide (Section 4). The options that are created do confront the people of Groningen with new transaction costs, but their benefit consists of a continuous stream of compensation that makes the contested damage reports redundant and also makes it possible for people to move to a different house, even outside the earthquake area. This article continues by discussing some of the many implementation problems of this market-based instrument, which would render its adoption difficult if not questionable (Section 5). Finally, a conclusion is presented (Section 6).

2. Current earthquake policy

The (*Napoleonic*) Mining Act of 1810 entered into force in the Netherlands during the French occupancy and applied until 2003 (Roggenkamp, 2007). This Act could be seen as to give the Dutch State (hence not the landowner) property rights over any minerals in the ground as it required mining companies to obtain a production concession from the Crown and entitled the government to a percentage of those companies' revenues. In 1963 NAM obtained a perpetual concession to exploit the Groningen gas field and under a separate cooperation agreement the government was entitled to 50% of the gas revenues (10% directly and 40% via EBN). However, the Dutch government currently receives about 90% of the total annual gas revenues and NAM the remaining 10% (primarily due to an additional private contract concluded in the seventies, referred to as *Meeropbrengst Regeling Groningen*) (Van der Hoeven, 2008).

Gas-induced earthquakes occur since the nineties but they have recently grown in number and magnitude (e.g. Van Thienen-Visser and Breunese, 2015). NAM has a duty of care under Article 33 of the new Mining Act of 2003 and is strictly liable for the earthquake damage based on Article 6:177 of the Dutch Civil Code. Currently the government of the Netherlands takes action against the earthquakes caused by gas extraction by direct regulation limiting NAM's ability to extract gas, especially around the epicenter of the municipality of Loppersum. Gas production was capped at 42.5 billion cubic meters in 2014, 27 billion cubic meters in 2016 and 21.6 billion cubic meters in 2017, with the government's intention (expressed in 2018) of setting the cap at 12 billion cubic meters 'as soon as possible'.[3] NAM itself finances the repair of cracks in the walls of houses: loss adjusters, in the past also paid by NAM but recently paid by the Ministry of Economic Affairs, have to determine whether those cracks were caused by (1) earthquakes as a result of (2) mining activities (double causality). In addition to compensating homeowners for proven damage, NAM also gave 4000 euros to every household where such property damage had been established. Those 4000 euros could only be spent on energy saving measures, such as solar panels and home insulation. This subsidy ended by February 1, 2016, but the Dutch Parliament restored the subsidy on April 3, 2017. In addition, if a homeowner in the province of Groningen succeeds in selling his house, NAM compensates for the reduction in price as a result of the earthquakes. Moreover, the weakest houses in the mining area of Groningen will be made earthquake-resistant, which is financed by the government. Private engineers commissioned by an independent executive agency (*Centrum Veilig Wonen*) apply public safety standards to determine which houses are relatively weak, while a public body (*Nationaal Coördinator Groningen*) prioritizes where and when the inspections will take place (NCG, 2017a).

From an economic perspective, current earthquake policy in the Netherlands is inadequate because homeowners in the province of Groningen are not fully compensated for mining damage. First, only the visible damage is restored: there may be hidden damage such as cracks in beams behind plasterboards or under floors. Moreover, after every earthquake that created damage, inhabitants need loss adjusters to prepare damage reports, which implies significant transaction costs. Second, the one-off compensation of 4000 euros for energy saving is only for households in Groningen whose property damage has been recognized (by NAM or the government) and whose damage is at least 1000 euros; people in the earthquake area of Groningen without cracks in their walls do not have access to this money. Third, houses have become less valuable both for homeowners with and without property damage, albeit to a different degree, as a result of the mining activities. This drop in house prices usually is much greater than the one-size-fits-all amount of 4000 euros (De Kam, 2016), although different calculation methods lead to different (also lower) estimates of this price fall (Bosker et al., 2016; Koster and Van Ommeren, 2015). NAM does provide compensation for the lower value of the house, but only for those homeowners who have been able to sell the house, which may be difficult and sometimes even impossible.[4] Fourth, it is expected that both the extraction of natural gas and the earthquakes will continue for years, which will lead to a certain degree of unsafety and reduced enjoyment of the environment also in the future. It can therefore be expected that the liquidity of the housing market in the province of Groningen will remain impaired for many years to come, although recently this housing market has shown slight improvement thanks to a recovering economy (Boumeester and Lamain, 2017). Finally, the weakest houses in Groningen will be made earthquake-resistant, starting in the municipality of Loppersum, but progress has been very slow.[5]

