An Open Economy with Capital

Based on *OEM* chapter 3

October 21, 2020

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1. For the most commonly used stationary specifications of the shock process (namely, AR(1) specifications) the endowment economy model presented before fails to predict the observed countercyclicality of the TB and the CA.

2. The assumption that output is an exogenously given stochastic process is unsatisfactory if the goal is to understand observed business cycles. For output is perhaps the main variable any theory of the business cycle should aim to explain.

To allow for a full characterization of the equilibrium dynamics using pen and paper we abstract from depreciation and uncertainty, and assume (as we did before), that $\beta(1+r) = 1$. Later on we will relax these assumptions.

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- Then the marginal product of capital is expected to be high not just in the period of the shock but also in the next couple of periods.
- Thus the economy has an incentive to invest more to take advantage of the higher productivity of capital.
- This increase in domestic demand might be so large that total domestic demand, consumption plus investment, rises by more than output, resulting in a countercyclical impact response of the trade balance.

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Principle II: The more pronounced are capital adjustment costs, the smaller will be the initial trade balance deterioration in response to a positive and persistent productivity shock.

Model

Small open economy, no uncertainty, no depreciation.

Preferences:

$$\sum_{t=0}^{\infty} \beta^t U(c_t) \tag{3.1}$$

Sequential budget constraint of the household:

$$c_t + i_t + (1+r)d_{t-1} = y_t + d_t \tag{3.2}$$

Interpretation: LHS displays the uses of wealth: purchases of consumption goods (c_t); purchases of investment goods (i_t); payment of principal and interest on outstanding debt ($(1+r)d_{t-1}$). RHS displays the sources of wealth: output (y_t) and new debt issuance (d_t).

Model (continued)

Production function:

$$y_t = A_t F(k_t) \tag{3.3}$$

A_t = exogenous and deterministic productivity factor

$F(\cdot)$ = increasing and concave production function

$k_t > 0$ physical capital, determined in $t-1$

Law of motion of capital:

$$k_{t+1} = k_t + i_t \tag{3.4}$$

No-Ponzi game constraint:

$$\lim_{j\to\infty} \frac{d_{t+j}}{(1+r)^j} \leq 0 \tag{3.5}$$

Let's solve the problem. Lagrangian of household's problem:

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \left\{ U(c_t) + \lambda_t \left[A_t F(k_t) + d_t - c_t - (k_{t+1} - k_t) - (1+r) d_{t-1} \right] \right\}.$$

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The first-order conditions corresponding to c_t, d_t, k_{t+1}, and λ_t, respectively, are

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Household optimization implies that NPG holds with equality (transversality condition):

$$\lim_{t\to\infty} \frac{d_t}{(1+r)^t} = 0. \tag{3.10}$$

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NOTE: we got perfect consumption smoothing **without** assuming quadratic utility

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Households invest in physical capital in period t until the expected marginal product of capital in period $t+1$ equals the rate of return on foreign debt.

It follows from this equilibrium condition that next period's level of physical capital, k_{t+1}, is an increasing function of the future expected level of productivity, A_{t+1}, and a decreasing function of the interest rate r.

$$k_{t+1} = \kappa\left(\frac{A_{t+1}}{r}\right), \tag{3.14}$$

with $\kappa' > 0$.

Next: let's derive the intertemporal budget constraint

Write the sequential budget constraint for period $t + j$:

$$A_{t+j}F(k_{t+j}) + d_{t+j} = c_{t+j} + k_{t+j+1} - k_{t+j} + (1+r)d_{t+j-1}$$

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$$\sum_{j=0}^{J} \frac{A_{t+j}F(k_{t+j})}{(1 + r)^j} + \frac{d_{t+J}}{(1 + r)^J} = \sum_{j=0}^{J} \frac{c_{t+j} + k_{t+j+1} - k_{t+j}}{(1 + r)^j} + (1 + r)d_{t-1}$$

