A Simple Guide to the Basic Macroeconomics of Oil*

Peter Sinclair¹
University of Birmingham

SEPTEMBER 2006

* Preliminary work: please do not quote without permission. The author is grateful to seminar audiences at the Universities of Adelaide, Birmingham, Oxford and QUT, Brisbane, and the Reserve Bank of Australia, Bank of England, el Banco Central de Chile, the Bangko Sentral ng Pilipinas and the Central Bank of Turkey, to which this paper or related papers have been presented.

¹ Email: Peter.sinclair@bankofengland.co.uk and p.j.n.sinclair@bham.ac.uk.
1 Introduction

We would like to understand the effects and the causes of oil price changes. What follows provides a very simple framework for trying to consider both simultaneously. But the emphasis here will be mainly on the latter\(^1\). One of the main ideas proposed here is that the price of oil is endogenous, and determined along with other variables in a system of relationships. Strictly speaking, an “oil price shock” is a misnomer. Oil prices can jump or collapse for any of a variety of possible reasons. The other developments that accompany the event depend on the nature of the shock.

The central feature of a fossil fuel is that, while burning it provides an essential input into production, the stock is finite; burning it now forecloses the option of burning it later. The intertemporal optimization problem posed by this relationship – different from capital accumulation, but with similarities – means that any thorough treatment of oil in the macroeconomy must be dynamic. One early approach, pioneered by Solow (1974), is Keynesian in the sense that saving is held to be a given fraction of income, and not derived from an explicit trade-off between jam today and jam tomorrow. This is not generally compatible with the optimizing approach first employed by Ramsey (1928). What follows

\(^1\) The classic references on the effects of oil price changes are Bruno and Sachs (1982, 1982 and 1985). A recent survey has been written by Barsky and Kilian (2004). Major textbooks on exhaustible resource theory – both oddly reticent, however, on macroeconomic models embedding them – are Heal and Dasgupta (1979) and Hartwick and Oleweiler (1998).
might be thought of as a simple marriage of Ramsey (1928) and Solow (1974).

2. A Model

2.1 Assumptions

We shall begin by setting up a small model of the world economy with the following assumptions:

(i) a single final good, which may be consumed or (dis-)invested;
(ii) perfect competition in its fullest sense – marginal productivity factor pricing, market clearance, no uninternalized externalities, perfect information;
(iii) energy inputs into final production come exclusively from a homogeneous set of exhaustible fossil fuels, called “oil”, the remaining total stock of which \( S(t) \) at time \( t \);
(iv) no fiscal activity;
(v) final production, \( Q(t) \) at time \( t \), is Cobb-Douglas in three factors, capital \( (K(t) \) in aggregate at \( t \)), total labour quality \( (B(t)N(t) \) in aggregate at \( t \)) and depletion of oil \( (−S(t)) \) at \( t \); there is a trendless Hicks neutral technology parameter \( T \); returns to scale are constant; competitive factor shares, all strictly positive, are defined as \( γ, δ \) and \( 1 − γ − δ \);
(vi) population \( (N(t) \) at \( t \)) grows at \( n \), and each person always supplies one unit of labour; the Harrod neutral technology parameter, \( (B(t) \) at \( t \)), grows at \( b \);
(vii) there are no extraction costs for oil;
(viii) there are no adjustment costs for any factors, nor for consumption;
(ix) agents are identical; they are immortal, or display full intergenerational altruism, but discount the utility from future consumption per head at a strictly positive constant rate of impatience $\beta$;
(x) the consumption-elasticity of the marginal utility of consumption per head (coefficient of relative risk aversion, reciprocal of the intertemporal elasticity of consumption substitution) is a strictly positive parameter, $\alpha$;
(xi) initial values of $B$, $K$, $N$ and $S$ are all given at the current planning date, $0$;
(xii) capital does not depreciate.

