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# Peak Oil profiles through the lens of a general equilibrium assessment

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## HIGHLIGHTS

- ▸ Geological determinants behind Hubbert curves in a general equilibrium framework.
- ▸ We endogenize the interactions between Peak Oil dates, oil prices and growth trends.
- ▸ Close Peak Oil dates lead to different trends of oil prices, exportation and growth.
- ▸ Low short-term prices benefit to the long-term macroeconomy of oil exporters.
- ▸ High short-term prices hedge oil importers against economic tensions after Peak Oil.

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## ABSTRACT

This paper disentangles the interactions between oil production profiles, the dynamics of oil prices and growth trends. We do so through a general equilibrium model in which Peak Oil endogenously emerges from the interplay between the geological, technical, macroeconomic and geopolitical determinants of supply and demand under non-perfect expectations. We analyze the macroeconomic effects of oil production profiles and demonstrate that Peak Oil dates that differ only slightly may lead to very different time profiles of oil prices, exportation flows and economic activity. We investigate Middle-East's trade-off between different pricing trajectories in function of two alternative objectives (maximisation of oil revenues or households' welfare) and assess its impact on OECD growth trajectories. A sensitivity analysis highlights the respective roles of the amount of resources, inertia on the deployment of non conventional oil and short-term oil price dynamics on Peak Oil dates and long-term oil prices. It also examines the effects of these assumptions on OECD growth and Middle-East strategic tradeoffs.



## 0. Introduction

The public debates about the future of oil markets have been largely shaped by the so-called 'Peak Oil', which relays concerns about the consequences of the inexorable decline of world oil production. The analyses have been focused on the date of this Peak Oil and are essentially conducted under the assumption that, given exogenous assumptions on the total amount of oil resources, oil production levels at a given point in time are only determined by remaining reserves in the soil, in turn depending on the sum of past production (see (Al-Husseini, 2006) for a review). This vision is supported by the generalization, at a global level, of bell-shaped profiles used by Hubbert to predict the decline of US production in the 1970s ((Hubbert, 1956, 1962; Deffeyes, 2002). Note that these curves are meant to capture geological constraints in the form of depletion effects and inertias on the deployment of production capacities.

This paper starts from the idea that the date of Peak Oil is an effective warning about constraints on cheap oil as a crucial energy source (Reynolds, 1994), but distracts the attention from its core determinants and economic consequences. Setting aside controversies about the generalization at a macro level of the Hubbert approach (Lynch, 2003), this paper argues that what matters is not so much the date of Peak Oil than the abruptness of the unanticipated break in oil trends at that period and the capacity of the economies to adapt to it.

This abruptness and its economic consequences are determined by the relative evolution rates of oil supply, fuel demand and oil substitutes under imperfect expectations and inertia constraints. To investigate the interplay between these dimensions, we use a Computable General Equilibrium (CGE) model, which incorporates a comprehensive description of the determinants of oil markets,

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including the geological constraints behind the Hubbert curves. This framework pictures a world with imperfect foresight, endogenous technical change and inertia on the deployment of end-use equipments and oil substitutes. Section 1 describes and justifies this modeling option.

Section 2 conducts a comparative analysis of two oil pricing trajectories: high short-term prices caused by a limited deployment of production capacities *vs.* moderate short term prices caused by a market flooding behavior. The former allows high short-term revenues for oil-producing countries, while it limits the vulnerability of oil-importing economies to Peak Oil by accelerating oil-free technical change; the latter discourages oil-saving technical change and triggers high prices after the occurrence of Peak Oil. The economic consequences of these two scenarios are investigated from the point of view of both oil exporters (in terms of oil revenues and macroeconomic effects) and oil importers (as measured by growth trajectories).

Section 3 conducts a sensitivity analysis on the results by considering different assumptions regarding the amount of oil resources and the extent of inertias that characterize non-conventional production. We assess their impact on economic outcomes and show in particular the parameter sets under which the temporary sacrifice of short-term oil profits under the market flooding option may prove beneficial for Middle-East producers thanks to the later increase of their revenue.

## 1. Endogenizing Peak Oil in a second-best economy

Long run general equilibrium interactions between oil markets and economic growth are conventionally investigated either with models picturing exhaustible resource exploitation à la Hotelling (1931) (see Anderson (1972), Solow (1974) or Stiglitz (1974) and Krautkraemer (1998) for a review), or with energy-economy models which conventionally assume steady growth pathways and aggregate supply curves (IPCC, 2007). The first approach cannot but conclude, instead of a Peak Oil, to a steady decline of production over time because they use an intertemporal optimization framework which confronts the "catch-22" syndrome[1]: "you need future information – what you will discover – to optimally control discovery in the present, but you cannot know future information until *after* you explore in the present, and thus you cannot optimally control your current exploration and production in a Hotelling principle sense" (Reynolds and Baek, 2012). The second approach, meant to explore long run pathways, neglects the importance of geological constraints on short term adaptability of oil production because oil demand, driven by steady growth, evolves smoothly.

