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Aggressive oil extraction and precautionary saving: Coping with volatility

Frederick van der Ploeg [1]

University of Oxford, United Kingdom

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ABSTRACT

The effects of stochastic oil demand on optimal oil extraction paths and tax, spending and government debt policies are analyzed when the oil demand schedule is linear and preferences quadratic. Without prudence, optimal oil extraction is governed by the Hotelling rule and optimal budgetary policies by the tax and consumption smoothing principle. Volatile oil demand brings forward oil extraction and induces a bigger government surplus. With prudence, the government depletes oil reserves even more aggressively and engages in additional precautionary saving financed by postponing spending and bringing taxes forward, especially if it has substantial monopoly power on the oil market, gives high priority to the public spending target, is very prudent, and future oil demand has high variance. Uncertain economic prospects induce even higher precautionary saving and, if non-oil revenue shocks and oil revenue shocks are positively correlated, even more aggressive oil extraction. In contrast, prudent governments deliberately underestimate oil reserves which induce less aggressive oil depletion and less government saving, but less so if uncertainty about reserves and oil demand are positively correlated.

1. Introduction

Countries blessed with substantial reserves of natural resources face major challenges on how to manage their wealth efficiently. In deciding how much oil to extract today and how much in the future, resource-rich countries rely on the Hotelling rule of optimal extraction (Hotelling, 1931).[2] This rule requires that one is indifferent between keeping the oil under the ground, on the one hand, and extracting, selling it and saving the oil proceeds, on the other hand. This arbitrage principle implies that the expected rate of change in marginal oil rents (revenue minus oil extraction costs) should equal the market rate of interest. The demand for oil together with the total amount of oil reserves then gives the optimal rates of oil extraction, which will be higher if demand for oil is more elastic. With a declining time path of oil proceeds, the government smoothes tax rates and public spending by saving in line with the well-known principle of tax smoothing (cf., Barro, 1979). With declining oil revenues, it is also optimal to reinvest all marginal rents from oil production in education, infrastructure, physical capital, sovereign wealth and other productive assets so that the boost to private and public consumption can be sustained as oil revenues dry up (cf., Hartwick, 1977).

The above restates standard wisdom on optimal oil extraction and management of windfall revenues (e.g., Davis et al., 2002; Barnett and Ossowski, 2003; Ossowski et al., 2008; Collier et al., in press). A major shortcoming of these three fundamental principles of optimal oil extraction and managing the oil proceeds – the Hotelling rule, the tax smoothing principle and the Hartwick rule – is that they fail to take account of stochastic volatility of oil demand and oil prices, uncertainty about the magnitude of oil reserves, uncertainty about marginal extraction costs, and uncertainty about economic prospects. The main objective of this paper is to investigate the implications of stochastic oil demand, oil prices, oil reserves and economic prospects on the rates of optimal oil extraction, debt management and the efficient setting of tax rates and public spending when policies are conducted by a prudent government. Although the title seems at first blush an oxymoron, we show that both aggressive oil extraction and precautionary saving are optimal outcomes if prudent policy makers try to hedge against oil price volatility driven by turbulent oil demand.

E-mail address: rick.vanderploeg@economics.ox.ac.uk.

[1] OxCarre, Department of Economics, Manor Road, Oxford OX1 3UQ, United Kingdom. Also affiliated with the University of Amsterdam, the Tinbergen Institute, CEPR and CESifo.

[2] Natural resources could be oil, gas, diamonds, silver, gold, copper, bauxite, coffee, etcetera and even foreign aid. For ease of discussion, we use the shorthand 'oil' for all of them.

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To focus on the most relevant issues, we use the starkest possible model. Hence, we adopt a linear two-period model of intertemporal choice for allocating resources to private and public consumption allowing for tax collection costs/distortions, endogenous public spending, endogenous private consumption, the dynamics of oil extraction, and price-sensitive demand for oil. Future oil demand, oil reserves and shocks to future private income and government income are uncertain and normally distributed. We suppose quadratic preferences. In the absence of prudence, the principle of certainty equivalence (Theil, 1958) does not hold and the conventional Hotelling rule and principle of tax smoothing must be modified. We show that oil demand and oil price volatility brings forward oil extraction and induces a bigger government surplus. Precautionary saving/borrowing does not occur if the third derivative of the utility function is zero (Leland, 1968; Sandmo, 1970; Kimball, 1990). To introduce an element of prudence in government extraction and budgetary policies, we use a double negative exponential transformation of future utility. This transformation function displays constant absolute prudence and is used to obtain the certainty-equivalent value of welfare to go (cf., Epstein and Zin, 1989; Weil, 1993).[3,4] We thus investigate how the Hotelling rule for optimal oil extraction and the tax smoothing principle for optimal debt management and setting of efficient tax rates and public spending have to be modified to allow for prudence.

