Financial Crises and Total Factor Productivity*

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Abstract

Measured total factor productivity (TFP) falls markedly in emerging nations that experience financial crises. For instance, during Mexico's 1994-95 crises, standard growth accounting suggests that TFP fell by about 10%, which is twice as large as any other quarterly TFP drop in Mexico over the past 20 years. A possible explanation for this drop is that capital utilization falls during financial crises. For typically short periods, interest rates (the opportunity cost of capital) are well above trend, while TFP is well below trend, which gives firms strong incentives to postpone the consumption of capital services. We calculate that capital utilization did fall noticeably in Mexico in 1995. In a model with homogenous capital, this accounts for almost a third of the drop in measured TFP. The homogenous capital model predicts a path for the energy to capital ratio that is near the relevant evidence. Introducing capital heterogeneity drastically reduces the importance of capital utilization, but we argue that models with heterogenous capital yield predictions for the energy to capital ratio that are at odds with the Mexican evidence. We also find that both models, like the standard neoclassical model, predict that in 1995 labor use should have fallen much more than in the data. This suggests that labor hoarding also played a role in the drop in measured TFP in 1995.

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1 Introduction

Financial crises in emerging nations are typically followed by a sharp fall in output. After Mexico devalued the peso in December of 1994, it entered its worst recession since the great depression. While much has been written on the causes of financial crises (see e.g. Calvo 1996, 1998, 2000, Cole and Kehoe, 1996, Sachs et al., 1996, Flood et al., 1996,) very little is known on what accounts for the real impact of financial crises. In the standard neoclassical model, total factor productivity (TFP) has to fall by 10 percent to account for the drop in GDP in Mexico in 1995. One way to account for this precipitous fall is to find and quantify reasons why technological opportunities suddenly worsen at the onset of financial crises. We believe however that one should first ask what share of the drop in measured TFP is attributable to changes in capital utilization.

One should expect large swings in capital utilization during financial crises. Financial crises are sudden and comparatively short-lived periods of high interest rates and low TFP, which gives firms strong incentives to postpone the consumption of capital services and economize on variable expenditures such as maintenance costs. The goal of this article is to measure the share of the 1995 drop in measured TFP for which capital utilization accounts.

We accomplish this objective in the context of an open-economy version of the standard neoclassical model. The supply of investment funds is perfectly elastic in every period at a price that follows an exogenous stochastic process. To keep investment from being excessively volatile given our open-economy assumption, we assume that it takes four periods to transform these funds into physical capital, as in Kydland and Prescott (1982). In each period, firms rent physical capital from intermediaries and labor services from households, and can choose to leave some physical capital idle to economize on depreciation, as in Greenwood et al. (1988). Our first task is to amend the standard growth accounting method to account for varying utilization rates. If those utilization rates were observable, this extension would be trivial. But in Mexico as in most (all?) countries, capital utilization rates are not measured. We develop a method that enables us to infer utilization rates from (observable) input, output and interest rate data. That method should be of independent interest to many readers.

Applying this method to Mexico under the assumption that capital is homogenous suggests that capital utilization accounts for a third of the drop of TFP in 1995, a share that is robust to even large change in exogenous parameters. Obviously, the interest of these calculations depends on how well the model approximates the behavior of capital utilization in the 1990's. We find that the model's prediction for the energy to capital ratio are near its empirical counterpart in Mexico. Since all evidence is that the energy intensity of capital is inelastic in the short-run (see Atkeson and Kehoe, 2000, for a review), this means that the path for capital utilization rates implied by the model is also consistent with the data. The predicted path for capital, labor and energy use mimic the data reasonably well, with two important exceptions. First, the model predicts a couterfactually high drop in energy use in the first quarter of 1995. Second, it predicts that labor should have fallen markedly more in 1995 than in the data.

A model with heterogenous capital (we introduce heterogeneity in a manner similar to Cooley et al., 1995) gives better predictions for the behavior of energy consumption in the first quarter of 1995. Also, we find that according to the heterogenous model, capital utilization accounted for 15% of the drop in measured TFP rather than a third. Capital utilization matters less for TFP in the heterogenous case because it is machines whose productivity is below average that are left idle. But he heterogenous model does not yield a better approximation of the behavior of labor use in Mexico in 1995. More critically, we find that the path for the energy to capital ratio predicted by such a model is at odds with the Mexican evidence.

The failure of both the homogenous and the heterogenous model to match the behavior of labor use suggests that labor mismeasurement accounts for some of the drop in TFP in 1995. We describe a simple method to gauge the potential importance of labor mismeasurement, and find that together with capital utilization, factor mismeasurement could account for half of the drop in TFP in 1995. Accounting for factor mismeasurement, we conclude, makes the TFP drop in 1995 much less unusual than what standard calculations suggest.

2 The environment

We consider a discrete time model with an infinite horizon, a continuum of mass one of households, a continuum of firms, and a continuum of financial intermediaries. Aggregate uncertainty is described by a stochastic process $\{\omega_t\}_{t=0}^{+\infty}$ where for all t, $\omega_t \in \Omega_t$, a finite set. We denote by $\Omega^t = \Pi_{j \leq t}\Omega_j$ the set of all possible aggregate state histories as of the start of date t. The process governing the evolution of ω_t is Markov, and we write $\pi_t(\omega_t, \omega_{t+1})$ for the likelihood that $(\omega_t, \omega_{t+1}) \in \Omega_t \times \Omega_{t+1}$ are two successive states.

2.1 Households

Households live for ever, and order consumption and labor supply processes $\{c_t, l_t\}$ according to

$$E \sum_{t=0}^{+\infty} \beta^t \log\left(c_t - \psi l_t^{\nu}\right)$$

where $\beta \in (0, 1), \nu > 1$ and $\psi > 0$. With these preferences, labor supply only depends on the wage rate. The accounting method we develop and apply in this paper is independent of the exact specification of preferences. But the simplifying functional form we adopt here will make computing equilibria tractable when we turn comparing the predictions of our model to the Mexican evidence.

