Future perspectives on sand extraction in Flanders, a simulation using dynamic optimization.

ABSTRACT

Sand mining is not only vital to provide resources for the building and construction sector, but also provides jobs. However, sand reserves in Flanders (Belgium) are limited due to a strict demarcation of mining areas, turning sand into an increasingly scarce resource. Furthermore, sand mining activities have environmental costs. In this paper, a dynamic optimization problem is used, assessing the impacts of policy instruments on the evolution of sand extraction in time. The simulations of mining volumes and price paths for different types of sand (construction sand and filling sand) generate a view on the efficiency of a sand extraction tax with respect to depletion and overall welfare. As the results show, extraction taxes can postpone the depletion of construction sand mines in Flanders from 30 years to 41 years. Similar conclusions can be drawn regarding filling sand: an extraction tax postpones depletion from 52 to 72 years. Seeing these results, it is clear that extraction taxes have the effect that yearly mined sand volumes decrease. In addition to slowing down depletion of locally available resources for the construction sector, an extraction tax improves the discounted total welfare thanks to environmental gains and efficient public revenues.

JEL classifications

Q320: Exhaustible Resources and Economic Development

O130: Economic Development: Agriculture; Natural Resources; Energy; Environment; Other Primary Products

Keywords

Exhaustible Resources, Scarcity, Sand mining, Extractive, Extraction tax

1. Introduction

For years, aggregates like sand and gravel are vital components for construction applications such as roads and buildings. Due to the volumes involved, sustainable materials management of construction materials is critical from both an environmental and economic point of view (Bleischwitz and Bahn-Walkowiak, 2007). Flanders (the northern part of Belgium) has a long tradition in extraction of minerals such as clay, sand and gravel. Although these extraction practices still provide local employment and revenues, there are some negative external aspects. Quarrying can be noisy and dusty and traffic to the mining pit can create disamenities for neighbors. Furthermore, the natural environment can be damaged by run-off water, waste generation and visual pollution (Eckermann et al., 2012). Next to these negative aspects, there is a problem of scarcity. After all, a strict demarcation of mining areas caused the remaining sand reserves in Flanders to be limited (LNE-ALBON, 2014). For these reasons, government policies should induce sound and sustainable extraction practices.

One economic policy instrument that recently receives significant attention is the tax on extraction of virgin materials. Directing at the exploitation of virgin materials, the aim of these taxes is not only to reduce the quantity of material used but also the volume of disposed waste (Smith, 2014). According to Söderholm (2011), there are four closely related environmental motives for taxing natural resources. Firstly, considering that a tax on resource extraction raises the price of resources, it offers incentives to increase efficiency and simultaneously reduce the amount of the extracted resource to a sustainable level, thereby mitigating depletion. This is an important issue, as this is what sets an extraction tax apart from widely used net profit royalties that aim to tax resource rents without influencing the amount of an extracted resource (Eckermann et al., 2012). Secondly, with a resource tax, negative externalities become internalized. That way, a natural resource owner has an incentive to take undesirables like for example landscape damage and air and underground water pollution into account. Thirdly, a further motive for taxation focuses on environmental externalities that arise downstream in the supply chain such as disposal of waste. Finally, extraction taxes give incentives to use recycled materials rather than virgin resources.