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Now use the fact that in eqm consumption is constant over time, (3.11), and rearrange terms

$$c_t \sum_{j=0}^{J} \frac{1}{(1+r)^j} + (1+r)d_{t-1} = \sum_{j=0}^{J} \frac{A_{t+j}F(k_{t+j}) - (k_{t+j+1} - k_{t+j})}{(1+r)^j} + \frac{d_{t+J}}{(1+r)^J}$$

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Take limit for $J \to \infty$ and use the transversality condition (3.10) to obtain

Intertemporal budget constraint

$$c_t + rd_{t-1} = y_t^p \equiv \frac{r}{1+r} \sum_{j=0}^{\infty} \frac{A_{t+j}F(k_{t+j}) - (k_{t+j+1} - k_{t+j})}{(1+r)^j} \tag{3.13}$$

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Interpretation: The right-hand side of (3.13) is the household's nonfinancial permanent income, y_t^p. (It is a natural generalization of a similar expression obtained in the endowment economy, see equation 2.10).

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In the present environment, nonfinancial permanent income is given by a weighted average of present and future expected output net of investment expenditure. Thus, equilibrium condition (3.13) states that each period households allocate their nonfinancial permanent income to consumption and to servicing their debt.

Equilibrium

A **perfect-foresight equilibrium** is a value c_0 and a sequence $\{k_{t+1}\}_{t=0}^{\infty}$ satisfying (3.13) evaluated at $t = 0$, and (3.12) for all $t \geq 0$, given the initial stock of physical capital, k_0, the initial net external debt position, d_{-1}, and the sequence of productivity $\{A_t\}_{t=0}^{\infty}$.

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Note that k_t for $t > 0$ is a function of the exogenous variable A_t only. Thus permanent income, y_t^p, is a function of productivity only and is increasing in present and future values of productivity.

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Next we study adjustment to permanent and temporary productivity shocks and ask whether the model predicts a countercyclical trade balance response.

Let's derive the steady state

Suppose $A_t = \bar{A}$ for all $t \geq 0$.

$$k_{t+1} = \kappa\left(\frac{A_{t+1}}{r}\right)$$

d_t?

$$y_t = A_t F(K_t)$$

$$ca_t = -(d_t - d_{t-1})$$

$$tb_t = ca_t + rd_{t-1}$$

Steady State Equilibrium

Suppose $A_t = \bar{A}$ for all $t \geq 0$, and $k_0 = \bar{k} \equiv \kappa\left(\frac{\bar{A}}{r}\right)$.

By (3.14), $k_t = \bar{k}$ for all $t > 0$

By (3.11) and (3.13), $c_t = \bar{c} \equiv -rd_{-1} + \bar{A}F(\bar{k})$

and $d_t = d_{-1}$ for all $t \geq 0$

Output: $y_t = \bar{y} \equiv \bar{A}F(\bar{k})$

Trade balance: $tb_t = \bar{tb} \equiv rd_{-1}$

Current account: $ca_t = d_{t-1} - d_t = 0$

Adjustment to a Permanent Unanticipated Increase in Productivity

Experiment: In period 0 it is learned that A_t increases from $\bar{A}$ to $A' > \bar{A}$ for all $t \geq 0$. Prior to period 0, A_t was expected to be $\bar{A}$ forever.

$$A_t = \begin{cases} \bar{A} & \text{for } t \leq -1 \\ A' > \bar{A} & \text{for } t \geq 0 \end{cases} .$$

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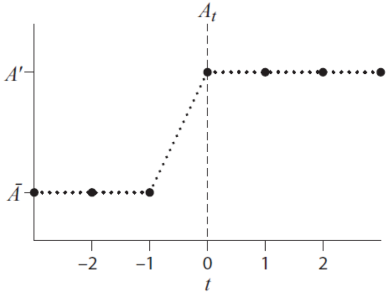

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$$t = 0 : i_0 = k' - \bar{k} > 0$$