2.2 Firms

Output is produced by firms who combine physical capital with inputs of energy and labor. In a given period, each unit of capital (to which we henceforth refer as *machines*) can transform quantity e of energy and n of labor into $z_t s e^{\alpha_e} n^{\alpha_n}$ units of the consumption good, where z_t is aggregate TFP at date t, s is a machine specific shock, and $\alpha_e + \alpha_n < 1$. The machine-specific shock is distributed uniformally on $[-\sigma, \sigma]$ and satisfies a law of large numbers. We emphasize that while this shock varies from machine to machine, the TFP shock, z, is common to all machines.

In a given period, firms rent capital at a rate $R_t(u)$ which depends on their chosen rate of utilization, i.e. the fraction of machines that are combined with positive amounts of labor and energy. Furthermore, proportion δu^{ϕ} of a firm's capital depreciates at the end of each period where $\delta > 0$, $\phi > 1$ and $1-u$ is the fraction of machines that are left idle. Firms hire labor services at rate w_t, and energy services at rate p_t^e. Like z_t, w_t and p_t^e are Ω^t-measurable.

2.3 Financial intermediaries

Financial intermediaries accept deposits from households. We assume that the economy is open in the sense that intermediaries have access to perfect outside capital markets where one-period risk-free claims to a unit of consumption good can be traded at a rate r_t at the beginning of period t, and r_t is Ω^t measurable. Intermediaries can lend and borrow funds at that rate, and can also invest in physical capital.

2.4 Time-to-build

Capital requires time, namely four periods, to build. As is well known in this open economy context, without a time-to-build assumption (or assuming ad hoc adjustment costs) investment would be excessively sensitive to movements in interest rates. Time-to-build reduces the volatility of investment because much of current investment is implied by past decisions, and because new investment depends on a moving average of 4 interest rates, rather than on the current rate only. A new machine comes on line in a given period provided 0.25 unit of the consumption good is invested in each of the previous 4 periods. We will refer to the total mass of machines operated in a given period as aggregate physical capital. Time t aggregate physical capital K_t satisfies

$$K_t = (1 - \delta u^{\phi})K_{t-1} + \eta_t$$

where η_t is the number of machines that come on line at the beginning of period t and u is period $t-1$ aggregate capital utilization rate. As we show in the next section, aggregate returns to scale are constant in this economy, and the average capital utilization rate is also the capital utilization rate of each firm. New machines require investment $x_{i,t} = 0.25\eta_t$ in periods $i \in \{t-5, t-4, t-3, t-1\}$. Period t aggregate investment, therefore, is:

$$I_t = \sum_{i=1}^{4} x_{t,t+i} = 0.25 \sum_{i=1}^{4} \eta_{t+i}.$$

We also assume that the energy input e of machines used in period t must be chosen by intermediaries at the same time as they choose η_t, i.e. 4 periods ahead. As a result, each machine's energy use is inelastic in a given period, but fully elastic in the long-run as in Atkeson and Kehoe, 2000.[1]

2.5 Equilibrium

Firms choose s-measurable labor allocations n to maximize average profits per machine:

$$\pi(z_t; R_t, p_e^t, w_t, e_t) \equiv \\ \max z_t e_t^{\alpha_e} \int_{1-\sigma}^{1+\sigma} s n(s)^{\alpha_n} ds - R_t(u) - \int_{1-\sigma}^{1+\sigma} n(s) ds w_t - \int_{1-\sigma}^{1+\sigma} 1_{\{n(s)>0\}} ds e_t p_e^t$$

where u is the utilization rate, i.e. $u = \frac{1+\sigma-\underline{s}}{2\sigma}$ where $\underline{s} = \inf\{s : n(s) > 0\}$ is the productivity threshold below which machines are not operated. An equilibrium in this economy are Ω^t-measurable labor supply and labor demand policies $\{l_t, n_t(\bullet)\}$, Ω^t-measurable wage and rental rate schedules w_t, R_t, Ω^{t-4}-measurable investment $\{x_{t-4,t-4+i}\}_{i=1}^4$ and energy e_t policies such that, for all periods t, and all possible histories:

1. Households choose labor supply optimally: $l_t = \left(\frac{w_t}{\psi\nu}\right)^{\frac{1}{\nu-1}}$;
2. $n_t(\bullet)$ solves the firm's problem;
3. Firm profits are zero: $\pi(z_t; R_t, p_e^t, w_t, e_t) = 0$;
4. The labor market clears: $l_t = \frac{K_t}{2\sigma} \int_{1-\sigma}^{1+\sigma} n_t(s) ds$
5. $x_{t,t+i} = x_{t-1,t+i}$ for all $i \in \{1, 2, 3\}$;

[1]Specifying a general putty-clay model of energy as they do, however, would make it impossible to compute equilibria. The computational shortcut employed in that paper requires that capital be fully utilized in all periods, a requirement which is necessarily violated in our paper.

6. The following arbitrage condition holds: $q_t = E_{t-4}\left\{R_t(u_t) + (1-\delta u_t^{\phi})q_{t+1}\right\}$

where $u_t = \frac{1+\sigma-\underline{s}}{2\sigma}$ is date t capital utilization, and $q_t \equiv E_{t-4}\sum_{i=1}^{4} 0.25\left(1+\Pi_{j=1}^{i-1}(1+r_j)\right)$. As of date $t-4$, q_t is the expected opportunity cost of a new machine in period t. The final condition requires that intermediaries make no profits in expected terms in equilibrium.