Several studies have stressed the potential contribution of environmental taxes to overall government revenues (Hogg et al., 2014; Bio IS, 2012). However, Belgium is one of the worst performers in Europe. Environmental revenues only account for 2,2% of GDP. In addition, pollution and resource taxes are only 4% of all revenues from environmental taxes (Eurostat, 2014; Bachus and Defloor, 2011). Comparison with other countries such as the Netherlands shows that the potential for additional revenues from environmental taxation is important. In the EU, pure aggregates taxes (including sand, gravel and crushed rock) are implemented in Denmark, Sweden, the United Kingdom, Belgium and Italy. As to Belgium, a gravel tax which differs for valley gravel and mountain gravel was implemented in Flanders. With the generated funds, social aspects and redevelopments of used mining areas are financed. In the United Kingdom, the rate of the aggregate tax is based on an estimate of the external costs and currently amounts 2 pounds (about 2,5 euro). The purpose of the tax here is to reduce the environmental costs associated with quarrying operations and reduce the demand for primary materials. In Sweden, the gravel tax was introduced in 1996. In 2006, it was raised to 1,4 euro per ton with the aim to encourage conservation of natural gravel resources and stimulate the use of substitutes. In Italy, no common national tax rate is applied, as each region can apply different rates at provincial and municipal levels. Although these figures indicate the levels of charges applied elsewhere, it is important to recognize that these charges apply to aggregates as such and not specifically to sand as is the case in this study (EEA, 2008; Eckermann et al., 2012).

Compared to energy resources, the external effects of material consumption are more complex to generalize because the external effects are often local and influenced by extraction technologies. Furthermore, feasibility of extraction taxes may be limited as most resources are imported. Aggregates like sand however, are available in for example Belgium. In addition, high transport costs of heavy construction materials diminish the impact of extraction taxes on cross-border shipments. Therefore, the situation in Belgium should allow for an effective implementation of extraction taxes. Moreover, as environmental effects are to a large extent site-specific, it should be possible to include at least some of the local externalities into cost-structures of extraction companies. In addition, tax imposition can act as a driving force for better management, planning and monitoring of extraction activities in Belgium (EEA, 2008; Eckermann et al., 2012).

This paper presents a dynamic model to assess the impact of an extraction tax with respect to the evolution of extracted volumes, tax revenues and externalities over time. To illustrate the theoretical approach, the model is applied to two types of sand in Flanders: construction sand and filling sand. Sands are defined as construction sand when their grain size is larger than 0,225mm. This type of sand is being used in high quality applications such as the production of concrete and asphalt for example. When the grain size is smaller than 0,225mm, we speak of filling sand which is used for embankment and filling applications (LNE-ALBON, 2013).

In the second section, the elements of the dynamic optimization model are introduced and the theoretical model is built. In the third section, the model is used to simulate the impact of an extraction tax on the evolution of construction sand and filling sand mining in Flanders. The article concludes with a discussion and an overview of the most important findings.

2. Dynamic optimization model

Numerical optimization problems not only make theoretical concepts less abstract but also allow analysis of real-world problems (Conrad, 1999). The following sections discuss the elements of the optimization model.

2.1 Sand demand

As depicted in (1), an inverse linear demand function represents the demand for minerals such as sand. In general, we write $p_t = D(X_t)$, where p_t is the price per ton of sand in period t and X_t is the aggregate volume of sand supplied to the market. We will assume that price decreases with increases in X_t (so $D'(X_t) < 0$).

$$p_t = D(X_t) = A - bX_t \tag{1}$$

with: p_t = sand price in year t (euro/ton)
X_t = volume extracted sand in year t (ton)
A = choke-off price, intercept on price axis (euro/ton)
b = absolute value slope of the inverse demand function

An important characteristic of the inverse linear demand curve is the implied maximum choke-off price, A. When this choke-off price is reached, the equilibrium quantity on the sand market falls to zero. Such an upper bound may result from the existence of a substitute, available at constant marginal cost MC = A. As substitutes for Flemish sand extraction, one can think of an increase in sand imports, an increase in the recycling rate of construction and demolition debris and the use of for example dredged materials and steel slags instead of virgin sand. In the model, we assume exhaustion occurs in t = T. At that time, the remaining sand reserve falls to zero and no sand is mined anymore ($X_T = 0$). The date of exhaustion, T, is unknown and must be determined along with the extraction and price paths.