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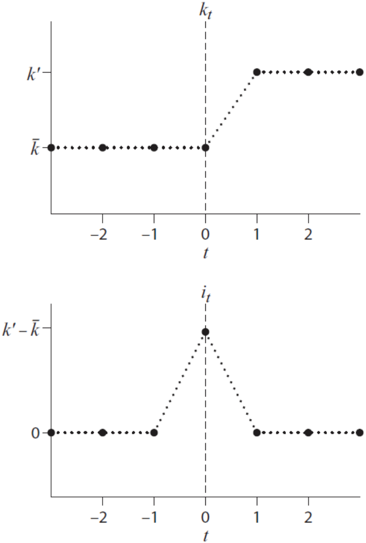

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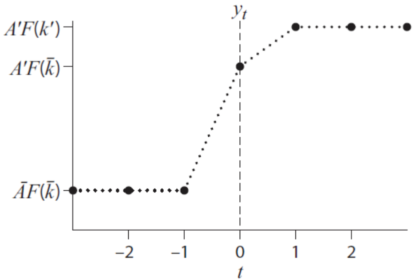

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By (3.13), $c_0 = y_0^p - rd_{-1}$. If permanent income in period 0 rises, so does consumption. Thus, let's find first the adjustment in y_0^p.

Adjustment of y_t^p

Recall $$y_t^p \equiv \frac{r}{1+r} \sum_{j=0}^{\infty} \frac{A_{t+j}F(k_{t+j}) - (k_{t+j+1} - k_{t+j})}{(1+r)^j}$$

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Can re-write as $\quad y_0^p \equiv \frac{r}{1+r} [A_0 F(k_0) - (k_1 - k_0)] + \frac{r}{1+r} \sum_{j=1}^{\infty} \frac{A_j F(k_j)-(k_{j+1}-k_j)}{(1+r)^j}$

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From period 1 on, $i_t = 0$, thus we have:

$$y_0^p = \frac{r}{1+r}\left[(A'F(\bar{k})-k'+\bar{k}\right]+\frac{1}{1+r}A'F(k')$$

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\begin{aligned}
y_0^p &= \frac{r}{1+r}\left[(A'F(\bar{k}) - k' + \bar{k}\right] + \frac{1}{1+r} A'F(k') \\
&= A'F(\bar{k}) + \frac{1}{1+r}\left[A'F(k') - A'F(\bar{k}) - r(k' - \bar{k})\right] \\
&= A'F(\bar{k}) + \frac{1}{1+r}\left[A'F(k') - A'F(\bar{k}) - A'F'(k')(k' - \bar{k})\right] \\
&> A'F(\bar{k})(= y_0) \\
&> \bar{A}F(\bar{k})(= y_{-1}^p).
\end{aligned}
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(The first inequality follows from the facts that $F(\cdot)$ is increasing and concave and that $k' > \bar{k}$)

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- Because in period 0 permanent income exceeds current income, we have that c_0 increases by more than y_0. This by itself—that is, ignoring the increase in i_0—leads to a negative trade balance response in period 0.

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- Because in period 0 permanent income exceeds current income, we have that c_0 increases by more than y_0. This by itself—that is, ignoring the increase in i_0—leads to a negative trade balance response in period 0.

- By contrast, in the endowment economy (of Chapter 2) a once-and-for-all increase in the endowment leaves the trade balance unchanged.

Adjustment of y_t^p

$$
\begin{aligned}
y_0^p &= A'F(\bar{k}) + \frac{1}{1+r}\left[A'F(k') - A'F(\bar{k}) - A'F'(k')(k'-\bar{k})\right] \\
&> A'F(\bar{k})(=y_0) > \bar{A}F(\bar{k})(=y_{-1}^p)
\end{aligned}
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- By contrast, in the endowment economy (of Chapter 2) a once-and-for-all increase in the endowment leaves the trade balance unchanged.
- **Intuition:** the path of output is upward sloping in the economy with capital in response to the permanent shock.

Adjustment of the Trade Balance

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For $t > 0$, $tb_t = tb' > tb_0$.