3 TFP accounting with endogenous capital utilization

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Assume that in a given period we observe aggregate input use K,N,E and output Y. What TFP level z is consistent with these data? Is it unique? Answering these two questions, as we do in this section, will enable us to calculate what part of the measured TFP drop in Mexico in 1995 is due to a fall in capital utilization. First note that given K, E, N, given the unobserved schedule of rental rates $R(\omega^t, u)$, given unobserved energy intensity e, and given unobserved TFP z, labor policies must solve the following problem in equilibrium:

$$\begin{array}{lrcl} \max & zKe^{\alpha_e}\dfrac{1}{2\sigma}\displaystyle\int_{1-\sigma}^{1+\sigma} sn(s)^{\alpha_n}ds & - & KR(\omega^t,u) \\ \text{subject to:} & \dfrac{1}{2\sigma}K\displaystyle\int_{1-\sigma}^{1+\sigma} n(s)ds & = & N \\ & \dfrac{1+\sigma-\underline{s}}{2\sigma}Ke & = & E \end{array}$$

where, as before, $u = \frac{1+\sigma-s}{2\sigma}$ and ω^t is the current history. Should labor policies fail to solve this problem, firms could reallocate labor and energy across machines so as to increase output. No such profit opportunity can exist in equilibrium. Using the last constraint to substitute away unobserved energy intensity, the problem becomes :

$$\begin{array}{lrcl} \max & zK^{1-\alpha_e}E^{\alpha_e}\left(\dfrac{2\sigma}{1+\sigma-\underline{s}}\right)^{\alpha_e}\dfrac{1}{2\sigma}\displaystyle\int_{1-\sigma}^{1+\sigma} sn(s)^{\alpha_n}ds & - & KR(\omega^t,u) \\ \text{subject to:} & \dfrac{1}{2\sigma}K\displaystyle\int_{1-\sigma}^{1+\sigma} n(s)ds & = & N \end{array}$$

Profit optimization requires that the marginal product of labor be equated across active machines. Together with the capital constraint, this implies:

$$n(z(1+\sigma)) = \frac{2\sigma}{\int_{\underline{s}}^{1+\sigma}\left(\frac{s}{1+\sigma}\right)^{\frac{1}{1-\alpha_n}} ds}\frac{N}{K}$$

Therefore, $\underline{s}$ solves

$$\max_{\underline{s}} zg(\underline{s})K^{1-\alpha_e-\alpha_n}E^{\alpha_e}N^{\alpha_n} - KR(\omega^t, u)$$

where $g(\underline{s}) \equiv (2\sigma)^{\alpha_e+\alpha_n-1}\left(\frac{1}{1+\sigma-\underline{s}}\right)^{\alpha_e}\left(\frac{1-\alpha_n}{2-\alpha_n}\right)^{1-\alpha_n}\left((1+\sigma)^{\frac{2-\alpha_n}{1-\alpha_n}} - \underline{s}^{\frac{2-\alpha_n}{1-\alpha_n}}\right)^{1-\alpha_n}$. Function g measures the impact of capital utilization on output. Denote by $\underline{s}^*$ the solution to this optimization problem. The following observation makes $\underline{s}^*$ unique.

Remark 1. $g : [1-\sigma, 1+\sigma] \to [0,1]$ *is strictly concave.*

Figure 1 illustrates remark 3 by plotting g (solid line) for a given set of exogenous parameters. Now note that given our model, aggregate output must satisfy:

$$Y = zg(\underline{s}^*)K^{1-\alpha_e-\alpha_n}E^{\alpha_e}N^{\alpha_n}$$

Note in particular that in deterministic steady state the aggregate production function is Cobb-Douglas and linear homogenous, and income shares are pinned down by technological parameters, as usual. One remaining problem is that schedule $R(\omega^t, u)$ is unobserved. The following proposition solves that problem:

Proposition 1. *In any equilibrium,* $R(\omega^t, u) = R(\omega^t, 0) + \delta u^{\phi} E_t q_{t+1}$ *for all* $u \in [0,1]$.

Proof. Consider any competitive equilibrium with rental rate schedule $R^*(\omega^t, u)$ and denote the equilibrium utilization rate at history ω^t by u^*. Demand for capital is positive at, and only at, that utilization rate. So we must have $R^*(\omega^t, u) + \delta u^{\phi} E_t q_{t+1} \leq R^*(\omega^t, u^*) + \delta (u^*)^{\phi} E_t q_{t+1}$. Indeed, assuming that, for some u, $R^*(\omega^t, u) + \delta u^{\phi} E_t q_{t+1} > R^*(\omega^t, u^*) + \delta (u^*)^{\phi} E_t q_{t+1}$ would imply that intermediaries supply no capital at u^* since it is more profitable to supply it at u. Conversely, *any* schedule that satisfies $R(\omega^t, u) + \delta u^{\phi} E_t q_{t+1} \leq R^*(\omega^t, u^*) + \delta (u^*)^{\phi} E_t q_{t+1}$ gives capital suppliers no incentive to change their plans. So the schedule $R(\omega^t, u) = R^*(\omega^t, u^*) +$

$\delta u^{\phi} E_t q_{t+1} - \delta (u^*)^{\phi} E_t q_{t+1}$ supports the same equilibrium allocation as R^* in history ω^t, and satisfies the condition stated in the proposition, which completes the proof. $\square$

The intuition for this result is simple. From the vantage point of history ω^t, augmenting the capital stock by one unit in period $t+1$ saves expected cost $E_t q_{t+1}$. Intermediaries, therefore, are willing to lower the rental rate of capital at rate $E_t q_{t+1}$ when utilization falls. Without loss of generality therefore, we can rewrite the optimal utilization problem as:

$$\max_{\underline{s}} zg(\underline{s}) K^{1-\alpha_e-\alpha_n} E^{\alpha_e} N^{\alpha_n} - K\delta \left(\frac{1+\sigma-\underline{s}}{2\sigma} \right)^{\phi} E_t q_{t+1}$$

Because $E_t q_{t+1}$ is known at ω^t, this optimization problem can be solved with observable information. We will think of $zg(\underline{s}^*)$ as *measured TFP*, while z is *true TFP*. Our accounting question is what part of the drop in measured TFP in 1995 is due to a drop in true TFP. That question can only be answered provided that any given data K,N,E, Y, imply a unique z. The following remark says that this is indeed the case.

Remark 2. *$\underline{s}^*$ falls while g rises as z rises.*

We now make use of the method developed in this section to gauge the role of capital utilization in the drop in measured TFP in Mexico in 1955.