2.2 Analysis

The agent’s optimization problem may be treated as governing the choice of the initial value of consumption ($c(0)$) and paths for the subsequent evolution of consumption, capital and remaining (unextracted) oil stocks, which will follow from maximizing the integral, call it $\phi$:

$$\int_0^\infty \{ e^{-\beta t} ((c(t))^{1-\alpha} - 1) / (1 - \alpha) \} + \lambda(t)[TK(t)^\gamma (B(t)N(t))^{\delta} (-S(t))^{1-\gamma}\delta - c(t)N(t) - K(t)] \, dt$$

subject to the initial conditions in assumption (xi). The budget constraint here is an aggregate one, an innocuous device for avoiding needless clutter.
First order conditions with respect to consumption per head at $t$ and the Lagrange multiplier at $t$ imply $e^{-\rho t}c(t)^{-\alpha} = \lambda(t)N(t)$ (so that

$$-\dot{\lambda}(t)/\lambda(t)[\equiv -\hat{\lambda}(t)] = \beta + n + \alpha\dot{c(t)}/c(t) \equiv \beta + n + \alpha\dot{\lambda}(t)$$

(2)

and a restatement of the budget restraint, respectively. There is also a pair of Euler conditions:

$$\phi / \partial K(t) = d\{\partial \phi / \partial K(t)\} / dt \Rightarrow -\dot{\lambda}(t) = r(t) = \gamma Q(t)/K(t)$$

(3)

$$\phi / \partial S(t) = d\{\partial \phi / \partial S(t)\} / dt \Rightarrow -\dot{\lambda}(t) = d\{\partial \phi / \partial S(t)\} / dt = \hat{P}(t)$$

(4).

Here, $r$ is the real rate of interest, and $P$ the price of oil. Together, (3) and (4) imply the Hotelling (Hotelling, (1931)) condition $r = \hat{P}$. This is an asset arbitrage condition, stating that capital and oil-left-in-the-ground must bear the same expected yields. Combining (2) and (3) gives the familiar law of motion for consumption per head, namely that its trend should equal the ratio of the gap between the real interest rate and the sum of the impatience and population growth rates, to the coefficient of relative risk aversion.

The list of *dramatis personae* in this set up is quite long, but can be helpfully divided into two categories: variables that will be stationary in the long run, and those that will not (except possibly by freak). In the first group come $r$ (the real interest rate), the growth rate of final output (call it $g$), the proportionate rate at which the stock of oil is extracted (call it $x$) and the ratio of consumption per head to capital per head (call it $\xi$).
The latter group includes aggregate output and capital ($Q(t)$ and $K(t)$), the price of oil ($P(t)$) and consumption per head ($c(t)$).

Let us start by pinpointing the steady state values of $r$, $g$, $x$ and $\xi$, and then examine the dynamics of these four variables out of steady state.

2.3 The Steady State

In steady state we have

$$r^* = \Lambda[\beta + n + ab]$$

$$g^* = \Lambda[b + n - (1 - \gamma - \delta)(\beta - n(\alpha - 1))/\delta]$$

$$x^* = \Lambda[(1 - \gamma)(\beta / \delta) + (\alpha - 1)(b - n(1 - \gamma - \delta)/\delta)]$$

$$\xi^* = -n + (\Lambda / \gamma)[b(\alpha - \gamma) + (\beta + n)(\gamma + \delta)(1 - \gamma)/\delta]$$

(5)

where $\Lambda \equiv [1 + \alpha(1 - \gamma - \delta)/\delta]^{-1}$.

Several features of interest are immediately apparent from (5). The impatience rate $\beta$ raises the long run oil depletion and real interest rates, and impedes growth. The energy rent share of income, $(1 - \gamma - \delta)$, also retards growth, but reduces the real rate of interest and the depletion rate if and only if the marginal utility of consumption is elastic $(\alpha > 1)$. If $(1 - \gamma - \delta)$ becomes vanishingly small, $\Lambda$ tends to unity, and the steady state growth and real interest rates go to their standard Ramsey values $(b+n, \text{ and } \beta+n+ab)$. The rate of technical progress exerts positive influences on growth and real interest, and raises (reduces) oil depletion when $\alpha - 1$ is positive (negative). A more basic point is that the four RHS variables in (9) are codetermined, so it is unwise, in this setting at least, to
ask how one of them affects another. The price of oil, $P$, climbs in steady state at the real interest rate, which is increasing in impatience, population growth, relative risk aversion, and technical progress.