Homeowners have had some success obtaining additional compensation through litigation. On September 2, 2015, the Groningen District Court (*Rechtbank Noord-Nederland*) ruled that NAM has to compensate for property devaluation, even in the absence of a sale prospect, in the earthquake area. NAM filed an appeal against this verdict but the company was not successful: on January 23, 2018, a Dutch Court of Appeal (*Gerechtshof Arnhem-Leeuwarden*) upheld the original judgement. On October 5, 2016, the Groningen District Court ruled that both NAM and *Energiebeheer Nederland* (EBN), whose shares are fully owned by the Dutch State, are (strictly) liable for the earthquake damage caused by mining activities in the country. The court reasoned that EBN (hence the State) is a 40% owner of the gas wholesale company

[2] Our idea of tradable earthquake certificates was first published in Dutch, in the main trade journal for economists in the Netherlands called *Economisch Statistische Berichten* (Dulleman and Woerdman, 2017). The present article in English builds upon and considerably expands and nuances the aforementioned short paper in Dutch.

[3] https://www.rijksoverheid.nl/onderwerpen/gaswinning-in-groningen/inhoud/minder-gaswinning-groningen.

[4] One or two real estate agents assess the value loss due to the earthquakes on a case-by-case basis, which usually results in compensation by NAM between 1% and 5% of the sales price (http://www.nam.nl/feiten-en-cijfers/voortgang-waarderegeling.html). Based on some of the literature (e.g. De Kam, 2016), one could doubt whether these percentages cover the entire value loss of the real estate. As a next step, the government started a pilot in 2016 - on the basis of 10 million euro paid by NAM- to buy up damaged houses that do not sell on the housing market from owners who suffer from socio-economic problems (e.g. old and sick homeowners who have obtained a medical indication to be hospitalized in a nursing home) only in the central part of the earthquake area (https://www.nationaalcoordinatorgroningen.nl/themas/k/koopinstrument). In 2016 there were 179 applications and by the end of 2017 NAM had bought 36 homes.

[5] Engineers calculated that about 90.000 of the 241.300 buildings in the earthquake area of Groningen need to be made earthquake-resistant, which is equal to 152.000 addresses (Van Rossum, 2015: 10). Early 2015 NAM said that 15.000 homes will have been inspected by the end of that year and that 8.000 homes will have been made safer by 2017 (EIF, 2015). In the epicenter of the earthquake area, where about 22.000 buildings can be found, a total of 4.567 inspections had been carried out by the end of 2017 and only 571 houses had been made earthquake-resistant (NCG, 2017b: 14).

GasTerra, therefore the entire country of the Netherlands profits from the sale of gas extracted from the Groningen area. On March 1, 2017, the same court ruled that NAM (but not the Dutch government) is also liable if people living in the mining area of Groningen suffer immaterial (psychological or emotional) damage. The court stated that NAM's gas extraction activity, when it causes earthquakes, violates the inhabitants' right to an undisturbed enjoyment of living space. NAM has also filed an appeal against this verdict. Perhaps the most significant victory for residents is the ruling of April 20, 2017, by a Dutch Court of Appeal (*Gerechtshof Arnhem-Leeuwarden*), which requires that the Dutch Public Prosecution Service (*Openbaar Ministerie*) investigates whether criminal charges should be pressed against NAM for imposing life-threatening damage to houses.

The above-mentioned policy measures are important, and the recent court rulings are encouraging, but they do not fully solve the underlying problem. The fundamental problem is (i) that not all costs of the earthquakes caused by mining activities are internalized to NAM and the government, (ii) that the process of damage report preparation by loss adjusters leads to significant transaction costs, and (iii) that the revenues from gas sales are not a direct source of income to the residents of the earthquake area, which together contribute to a depressed regional housing market. The core of the solution is therefore that both gas extraction and the costs of the earthquakes should lead to shared interests between NAM and the inhabitants of Groningen. An instrument, or a mix of instruments, is needed that (a) more fully internalizes the earthquake damage by gas extraction, (b) implies less transaction costs for homeowners and better reflects the varying degrees and types of damage they experience and (c) helps to further stimulate the housing market in the province of Groningen. How could this be achieved?

