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The elephant in Hotelling's room

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ABSTRACT

This paper questions the assumption, commonly used in theoretical and policy research, that scarcity rents make up a large proportion of market prices for oil and coal. We show that the empirical literature, simple calculations of historical and future scarcity rent shares, and possible theoretical explanations all imply the same overall conclusions: that scarcity rents seem to have been marginal or non-existent historically; that they almost certainly do not dominate fossil resource prices today; and that there will be other factors shaping the prices in the upcoming decades. We therefore argue that using the scarcity rent as the main or only basis for policy or for explaining empirical outcomes is ill-advised.

1. Introduction

The study of markets for non-renewable natural resources—such as fossil fuels—has grown in importance over the last 40 years. Initially this was due to the oil-price shocks of the 1970s, and more recently due to the recognition of the dangers of climate change. An essential prerequisite for successful climate policy is an understanding of how resource markets will react—dynamically—to regulatory measures. The single most important advance in understanding these markets occurred much earlier, with the publication by Hotelling (1931) of a theory of resource pricing based on the insight that resource owners should treat their holdings as assets. Hotelling showed that if a resource owner chooses to retain her asset (i.e. not extract it and sell it) it must be because the *in situ* price of the asset (henceforth the *scarcity rent*) is appreciating at the same rate as the prices of other assets in which the resource owner could invest. If markets are perfect and there are no extraction costs,[1] and there is no uncertainty in the economy, then the resource price is equal to the scarcity rent, which must rise at the rate of interest.

The fly in the ointment for Hotelling has been the well-documented failure of observed resource prices to rise. This casts doubt on the existence and relative importance of the scarcity rent, at least historically. Nevertheless, the idea of the scarcity rent has exerted a powerful influence in the literature on resource and climate policy, where it is common to assume that the scarcity rent is the only factor shaping the price. Do scarcity rents make up a large proportion of market prices for coal and oil? In this paper we use very simple analysis to show that the answer to this question is that scarcity rents seem to have been marginal or non-existent historically, that they almost certainly do not dominate resource prices today and that, at the very least, there will be other factors shaping resource prices in the upcoming decades. We therefore argue that the burden of proof should rest on those who claim that scarcity rents are large, or who build policy models implicitly based on this claim.

2. What's at stake

The Hotelling model has a few clear policy implications. For example, if the scarcity rent is large then any measure which has the *prima facie* effect of reducing the scarcity of the resource will cause a compensating fall in the scarcity rent, thus tending to reduce the resource price and raise consumption rates. For clarity, define a resource whose price is equal to the scarcity rent as a *Hotelling resource*. It has long been known that a constant *ad valorem* tax on a Hotelling resource has no effect on the extraction path (see for instance Dasgupta and Heal, 1979). The scarcity rent is pushed down, but the deficit is filled precisely by the tax, and the overall effect is that income flows are transferred from the resource owner (rents) to the regulator (taxes). In order to delay depletion, a falling *ad valorem* tax would be required, whereas rising tax rates would hasten depletion.[2] Since a changing tax rate may be politically infeasible, the assumption of a Hotelling resource may lead to the conclusion that a cap-and-trade system is preferred over taxation for curbing CO_2 emissions.

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[1] Note that extraction costs should be taken to include all costs of getting the finished resource to market.

[2] See also Ulph and Ulph (1994) and Sinclair (1994) for extensions.

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A second implication applies to the effect of expectations. Anything that creates expectations of lower future demand for a Hotelling resource—such as the announcement of future taxes, or R&D investments in finding substitutes for the resource—will lower the scarcity rent, and thus tend to reduce the price and raise consumption in the present. This mechanism has recently been labelled the 'green paradox' (Sinn, 2008), and judging from recent publications and conference presentations it is a very active strand of research (e.g. Sinn, 2008; Hoel, 2008; Di Maria et al., 2008; van der Ploeg and Withagen, 2010).[3]

A final example regards how natural resources affect the endogenous growth process and potential intergenerational equity. With a few exceptions, the standard in this literature is to assume a pure Hotelling resource; see for instance Hartwick (1977) on intergenerational equity, and extensions which include endogenous growth mechanisms such as Grimaud and Rouge (2003) and Groth and Schou (2007). The policy conclusions regarding for example government interventions and whether intergenerational equity can be achieved by the market are closely tied to that assumption.