Is tb' greater or less than tb_{-1}? By (3.2) for $t > 0$

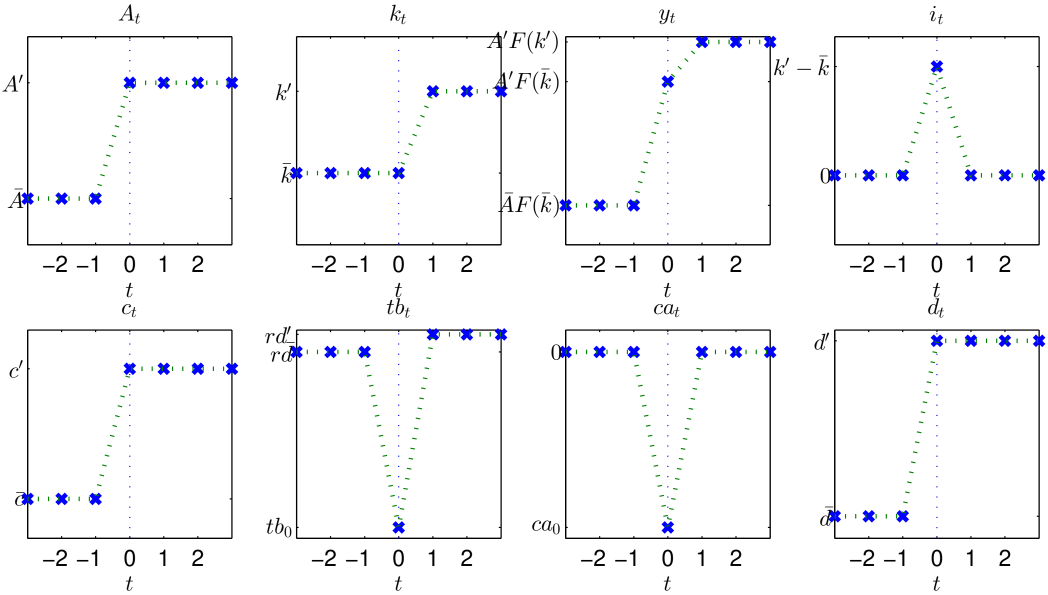
$$d_t = (1 + r)d_{t-1} - tb'$$

This will satisfy (3.10) only if

$$tb' = rd_0$$

where $d_0 = d_{-1} + y_0^p - y_0 > d_{-1}$. The new level of debt is permanently higher than it was prior to the productivity shock and therefore the trade balance, which is used to service the interest on the debt, must also be permanently higher.

Summary of Adjustment to Permanent Productivity Shock



Adjustment to Temporary Productivity Shocks

Experiment: In $t = 0$ we learn that $A_0 = A' > A_{-1} = \bar{A}$ and that $A_t = \bar{A}$ for all $t > 0$.

$$A_t = \begin{cases} \bar{A} & \text{for } t \leq -1 \\ A' > \bar{A} & \text{for } t = 0 \\ \bar{A} & \text{for } t > 0 \end{cases}$$

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Note: the adjustment to a purely temporary shock in the economy w/ capital is thus the same as the adjustment to a purely temporary endowment shock in the economy w/o capital

Adjustment to Temporary Productivity Shocks (cont'd)

By (3.11)

$$c_t = c_0 \quad \text{for all } t \geq 0$$

By (3.13)

$$c_0 = -rd_{-1} + \bar{A}F(\bar{k}) + \frac{r}{1+r}\left(A'F(\bar{k}) - \bar{A}F(\bar{k})\right)$$

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Recalling that $c_{-1} = -r\bar{d} + \bar{A}F(\bar{k})$ and that $d_{-1} = \bar{d}$ yields

$$c_0 - c_1 = \frac{r}{1+r}\left(A'F(\bar{k}) - \bar{A}F(\bar{k})\right) > 0$$

Thus consumption increases by only a small fraction of the increase in income.