3. A market for earthquake certificates

The general idea of allocating property rights that can be traded on a market to internalize externalities can be found in seminal articles written by some of the founding fathers of law and economics, such as Coase (1960) and Calabresi and Melamed (1972). Building upon this general idea we develop the concept of tradable earthquake certificates. These certificates can be seen as a kind of Pigouvian tax on earthquakes, giving the certificate owners a share of the gas revenues obtained by the government and NAM, while the possible trade in those certificates can be viewed as a form of Coasean bargaining between people in the Netherlands to improve individual welfare positions given their differences in damage and risk perception, as will be explained in more detail below. A system of tradable earthquake certificates is thus a market-oriented way to align the above-mentioned conflicting interests and to compensate homeowners for earthquake damage. There are multiple design options for such a market. One such design, as developed below, intends to provide a more efficient internalization of the earthquake damage in Groningen and to create a more equitable link between the interests of gas consumers throughout the Netherlands and the interests of the affected residents in Groningen. This policy may be structured as follows.

NAM could be obliged by the government to issue earthquake certificates, one per existing house, as determined by the Land Registry (Bureau of Records, called *Kadaster* in the Netherlands). Every household would then receive an earthquake certificate based on an allocation principle that is linked to Land Registry data and to the value and building construction of the house. To respect differences in economic damage due to the gas-induced earthquakes, more expensive (usually bigger) houses could receive a higher compensation than cheaper (typically smaller) ones, to be evaluated on the basis of real-property value. Moreover, to respect differences in safety, weaker (mostly older) houses could receive a higher compensation than stronger (newer) ones, to be evaluated on the basis of building construction. While new houses tend to be better resistant to the earthquakes than old ones, the problem is that more than a quarter of the houses in the province of Groningen was built before World War II, when the Groningen gas field was not even discovered and the gas-induced earthquake damage could not yet be foreseen.[6]

The earthquake certificate could give its owner an indemnity based on the following two principles.

(1) First, the certificate will annually provide an income to the owner associated with the (gross) joint annual gas revenues of the Dutch government and NAM to compensate for the degradation of living space. Social welfare is increased by transferring part of the gas producer surplus to consumers in Groningen who experience stress and unsafety due to gas-induced earthquakes. In total, the government and NAM must from now on pay the certificate holders, for example, 30% of their joint annual gas revenues.[7] This percentage could also be higher or lower as we do not know the optimal percentage.[8] Because the Dutch State profits from the sale of gas (as a co-shareholder of GasTerra), the proceeds from the certificate may be tax-exempt if used to maintain the house to incentivize home improvement in the earthquake area or if used to repay the mortgage to reduce the financial risk of residual debt for homeowners in the earthquake area. This certificate is also made tradable: it can be separated from the house to stimulate a liquid certificates market with efficient price formation. A market will thus develop for these certificates, as will be further illustrated in the following section, which will give them a (varying) market value. That market value is anticipated to be based on the sum of all expected (and discounted) future benefits of the certificate.
(2) Second, the certificate will annually provide an income to the owner which is related to the frequency and intensity of the earthquakes (on the Richter scale) so as to compensate for property damage. Residents around the observed epicenters could get a higher benefit than people who live further away from them. After the certificates begin to be traded on a market, the certificates will spread over the country. Together with the government, NAM will set up a fund (for instance based on past gas revenues) to pay the income to certificate holders. Annual withdrawals from this fund are dynamic: they go up or down depending on the earthquakes in that year and deposits into the fund must be determined in such a way that over the longer term the fund is sufficient to cover the risk of future earthquake damages.[9] Sample data on actual earthquake damage to houses can help establish the amounts needed to be deposited into the fund. Unlike current policy, in such a scheme of tradable earthquake certificates there is no direct relationship between damage and compensation, but only an indirect relationship which also makes causality checks redundant. The advantage of this is that residents do not have to struggle with loss adjusters and damage reports before they receive compensation, as they will receive it anyway through the vehicle of the earthquake certificate, which saves on transaction costs. The disadvantage is that if two families live next to each other in a comparable house, and one family has more damage than the other, they will still receive the same certificate and therefore the same amount of compensation.