The policy relevance of the above research obviously hinges on the existence of a significant scarcity rent, as has been noted for instance by Gerlagh (2010). Considerable effort, both by policy makers and researchers, is now being devoted to figuring out how to tax carbon. Whether the underlying assumptions are in tune with reality will have a great impact on what comes out of this work and thus on the success of future policy decisions.

3. Empirical literature

Empirically, there is little or no evidence for substantial scarcity rents. First, ocular inspection of real prices (see for instance Krautkraemer, 1998) shows that the price trend of exhaustible resources is typically almost constant. Although this observation can be reconciled theoretically by adding other factors to the basic model (as discussed further in Section 4), it effectively rules out pure Hotelling resources and is suggestive of low scarcity rents.

Since the components of the overall price cannot in general be observed directly, empirical approaches focus on measuring the correlation between resource prices and other exogenous changes, the effect of which is expected to differ depending on the size of the scarcity rent. For instance, there is a substantial literature based on the idea that changes in interest rates should be positively correlated with resource price increases if the scarcity rent is significant. The majority of these papers find no such correlation.[4] The few papers that do find support for the existence of a scarcity rent do not support that it is a dominant component.[5]

Another approach is to treat resources in the ground as one among several inputs for the production of the finished resource, in which case the marginal cost saving from increasing extraction (saving costs on other inputs) should be equal to the scarcity rent. To estimate a model, data on extraction costs is required. Chermak and Patrick (2001) and Ellis and Halvorsen (2002) apply this approach to extraction of natural gas and nickel respectively, both finding only low levels of the scarcity rent.[6]

4. Theoretical explanations for constant prices

In terms of Hotelling's analysis, there are two possible reasons for the failure of prices to rise: either (i) resource markets systematically fail to value resources in the ground according to the theory or (ii) the scarcity rent is well-behaved, but masked by other factors. In both cases, the implication is that factors other than the scarcity rent are important in shaping the resource price. Failure to value resources correctly could for instance be due to a failure to foresee (stochastic) discoveries, leading to a fall in the rent each time a discovery is made; this is illustrated in Fig. 1(b). However, as was shown as early as 1982 by Arrow and Chang (1982), rational actors will take account of the probability of new discoveries being made, and the effect of allowing for stochasticity will be for the rent to fluctuate around the original trend. Only in the case of a constant series of surprises, all in the same direction, could new discoveries hold back the long-run growth in the rent. Imputing such a series of surprises boils down to assuming that actors on the resource market are not rational, hence the analysis is hoist by its own petard; that is, if market actors are not rational then other fundamental elements of the market analysis also break down. Another reason for markets not to value resources according to the theory could be that politico-economic factors play an important role, as argued by many authors in the resource curse literature.[7] Resources are frequently state-owned, and in such cases it is a reasonable conjecture that there are other, non-market, mechanisms shaping extraction and price paths.

Turning to the possible masking of the scarcity rent, note first that other components of the price may be a combination of extraction costs and rents due to market power, which we denote as 'resource costs'. Resource costs could mask a rising scarcity rent in two different ways, illustrated in Fig. 1(c) and (d). In the first, which we denote 'declining costs', the rent is a significant component of the price, but the fall in resource costs compensates for its rise. In the second, 'low scarcity', the rent is only a tiny component of the overall price, and hence its rise has an insignificant effect on the overall price. It is straightforward to demonstrate both cases in theory. For instance, a popular explanation for declining costs is that technological progress in extraction pushes down unit extraction costs; see for instance Lin and Wagner (2007). However, as Hart (2009) points out, this should only occur if technological progress in extraction outstrips progress in other sectors, since otherwise the prices of inputs (such as labour) should rise in line with increasing productivity.

Note that low scarcity rents can arise in a number of ways despite finite stocks, for example if there is a renewable substitute. For brevity, we follow Nordhaus (1973) in the following argument by assuming a *backstop technology*, i.e. a technology capable of substituting for the resource at a price which is independent of demand. Then if extraction costs are equal to the cost of a backstop technology, it is obvious that the scarcity

[3] Note that complex, 'paradoxical' results may also emerge in the absence of a scarcity rent. For instance, Smulders et al. (2010) show that there may be demand-side effects whereby producers of dirty capital reduce their prices if they know that they are about to be wiped out by regulation.

[4] See Slade and Thille (2009) for a survey. Heal and Barrow (1980, 1981) and Agbeyegbe (1989) reject the correlation between metal price movements and the level of the interest rate. So does Farrow (1985) for mining and Young (1992) for copper. Halvorsen and Smith (1984, 1991) show that the value of stored mining resources has fallen over time. Adelman and Watkins (2008) cannot find an upward trend in gas and oil prices.