From the definition of the trade balance we have

$$tb_0 - tb_{-1} = (y_0 - y_{-1}) - (c_0 - c_{-1}) - (i_0 - i_{-1}) = \frac{1}{1+r}(y_0 - y_{-1}) > 0$$

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For $t > 0$: c_t, y_t, i_t are all constant. Hence tb_t is also constant. At what level? By same argument as above

$$tb_t = tb' = rd_0; \text{ and } d_t = d_0; \quad \forall t > 0$$

Because c_0 increases by less than y_0 and i_0 is unchanged (at zero), it must be that $d_0 < d_{-1} = \bar{d}$. It follows that

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Because c_0 increases by less than y_0 and i_0 is unchanged (at zero), it must be that $d_0 < d_{-1} = \bar{d}$. It follows that

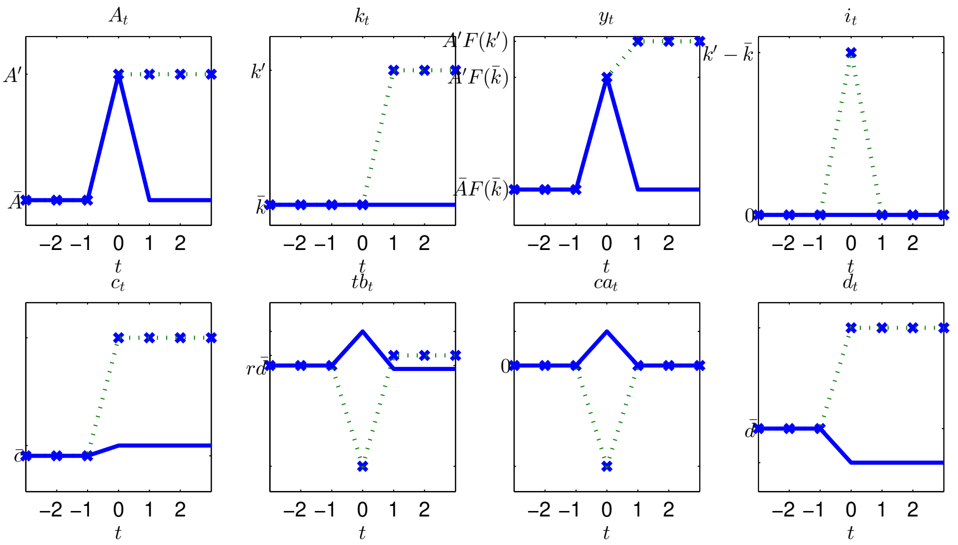
$$tb' < tb_{-1} < tb_0$$

Finally, the adjustment of the current account is

$$ca_0 - ca_{-1} = tb_0 - tb_{-1} > 0$$

and

$$ca_t = 0; \quad \forall t > 0$$



Principle I: The more persistent productivity shocks are, the more likely an initial deterioration of the trade balance will be.

Capital Adjustment Costs

Motivation:

- Capital adjustment costs are a standard feature of open economy business cycle models. They are used to ensure that the predicted volatility of investment relative to the volatility of output does not exceed the observed one.

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  1. the increase in investment in period 0 will be lower.
  2. the increase in permanent income will be lower (because output increases slower to its new permanently higher level) and therefore the consumption response in period 0 will be lower.

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  Both factors contribute to a more muted trade balance response.

Capital Adjustment Costs

We will show that:

Principle II: The more pronounced are capital adjustment costs, the smaller will be the initial trade balance deterioration in response to a positive and persistent productivity shock.

K adjustment costs: functional form

Capital Adj costs: $\frac{1}{2} \frac{i_t^2}{k_t}$

- If $i_t = 0$, then adj costs are nil.
- adj costs are convex in i_t
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- [Draw the adjustment costs]
- Slope of adjustment costs: $\frac{\partial \frac{i_t^2}{2k_t}}{\partial i_t} = \frac{i_t}{k_t}$
- in our model in steady state $i_t = 0$, so adjustment costs and marginal adjustment costs are nil in steady state.