2.2 Competitive sand mining companies

The model assumes that profit-maximizing sand mining companies are working in a perfectly competitive market. As these companies are maximizing their profits, they will try to offer sand volumes so as to:

$$\text{Maximize}_{X_t}\, \pi = \sum_{t=0}^{T} \beta^t * \pi_t = \sum_{t=0}^{T} \beta^t * [p_t - c - l] X_t \qquad (2)$$

$$\text{s.t.} \sum_{t=0}^{T} X_t = \bar{S}_0$$

with: π_t = profit in year t (euro)
c = marginal sand extraction cost (euro/ton)
l = extraction tax (euro/ton)
$\bar{S}_0$ = Initial sand reserve at time zero (ton)
$\beta = 1/(1 + \delta)$ and δ is the discount rate

To resolve the optimization problem, GAMS modeling software was used in line with previous studies (Flakowski, 2004; Caplan, 2004; Conrad, 1999). By using a mixed complementary problem formulation, optimal yearly extraction volumes could be identified, taking into account the initial sand reserve. Moreover, evolving price paths could be modeled, together with shadow price, profit and social welfare figures. In the current context, the shadow price of volume restriction can be regarded as an economic measure of resource scarcity which is different from standard measures based on physical abundance (Krautkraemer, 2005). From an economic point of view, scarcity should reflect the marginal value of mining a ton of sand, taking into account the associated marginal costs. The shadow price forms the opportunity cost associated with extracting sand today rather than leaving it in the ground to extract it in the next period. All results for both the construction and the filling sand case, are displayed in detail in section 3.

2.3 Extraction tax

As can be seen in the profit maximization equation (2), an extraction tax l was included. In analogy to the differentiated gravel tax in Flanders and given the distinct nature of the construction and filling sand markets, two theoretically similar dynamic models were built. However, the models differ with regard to the values of the exogenous parameters, like for example the applied tax level. It can be assumed that mining construction sand entails more externalities as the extracted sand goes through a number of additional process steps like handling, sieving and purging (Jacobs et al., 2005). Moreover, filling sand is more abundant than construction sand (LNE-ALBON, 2013 & 2014). For these reasons, a higher extraction tax was assigned to construction sand mining.

Important when introducing extraction taxes, is to consider the elasticity of demand since it determines how sensitive producers and consumers will be to changes in price and thus, how effective a tax will be. The typical combination of low extraction taxes and low elasticity of demand for minerals keeps the current impact of extraction taxes low (Eckermann et al., 2012). In addition, whether extraction taxes effectively reduce extraction activity or not also depends on international trade which may influence the degree to which foreign extractors may compensate and increase their production. As the model will show in section 3, both the demand for construction sand as well as the demand for filling sand are inelastic. Consequently, taxing sand extraction will cause the price of sand to rise. On turn, demand for and extraction of sand will decrease more or less, depending upon the exact rate of price inelasticity. As a result, implementing a higher tax rate is justified when aiming at a significant impact on resource consumption. Although aggregates like sand are mostly subject to very limited international trade because transport costs are high (especially for filling sand), Belgian import and export flows are considerable (LNE-ALBON, 2012 & 2013). Therefore, it would be possible to implement so called border tax adjustments (BTA) in order to create an international level playing field for domestic industries, thereby preventing competitive disadvantages for domestic industries while transmitting the resource saving incentive internationally.

2.4 Societal point of view

From a societal point of view, there are two major problems related to sand mining. First of all, sand mining has some negative externalities, like for example soil contamination, landscape damage, groundwater pollution and air emissions (OECD, 2008). As these externalities have an impact on society, they carry a cost with them, which is called an externality cost. In the model, the unit externality of sand mining is presented by parameter e, whose value is strictly larger than zero. The second problem relates to the Marginal Cost of Public Funds (MCPF). Government revenues are typically expensive for society because of tax dodging and administration (Barrios, 2013; Glomm et al., 2008; Schob, 1997). In contrast, sand extraction taxes are easier to monitor, especially in developed regions such as Flanders. Indeed, resource extraction is relatively easy to administrate and monitoring would happen regardless of the fact whether taxes apply or not. The Marginal Cost of Extraction Taxes (MCET) is therefore lower. This gives:

$$\chi = MCPF - MCET > 0 \tag{3}$$

In (3), χ represents the relative benefit of using sand extraction taxes instead of other, more expensive taxes like for example a labor tax, thereby supporting the double dividend hypothesis (Groth and Schou, 2007; Schob, 2003).