4 Quantitative results

4.1 Homogenous capital

As a benchmark, we first measure the quantitative importance of capital utilization in a version of our model with homogenous capital. That is, assume that all machines are equally productive. Then, $Y = \left(\frac{1+\sigma-\underline{s}}{2\sigma}\right)^{\alpha_k} K^{1-\alpha_e-\alpha_n} E^{\alpha_e} N^{\alpha_n}$. The only motive to leave a machine idle in this model, as in Greenwood et al. (1988) or Burnside and Eichenbaum (1994), is to lower depreciation. That incentive becomes stronger when aggregate TFP is low and interest rates are high, and therefore, is strongest during financial crises.

4.1.1 Calibration

Appendix A explains how we obtain times series for the capital, labor and energy use in the ex-energy business sector in Mexico that are consistent with our model. Our series for the relative price of energy uses the method outlined in Atkeson and Kehoe (2000). Based on that series we calculate an income share of energy (α_e) of 1.5 %. As we point out in the appendix, we set δ and ϕ jointly so that 1) $u = 80\%$ turns out is optimal in the first quarter of 1994 and, 2), the effective quarterly depreciation rate (δu^{ϕ}) is 2.5%. This utilization target is somewhat arbitrary since we have no direct empirical counterpart for it, but we will argue in section 5 that our results are not sensitive to that choice. Finally, we set $\alpha_k = 0.66$ because, as we will argue shortly, this choice makes the capital-output ratio that obtains in equilibrium approximately equal to its empirical counterpart in Mexico. Our series for interest rates is a series of three months rates on dollar-denominated Brady bonds, deflated by the US consumer price index. Chart 2 shows the behavior of these rates and the behavior of the relative price of energy in Mexico over the past 10 years. The two vertical bars, in this as in all charts in the paper, mark the beginning and the end of the 1994-1995 crisis.[2] Note that interest rates rose sharply in 1995, and that relative energy prices rose as well. As explained by Meza (2003), the Mexican government raised many of its mandated prices in the first quarter of 1995 to try and address its fiscal difficulties. Brady bonds interest rate data are only available as of the last quarter of 1992, and all our results pertain to the time period between that quarter and today.

4.1.2 True TFP vs. measured TFP

Chart 3 plots the measured and true TFP implied by the homogenous capital model. First notice that the two series are very similar in years other than 1995 and 1996. This result turns out to be robust in all our simulations: capital utilization accounts for but a negligible part of movements in TFP in non-crisis quarters. But in 1995, capital utilization reduces the drop in TFP by roughly a third. Potentially therefore, accounting for capital utilization markedly reduces the total factor productivity puzzle.

[2] By end of the crisis, we mean somewhat arbitrarily the third quarter of 1996, since in that period interest rates reverted to their average for the period we consider.

4.1.3 Predicted utilization rates and the evidence

The reliability of this measure of the importance of capital utilization depends on whether the homogenous capital model approximates reasonably well the behavior of capital utilization in the Mexican economy during the crisis. In turn, evaluating this requires computing competitive equilibria, a much more demanding computational exercise than the accounting calculations we have carried out so far. To compute equilibria, we must first calibrate several parameters that have played no role heretofore. The wage-elasticity of labor supply is set to $\nu = 1.5$ as suggested by US microeconomic evidence. The capital share $\alpha_k = 0.66$ yields an average capital-output ratio near its empirical counterpart, and we set ψ to match our measured average per capita labor input in the ex-energy business sector in Mexico.

To allow for computational tractability, we need to limit the number of possible histories of true total factor productivity, interest rates, and the price of energy. Indeed, describing the state of the economy in any given period requires storing investment and energy intensity choices over the previous 3 periods, and investment/energy intensity decisions on the part of intermediaries in the current period are contingent on the set of possible histories over the next four periods.[3] We assume that exogenous variables can follow one of 4 paths. The first history ("the data") is $w_t^D = (z_t^D, p_t^{e,D}, r_t^D)$ for all $t \in \{1992Q1, 2000Q4\}$ where $\{p_t^{e,D}, r_t^D\}$ are the actual values for relative energy prices and interest rates in Mexico between 1992Q1 and 2000Q4, while for all periods t z_t^D is the true TFP computed in section 4.1.2. To this observed path of exogenous variables, we add three counterfactual histories. The first counterfactual history ("no crisis") smoothes away the 1995 crisis as follows:

$$\omega_t^{NC} = \begin{cases} \omega_t^D & \text{if } t \notin \{1995Q1, \ldots, 1996Q2\} \\ \omega_{1994Q4}^D + \frac{t-1994Q4}{5}(\omega_{1996Q3}^D - \omega_{1994Q4}^D) & \text{otherwise.} \end{cases}$$

Here the notation $t - 1994Q4$ is short-hand for the number of periods elapsed since the last quarter of 1994, as of period t. The second counterfactual history ("short crisis") has the 1995 crisis end after two periods and all exogenous variables permanently return to their

[3] Assigning mass to only 4 possible paths of exogenous variables as we do in this paper suffices for convergence to require several hours of computing time.

pre-1994 averages $(\bar{z}, \bar{p^e}, \bar{r})$. That is,

$$\omega_t^{SC} = \begin{cases} \omega_t^D & \text{if } t < 1995Q3 \\ (\bar{z}, \bar{p^e}, \bar{r}) & \text{otherwise.} \end{cases}$$

The third counterfactual history ("no crisis") makes interest rates and TFP constant at their 1996Q2 values after the crisis ends:

$$\omega_t^{NDD} = \begin{cases} \omega_t^D & \text{if } t < 1996Q2 \\ \omega_{1996Q2}^D & \text{otherwise.} \end{cases}$$

To illustrate the construct, the four histories we consider for interest rates and true TFP are depicted in charts 4 and 5. Next we need to assign probabilities p^{NC}, p^{SC}, and p^{NDD} to the three counterfactual histories. We set those so that the behavior of GDP predicted by the model best approximates its data counterpart in mean-squared error terms. This leads us first to assign a high probability (99%) to the no-crisis outcome. Should agents expect the crisis to happen, the capital stock would drop like TFP in 1995, leading to a counterfactually high drop in GDP. Similarly, avoiding a counterfactually large output in 1996Q1 and Q2 requires that conditional on the crisis having started, agents expect it to end after two quarters with a high likelihood. We set $p^{SC} = (1 - p^{NC}) \times 0.85$. Finally, avoiding large swings in GDP in the quarters following the crisis requires putting a lot of mass on the no-double dip scenario. We set $p^{NDD} = (1 - p^{NC})(1 - p^{SC}) \times 0.90$.