With adjustment costs the sequential budget constraint becomes:

$$c_t + i_t + \frac{1}{2}\frac{i_t^2}{k_t} + (1+r)d_{t-1} = A_t F(k_t) + d_t \tag{3.16}$$

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Lagrangian:

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \left\{ U(c_t) + \lambda_t \left[A_t F(k_t) + d_t - (1+r)d_{t-1} - c_t - i_t - \frac{1}{2}\frac{i_t^2}{k_t} + q_t(k_t + i_t - k_{t+1}) \right] \right\}$$

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$$1 + \frac{i_t}{k_t} = q_t \tag{3.17}$$

$$\lambda_t q_t = \beta \lambda_{t+1} \left[q_{t+1} + A_{t+1} F'(k_{t+1}) + \frac{1}{2} \left(\frac{i_{t+1}}{k_{t+1}} \right)^2 \right] \tag{3.18}$$

q_t = Tobin's q, shadow price of capital in terms of consumption goods

Again assume that $\beta(1+r)=1$, then (3.18) be written as

$$(1+r)q_t = A_{t+1}F'(k_{t+1}) + q_{t+1} + \frac{1}{2}\left(\frac{i_{t+1}}{k_{t+1}}\right)^2 \tag{3.19}$$

Interpretation: Suppose you have q_t units of consumption goods. LHS is the return if those are invested in bonds. RHS is the return if those are invested in capital, which is the marginal product of capital, the undepreciated capital, and the reduction in investment adjustment costs (in the next period).

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This is by now a familiar expression.

- Households split their nonfinancial permanent income, given by the second term on the RHS, to service their outstanding debt and to consume.
- The definition of nonfinancial permanent income is adapted to include adjustment costs as one additional component of domestic absorption subtracted from the flow of output.
- The RHS of the above expression is known as *permanent income* and is given by the sum of net investment income ($-rd_{t-1}$) and nonfinancial permanent income.

Dynamics of the Capital Stock

Combine (3.4), (3.17), and (3.19), to obtain two first-order, nonlinear difference equations in k_t and q_t:

$$k_{t+1} = q_t k_t \tag{3.20}$$

$$q_t = \frac{A_{t+1} F'(q_t k_t) + (q_{t+1} - 1)^2/2 + q_{t+1}}{1 + r} \tag{3.21}$$

Dynamics of the Capital Stock – Steady state

Let's first determine the steady state solution: (q, k)

Suppose $A_t = \bar{A}$ for all t

By (3.20),

$$q = 1$$

And using this result in (3.21)

$$r = \bar{A}F'(k)$$

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$\rightarrow$ investment adjustment costs play no role for long run values of k and q

but they do play a role for the short-run dynamics, which we will analyze next using a phase diagram

Constructing the phase diagram (1)

Let's plot the locus of pairs (k_t, q_t) such that $k_{t+1} = k_t$. Call it the $\overline{KK'}$ locus.

By (3.20) if

$$
\begin{aligned}
q_t > 1, &\quad k_{t+1} > k_t \\
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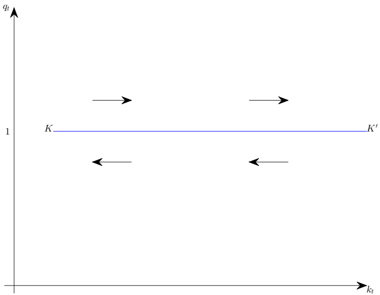

Constructing the phase diagram (2)

Assume that $A_t = \bar{A}$ for all t. Plot the locus of pairs (k_t, q_t) such that $q_{t+1} = q_t$ in a neighborhood around $q_t = 1$. (This is a local analysis.) Call this the $\overline{QQ'}$ locus. By (3.21), the $\overline{QQ'}$ locus is given by

$$rq_t = \bar{A}F'(q_t k_t) + (q_t - 1)^2/2$$

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$$\text{If} \quad \begin{cases} (k_t, q_t) \text{ above } \overline{QQ'}, & q_{t+1} > q_t \\ (k_t, q_t) \text{ on } \overline{QQ'}, & q_{t+1} = q_t \\ (k_t, q_t) \text{ below } \overline{QQ'}, & q_{t+1} < q_t \end{cases}$$