Based on all preceding equations, total welfare can be calculated with B = 0 as the residual benefit of sand reserve after year T:

$$W = \sum_{t=0}^{T} \beta^t * [\int D(X_t) - c - e + \chi l]X_t + B \tag{4}$$

In the next section, all of the foregoing formulas will be used in an illustrative simulation. With these formula, values are defined for T, p_t, X_t, π_t and W. All other variables are defined exogenously.

3. Case study: sand extraction in Flanders

3.1 Construction sand

Carrying out a simulation to illustrate the theoretical approach, data from the Flemish part of Belgium were used. Making use of equation (2) and using exogenously determined values for parameters A, c, l, b, e, δ, χ and $\bar{S}_0$, a value can endogenously be determined for parameter T. The exogenous values that were used for the construction sand case, are presented in Table 1.

Table 1. Exogenous parameters construction sand case.

Parameter	*Value*	*Parameter*	*Value*
A	12	e	2
c	3	δ	0,10
l	3	χ	0,10
b	3,48E-06	$\bar{S}_0$	52.324.000

As private actors usually value the future much less than the present and therefore tend to have a higher rate of discount than the society, throughout this study a discount rate of 10% will be used. Using the choke-off price and taking into account construction sand volumes and prices from previous years, the linear inverse demand function was estimated resulting in the displayed slope. At current prices, this demand function was found to be inelastic (price elasticity equal to -0,42). Based on a study carried out by LNE-ALBON (2013 & 2014), the remaining construction sand reserve in period zero was taken to be 52.324.000 tons, being the value of parameter $\bar{S}_0$. All other figures were chosen in such a manner that they reflect reality as closely as possible. Below, the simulation results are given for two scenarios, one with and one without using extraction taxes.

3.1.1 Scenario 1: simulation with extraction taxes

By assigning parameter l a positive value, an extraction tax is directly taken up in the simulation exercise (this tax does not include municipal surcharges). By solving the optimization problem and using equation (2) to define a value for parameter T, results like presented in Table 2 can be obtained.

Table 2. Simulation with extraction taxes.

t	X_t	p_t	π_t *(discounted)*	W_t *(discounted)*	*Shadow price*
0	1.686.365,63	6,13	220.877,00	7.361.810,67	0,13
1	1.682.602,19	6,14	220.384,07	6.687.636,93	0,14
2	1.678.462,41	6,16	219.841,85	6.074.704,66	0,16
…					
39	175.541,80	11,39	22.992,14	29.841,77	5,39
40	20.695,97	11,93	2.710,73	3.321,65	5,93
41	0	12	0	0	6,00
$\sum_{t=0}^{T}$	52.324.000		6.853.299,02	76.698.967,26	

As can be deduced from Table 2, the value obtained for variable T equals 41. This means that it takes 41 years before construction sand reserves will be exhausted. The bottom row in Table 2 shows the total extracted construction sand volume, the discounted total profits of the construction sand mining companies and the discounted total welfare. In the above model, the shadow price represents the value of marginally loosening the constraint, that is, increasing the construction sand reserve. It can be seen that this shadow price rises at the rate of interest, reflecting the increasing opportunity cost as the construction sand reserve is depleted. This phenomenon is also known as the Hotelling Rule (Hotelling, 1931; Perloff, 2011).

3.1.2 Scenario 2: simulation without extraction taxes

By setting the value of parameter l equal to zero, extraction taxes are left out of the model. When we then solve the optimization problem and use equation (2) to define a value for parameter T, results like presented in Table 3 are obtained.