Having set all parameters, we employ the following algorithm. We begin by guessing a sequence $K^U = \{K_{t-1}^U(1 - \delta u_{t-1}^\phi\}$ of undepreciated capital for every period and every possible history. Then we solve for the sequence $\{\eta_t, e_t\}$ of new machines and energy intensity choices, such that, given that R_t and w_t must be such that firms make zero profits and labor markets clear, the arbitrage condition hold. Then we update our guess for K^U by $K_{t,new}^U = K_{t-1}^U(1 - \delta u_{t-1}^\phi) + \eta_{t-1}$ where u_{t-1} and η_{t-1} are optimal investment and utilization policies given our initial guess for K^U. We iterate until the capital sequence becomes approximately invariant. By construction, we have then obtained an approximate competitive equilibrium.

The outcome is shown in chart 6. Not surprisingly given our open economy assumption, the path for capital predicted by our model is more volatile than in the data. Therefore, the path predicted for energy consumption is also more volatile than in the data. In particular, energy consumption falls much more than in the data in the first two quarters of 1995. But chart 7 shows that the energy to capital ratio predicted by the model closely tracks its empirical counterpart. Since energy intensity is low in the short-run, this means that the model is largely consistent with the behavior of capital utilization in Mexico during the 1995 crisis. The ratio predicted by the model is more volatile that in the data however, and we will now ask whether introducing capital heterogeneity reduces the distance between these two statistics. Before turning to that question, we also note that like the standard neoclassical model (see Meza, 2003) our model predicts that the aggregate labor input should have fallen much more than it did in Mexico in 1995.

4.2 Heterogenous capital

Introducing capital heterogeneity should reduce the predicted drop of energy consumption in the first quarter of 1995, and more generally the volatility of energy consumption, for at least two reasons. First, simple manipulations show that the function g is more concave (in the formal sense of Debreu, 1976) in $\underline{s}$ than its version in the homogenous case, $g^H(\underline{s}) = \left(\frac{1+\sigma-\underline{s}}{2\sigma}\right)$. This is illustrated in figure 1. This implies that changes in exogenous parameters will be associated with smaller changes in capital utilization. Second, because labor and energy are now complements, and more productive machines use more labor, changes in utilization will tend to be associated with less than proportional changes in energy consumption. For instance, in the first quarter of 1994, intermediaries know that four periods hence, TFP will fall (although of course they do not know the magnitude of the drop with certainty.) This leads them to anticipate a fall in utilization rates. Average machine productivity, therefore, will rise, as does as a result the optimal energy intensity of capital. This effect, of course, is absent from the homogenous model. But in such a model, we also expect capital utilization to account for a smaller part of TFP movements. This is because at the margin activating more machines, lowers average machine productivity, which was not the case in the homogenous case. Our results below confirm this intuition. But the key question we will ask is whether a model with heterogenous capital yields predictions for the energy to capital ratio that are superior to those of the homogenous model.

4.2.1 Calibration

We report results for $\sigma = .3$ since this value yields to the best approximation of the behavior of energy consumption in Mexico during the 1995 crisis. To maintain our 80% utilization target for 1994Q1, we find it necessary to lower ϕ from 1.46 to 1.10, and to adjust δ accordingly. Also, we need to raise α_k from 0.32 to 0.40 to continue matching Mexico's average capital-output ratio. Other parameters are left unchanged.

4.2.2 True TFP vs. measured TFP

Chart 9 confirms that in the heterogenous model capital utilization is less volatile than in the homogenous model. It also accounts for a smaller share of the TFP drop in 1995. That share goes from one third to a little over 15%. Once again, outside of 1995, capital utilization accounts for a negligible fraction of the variance in measured TFP.

4.2.3 Predicted utilization rates and the evidence

Chart 9 shows that the heterogenous model predicts (correctly) that no sharp drop should occur in aggregate energy consumption in the first quarter of 1995. More generally, it also reduces the overall volatility in energy consumption, although very little because the capital stock remains quite volatile. But improvements along those dimensions lead to predictions for the energy to capital ratio that are at odds with the data. That ratio no longer falls in 1995 (see chart **??**). The heterogenous model does not outperform the homogenous model in another important respect. It also predicts that labor should have fallen in proportion to TFP in 1995, which is at odds with the Mexican evidence.

5 Sensitivity analysis and extensions

5.1 Exogenous parameters

Our estimate of the ratio of true TFP to measured TFP in 1995 depends on our calibration choices for factor shares, the width of the support of the idiosyncratic shock and the shape of the depreciation function. In this section we evaluate the robustness of our quantitative claims to changes in those choices, one at a time, holding all other parameters constant. Lowering the labor share (α_n) reduces the curvature of g and, therefore, makes capital utilization more sensitive to changes in exogenous variables. But the upper panel of chart 10 shows that even large drops in α_n have a negligible impact on the distance between true and measured TFP. Changing the curvature (ϕ) of the depreciation function similarly affects the elasticity of utilization with respect to exogenous variables, but once again, the middle panel of chart 10 shows that the quantitative importance of this effect is small. In all cases the importance of capital utilization is small.

The bottom panel of chart 10 confirms that the width of the support of the idiosyncratic shock does matter quantitatively. This is not surprising. We have shown that introducing heterogeneity can cut the distance between measured and true TFP in half. On the other hand, as σ converges to 0, g^H converges to g, so that, by continuity, the distance must rise to the estimate one would obtain in a homogenous capital version of the model.