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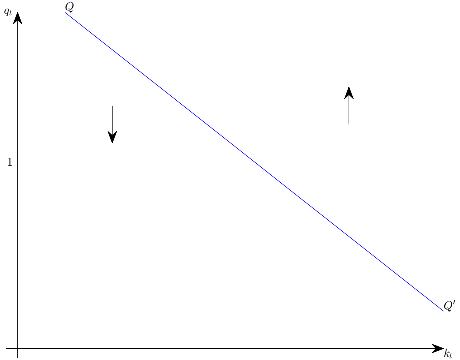
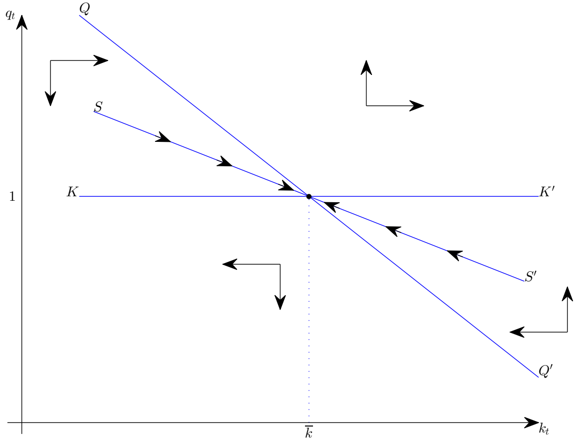


This yields the phase diagram:



- The intersection of $\overline{KK'}$ and $\overline{QQ'}$ is the steady state pair $(k, q) = (\bar{k}, 1)$
- The locus $\overline{SS'}$ is the saddle path.
- Given the initial capital stock, k_0, Tobin's q, q_0, jumps to the saddle path, and (k_t, q_t) converge monotonically to $(\bar{k}, 1)$.

Experiment 1: Adjustment to a temporary productivity shock. $\rightarrow$ identical to the economy without capital adjustment costs, as there is no reason to adjust the capital stock. (results as in Section 3.4).

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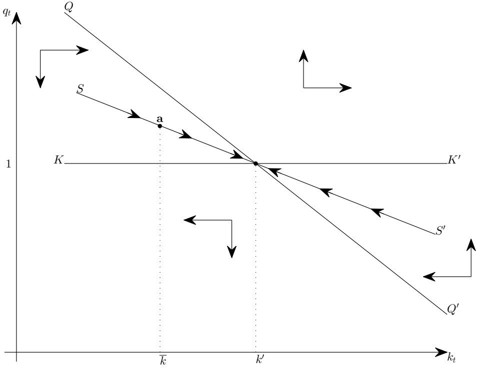
Experiment 2: Adjustment to a permanent productivity shock.
In period 0 it is learned that A_t increases from $\bar{A}$ to $A' > \bar{A}$ for all $t \geq 0$. Prior to period 0, A_t was expected to be $\bar{A}$ forever.

$$A_t = \begin{cases} \bar{A} & \text{for } t \leq -1 \\ A' > \bar{A} & \text{for } t \geq 0 \end{cases} .$$

How can we capture this in the phase diagram? The $\overline{KK'}$ locus does not change. But the $\overline{QQ'}$ locus changes. The new locus is implicitly given by $rq_t = A'F'(q_t k_t) + (q_t - 1)^2/2$. This means that the $\overline{QQ'}$ locus shifts up and to the right. The new steady state is $(k_t, q_t) = (k', 1)$, where k' solves $r = A'F'(k')$. The initial capital stock is $k_0 = \bar{k}$, hence $k_0 < k'$.

The dynamics of the capital stock can be read of the graph below.