The short-term consequences on the economy are only considered in two independent traditions. On the one hand, econometric analyses developed after the oil shocks investigate the transmission channels between oil prices and GDP but do not account for long term resource depletion because of their short-term focus (Hamilton, 2008). These studies demonstrate that modeling exercises can better reproduce the observed magnitude of the economic effect of oil price variations if they include (1) *mark-up pricing* to capture market imperfections (Rotemberg and Woodford, 1996); (2) *partial utilization rate of capital* when the full utilization of installed production capacities cannot be achieved due to limits in the substitution between capital and energy (Finn, 2000); (3) *a putty-clay description of technologies* to represent the inertias in the renewal of capital stock (Atkeson and Kehoe, 1999); (4) *frictions in the reallocation of capital across heterogeneous sectors* causing differentiated levels of idle production capacities (Bresnahan and Ramey, 1993); (5) *frictions in the reallocation of labor across heterogeneous sectors* causing differentiated levels of unemployment (Davis and Haltiwanger, 2001). On the other hand, recursive partial equilibrium analyses of supply/demand adjustments can predict Peak Oil if they take into account the information and depletion effects at the origin of the small-large-small sequence of discoveries (Reynolds, 1999a). This group of studies teaches us the crucial role played by geological constraints, geopolitical dimensions, technical inertias and imperfect foresight on short-run oil supply adaptability (Reynolds, 2009). But, these approaches fail to consider macroeconomic impacts of Peak Oil (see Fattouh, 2007 for a review).The purpose of this paper is thus to embark them in such a geological-based analysis. This is done using the CGE model Imaclim-R, which captures the general equilibrium effects of short-term dynamics in second-best economies at different time horizons.

### 1.1. Modeling the impact of oil markets on macroeconomic dynamics

Imaclim-R (Waisman et al, 2012) is a recursive CGE model of the world economy, divided in 12 regions[2] and 12 sectors[3]. It is calibrated for the 2001 base year by modifying the set of balanced input–output tables provided by the GTAP-6 dataset (Dimaranan, 2006) to make them fully compatible with 2001 IEA energy balances (in Mtoe) and data on passengers' mobility (in passenger-km) from (Schäfer and Victor, 2000). The model was tested against historic data up to 2006 (Guivarch et al., 2009) and covers the period 2001–2050 in yearly steps through the recursive succession of static equilibria and dynamic modules. It incorporates the above listed five features identified from econometric analyses as crucial for the representation of energy-economy interactions.

The *static equilibrium* represents short-run macroeconomic interactions at each date $t$ under technology and capacity constraints. It is calculated assuming Leontief production functions with fixed intermediate consumption and labor inputs, decreasing static returns caused by higher labor costs at high utilization rate of production capacities (Corrado and Mattey, 1997) and fixed mark-up in non-energy sectors (feature 1). Households maximize their utility through a tradeoff between consumption goods, mobility services and residential energy uses considering fixed end-use equipments. Market clearing conditions can lead to a partial utilization of production capacities (feature 2) given the fixed mark-up pricing and the stickiness of labor markets (feature 5). This equilibrium provides a snapshot of the economy at date $t$ in terms of relative prices, wages, employment, production levels and trade flows.

The *dynamic modules* are reduced forms of bottom-up models, which describe the evolution of structural and technical parameters between $t$ and $t+1$ in response to past and current economic signals. Available techniques at date $t$ result from the structure and amount of cumulated learning-by-doing processes within the innovation possibility frontier characterizing explicitly the ultimate potentials on the supply and demand side (Ahmad, 1966). Technical choices modify only new input–output coefficients

[1] A notable exception is in Holland (2008) who obtains a peak of production in an Hotelling-like framework by embarking forces that increase the equilibrium production and counterbalance the decreasing trend imposed by the depletion effect.

[2] USA, Canada, Europe, OECD Pacific, Former Soviet Union, China, India, Brazil, Middle-East, Africa, rest of Asia, Rest of Latin America.

[3] Three primary energy sectors (Coal, Oil, Gas), two transformed energy sectors (Liquid fuels, Electricity), three transport sectors (Air, Water, Terrestrial Public Transport) and four productive sectors (Construction, Agriculture, Industry, Services).