5.2 Rigid labor

We assumed throughout that a given machine's labor intensity can vary freely across periods. In practice, the implied labor movements may be costly.[4] To gauge the robustness of our main result to the assumption that labor is fully mobile, we study the impact of restricting labor use to be constant across plants, i.e., $n(s) = n$ for all s. This means that no labor movements can occur between machines after idiosyncratic shocks are realized. We think of this experiment as proxying for barriers to movements across industries. In that case, the

[4] Note in particular that even though a law of large number holds for s, machine productivity may be correlated within firms or subset of firms that one could think of as industries. Among other costs, movements of labor across firms sectors of activity entail search and re-training time.

optimal capital utilization problem becomes:

$$\begin{array}{lrcl} \max & z\frac{1}{2\sigma}Ke^{\alpha_e}n^{\alpha_n}\int_{\underline{s}}^{1+\sigma} sds & - & KR\left(\frac{1+\sigma-\underline{s}}{2\sigma}\right) \\ \text{subject to:} & \frac{1+\sigma-\underline{s}}{2\sigma}Kn & = & N \\ & \frac{1+\sigma-\underline{s}}{2\sigma}Ke & = & E \end{array}$$

Solving for n and e in the last two constraints and plugging gives the following problem:

$$\max z\hat{g}(\underline{s})K^{1-\alpha_e-\alpha_n}E^{\alpha_e}N^{\alpha_n} - KR(\frac{1+\sigma-\underline{s}}{2\sigma})$$

where

$$\hat{g}(\underline{s}) = (2\sigma)^{\alpha_e+\alpha_n-1}\left(\frac{1}{1+\sigma-\underline{s}}\right)^{\alpha_e+\alpha_n}\left((1+\sigma)^2-\underline{s}^2\right)$$

[incomplete ...]

5.3 Labor hoarding

All the models we have considered suggest that the aggregate labor input should have fallen more markedly in 1995 than the data suggests. This suggests to us that labor hoarding in the sense of (among others) Burnside and Einchenbaum (1996) may account for part of the drop in measured TFP. In the model of Burnside and Einchenbaum, effective labor demand and supply are aggregate hours times average effort. Average effort, naturally, is unobserved. Assume however that the path of effective labor is the labor-market clearing path that obtains in the homogenous model. Under that assumption average effort is simply the ratio of the labor use predicted by our model to labor hours. But since effective labor input is now different from the data, the path for true TFP is now different from the one we computed in section 4.1.2. Therefore one needs to solve the fixed point problem we shall now outline.

Let $\mathcal{N}$ be the set of possible sequence of effective quarterly labor input in Mexico between 1991Q4 and 2000Q3, and $\mathcal{Z}$ be the set of possible sequences for true TFP in Mexico for the same time period. Denote by $T^z : \mathcal{N} \longmapsto \mathcal{Z}$ the mapping described in section **??** that associates to every possible labor sequence $\{N_t\} \in \mathcal{N}$ the unique sequence $\{Z_t\} \in \mathcal{Z}$ for true TFP compatible with $\{N_t\}$.[5] Finally denote by $T^N : \mathcal{Z} \longmapsto \mathcal{N}$ the mapping that gives the sequence of labor inputs predicted by the homogenous model given any true TFP path.

Effective labor input sequences compatible with Mexican data are elements of $\mathcal{N}$ that are fixed points of $T^z \times T^N$. We were not able to argue analytically that there is only one such fixed point, but it should be obvious that $T^z \times T^N$ is continuous and bounded on $\mathcal{N}$ (equipped with the Euclidian norm), and that therefore the set of fixed points is not empty. We compute one such fixed point by iterating on $T^z \times T^N$ until the labor sequence becomes approximately invariant.

[incomplete . . .]

6 Conclusion

Capital utilization can accounts for as much as a third of the observed drop in measured total factor productivity in Mexico in 1995. We obtain this estimate in the context of a model whose predictions for the behavior of capital utilization are consistent with the empirical behavior of the energy to capital ratio during the Tequila crisis. This tells us that capital utilization played a role in the 1995 TFP shock, but the output puzzle remains large: why did output fall so much when productive inputs fell rather little? Our results suggest a promising route to obtain an answer that question. All the models we consider predict a drop in labor input in 1995 much larger than in the Mexican data. This is also a prediction of the standard neoclassical model: labor input should have fallen by about as much as TFP in 1995. This suggests to us that labor hoarding and other forms of labor measurement errors are at play. We view those numbers as strong indication that accounting for factor utilization during financial crises will greatly enhance our understanding of the real effects of financial crisis.

[5]Throughout, we fix the capital and energy sequences at their values in the data.

A Data appendix

A.1 Output

The major difference between national accounts variables and those in the model is the role of energy. To obtain an output measure consistent with our model one my first subtracting the output of the energy sector from total GDP:

$$\widehat{GDP} = GDP_{Total} - GDP_{energy}.$$

Next, in national accounts, GDP is a measure of value added, once all intermediate goods are taken into account. In the model, output is equal to the sum of the payments to capital, labor and energy. In order to make the national accounts data compatible with our model, we need to add the intermediate consumption of energy to $\widehat{GDP}$ to obtain:

$$\overline{GDP} = \widehat{GDP} + Intermediate\ consumption\ of\ energy$$

This is the empirical counterpart for Y we shall use.

A.2 Physical capital

On the product side of the national accounts, we must first subtract investment in the energy sector from total investment. We thus define investment as the sum of fixed capital formation and purchases of durable goods, excluding investment in the energy sector. Using the resulting investment series and the perpetual inventory method with 4 periods to build yield a measure of the capital stock K consistent with our model. In doing so, we assume that investment in a given year is divided equally among new machines in the following four years (as they would be in deterministic steady state). We set δ so that when $u = 80\%$, the yearly depreciation rate is 10%. Note that in our model the effective depreciation rate varies from period to period, since optimal utilization does.

A.3 Labor

The variable consistent with the neoclassical growth model is discretionary time allocated to work. We measure it as a fraction of total discretionary time available. This fraction is defined as the ratio of total hours worked in the economy to total working age population, relative to total discretionary time available. However, in Mexico there are no data available on hours worked for the whole economy. To measure the labor input I first calculate average hours worked in the manufacturing sector from the Manufacturing Sector Survey (MSS).[6] We implicitly assume, therefore, that average hours behave similarly in both the manufacturing sector and the rest of the economy. We then take the ratio of workers to population of 12 years of age and more from the Urban Employment Survey (UES).[7] We consider only workers who report strictly positive hours worked. To make the labor input consistent with

[6] See documentation available at INEGI website http://www.inegi.gob.mx/difusion/espanol/fbie.html.