Besides the above payment obligations, NAM could be obliged to

[6] https://opendata.cbs.nl/#/CBS/nl/.

[7] Total gas revenues have gone down, due to the production caps and lower gas prices, from roughly around 10 billion euros per year to about 4 billion euros per annum (e.g. 4062 million euros in 2016) (Marcelis and De Wilde, 2017: 5).

[8] According to Koster and Van Ommeren : 133) (2015), the annual ('non-monetary') costs resulting from a reduction in living comfort are 'in the same order of magnitude' as the monetary costs of property damage due to the gas-induced earthquakes.

[9] These dynamic withdrawals could be seen as an example of 'adaptive governance' (Janssen and Van der Voort, 2016). Because the yearly withdrawals will be dynamic since they are based on actual earthquakes, the price of these certificates will be positive, unless the earthquakes completely stop.

buy the house as well as the earthquake certificate from a resident who wants to leave the earthquake area. NAM would then also be entitled to sell this house as well as the certificate to someone who is willing to bear the risk. This might be attractive to someone who is looking for a characteristic house in a quiet area (of which there are many in Groningen). In this way, the earthquake costs are better internalized by NAM and the government, and the gas revenues are a direct source of income for the residents of the earthquake area. As an alternative, not only NAM but also the government could be involved in this purchase obligation, given their shared liability. The tradable certificates system could thus be seen as a market-oriented Public-Private Partnership (PPP), which is also common in insurance programs for natural (instead of induced) earthquakes (Noy et al., 2017).

Earthquake damage is compensated by means of earthquake certificates from the moment that this new system would be implemented, which basically ends the ability for homeowners to sue for compensation. Although the awarded remuneration depends on future variables, there is an important link with the past. The initial starting balance for the fund that would be created by the government and NAM could be based on historic gas revenues and historic records of earthquake damage that resulted from its extraction.

In theory, there could be a time limit to the certificate system considered above, depending on the expected time frame for future gas-induced earthquakes in Groningen. *Statistics Netherlands*, for instance, expects that Groningen gas can be produced until at least 2029, but because the government is likely to respond to the earthquakes by further lowering the production cap, NAM expects to deliver gas for many years longer (e.g. CBS, 2015: 16–17). Geologists know that earthquakes may continue for some more years even after gas production has ceased (e.g. Van Thienen-Visser and Breunese, 2015), so that the duration of the certificate system should be at least until about 2035 and can be extended with more years as geological insights and regulatory interventions progress. In practice, the time limit should not be set too early or may not even be necessary at all since the market value of the tradable certificates will be zero if the earthquakes stop.

4. Differences in damage and risk attitude

To illustrate the operation of a system of tradable earthquake certificates, this article now turns to examples with hypothetical residents A, B, C and D. These people differ in the degree of harm suffered as a result of the earthquakes and in their degree of risk preference.

4.1. Inhabitant A: satisfied resident of Groningen, not afraid of earthquake damage

Inhabitant A receives a certificate and is a satisfied resident of Groningen. Each year he acquires a limited income from the certificate, based on the joint annual gas revenues of the government and NAM and on the number and intensity of earthquakes. In years with few mild earthquakes, he only receives the payment based on the above-mentioned 30%. In years with more frequent and more severe earthquakes an additional payment is made from the aforementioned fund. The total compensation gives him sufficient resources to bear the earthquake costs. Because of the direct connection between the gas revenues of both NAM and the government and the income of inhabitant A, both he and NAM benefit from a long-term optimization of gas extraction (cf. Fischel, 1995). Inhabitant A may sell his certificate only once, either to NAM or to another inhabitant of the Netherlands (for instance inhabitant D, see below). After selling the certificate, he has no further right to compensation, but he has received the proceeds from the sale of the certificate, which may be used to cope with any damage that may follow (or for any other purpose).