2.4 Adjustment to the Steady State

The next task is to study how this steady state is approached. Since $r = \gamma Q / K$ at all dates, the dynamics of $r$ will obey $\dot{r}(t) = \dot{Q}(t) - \dot{K}(t)$, while the budget constraint implies $K(t) = r(t)/\gamma - \xi$, so that

$$\dot{r}(t) = g(t) + \xi - r(t)/\gamma.$$  

The growth rate of the consumption – capital ratio, $\xi$, will meanwhile be

$$\dot{\xi}(t) = c(t) + n - K(t),$$

which, from (2), (3) and the budget constraint implies

$$\dot{\xi}(t) = [r(t) - \beta - n]/\alpha + n - r(t)/\gamma + \xi(t) = \xi(t) - \frac{\beta + (1 - \alpha)n}{\alpha} - \frac{(\alpha - \gamma)}{\alpha\gamma}r(t).$$  

(7)

Totally differentiating the marginal productivity condition for oil

$$\left(\frac{\partial Q(t)}{\partial(-S(t))} = P(t)\right)$$

and use of the Hotelling condition give

$$g(t) = r(t) + \dot{x}(t) - x(t),$$

and total differentiation of the production function implies $g(t) = \gamma \dot{K}(t) + \delta(b + n + (1 - \gamma - \delta)(x(t) - x(t)))$, so that

$$(\gamma + \delta)(x(t) - x(t)) = \delta(b + n) - \gamma\xi;$$  

(8)

and substitution for $g(t)$ in (6) establishes the dynamics of the real interest rate:
Together, (7), (8) and (9) constitute the system’s dynamics in terms of three independent variables, the real interest rate, the consumption-capital ratio and the rate of extraction of oil. The growth rate has been substituted out.

The geometry of this model can take three forms. The simplest occurs when the competitive profit share equals the coefficient of relative risk aversion, since, in that special case, the path to the steady state involves nothing more than a gradual convergence of the real interest rate. The extraction rate and the consumption-capital ratio are trendless in transitions. The log of the oil price rises, asymptotically decelerating or accelerating, depending on whether the initial stock of capital, relative to other variables, is scarcer or more abundant then than later on. In this freak case where \( \alpha = \gamma \), the saddle path in consumption-capital space is unit-elastic, and agents’ labour supplies – were they to enter intratemporal utility – would be constant along any transition, too.

Much likelier, however, is the case where \( \alpha > \gamma \). Unity lies at the lower end of estimates and assumptions commonly made\(^2\) about \( \alpha \), and an immense volume of data, covering most countries for quite long periods, pinpoints the profit share of income firmly within the range 0.3 to 0.4. So here utility is essentially more concave in consumption, than output in capital. In this case, the stationarity loci for all three variables (for \( r \) and

\[ r(t) = -r(t)(1 - \gamma) / \gamma + \delta \{ b + n + \xi \} / (\gamma + \delta). \]  

\[ (9) \]
\( \xi \) in \((r, \xi)\) space, and \( x \) in \((x, \xi)\) space) all slope upwards. Scrutiny reveals that there is a unique saddle path towards the steady state, in which \( r, x \) and \( \xi \) all move in the same direction, and the adjustment speed for \( r \) is slower than when \( \alpha = \gamma \). (This reflects the fact that agents display a distaste for consumption varying much over time, so that capital cannot adjust rapidly, and neither, therefore, could \( r \).) Here, assuming that \( r \) converges from above, capital will be climbing faster than consumption, though neither will be rising very fast. The fact that intertemporal substitution in consumption is not particularly strong here warns us to expect (correctly) that oil depletion begins at a higher rate than later on. When \( r \) is falling (rising) in the transition, the log of the oil price will be decelerating (accelerating). In what follows, this case where the marginal utility of consumption is more elastic in consumption, than output in capital, will receive the greatest attention below.

Formal completeness calls on us to consider the opposite case. The stationarity locus for \( \xi \) now slopes downward. Adjustment towards the steady state is rather rapid this time, with consumption moving more quickly than capital. Agents exhibit a very high degree of flexibility in their consumption behaviour, and it is this that implies that \( x \) will climb towards its steady state value when \( r \) is falling, improbable as this may seem.

The degenerate knife-edge case where \( \alpha = \gamma \), the “usual” case where \( \alpha > \gamma \), and the improbable case where \( \alpha < \gamma \) are illustrated, respectively, in Figs 1, 2 and 3.

2.5 Shocks
The point has now been reached where we can now amend our assumption about foresight, and entertain the possibility of permanent shocks to the parameters that frame the system. These parameters include:

(i) the level of (Hicks-neutral) technology;
(ii) the level of current population;
(iii) the level of (Harrod-neutral) technology;
(iv) the stock of unextracted oil in the earth’s crust;
(v) the current stock of capital;
(vi) the trend in population;
(vii) the trend in the (Harrod-neutral) technology parameter;
(viii) the rate of impatience.