[7] For documentation on the UES, see http://www.inegi.gob.mx/difusion/espanol/fbie.html.

the model we exclude from the aforementioned ratio the fraction of workers in the mining industry. There exists a total number of workers for the oil and electricity industries in Mexico, but not a total number of workers in the energy sector. We then multiply average hours by the ratio of workers to population. Finally, we divide this series by 1300, the total discretionary time available in a quarter, under the assumption that a working age person has 100 hours of discretionary time per week.

A.4 Energy

Annual energy consumption data for the business sector is taken from the Secretaría de Energía (SENER). It is total consumption less residential and public consumption. Price data comes from the Instituto Nacional de Estadística Geografía y Informática (INEGI). Electricity prices are average prices charged by the public sector to the industrial sector (Precios Promedio de Energía Eléctrica del Sector Eléctrico Paraestatal). Oil related product prices are the prices charged in Mexico (Precios Internos de los Principales Productos) as reported by INEGI. After converting the prices per unit for the different types of energy into a common unit (pesos/MJ), the consumption numbers were used to calculate a weighted price index, which was then converted into real terms using the GDP deflator. These calculations reveal that the relative price of energy is quite flat before and after 1995, but that it jumped up by 20% during that year.

Quarterly consumption data also come from INEGI. Consumption numbers for the non-energy sector for gas licuado (LPG), combustóleo (fuel oil), diesel, and gasolinas (gasoline) are based on internal sales (ventas internas) plus imports into Mexico. Since this approximates consumption by all sectors other than the energy producing sector, the residential and public sectors were removed using the weights from the annual consumption data from SENER. The Quarterly electricity data from INEGI includes only the industrial sector, so annual industrial electricity consumption as a percentage of total business sector consumption from SENER was used to account for the rest of the business sector. All of the series were converted into megajoules. The INEGI series was used to map SENER's annual data into each quarter of every year.

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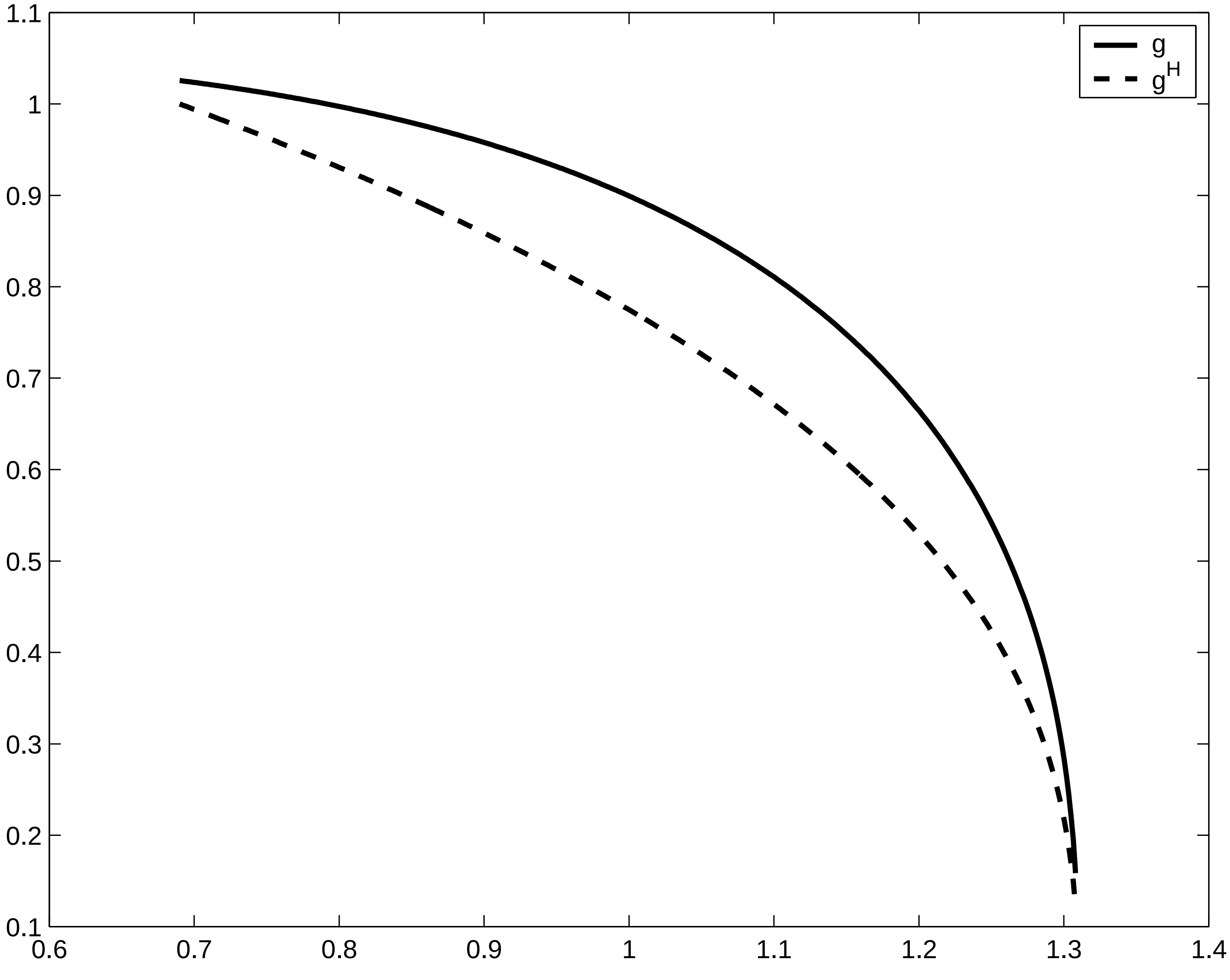
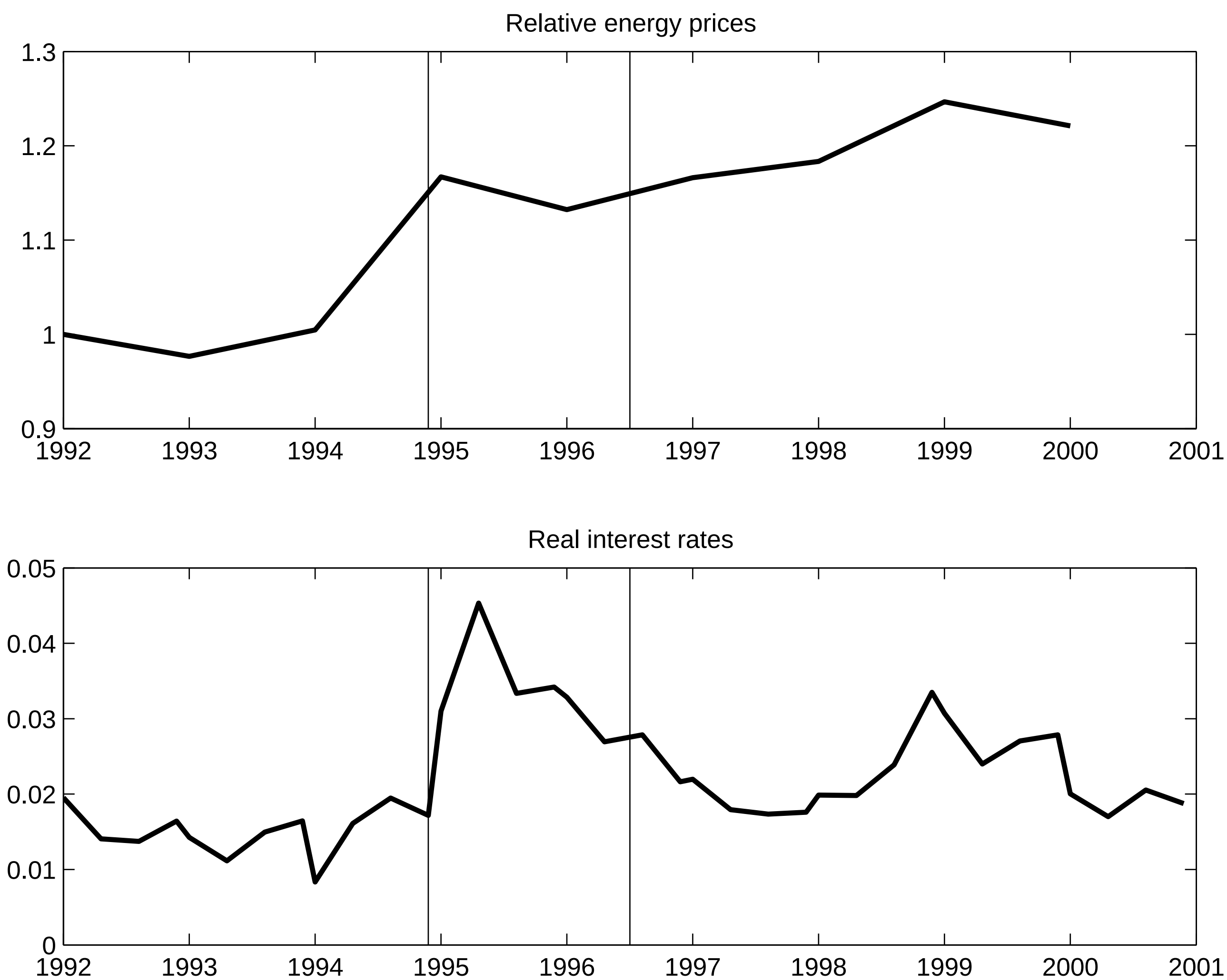
Figure 1: Utilization rates and Total factor Productivity