4.2. Inhabitant B: unsatisfied resident of Groningen, afraid of earthquake damage

Inhabitant B of Groningen is not satisfied with his living conditions. To him, the expected damage and the possible insecurity caused by the earthquakes outweigh the annual payments from the certificate. Despite the relatively low house price due to the earthquakes, this resident has the ability to move and to find a better, safer location. He sells his house, along with the earthquake certificate, to NAM (or to another occupant). Inhabitant B not only receives the proceeds from the sale of his home, but also the market value of the certificate (the total of which is likely to be equivalent to the market value of the home absent earthquake risk). With these two payments he should be able to find a replacement home outside the earthquake area that gives him more enjoyment than his current home.

4.3. Inhabitant C: resident outside Groningen, not afraid of earthquake damage

Inhabitant C resides outside Groningen and sees opportunities rather than threats. He is not afraid of the earthquakes and is a handyman. C can purchase B's home in Groningen, either from NAM or directly from B. There are now two possible alternatives. C can purchase both the home and the earthquake certificate, or C can purchase only the home. If C buys both the home and the earthquake certificate, the house is a bargain but C also has to pay for the certificate; together this yields an efficient price. Inhabitant C then receives an annual compensation by NAM and uses this revenue to maintain his home (by himself or via a contractor), possibly at a lower cost than the benefit of the certificate. If NAM had previously purchased the home from B, NAM could sell it without the certificate. NAM would then receive less money but it could withdraw the certificate from the market, which is a legitimate financial decision by NAM in order to reduce future expenses.

4.4. Inhabitant D: resident outside Groningen, no desire for earthquake damage

Finally, there is dweller D who lives outside Groningen and wants to keep it that way. Because the gas and its revenues are used throughout the Netherlands, the earthquakes from gas extraction in Groningen are a national problem. Therefore, under the policy considered, D is allowed to buy an earthquake certificate with his savings, such as the one offered by inhabitant B. Inhabitant D who owns a home outside Groningen now also benefits from the tax-friendly facilities for maintenance or mortgage repayment combined with an annual payment based on the gas revenues of both government and NAM and the intensity of the earthquakes. Building contractors in the rest of the Netherlands do not have to look enviously at their colleagues in Groningen, because home maintenance can be performed at reduced tax levels as a result of the gradual spread of certificates throughout the country. If D would not own a home, there would be less incentive for him to purchase the certificate because the tax-friendly arrangements are related to homeownership, but he might still be interested in buying such a certificate if the expected proceeds from the annual payment are high enough.

Unfortunately, the housing market in Groningen is depressed (Boelhouwer et al., 2016), although recently it is slightly improving (Boumeester and Lamain, 2017). The continuing earthquakes weaken demand for houses in the province of Groningen, next to uncertainty about damage compensation and regional population decline, but the development of compensation arrangements and a recovering economy have helped to raise confidence in the regional housing market a bit. The deployment of earthquake certificates implies that houses (hence including these certificates) could be more efficiently valued. Under a scheme of tradable earthquake certificates, it may be expected that

more people will relocate: in the example above, inhabitants B and C have moved and both are happy with their new home. The certificates improve the internalization of the earthquake costs and eventually people can live where it suits their risk attitude towards the earthquakes.

A simple alternative for tradable earthquake certificates would be to give people living in the province of Groningen (tradable) shares in the company NAM. Another straightforward option would be to give each household in this province a sum of 'danger money', for instance 1000 euro per year, taken from the gas revenues, as proposed by Hagoort (2016). The most important disadvantages of shares in NAM or fixed payments are that those options have no direct link with the earthquake damage and do not improve the housing market in Groningen. Earthquake certificates, however, are linked to the damage in the earthquake area and because they are tradable on a national scale, people can freely move from or to the mining region of Groningen.

5. Implementation problems

It is possible to conceptualize a market for tradable earthquake certificates, as demonstrated above, but it will be argued below that practical implementation is difficult if not questionable.

To make a system of tradable earthquake certificates work, there should be a transparent certificates market that leads to an efficient market price. In addition, the issue and procurement of certificates must run efficiently. As a for-profit gas company, NAM would not be appropriate to execute these tasks. A kind of 'NAMTerra' could therefore be established (comparable to the aforementioned Dutch wholesale gas trader GasTerra), which manages the trade in these certificates. Both the Dutch central bank (*De Nederlandsche Bank*) and the Netherlands Authority for the Financial Markets (*Autoriteit Financiële Markten*) could play a pro-active role in designing these certificates as a new financial instrument. A somewhat gradual introduction might be required to ensure that 'NAMTerra' does not have to buy too many houses at the same time and that the pricing of the certificates takes shape steadily without excessive transaction volumes.