[5] For example Stollery (1983) finds that depletion is part of shaping the price for nickel but makes for less than a 20 percent share of the total price. Another interesting detail is that the time period used in this paper (1952–1972) is the only one where the nickel price has been increasing.

[6] Chermak and Patrick (2001) find mean levels for the scarcity rent of $0.21 per mcf, which should be compared to EIA price data showing that commercial gas prices were in the interval $4–5 over the same period; Ellis and Halvorsen (2002) conclude that the scarcity rent accounts for an average of 8 percent of the nickel price of the period of study, whereas market power accounts for 61 percent.

[7] For a survey of this literature see van der Ploeg (2011).

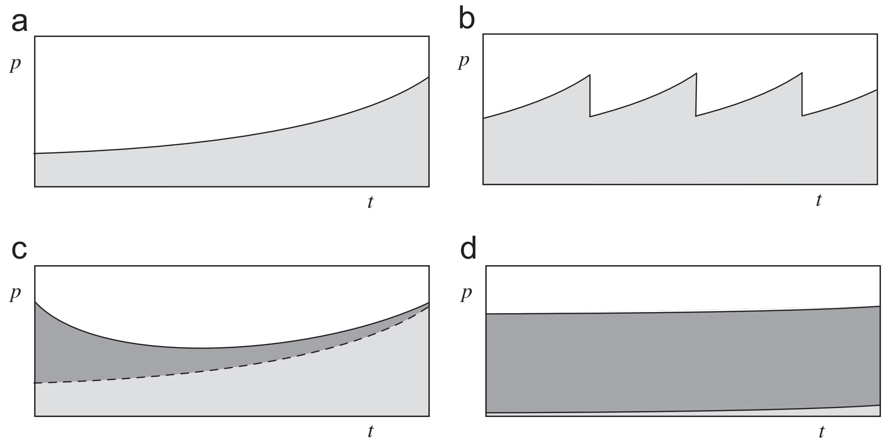

Fig. 1. Resource price as a function of time: (a) Hotelling resource; (b) Non-rational agents; (c) Declining costs; and (d) Low scarcity. The lightly shaded area represents the scarcity rent, the heavily shaded area represents other factors, i.e. the sum of extraction costs and rents due to market power.

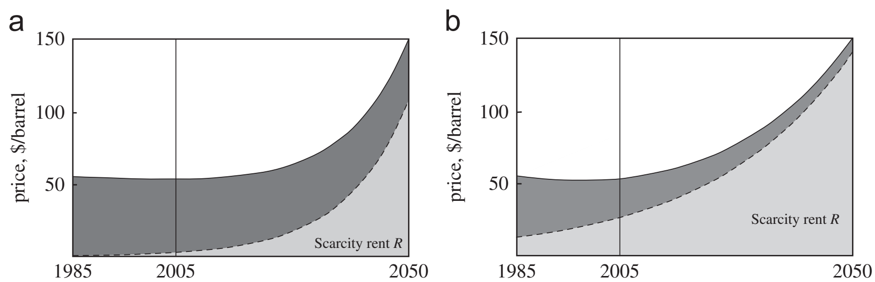

Fig. 2. Graphs of price (dollars per barrel) against time for an crude oil, showing alternative paths between the same observed prices for 1980–1989, 2000–2009, and in 2050 when the backstop is assumed to take over. The lightly shaded area represents the scarcity rent, which grows at rate r, and the darker area represents resource costs, which shrink at rate γ. In (a) low scarcity rent, high returns–$R_{2005}=5$ percent, implying a high rate of return r=8.5 percent/yr, and a slow decline in costs, $\gamma=0.4$ percent/yr; in (b) high scarcity rent, low returns–$R_{2005}=50$ percent, implying a lower rate of return r=3.8 percent/yr, and a more rapid decline in costs, $\gamma=2.4$ percent/yr.

rent will be zero up to the point of exhaustion.[8] More subtly, this will also be the case if extraction costs are expected to be equal to the backstop cost *at the time of resource exhaustion*. Furthermore, it has long been known that given a sufficient degree of market power prices will go straight to the backstop price and stay there, even in the absence of extraction costs; see for instance Teece et al. (1993) or Dasgupta and Heal (1979).