By refining the model, this list of shocks could be easily expanded to add in such things as a shock to the rate of depreciation\(^3\), or change in the extent to which income taxation was intertemporally distorting\(^4\). Yet other possibilities include shocks to current beliefs about the value any of the above parameters might take on and after some future date; and combining current actual shocks with current shocks to beliefs about the future allows one to entertain the possibility of transitory shocks as well. These further cases will not be discussed here.

---

\(^3\) The budget constraint is amended to distinguish net from gross investment, and the marginal product of capital will now exceed the real rate of interest; while qualitative implications for the steady state solutions and saddle paths are not radical, faster (slower) depreciation would act much like a drop (rise) in (i).

\(^4\) This would drive a wedge between \(r\) (the cost of capital) and \((\dot{\beta} + n + \alpha c)\), acting not unlike a drop in (i).
Suppose a shock occurs when the economy has attained its steady state. Rises in (i), (ii), (iii) and (iv), and falls in (v), all have the effect of raising the marginal product of capital. This is guaranteed within our Cobb-Douglas set up, where the marginal product of any factor is increased following a rise in the input of another\(^5\). There is no impact on the steady state solutions for \(r\), \(x\) or \(\xi\). None of the three stationarity loci is disturbed. Unless shocked again, the economy evolves back towards its steady state in the space of our key three variables. Since \(r\) jumps, only to slide back subsequently, the same thing happens to the consumption-capital ratio, and to \(x\), the oil extraction rate.

How is the oil price affected? The first three events (permanent, surprise increases in \(B\), \(N\) or \(T\)) would cause it to jump upwards: this is suggested by the marginal productivity condition 
\[
P(t) = (1 - \gamma - \delta)Q(t)/x(t)S(t).
\]
Population and technology jumps raise \(Q(t)\). But the impact is weakened somewhat, though not negated, by the (temporary) rise in the real interest rate, and the accompanying rise in \(x\) that we must experience if \(\alpha > \gamma\). After this, the oil price will grow at a faster, but slowly declining rate, until the steady state is reattained.

A fall in capital, event (v), would trigger two downward pressures on the price of oil: first, output would fall (but by a smaller proportion, since \(\gamma < 1\)); and second, the (temporary) jump in the real interest rate would act to lower the discounted present value of every asset, including oil.

---

\(^5\) With three factor, constant returns to scale production functions it is possible that this condition might fail for some pair of factors; and with substitution elasticities non-unitary, technological progress can, in pathological cases, reduce the marginal product of some factor. But none of these things happen here.
From then on, oil prices would drift up at an elevated but diminishing speed.

Unexpected discoveries lead to an unanticipated jump in $S(t)$. If $x(t)$ and $Q(t)$ were unchanged, $P(t)$ would fall equiproportionately. But $Q(t)$ will tend to rise (the direct effect displays an elasticity of $1 - \gamma - \delta$). That acts to cushion the fall in the oil price, while the transitory upward pressure on the marginal product of capital operates in the opposite direction, and reinforces it. These conflicting secondary effects could cancel as a special case; the prediction of a negative overall impact effect on the price of oil is secure.

None of these five events has any effect on the steady state values of the rates of depletion, interest or growth. All that happens is a sudden shift to the relevant saddle path leading back to an unchanged long run equilibrium, as far as these variables are concerned. But there is of course a permanent shift in the level of oil prices, as well as a phase during which they grow (future shocks apart) at a rate that differs from $r^*$. 

But the invariance of the steady state values of growth, interest, depletion and the consumption-capital ratio does not hold true, however, for our sixth, seventh and eighth events. As (5) makes plain, the steady state now changes. A faster growth rate of population, suddenly anticipated now for the indefinite future, would, (7), (8) and (9) tell us, shift the stationarity loci up for $x(t)$, down for $r(t)$, and up (down) for $\xi$, if $\alpha$ was less (more) than unity. The changes in the three stationarity loci, and the impact upon the steady state values of $r$, $x$ and $\xi$, are presented in the
following Table. The three shocks considered here are falls in the rates of impatience, Harrod neutral technical progress, and population growth.