Tradable earthquake certificates include a variety of distributional considerations, so as with any policy instrument, several political decisions need to be made to achieve effective implementation. As part of this process, various details must be filled in and interactions must be anticipated with existing or proposed laws and regulations.

For example, what is the appropriate percentage of the Dutch government and NAM's joint annual gas revenues to be paid to the certificate holders? We believe that something around 30% is reasonable for three reasons. First, economists have calculated that 3% of the gas revenues is currently spent on earthquake damage compensation, which is expected to rise under current policy to between 8% and 27% after 2024, depending on whether the earthquake damage will be moderate or extensive (Marcelis and De Wilde, 2017). Second, maximum (hence full) reimbursement of the earthquake damage is needed to cover external costs, because the inhabitants themselves had no opportunities in the past to mitigate the damage (Couwenberg, 2015). Third, a percentage lower than 50% has the advantage that more than half of the revenues still goes to the government and NAM, so that they retain a relatively strong incentive to continue the extraction of natural gas.

A temporary albeit limited continuation of gas extraction makes sense, not only because of the sunk costs of the gas infrastructure, but also because of two other externalities: security of supply and, to some extent, also climate change. A stable economy must minimize dependence on gas imports from politically unpredictable countries outside the European Union (EU), such as the Russian Federation. Moreover, gas combustion produces about half of the amount of CO_2 per unit of energy generated compared with the burning of coal. Gas can therefore be seen as a transitional fuel towards a more sustainable energy system, in which natural gas soon needs to be phased out in favor of low-carbon or no-carbon technologies, such as solar power, wind energy and geothermal energy.

Another distributional issue is how the Dutch government and NAM should divide their share of the aforementioned (for instance) 30%. As explained earlier, the government currently receives about 90% of the total annual gas revenues and NAM the remaining 10% (based on a private contract referred to as *Meeropbrengst Regeling Groningen*) (Van der Hoeven, 2008). Taking this division as a starting point, the Dutch government would then pay 27% and NAM 3% of the total gas revenues to the earthquake certificate holders. In the (unlikely) event that NAM goes bankrupt it seems reasonable that the government would take over NAM's remuneration requirement because the government already receives 90% of the gas revenues.

An example of necessary details of the instrument is the determination of the value and safety of a house to determine the drawing right from the earthquake certificate. First of all, which value should be chosen? Choosing the 'correct price' for a house is a serious challenge since many factors determine house prices. A relatively low-cost option to solve this problem would be to choose the fiscal value of the house (called *WOZ-waarde* in the Netherlands), which is determined each year by the local authorities. A baseline value could be established by looking at fiscal value records prior to 2012 when the first big earthquake occurred (near the small village of Huizinge). The reason for choosing this date is that the depreciation of property due to the earthquake damage is already discounted in the current (lower) value of the house.[10] A probably more costly alternative to determine the price of a house would be to require one (or two) real estate agent(s) to assess its value (and take the average of their monetary valuations). Secondly, how to judge the safety of a house? This requires an assessment of its building construction for which date of construction could be used as an indicator since new houses in the province of Groningen (for instance those built after 2000) are better able to withstand the earthquakes than old ones (for instance those built before World War II). To save administrative costs, houses would not have to be inspected but they can be classified into safety categories based on date of construction (say, from A to G, comparable to the energy label for products in the EU).

Owners of buildings in the province of Groningen would receive tradable earthquake certificates, but should renters of buildings receive them as well? From the perspective of property damage compensation that might not be necessary if the owner who receives a yearly stream of income from the certificate uses that money to repair the building's earthquake damage. Moreover, renters and owners have different risks: a renter can easily end the tenancy and leave, whereas homeowners in this mining region may have difficulties selling the house. However, an earthquake certificate not only provides money to repair property damage but also to compensate for deterioration of living space. The problem is that renters suffer from a degraded living environment, not (just) the owner. Should the owner then (be legally obliged to) pass on this part of the income from the certificate to his renters?