Table 3. Simulation without extraction taxes.

t	X_t	p_t	π_t *(discounted)*	W_t *(discounted)*	*Shadow price*
0	2.432.462,65	3,53	1.299.794,19	6.731.053,36	0,53
1	2.417.108,91	3,59	1.291.589,86	6.139.223,93	0,59
2	2.400.219,80	3,65	1.282.565,11	5.600.414,03	0,65
…					
28	371.836,29	10,71	3.286.344,01	1.335.310,58	7,71
29	150.419,91	11,48	80.377,66	63.894,87	8,48
30	0	12	0	0	9,00
$\sum_{t=0}^{T}$	52.324.000		27.959.498,25	69.503.939,31	

Looking at Table 3, we see that the value of T satisfying equation (2) has decreased from T = 41 in the case of using extraction taxes, to T = 30. Without using taxes, it takes only 30 years for exhaustion to occur. When we compare Table 2 with Table 3, we see that an extraction tax reduces the construction sand volumes that are mined each year. With regard to the shadow price, it can be seen that the value of the scarcity indicator is higher than before. This is quite logical, taking into account that the remaining sand reserve is depleted at a higher rate when no extraction taxes are being used, making the remaining stock more scarce and valuable. As expected, the construction sand mining companies' discounted total profits are much higher when no extraction taxes have to be paid. However, when we look at discounted total welfare, we see that from a societal point of view, the use of extraction taxes is preferable. In Table 4, the different components of the total welfare figures are presented. As can be seen, the sand mining operator earns an economic rent, due to the scarcity of the sand reserves. Basically, this rent is a payment to the owner of a sand mine beyond the minimum amount necessary for him to supply sand volumes (Perloff, 2011).

Table 4. Total welfare components, construction sand.

	Extraction taxes	No extraction taxes
Component	Value	Value
Rent sand mining operator	6.853.299,02	27.959.498,25
Tax revenue	51.120.221,69	/
Consumer surplus	47.693.572,18	85.963.793,22
Green tax reform	5.112.022	/
Externalities	-34.080.147,79	-44.419.352,31
Total	76.698.967,26	69.503.939,31

Given the results in Table 2 and 3, one could numerically plot the associated evolving time paths for construction sand volume and price. These are shown in Figure 1 and Figure 2 below.

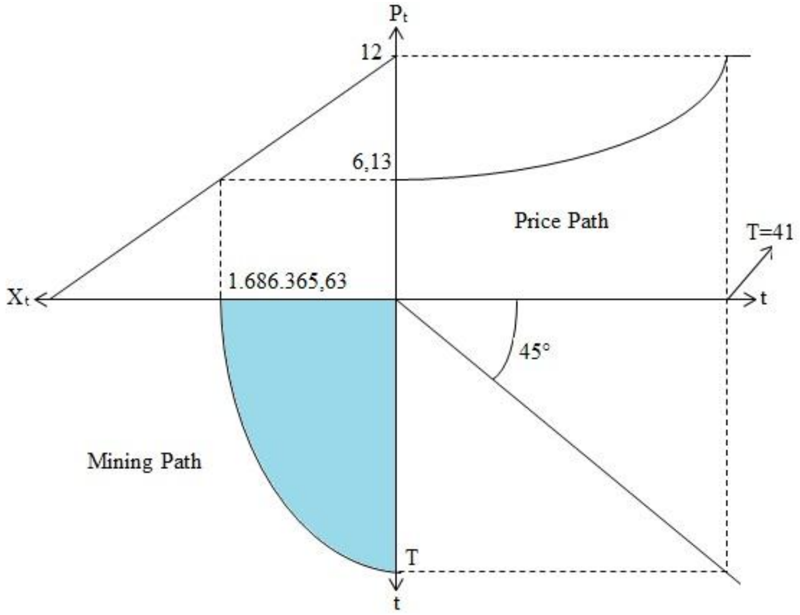

Figure 1: Overview construction sand, using extraction taxes.