**TABLE: EFFECTS OF PARAMETER DISTURBANCES 6, 7 and 8**

<table>
<thead>
<tr>
<th>Shock:</th>
<th>( r^* )</th>
<th>( x^* )</th>
<th>( \xi^* )</th>
<th>( r = 0 ) locus</th>
<th>( \xi = 0 ) locus</th>
<th>( x = 0 ) locus</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta )</td>
<td>down</td>
<td>down</td>
<td>down</td>
<td>no</td>
<td>shifts R</td>
<td>no</td>
</tr>
<tr>
<td>( b )</td>
<td>down</td>
<td>down</td>
<td>down (iff ( \alpha &gt; 1 ))</td>
<td>shifts L</td>
<td>no</td>
<td>shifts L</td>
</tr>
<tr>
<td>( n )</td>
<td>down</td>
<td>up (iff ( \alpha &gt; 1 ))</td>
<td>down (?)</td>
<td>shifts L</td>
<td>shifts L (if ( \alpha &gt; 1 ))</td>
<td>shifts L</td>
</tr>
</tbody>
</table>

3. Wrinkles

There are numerous additional considerations (as well as those alluded to above) that one would wish to introduce in a more realistic framework. A brief list could include:

(a) renewables;
(b) the apparent failure of ex post oil price paths to match Hotelling’s predictions;
(c) extraction costs;
(d) imperfect competition on the part of oil owners;
(e) global warming;
(f) tax issues;
(g) stochastics;
(h) crude refinement;
(i) temporary restrictions on supply;
(j) oil as a consumer good, and, more generally, consumption disaggregation;
(k) capital disaggregation and vintage effects;
(l) international disaggregation;
(m) money, (temporary) non-clearing and nominal inertia.

Wrinkle (a): renewables

Wave, wind and hydro are all renewable energy sources. So, more arguably, is nuclear (uranium and plutonium stocks are the only restriction here). The first three provide as yet only a tiny fraction of world energy supplies, though it is expected to grow; nuclear’s contribution has been dwindling, with decommissioning outpacing construction of new stations for nearly two decades. But there is the distinct possibility that hydrogen-based energy (a proven though fledgling and as yet inconvenient technology) could displace one day fossil fuels in most if not all applications. More speculatively, cold fusion is one of a gamut of conceivable alternatives that might eventually eliminate the need for burning fossil fuels. Economists generally start to model such alternatives by hypothesizing either a date, or a unit cost, at which this “backstop technology” suddenly becomes viable and takes over completely. It follows that, under certainty, the earth’s proven reserves of oil will all presumably have been extracted at this date (at least all oil reserves that are worth extracting). The price path from now to the
takeover date follows Hotelling, and the demand integral over this period must match today’s stock. That is why prespecifying both the date and the cost of the new technology would lead to overdetermination.

(b) Does Hotelling Work?

There should be nothing systematic about surprises. Yet real oil prices have displayed long periods with a downward trend, not the upward trend at the real rate of interest predicted ex ante by the simplest version of Hotelling’s model. This was especially true of the years from the Korean War peak (1951) down to 1971-2, and again from 1980 to the late 1990s (apart from a brief jump in the first Iraq war). Trends for much of the inter-war years, and even before 1914, are not dissimilar. A crude representation of the data suggests sudden, occasional jumps, often triggered by war, followed by protracted unwinding.

This broad pattern of non-stationarity, or rather difference-stationarity with stochastic trends, is certainly the main finding by the influential 120 year study of oil and other primary commodity prices by Ahrens and Sharma (1997), among others; similar views are discussed, and mainly upheld, in several surveys (eg Labys (2005)). But Lee, List and Strazicich (2005), exploiting new techniques for multiple unknown break detection, conclude that the Ahrens-Sharma data for eleven non-renewable natural resource prices in fact display stationarity around stochastic trends, with structural breaks in both height and trend. These interesting results are certainly less inconsistent with the Hotelling story.

Extending the model above may also help to reconcile the Hotelling hypothesis with the data. Negative trends in real oil prices may be due to
falling extraction costs: it is the margin above these that, according to simple arbitrage, should be expected to climb at the real rate of interest, not the oil price itself. And technological progress that reduces extraction costs does not have to come as a surprise here – the mechanism works most strongly when it is predicted. Relaxing the assumption of perfect competition, replacing it instead by monopoly, leads to the result that the marginal revenue, net of extraction costs, that should ascend at this rate. Stiglitz (1974) shows that if the demand for oil is log-concave, the elasticity of demand should rise over time, and that the monopolist’s time path for real oil prices would trend up more gradually. One can also argue that oil discoveries have in fact usually occurred as surprises.

(c): extraction costs

Unfortunately, very strict restrictions on these are required to generate a steady state in our model; but partial equilibrium simplifications can be adapted to handle a wide variety of possibilities (costs that may vary with the rate of extraction, with short run adjustment costs, with the remaining stocks, and across wells). The Hotelling rule also changes: see (b) above.