In more practical terms, prudence is the ability to judge between virtuous and vicious actions at a given time and place. Distinguishing when acts are courageous or reckless is an act of virtue. It should be clear that prudence does not always mean that one has to be cautious or less activist in policies. For example, we know from the literature on prudent optimal monetary policy that more volatility leads to more aggressive Taylor rules for the nominal interest rate (e.g., Sargent, 1999; Leitemo and Söderström, 2008; van der Ploeg, 2009). Indeed, we show that it is prudent to extract more oil more aggressively in the face of volatile oil demand whereas a more common-sense approach suggests that it is best to preserve oil and extract oil less quickly from the ground. What comes out depends on the particular circumstances, since when the uncertainty derives from the amount of oil that is under the ground rather than from uncertainty about future oil demand and oil prices, we show that oil is extracted less vigorously. The term prudence therefore better captures what is going on than the term cautiousness, since the latter term implies the presumption that policy becomes less active. Caution is better reserved to mean risk mitigation or the reluctance to take risks. Prudence is also different from the concept of cunning, since the latter distinguishes itself from the former in the intent with which the decisions to take action are taken. Prudence is viewed to be one of the cardinal virtues. In practical terms, prudent ministers of finance deliberately underestimate growth and thus underestimate the tax base and tax revenues for the coming year (van der Ploeg, 2010). Similarly, prudent businesses do well to estimate costs at the high end and revenues at the low end of the range of forecasts. Our result to deliberately underestimate oil reserves is related to this practical concept of prudence accounting (i.e., businesses deliberately recording inventories in their accounts at the lower of cost and net realizable value rather than at sale price).

We analyze financial buffers of sovereign wealth, not oil inventories. Although in the 1970s and early 1980s there was some hope of *global* commodity price stabilization schemes for commodities like cacao or coffee and relevant theories on optimal commodity stockpiling rules that trade off the benefits of stabilization against the costs of storage are available (Newbery and Stiglitz, 1981), such schemes have mostly been given up. Effective global governance to manage commodity inventories for stabilization purposes at the global level is tough. Other factors are that such schemes distort price signals and may be counterproductive. Hence, we suppose that there is no use of *primary commodity* buffers and focus attention at *financial* buffers. A small country that does not have access to international financial markets may use oil storage to cope with variable and unpredictable oil revenue streams. But oil in situ corresponds to costless storage of oil and costly physical ex situ storage of oil in containers is pointless.[5]

We consider a country that has some degree of monopoly power on the world market for its natural resources. It may be a monopolist, which only seems be the case for very few commodities. More realistic may be that the world market for natural resources is oligopolistic. For example, the world market for resources may be characterized by Cournot or Nash-Cournot equilibrium (e.g., Salant, 1976; Pindyck, 1978; Ulph and Folie, 1980; Loury, 1986; van der Ploeg, 1987; Karp, 1992; Salo and Tahvonen, 2001). If the world market has a limited number of price-taking countries, the effective price elasticity facing each resource-exporting country is the price elasticity for the world demand for natural resources divided by the country's share of the world market for natural resources.[6] The inverse of this effective price elasticity, i.e., the market share times the price elasticity of the world demand for oil, corresponds to the monopoly power of this oil-exporting country in the world oil market. We suppose that the country faces only one deposit of reserves and abstract from the issue of optimal sequencing of easily accessible and deeper layers of reserves (e.g., Herfindahl, 1967; Solow and Wan, 1976; Kemp and Long, 1980a, in press; Amigues et al., 1998). [7]

Our main result is that it is optimal for prudent governments to extract oil even more aggressively at the expense of future oil production and to set up additional precautionary financial buffers to cope with volatile oil demand and prices, especially if the policy maker is very prudent and attaches a higher priority to the public spending target, the country enjoys substantial monopoly power on the global oil market, and oil demand is very turbulent. We also show that uncertainty about future public revenues or spending needs leads to even more precautionary saving and, if non-oil public revenue shocks and oil revenue shocks are positively correlated, even more aggressive oil depletion. Furthermore, we show that prudent governments deliberately underestimate their oil reserves, thereby offsetting the tendency to extract oil aggressively and reducing the government budget surplus. This effect is, however, weaker if uncertainty about reserves and oil demand are positively correlated.

The outline of the paper is as follows. Section 2 sets up the model. Section 3 first discusses the impact of temporary and permanent oil price shocks on the optimal budgetary policy and oil extraction plans. Since expected marginal oil rents and oil prices rise over time, oil revenues decline over time. To deal with declining oil revenue resulting from rising Hotelling scarcity rents, the government runs a surplus in order to smooth taxes and levels of public spending. If current oil demand is high, the country pumps more oil at the expense of future oil production, especially if the shock to oil demand is more persistent, and thus current oil prices and revenues are higher today

[3] This extends the linear–quadratic–Gaussian optimal control framework to allow for constant absolute prudence. Alternatives based on, for example, the linear–exponential–Gaussian framework to analyze precautionary saving are less easy to adopt for our purposes, since we are interested in the intratemporal tradeoff between tax cuts and public spending increases.

[4] As is known from Kimball (1990) and others, prudence results from a positive third derivative whereas risk aversion comes from a negative second derivate of this transformation function. The double negative exponential transformation happens to display both constant absolute risk aversion and constant absolute prudence.

[5] If oil extraction faces convex extraction costs, a case for ex situ storage might be made. In that case, oil buffers may be an alternative for financial buffers of sovereign wealth. We suppose, however, that in situ oil storage is not too costly or, alternatively, that costs of ex situ oil storage are prohibitive in which case ex situ oil storage is not an attractive option.

[6] In our two- or three-period setting, we do not distinguish between open-loop and closed-loop solution concepts. Given the dominance of OPEC in the global oil market, the oil market may also be characterized by a Stackelberg equilibrium with the OPEC cartel as leader and a competitive fringe of other oil-producing countries as followers (Maskin and Newbery, 1980; de Groot et al., 2003).

[7] With imperfect competition in the world oil market, simultaneous exploitation of deposits of different marginal extraction costs is possible as the market shares associated with the production of each deposit or the elasticities of demand faced by individual countries can change over time.