5. Numerical simulations

Here we report the results of some back-of-the-envelope simulations for crude oil.[9] The aim is not to prove the level of the scarcity rent, but instead to illustrate the necessary implications of a high scarcity rent. We build on the analysis of how the scarcity rent may be masked, continuing to assume that resource costs change at a constant rate, while the scarcity rent rises at a constant rate (implying that the rate of return on holding the resource is constant). Under these circumstances, if prices are known at three points in time—such as past, present, and at the time of exhaustion—then if any one of the rate of return on the asset, the rate of cost decline, and the current scarcity rent are known, then the other two are fixed by the model. Furthermore, the lower the rate of return, the higher the current scarcity rent, and the steeper the rate of cost decline. We illustrate this in Fig. 2, in which we take the average prices for 1980–1989 and 2000–2009,[10] and assume that oil reserves will run out in 2050 at a backstop price of 150 dollars/barrel,[11] and illustrate two of the possible combinations which are consistent with the model.

Fig. 2 shows how a higher level of the current scarcity rent with a given backstop price and time of exhaustion implies, ceteris paribus, that resource holders demand a lower rate of return for holding the resource in the ground, and that extraction costs are falling more steeply. However, we wish to focus on the relationship between R (the current percentage of the price made up by the scarcity rent), the time of exhaustion, the backstop price, and the rate of return demanded by resource holders. To do so we plot level curves for R as a function of the backstop price and rate of return, for two different exhaustion dates (Fig. 3).

In Fig. 3 we see that the rate of return demanded on *in situ* resources is crucial to the level of the scarcity rent obtained from the model. If resource holders are happy with a rate of return

[8] See Tahvonen and Salo (2001) for a model in which a renewable substitute plays the role of backstop, putting a cap on resource prices.

[9] Going through a similar exercise for coal entails many problems. On the one hand, the reserve/production ratio is estimated to be over 100 years, while prices have traditionally been stable, both suggesting low scarcity rent. On the other hand, both consumption and price rose steeply in the period 2002–2008 (BP Statistical Review of World Energy 2010, www.bp.com), suggesting either short-run supply limits or increasing scarcity rent. Market analyses such as Kavalov and Peteves (2007) suggest that a variety of factors have been responsible for the price increase. Finally, historical data is limited and recent data seems very unreliable. For example, according to Zittel and Schindler (2007) remaining German reserves were downgraded by 99 percent in 2004, and the global reserve lifetime halved. We settle for noting that the large reserves and obvious extraction costs strongly suggest that the scarcity rent is not the dominant element in the coal price, although the rent may have risen over the last 10 years in response to shocks in observed and expected demand.

[10] About 55.4 dollars/barrel and 53.5 dollars/barrel, in constant 2009 dollars. For data see BP (2010).

[11] The current reserve to production ratio is 46 implying 2055 to be the expected time of exhaustion if current production continues. See BP (2010) for the data.

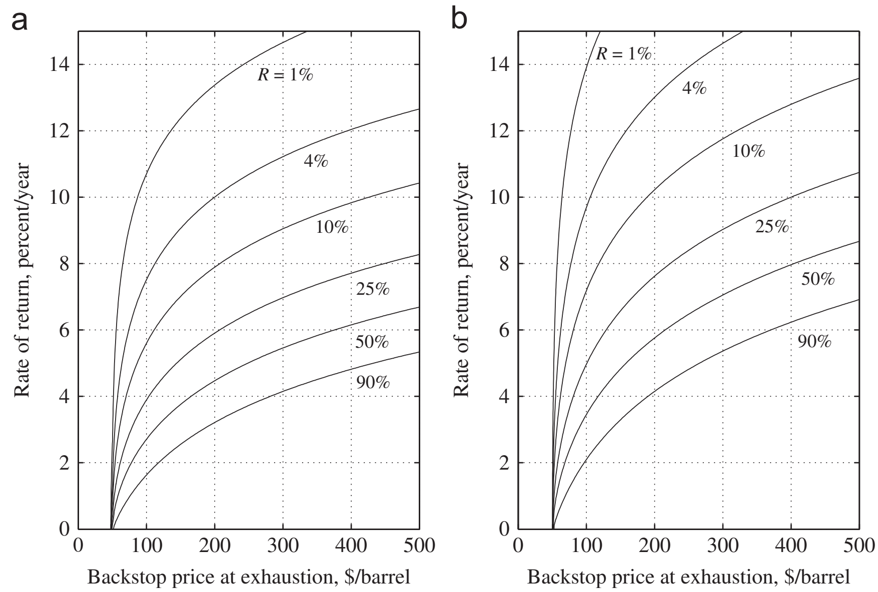

Fig. 3. Simulated level curves for the current scarcity rent as a percentage of current price of oil, where the variables are the final (backstop) oil price and the rate of return (in percent per year) demanded by resource holders: (a) Cheap oil runs out 2050; and (b) Cheap oil runs at 2040.