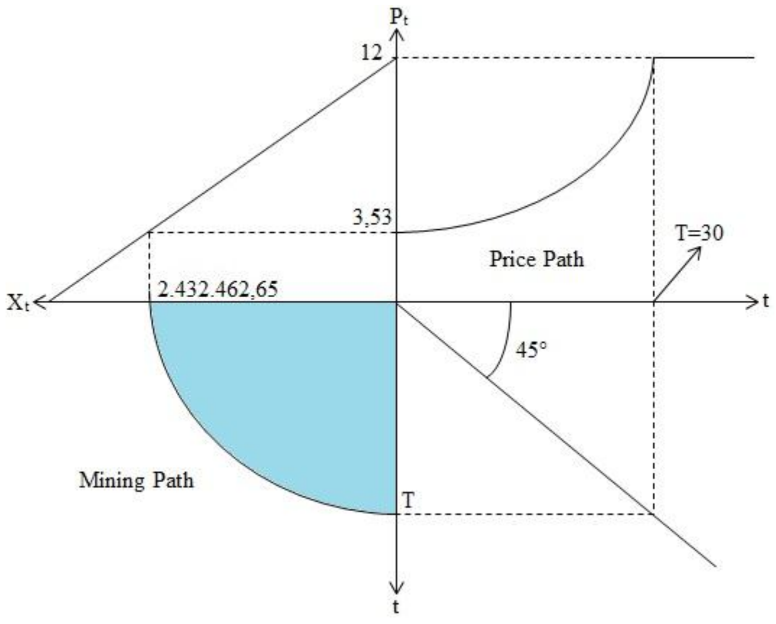

Figure 2: Overview construction sand, without using extraction taxes.

Figure 1 and Figure 2 show how extraction volumes and construction sand prices change in time, respectively when extraction taxes are being applied and when they are not being applied. As can be seen, when extraction taxes are used, prices start at a higher level than when no extraction taxes would be applied. Also, the implementation of the extraction taxes implies that the price moves less rapidly to the choke-off price level, delaying the moment of full reserve exhaustion. The blue shaded areas in both figures depict the total construction sand volume that is extracted over T years, being equal to the initial construction sand reserve.

3.2 Filling sand

Having analyzed the construction sand case, similar computations can be made for the filling sand case. The exogenous values that were used for this specific case, are presented in Table 5.

Table 5. Exogenous parameters filling sand case.

Parameter	*Value*	*Parameter*	*Value*
A	6	e	1
c	1,50	δ	0,10
l	1,50	χ	0,10
b	2,98E-06	$\bar{S}_0$	62.129.000*

* This reserve of filling sand corresponds with the reserve that is present within existing and potentially permissible mining areas.

At current prices, the demand function for filling sand was found to be more inelastic than the one for constructing sand, with a price elasticity equal to -0,34. Based on the study carried out by LNE-ALBON (2013 & 2014), the remaining filling sand reserve in period zero was taken to be 62.129.000 tons, being the value of parameter $\bar{S}_0$. Below, the simulation results are again given for two scenarios, one with and one without using extraction taxes.

3.2.1 Scenario 1: simulation with extraction taxes

By solving the same optimization problem and using equation (2) to define a value for parameter T, the results in Table 6 were obtained.

Table 6. Simulation with extraction taxes.

t	X_t	p_t	π_t *(discounted)*	W_t *(discounted)*	*Shadow price*
0	1.004.920,70	3,00	3.234,45	2.162.196,71	0,003
1	1.004.812,76	3,00	3.234,10	1.965.569,27	0,004
2	1.004.694,04	3,00	3.233,72	1.786.817,01	0,004
…					
70	153.620,36	5,54	494,44	665,44	2,54
71	68.382,40	5,80	220,10	279,29	2,80
72	0	6	0	0	3,00
$\sum_{t=0}^{T}$	62.129.000		199.969,02	23.699.910,25	

As can be deduced from Table 6, the value obtained for variable T equals 72. This means that it takes 72 years before filling sand reserves will be exhausted. The bottom row in Table 6 shows the total extracted filling sand volume, the discounted total profits of the filling sand mining companies and the discounted total welfare. In the above model, the shadow price represents the value of marginally loosening the constraint, that is, increasing the filling sand reserve. It can be seen that again, as this shadow price rises at the rate of interest, the Hotelling Rule is applied (Hotelling, 1931; Perloff, 2011).