(d): imperfect competition among oil owners

The monopoly story is straightforward (see Stiglitz (1974)). Buiter (1981) has an extension to the relation between a colluding oligopoly, OPEC, and a competitive fringe. Hartwick and Sadorsky (1990) have a duopoly model. More complex oligopoly models have proved intractable thus far, except in simple cases like symmetric Cournot with isoelastic demand and no backstop technology: for in these circumstances, the
principle that all oil must have been extracted at time infinity means that the difference with perfect competition vanishes.

(e) global warming

The model sketched out in this paper can be adapted to cope with a linear negative feedback from the rate of oil extraction to the rate of technical progress, and a modified steady state results (Sinclair, 1994); an earlier paper (1992) does this in the context of a Solowian (1974) setup. Ulph and Ulph (1994) contest Sinclair’s policy inferences, but in a partial framework; they argue that oil taxes may decline in a social optimum but do not necessarily have to do so. Barrett (1990), Nordhaus (1994) and Seabright (1993) are other early papers that address aspects of this problem. One of many difficulties here is that policies to stimulate or advance the date of a backstop technology can be perverse, if they lead oil owners to accelerate depletion.

(f): tax issues

One problem that arises is that the steady state marginal product of capital can easily become contaminated by taxation. This must occur if all income is taxed, with deduction for neither capital income nor net investment (Chamley (1986), Lucas (1990))\(^6\). Intertemporally distorting taxation can clearly alter long run equilibrium oil extraction rates and price paths. Expectations of future tax rates also matter. And the tax treatment of oil is particularly relevant. In the simplest, infinite horizon case, with a fixed stock of oil that will all be extracted eventually, the

\(^6\) Although, when confronted with the inconvenient fact of mortality, these findings may be modified in the absence of full intergenerational altruism.
excess of the price of oil over its extraction cost pure rent, that can be
taxed away with no effects save on the net incomes of oil sellers. This
follows if the oil tax is constant and ad valorem. A trend in this tax rate,
however, is not neutral.

(g): stochastics

Our model can be extended to a random environment by applying
Bellman equations and the techniques and ideas explored by Lucas and
Stokey (1991). An early application to oil is by Hartwick and Yeung
(1988).

(h): crude refinement

It is refined oil, not crude oil, that generates electricity, heats buildings
and powers vehicles. There are capacity constraints on refined output,
and when these are suddenly changed, the price margins between the two
sets of fuel can change sharply, if only temporarily. Refiners are also
imperfect competitors, leading to the possibility of double-margining of
retail prices (treble-margining, when indirect taxes are added) as well as
backward-passing to crude sellers.

(i): temporary restrictions on supply

In the very short run, both supply and demand elasticities for oil are very
low; 0.1 is a typical number attached to both. This means that oil prices
can spike up or down by large amounts with unexpected changes in
supply (war, hurricanes, embargos) or indeed demand (exceptional
weather). What frequently limits the size of these changes, however, is
the reserves of private oil companies, the strategic reserves of governments, and opportunities for some large, very low marginal cost suppliers (e.g., Saudi Arabia) to adjust supply quite quickly or run down or add to stocks.

(j): *oil as a consumer’s good, and, more generally, consumption disaggregation*

Our model treats oil as a producer’s good, not a consumption good. Extending the set up to allow for the latter is straightforward when Cobb Douglas intratemporal preferences are assumed between oil consumption and other types of consumption, but less so when preferences are more complex than this – if a closed form steady state solution is required. There may also be a multiplicity of consumption goods, varying in the oil intensity of their production. In this case, a unique steady state solution calls for a unit-elastic aggregate demand elasticity for oil as an input, clearly a restrictive assumption.

(k) *capital disaggregation, and vintage effects*

Econometricians, led by Jorgenson, have found that substitution between energy and capital is much larger in the long run (around unity) than the short run (e.g., 0.1 on a current – quarter basis). Substitution is easier ex ante than ex post (although not strictly impossible ex post). Empirical models built on Ramsey-type foundations need to allow for this, as much as for other wrinkles.

(l) *international disaggregation*
The model presented here displays no geography; it is a model for a closed system, or the world as a whole. Geographical disaggregation is easy, if transport costs are ignored, and capital markets integrated: countries with larger (smaller) endowments of oil, relative to their GDP, are exporters (importers). Oil export revenues are not matched by imports of the standard consumption good: part of them goes to fund accumulation of capital claims, and with marginal products of capital equalized across the world, the physical capital to which the claim is title will often reside in oil importing countries. The short run consequences of unexpected oil price changes on exporting and importing countries are well surveyed by Corden (1984).