An additional decision problem is whether to assign tradable earthquake certificates only to citizens who own private homes or also to commercial enterprises with offices and warehouses in the province of Groningen. The inclusion of company buildings could lead to a more complete internalization of the mining damage and to a thicker market for earthquake certificates. However, should a company receive one certificate per building, irrespective of its size, or should the number of certificates be differentiated based on size so that larger buildings obtain more certificates? One could perhaps argue that companies should be excluded from the tradable certificates system all together, because the market for offices and warehouses is more heterogeneous than the market for private homes, or that they should only be excluded from

[10] The baseline value could be adjusted for inflation because of the economic downturn at the time.

that part of the certificate's income which provides compensation for reduced living comfort.

Another implementation issue is the gradual introduction of tradable earthquake certificates. The advantage of a gradual introduction is that 'NAMTerra' does not run the risk of having to buy too many houses at the same time (provided that such a situation would occur in the first place), but the disadvantage would be a thinner market for earthquake certificates. An option would be to start at the municipality of Loppersum, the epicenter of the heaviest earthquakes so far, from where the certificate system could be further expanded across the province of Groningen.

The instrument of tradable earthquake certificates also entails various uncertainties. One of the questions is whether there will be sufficient demand for the certificates. This again raises the important issue of market liquidity, which cannot be taken for granted, but liquidity is at least stimulated by the option to disconnect the certificate from the house and trade it throughout the Netherlands. Moreover, from a behavioral point of view, some inhabitants of Groningen will be confused about the various options that the certificates offer them. For these inhabitants, the freedom of choice would then degenerate into choice overload and stress (e.g. Scheibehenne et al., 2010). In addition, in a different context, it has been argued that the government's expectations of the financial literacy of its citizens are too high (Tiemeijer, 2016). These could even be valid reasons not to make the earthquake certificates tradable at all, as earthquake policies need to be 'transparent and simple' (Boelhouwer et al., 2016: 6.), but without tradability the important advantage of a more active housing market is also lost. Another issue of uncertainty concerns the magnitude and predictability of the future payments from the earthquake certificate, which depends on the gas revenues of the government and NAM and on the intensity of the earthquakes. That uncertainty could be limited, however, for instance if inhabitants would be able to take out (perhaps even subsidized) insurance so that private insurance companies can take over this risk. Nevertheless, the price of the earthquake certificate will be inherently uncertain as many factors would influence its value. Interest rates always have an effect on financial instruments, hence also on the price of an earthquake certificate. NAM may even have some market power, but this could be temporary as certificates would be gradually introduced, while competition and financial authorities could monitor and penalize any abuse of such power. Differences in discount rates, risk attitudes and damage assessments will all come back in the supply and demand for those certificates which ultimately determine its price.

An important overarching implementation issue is whether tradable earthquake certificates should replace or complement current earthquake policy. Replacement avoids the risk and cost of inefficient overlaps from potential double regulation. Moreover, NAM is likely to lobby against an expansion of compensation instruments and could thus require that earthquake certificates be a replacement for other compensation. Unfortunately, however, replacement also introduces new risks. There is the risk of a thin market, as mentioned above, but there are also additional institutional questions that need to be answered. For instance: what if a homeowner in Groningen has sold his certificate, or someone from outside the province has bought a house in Groningen without a certificate, and the house is damaged due to a new earthquake? Will he indeed not receive any additional compensation or should flanking compensation policies be developed as a back-up? And would such complementary policies strengthen or undermine the efficiency of tradable earthquake certificates?

In relation to the latter question and to the various issues raised above, policymakers could benefit from the experience with other forms of tradable rights and compensation in energy projects, such as emissions trading and shares in wind energy, which are discussed in turn below.

The first example is emissions trading: the so-called European Union Emissions Trading Scheme (EU ETS), which provides a market for CO_2 emission rights in order to curb climate damage. The EU ETS is fairly liquid, but its operation is complicated due to exceptions, overlapping regulations and related legislation, including laws that apply to financial instruments (Woerdman, 2015). Perhaps the market for tradable earthquake certificates would meet the same fate, especially if it fails to fully internalize the earthquake damage. A patchwork of regulations would then arise which could reduce the instrument's efficiency. Moreover, in the EU ETS, the effectiveness of the market was impaired by the low CO_2 price caused by an overallocation of emission rights. The disappointment about the operation of the market for tradable emission allowances will not increase confidence in the functioning of a potential system of tradable earthquake certificates. Nevertheless, it must be stressed that the EU ETS operates sufficiently smoothly: each day millions of emission rights are traded and the European Commission still perceives it as the 'flagship' of European climate policy.