3.2.2 Scenario 2: simulation without extraction taxes

When we set the value of parameter l back to zero and then solve the optimization problem using equation (2), we obtain the results presented in Table 7.

Table 7. Simulation without extraction taxes.

t	X_t	p_t	π_t (discounted)	W_t (discounted)	*Shadow price*
0	1.497.415,68	1,53	51.729,68	1.897.634,32	0,04
1	1.496.257,24	1,54	51.689,66	1.726.137,04	0,04
2	1.494.982,97	1,54	51.645,64	1.570.226,60	0,04
…					
50	149.094,64	5,56	5.150,65	4.162,92	4,06
51	13.104,10	5,96	452,73	353,22	4,46
52	0	6	0	0	4,50
$\sum_{t=0}^{T}$	62.129.000		2.146.306,71	20.922.842,52	

Looking at Table 7, we see that the value of T satisfying equation (2) has decreased from T = 72 in the case of using extraction taxes, to T = 52. Without using taxes, it takes only 52 years for exhaustion to occur. When we compare Table 6 with Table 7, we see that an extraction tax reduces the filling sand volumes that are mined each year. With regard to the shadow price, it can be seen that the value of the scarcity indicator is higher than before. Again, this is quite logical, taking into account that the remaining sand reserve is depleted at a higher rate when no extraction taxes are being used, making the remaining stock more scarce and valuable. As expected, the filling sand mining companies' discounted total profits are much higher when no extraction taxes have to be paid. However, when we look at discounted total welfare, we again see that from a societal point of view, the use of extraction taxes is preferable. In Table 8, the different components of the total welfare figures are presented.

Table 8. Total welfare components, filling sand.

	Extraction taxes	No extraction taxes
Component	Value	Value
Rent sand mining operator	199.969,02	2.146.306,71
Tax revenue	16.465.064,47	/
Consumer surplus	16.365.079,96	34.656.287,14
Green tax reform	1.646.506,45	/
Externalities	-10.976.709,65	-15.879.751,33
Total	23.699.910,25	20.922.842,52

Given the results in Table 6 and 7, one could numerically plot the associated evolving time paths for filling sand volume and price. These are shown in Figure 3 and Figure 4 below.

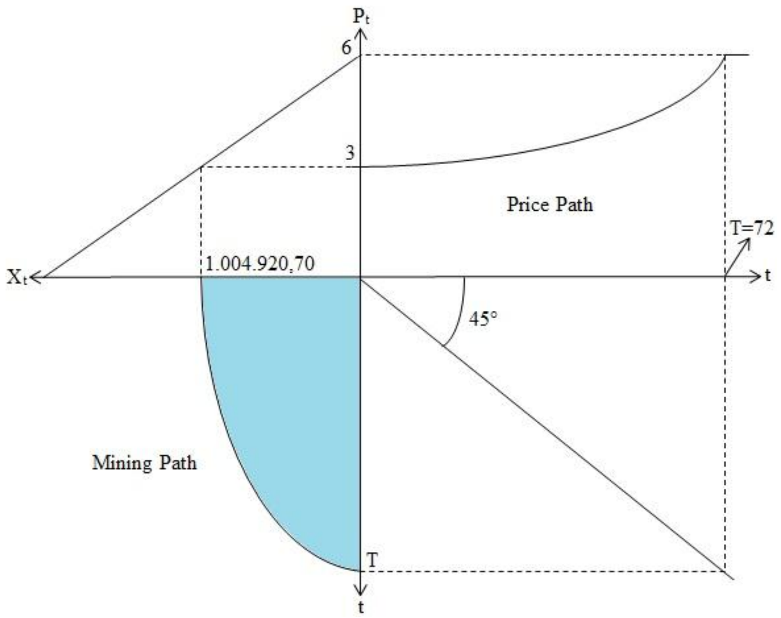

Figure 3: Overview filling sand, using extraction taxes.