(j) money, disequilibrium, nominal inertia, etc.

The shorter-run effects of oil price changes on employment, growth, and the inflation-unemployment trade-off are examined by many authors; Bruno and Sachs (1982, 1982) provide classic treatments.

It is helpful to think of a three dimensional factor-price frontier, depicting the largest real wage rate that can be paid for given levels of the real price of oil and the real return to capital. A sudden jump in either of the latter two, unaccompanied by a compensating fall in the other, must, with given technology, imply a fall in the equilibrium real wage rate. If legal restrictions, union power, monetary policy and information asymmetries combine to stop real wage rates falling (enough), unemployment can only go up. But a higher oil price may also accompany a lower return to capital, and in two ways: as in our model, the prospect of a lower return to capital may generate an oil price jump, to a saddle path to a new steady state; or, and this is the Bruno-Sachs interpretation, an exogenous oil
price jump may just (temporarily?) transfer profits to oil rents. In the latter case, one expects investment to slip. Monetary policies that attempt to insulate investment and employment from the effects of dearer oil risk a large lurch in actual and expected inflation, with, the data from the 1970s suggest, very little in the way of transitory benefits to offset those costs.

References:
Barrett, S. (1990), *OREP*
Barsky, R. and L. Kilian (2004), *JEP*
Chamley, (1986), *Emet*
Corden, W. (1984), *OEP*
Hartwick, J. and P. Sadersky (1990), *CJE*
Hartwick, J. and N. Oleweiler (1998), *Economics of Natural Resource Use* (2e)
Hartwick, J. and D. Yeung (1988), *Resources and Energy*
Heal, J. and P. Dasgupta (1979), *Economic Theory and Exhaustible Resources*
Hotelling, H. (1931), *JPE*
Jorgenson, D. and K. Stiroh (2000), *BPEA*
Labys, W. (2005), U of W Va, mimeo
Lee, J., J. List and M. Strazicich (2005), *NBERwp 11487*
Nordhaus, W. (1994), *Managing the Global Commons*
Ramsey, F. P. (1928), *EJ*
Seabright, P. (1993), *JEP*
Stokey, N and R. Lucas (1990), *Recursive Methods of Economic Dynamics*
Solow, R. M. (1974), *RES*
Stiglitz, J. E. (1974), *RES*
Ulph, A. and D. (1994), *OEP*
ABOUT THE CDMA

The Centre for Dynamic Macroeconomic Analysis was established by a direct grant from the University of St Andrews in 2003. The Centre funds PhD students and facilitates a programme of research centred on macroeconomic theory and policy. The Centre has research interests in areas such as: characterising the key stylised facts of the business cycle; constructing theoretical models that can match these business cycles; using theoretical models to understand the normative and positive aspects of the macroeconomic policymakers' stabilisation problem, in both open and closed economies; understanding the conduct of monetary/macroeconomic policy in the UK and other countries; analyzing the impact of globalization and policy reform on the macroeconomy; and analyzing the impact of financial factors on the long-run growth of the UK economy, from both an historical and a theoretical perspective. The Centre also has interests in developing numerical techniques for analyzing dynamic stochastic general equilibrium models. Its affiliated members are Faculty members at St Andrews and elsewhere with interests in the broad area of dynamic macroeconomics. Its international Advisory Board comprises a group of leading macroeconomists and, ex officio, the University's Principal.

Affiliated Members of the School
Dr Arnab Bhattacharjee.
Dr Tatiana Damjanovic.
Dr Vladislav Damjanovic.
Dr Laurence Lasselle.
Dr Peter Macmillan.
Prof Kaushik Mitra.
Prof Charles Nolan (Director).
Dr Gary Shea.
Prof Alan Sutherland.
Dr Christoph Thoenissen.

Senior Research Fellow
Prof Andrew Hughes Hallett, Professor of Economics, Vanderbilt University.