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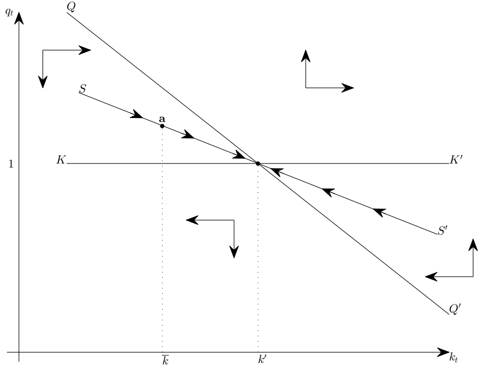

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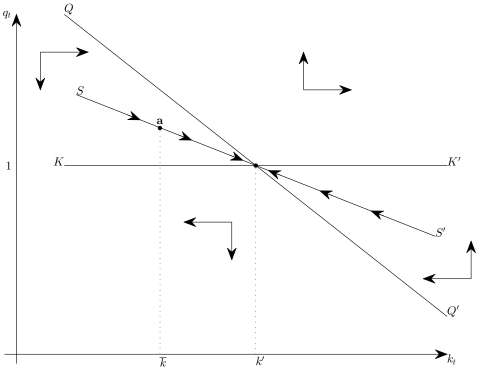

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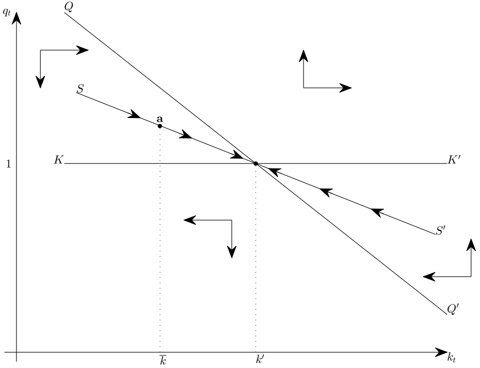

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- k converges monotonically to k' from below and q converges monotonically to 1 from above
- Investment is positive during the entire transition, but, **importantly**, $i_0 < k' - \bar{k}$.
- It follows that domestic absorption increases by less on impact in the presence of capital adjustment costs. And thus, the deterioration of the trade balance in response to a positive permanent productivity shock is smaller on impact.

We summarize these results as follows:

Principle II: The more pronounced are capital adjustment costs, the smaller will be the initial trade balance deterioration in response to a positive and persistent productivity shock.

Thus far, to determine the dynamics in the model with capital adjustment costs we used a phase diagram. The phase diagram is a convenient graphical tool to analyze dynamics qualitatively. Specifically, we used the phase diagram to establish that if k_0 is below steady state, then

- the model is saddle path stable
- the price of capital converges to its steady state value from above
- capital converges to its steady state value from below.
- investement is positive along the entire transition.
- capital adjustment costs dampen the trade balance deterioration in response to a permanent productivity increase.

Thus far, to determine the dynamics in the model with capital adjustment costs we used a phase diagram. The phase diagram is a convenient graphical tool to analyze dynamics qualitatively. Specifically, we used the phase diagram to establish that if k_0 is below steady state, then

- the model is saddle path stable
- the price of capital converges to its steady state value from above
- capital converges to its steady state value from below.
- investement is positive along the entire transition.
- capital adjustment costs dampen the trade balance deterioration in response to a permanent productivity increase.

Alternative method to determine whether the model is saddle path stable and to characterize the adjustment of the economy when k_0 is below its steady state value. Using a log-linear approximation. **READ IT**

Wrapping up

Allowing for k accumulation might induce the model to predict $corr(y, TB) < 0$, even for AR(1) shock processes :

- Suppose persistent AR(1) productivity shocks are the main source of uncertainty.
- Then the MPK is expected to be high not just in the period of the shock but also in the next couple of periods.
- Thus the economy has an incentive to invest more to take advantage of the higher productivity of capital.
- This increase in domestic demand might be so large that total domestic demand, consumption plus investment, rises by more than output, resulting in a countercyclical impact response of the trade balance.

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- Capital adjustment costs **dampen** this response.

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Principle II: The more pronounced are capital adjustment costs, the smaller will be the initial trade balance deterioration in response to a positive and persistent productivity shock.