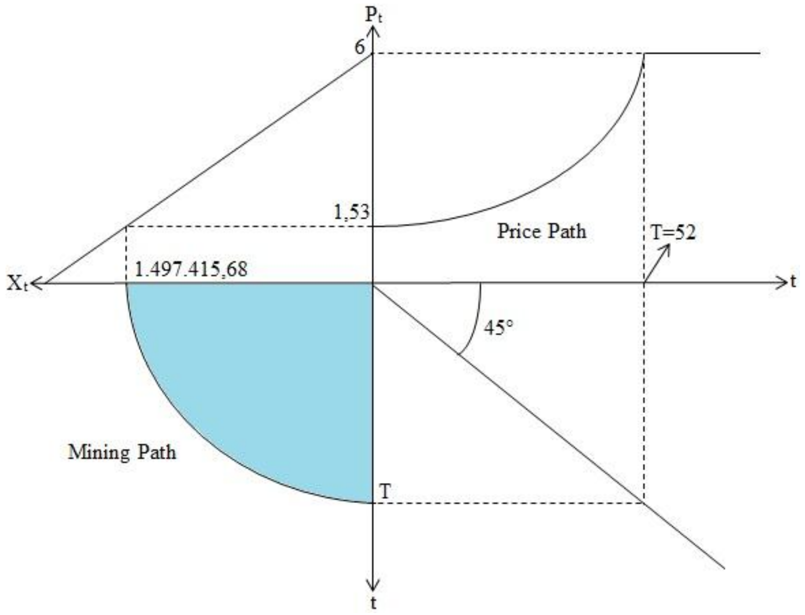

Figure 4: Overview filling sand, without using extraction taxes.

Figure 3 and Figure 4 show how extraction volumes and filling sand prices change in time, respectively when extraction taxes are being applied and when they are not being applied. As can be seen, when extraction taxes are used, prices start at a higher level than when no extraction taxes would be applied. Also, the implementation of the extraction taxes implies that the price moves less rapidly to the choke-off price level, delaying the moment of full reserve exhaustion. The blue shaded areas in both figures depict the total filling sand volume that is extracted over T years, being equal to the initial filling sand reserve.

4. Discussion and conclusions

As remaining sand reserves are limited, care has to be taken to mine these reserves in the most optimal way. Extraction taxes form an instrument that can be used to increase the cost of sand mining such that other materials become more attractive. This way, the tax can postpone the depletion of sand mines in Flanders. Although effectiveness of extraction taxes may be limited when most resources are imported, aggregates like sand however, are available in Belgium. In addition, high transport costs of heavy construction materials diminish the impact of extraction taxes on cross-border shipments.

By gradually elaborating a dynamic optimization problem, optimal sand mining and price paths could be defined by running the algorithm which includes maximizing the profits of the sand mining companies taking into account that the sum of all sand volumes that are extracted yearly should equalize the initial remaining sand reserve. Using data of Flanders, mining paths and price paths were defined for both the construction sand as well as the filling sand case. Regarding construction sand, Figure 1 and 2 show that when extraction taxes are used, the period until the moment of full reserve depletion equals 41 years. Would no taxes be used however, this would only take 30 years. Besides this, although discounted total profits fall when extraction taxes are used, discounted total welfare increases (from 69.503.939,31 euro to 76.698.967,26 euro). The various components of this difference were presented in Table 4.

As to filling sand, Figure 3 and 4 show that when extraction are used, the period until the moment of full reserve depletion equals 72 years. Would no taxes be used however, this would only take 52 years. Besides this, although discounted total profits fall when extraction taxes are used, discounted total welfare increases (from 20.922.842,52 euro to 23.699.910,25 euro). The various components of this difference were presented in Table 8.

To conclude we can say that, from a broad societal point of view and knowing that remaining sand reserves are scarce, the added value of an extraction tax is considerable in terms of welfare gains. Not only the produced externalities would be reduced, but also the depletion of sand mines in Flanders would be postponed.

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