Research Affiliates
Prof Keith Blackburn, Manchester University.
Prof David Cobham, Heriot-Watt University.
Dr Luisa Corrado, Università degli Studi di Roma.
Prof Huw Dixon, York University.
Dr Anthony Garratt, Birkbeck College London.
Dr Sugata Ghosh, Brunel University.
Dr Aditya Goenka, Essex University.
Dr Campbell Leith, Glasgow University.
Dr Richard Mash, New College, Oxford.
Prof Patrick Minford, Cardiff Business School.
Dr Gulecin Ozkan, York University.
Prof Joe Pearlman, London Metropolitan University.
Prof Neil Rankin, Warwick University.
Prof Lucio Sarno, Warwick University.
Prof Eric Schaling, Rand Afrikaans University.
Prof Peter N. Smith, York University.
Dr Frank Smets, European Central Bank.
Dr Robert Sollis, Durham University.
Dr Peter Tinsley, George Washington University and Federal Reserve Board.
Dr Mark Weder, University of Adelaide.

Research Associates
Mr Nikola Bokan.
Mr Michal Horvath.
Ms Elisa Newby.
Mr Qi Sun.
Mr Alex Trew.

Advisory Board
Prof Sumru Altug, Koç University.
Prof V V Chari, Minnesota University.
Prof John Driffill, Birkbeck College London.
Dr Sean Holly, Director of the Department of Applied Economics, Cambridge University.
Prof Seppo Honkapohja, Cambridge University.
Dr Brian Lang, Principal of St Andrews University.
Prof Anton Muscatelli, Glasgow University.
Prof Charles Nolan, St Andrews University.
Prof Peter Sinclair, Birmingham University and Bank of England.
Prof Stephen J Turnovsky, Washington University.
Mr Martin Weale, CBE, Director of the National Institute of Economic and Social Research.
Prof Michael Wickens, York University.
Prof Simon Wren-Lewis, Exeter University.

**PAPERS PRESENTED AT THE CONFERENCE, IN ORDER OF PRESENTATION:**

<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s) (presenter(s) in bold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding the Macroeconomics of Oil</td>
<td>Peter Sinclair (Birmingham)</td>
</tr>
<tr>
<td>Caution of Activism? Monetary Policy Strategies in an Open Economy</td>
<td>Martin Ellison (Warwick and CEPR), Lucio Sarno (Warwick BS and CEPR) and Juoko Vilmunen (Bank of Finland)</td>
</tr>
<tr>
<td>Interest Rate Smoothing and Monetary Policy Activism in the Bank of England, the ECB and the Fed</td>
<td>David Cobham (Heriot-Watt)</td>
</tr>
<tr>
<td>Linear-Quadratic Approximation, Efficiency and Target-Implementability</td>
<td>Paul Levine (Surrey), Joseph Pearlman (London Metropolitan) and Richard Pierse (Surrey)</td>
</tr>
<tr>
<td>The Relationship between Output and Unemployment with Efficiency Wages</td>
<td>Jim Malley (Glasgow) and Hassan Molana (Dundee)</td>
</tr>
<tr>
<td>Understanding Labour Market FrictionsL A Tobin’s Q Approach</td>
<td>Parantap Basu (Durham)</td>
</tr>
<tr>
<td>Money Velocity in an Endogenous Growth Business Cycle with Credit Shocks</td>
<td>Szilárd Benk (Magyar Nemzeti Bank and Central European University), Max Gillman (Cardiff and Hungarian Academy of Sciences) and Michal Kejak (CERGE-EI)</td>
</tr>
<tr>
<td>Partial Contracts</td>
<td>Oliver Hart (Harvard) and John Hardman Moore (Edinburgh and LSE)</td>
</tr>
<tr>
<td>Optimal Fiscal Feedback on Debt in an Economy with Nominal Rigidities</td>
<td>Tatiana Kirsanova (Exeter) and Simon Wren-Lewis (Exeter)</td>
</tr>
<tr>
<td>Inflation Targeting: Is the NKM fit for purpose?</td>
<td>Peter N. Smith (York) and Mike Wickens (York)</td>
</tr>
<tr>
<td>Testing a Simple Structural Model of Endogenous Growth</td>
<td>Patrick Minford (Cardiff and CEPR), David Meenagh (Cardiff) and Jiang Wang (Cardiff)</td>
</tr>
<tr>
<td>The Optimal Monetary Policy Response to Exchange Rate Misalignments</td>
<td>Cambell Leith (Glasgow) and Simon Wren-Lewis (Exeter)</td>
</tr>
<tr>
<td>Labor Contracts, Equal Treatment and Wage-Unemployment Dynamics</td>
<td>Andy Snell (Edinburgh) and Jonathan Thomas (Edinburgh)</td>
</tr>
</tbody>
</table>

See also the CDMA Working Paper series at [www.st-andrews.ac.uk/cdma/papers.html](http://www.st-andrews.ac.uk/cdma/papers.html).