similar to the average returns on bonds, around 3 percent,[12] then in the baseline scenario (backstop price 150, oil runs out 2050), the figure shows that the scarcity rent makes up between 50 and 90 percent of the current price. On the other hand, if resource holders demand returns similar to average returns on shares, around 7 percent, then the scarcity rent accounts for just 10 percent of the current price.

The question of what rate of return demanded by resource holders has received little attention in the literature. Note however that Stollery (1983) finds by estimation of a CAPM model that the best fit comes from a rate of return of 14 percent for Canadian Nickel. We do not go deeply into the question here, but only note that commodity markets in general, and the oil market in particular, is considered volatile; see for instance Pindyck (2004). Thus it seems reasonable *prima facie* to assume that crude oil holders demand expected returns of at least 7 percent on *in situ* oil, probably significantly higher. This in turn suggests a scarcity rent of up to 25 percent.

From Fig. 3 we can see that the backstop price and time of exhaustion also have significant effects. There is of course a lot of uncertainty about both numbers. However, Lindholt (2005) use a *current* backstop price of $105/barrel (based on Manne et al., 1995), and assume a steady decline over time; it is common to assume declining backstop prices due to technological progress. Note that a reasonable first guess might be to assume that the backstop price falls at the same rate as the resource cost. If we impose this further restriction, then we can instead plot level curves for Hotelling rent as a function of *current* backstop price and rate of return. The result (not shown graphically) is that the level curves shift down significantly, because a high current scarcity rent implies rapidly falling resource costs, implying that the backstop price is also likely to fall. Specifically, a current backstop price of over $500/barrel is required to yield a 25 percent Hotelling rent assuming 7 percent rate of return, while if the backstop price is limited to a more reasonable $200/barrel then the current Hotelling rent is limited to 10 percent of the price.

[12] Average returns on 3-month UK treasury bonds are approximately 3 percent per annum.

6. Concluding remarks

In this paper we have shown that the empirical literature, simple calculations of historical and future scarcity rent shares and possible theoretical explanations all imply the same overall conclusions: (i) that Hotelling's scarcity rent, historically, has played a small role in determining market outcomes, (ii) that the scarcity rent does not dominate the prices for coal and oil today and (iii) at the very least that there will be other important components shaping resource prices in the upcoming decades. We therefore argue that using the scarcity rent as the main or only basis for policy or for explaining empirical outcomes is ill-advised. Since misguided policy may have far-reaching consequences we urge researchers to first get the mechanisms and their weights right before proceeding to more applied exercises.

References

Adelman, M.A., Watkins, G.C., 2008. Reserve prices and mineral resource theory. Energy Journal, pp. 1–16.
Agbeyegbe, T.D., 1989. Interest-rates and metal price movements: further evidence. Journal of Environmental Economics and Management 16 (2), 184–192.
Arrow, K.J., Chang, S., 1982. Optimal pricing, use, and exploration of uncertain natural resource stocks. Journal of Environmental Economics and Management 9 (1), 1–10.
Chermak, J.M., Patrick, R.H., 2001. A microeconometric test of the theory of exhaustible resources. Journal of Environmental Economics and Management 42, 82–103.
Dasgupta, P., Heal, G., 1979. Economic Theory and Exhaustible Resources. Cambridge University Press, Cambridge.
Di Maria, C., Smulders, J.S.A., Van der Werf, E., 2008. Absolute Abundance and Relative Scarcity: Announced Policy, Resource Extraction, and Carbon Emissions. SSRN eLibrary.
Ellis, G.M., Halvorsen, R., 2002. Estimation of market power in a nonrenewable resource industry. Journal of Political Economy 110 (4), 883–899.
Farrow, S., 1985. Testing the efficiency of extraction from a stock resource. Journal of Political Economy 93 (3), 452–487.
Gerlagh, R., 2010. Too Much Oil. SSRN eLibrary.
Grimaud, A., Rouge, L., 2003. Non-renewable resources and growth with vertical innovations: optimum, equilibrium and economic policies. Journal of Environmental Economics and Management 45 (2), 433–453.
Groth, C., Schou, P., 2007. Growth and non-renewable resources: the different roles of capital and resource taxes. Journal of Environmental Economics and Management 53 (1), 80–98.
Halvorsen, R., Smith, T.R., 1984. On measuring natural-resource scarcity. Journal of Political Economy 92 (5), 954–964.