The second example is shares in wind energy. In Denmark, local residents receive shares in wind farms to offset another external effect: the degradation of living space by the noise and visual pollution of wind turbines. That policy has been reasonably successful. Wind energy producers are obliged to offer nearby residents the opportunity to acquire, at cost price, at least 20% ownership of a wind turbine. In this way, local residents not only have the burden but also a share in the proceeds of the local production of wind energy. Although a resident may also receive direct compensation for the lower value of his house, this additional instrument of (tradable) shares has proven to be fairly effective in uniting the interests of the wind energy producers and the residents, in compensating some of the non-monetary damage and in increasing social acceptance of wind energy production (Bengtsson, 2011). Yet there are Danish residents who decline the share option, for among other reasons because of the complexity and the uncertainty that these shares represent.

In summary, tradable earthquake certificates could be a means to configure the shared liability for earthquake damage by NAM and state-owned company EBN in a market-oriented way and to reflect the recognition of liability found by the previously mentioned Groningen District Court rulings from 2015, 2016 and 2017. The core of a system of tradable earthquake certificates is attractive: providing a yearly income to homeowners in the earthquake area and avoiding the burden of damage reports after each and every minor or moderate earthquake. Additional policies may be necessary, however, to deal with the residual risk of rare but major earthquakes, for example by further limiting gas production on the Groningen field. Moreover, the transaction costs of reducing and compensating earthquake damage under the current regime of direct regulation and liability may still be less than the transaction costs necessary to create such a certificates market, to administer its rules and to understand its functioning. Each institutional arrangement thus has its drawbacks, as argued above, and legal cases will always emerge, even in a system of earthquake certificates. For example, a homeowner who believes that his house has been wrongly classified in a relatively safe building construction category as a result of which he misses out on some certificate revenues could seek recourse in the courts. Future research should thus shed more light on the tradable earthquake paradigm, including the preferences and opinions of property owners and gas producers in Groningen which are crucial to the public acceptance of any monetary compensation scheme (e.g. Terwel et al., 2014). However, if implemented, tradable earthquake certificates could act as a precedent for mining regions in other countries (especially where there is no earthquake policy yet), and could perhaps even lead to similar systems for other types of externalities.

6. Conclusion

This article neither pleads in favor nor against tradable earthquake certificates but merely presents one design of such a system and analyzes some of its potential consequences. A market for earthquake certificates is a possible instrument to internalize the earthquake

damage from natural gas extraction, in this case by NAM (a joint venture of Shell and ExxonMobil) in the province of Groningen in the Netherlands. These certificates would not give a one-off payment but rather an ongoing entitlement to compensation by the Dutch government and NAM for both property damage and degradation of living space caused by the mining-related earthquakes. The tradability of these certificates could stimulate people to move and should help homes in Groningen to obtain a more efficient economic value. In time, people could live where it suits their risk attitude towards the earthquakes. The political feasibility of this instrument cannot be taken for granted and depends inter alia on the myriad implementation decisions that need to be taken, for example about the level of compensation to be paid by the government and NAM.

The advantage of this innovative system would be that compensation is carried out without the necessity and transaction costs of repeatedly having to determine the precise level of damage in advance. Inhabitants are 'unburdened' because they do not have to struggle with loss adjusters and damage reports anymore. The system could internalize the earthquake damage more completely via a yearly stream of income and offers freedom of choice to residents by being able to sell both the house and the certificate.

The downside would be that this system introduces the transaction costs of market creation and choice complexity by 'burdening' the inhabitants with the options that the tradable earthquake certificates offer. There is also uncertainty about the expected robustness of the certificates market. Moreover, some of the damage could remain uncompensated due to the indirect relationship between damage and compensation. In that case the instrument would not fully internalize the earthquake externality, so that additional tools are needed to cover the entire damage. Possibly a mix of instruments would then emerge that not only limits the potential efficiency gains of a tradable certificate system but could also be perceived as more complex by the inhabitants of Groningen than current earthquake policies.

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