Halvorsen, R., Smith, T.R., 1991. A test of the theory of exhaustible resources. Quarterly Journal of Economics 106 (1), 123–140.
Hart, R., 2009. The natural-resource see-saw: resource extraction and consumption with directed technological change. Presented at EAERE 2009, currently under revision for the Journal of Environmental Economics and Management.
Hartwick, J.M., 1977. Intergenerational equity and the investing of rents from exhaustible resources. American Economic Review 67, 972–974.
Heal, G., Barrow, M., 1980. The relationship between interest rates and metal price movements. The Review of Economic Studies 47 (1), 161–181.
Heal, G., Barrow, M., 1981. Empirical investigation of the long-term movement of resource prices – a preliminary report. Economics Letters 7 (1), 95–103.
Hoel, M., 2008. Bush Meets Hotelling: Effects of Improved Renewable Energy Technology on Greenhouse Gas Emissions. Memorandum 29/08, Department of Economics, University of Oslo.
Hotelling, H., 1931. The economics of exhaustible resources. Journal of Political Economy 39, 137–175.
Kavalov, B., Peteves, S.D., 2007. The Future of Coal. Technical Report, EU Directorate General, Joint Research Centre, Institute for Energy.
Krautkraemer, J., 1998. Nonrenewable resource scarcity. Journal of Economic Literature 36, 2065–2107.
Lin, C.-Y.C., Wagner, G., 2007. Steady-state growth in a Hotelling model of resource extraction. Journal of Environmental Economics and Management 54 (1), 68–83.
Lindholt, L., 2005. Beyond kyoto: backstop technologies and endogenous prices on CO2 permits and fossil fuels. Applied Economics 37 (17), 2019–2036.
Manne, A., Mendelsohn, R., Richels, R., 1995. A model for evaluating regional and global effects of GHG reduction policies. Energy Policy 23 (1), 17–34.
Nordhaus, W.D., 1973. The allocation of energy resources. Brookings Papers on Economic Activity 4 (3), 529–576.
Pindyck, R.S., 2004. Volatility and commodity price dynamics. Journal of Futures Markets 24 (11), 1029–1047.
Sinclair, P.J.N., 1994. On the optimum trend of fossil fuel taxation. Oxford Economic Papers – New Series 46 (October), 869–877.
Sinn, H.-W., 2008. Public policies against global warming: a supply side approach. International Tax and Public Finance 15 (4), 360–394.
Slade, M.E., Thille, H., 2009. Whither Hotelling: tests of the theory of exhaustible resources. Annual Review of Resource Economics 1, 239–259.
Smulders, S., Tsur, Y., Zemel, A., 2010. Announcing climate policy: Can a green paradox arise without scarcity? Paper presented at the SURED conference, Ascona.
Stollery, K.R., 1983. Mineral depletion with cost as the extraction limit – a model applied to the behavior of prices in the nickel industry. Journal of Environmental Economics and Management 10 (2), 151–165.
Tahvonen, O., Salo, S., 2001. Economic growth and transitions between renewable and nonrenewable energy resources. European Economic Review 45 (8), 1379–1398.
Teece, D.J., Sunding, D., Mosakowski, E., 1993. Natural resource cartels. In: Kneese, A., Sweeney, J. (Eds.), Handbook of Natural Resource and Energy Economics, vol. 3. , Elsevier, pp. 1131–1165 (Chapter 24).
Ulph, A., Ulph, D., 1994. The optimal time path of a carbon tax. Oxford Economic Papers 46, 857–868.
van der Ploeg, F., 2011. Natural resources: curse or blessing? Journal of Economic Literature 49 (2), 366–420.
van der Ploeg, F., Withagen, C.A., 2010. Is There Really a Green Paradox? SSRN eLibrary.
Young, D., 1992. Cost specification and firm behavior in a Hotelling model of resource extraction. Canadian Journal of Economics – Revue Canadienne d'Economique 25 (1), 41–59.
Zittel, W., Schindler, J., 2007. Coal: Resources and Future Production. Technical Report, Energy Watch Group.