Notes: plots assume $\sigma = .3$, $\alpha_n = .66$, $\alpha_e = 1.5$.

Figure 2: Interest rates and energy prices



Notes: Relative energy prices are obtained by dividing nominal prices by Mexico's GDP deflator. Real interest rates are 3-month rates on Mexican Brady bonds. Because Brady bonds are dollar-denominated, the US CPI is used as deflator.

Figure 3: TFP accounting in homogenous capital model

Figure 4: Possible histories for interest rates

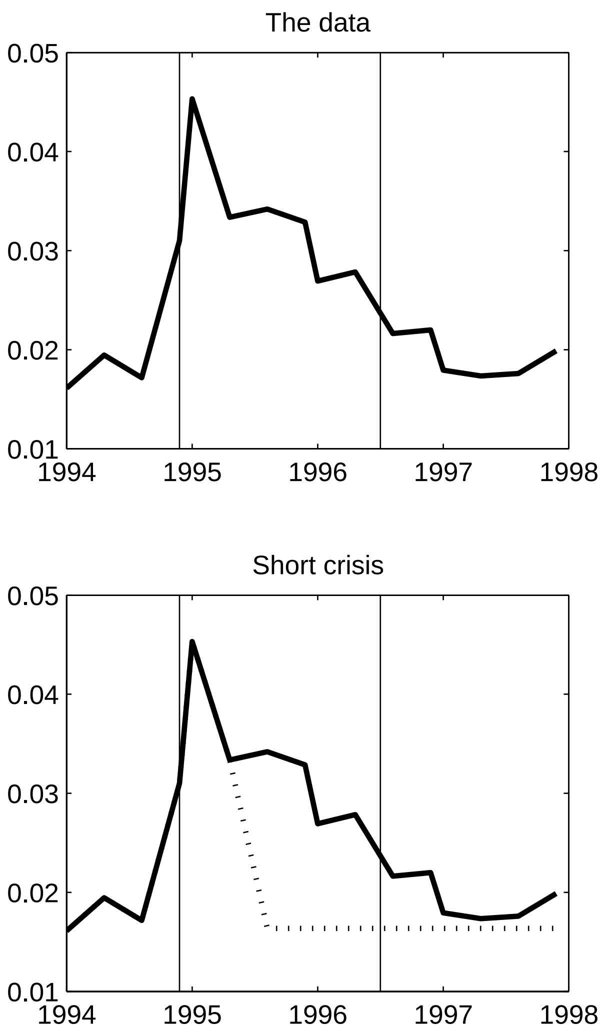


Figure 5: Possible histories for true TFP

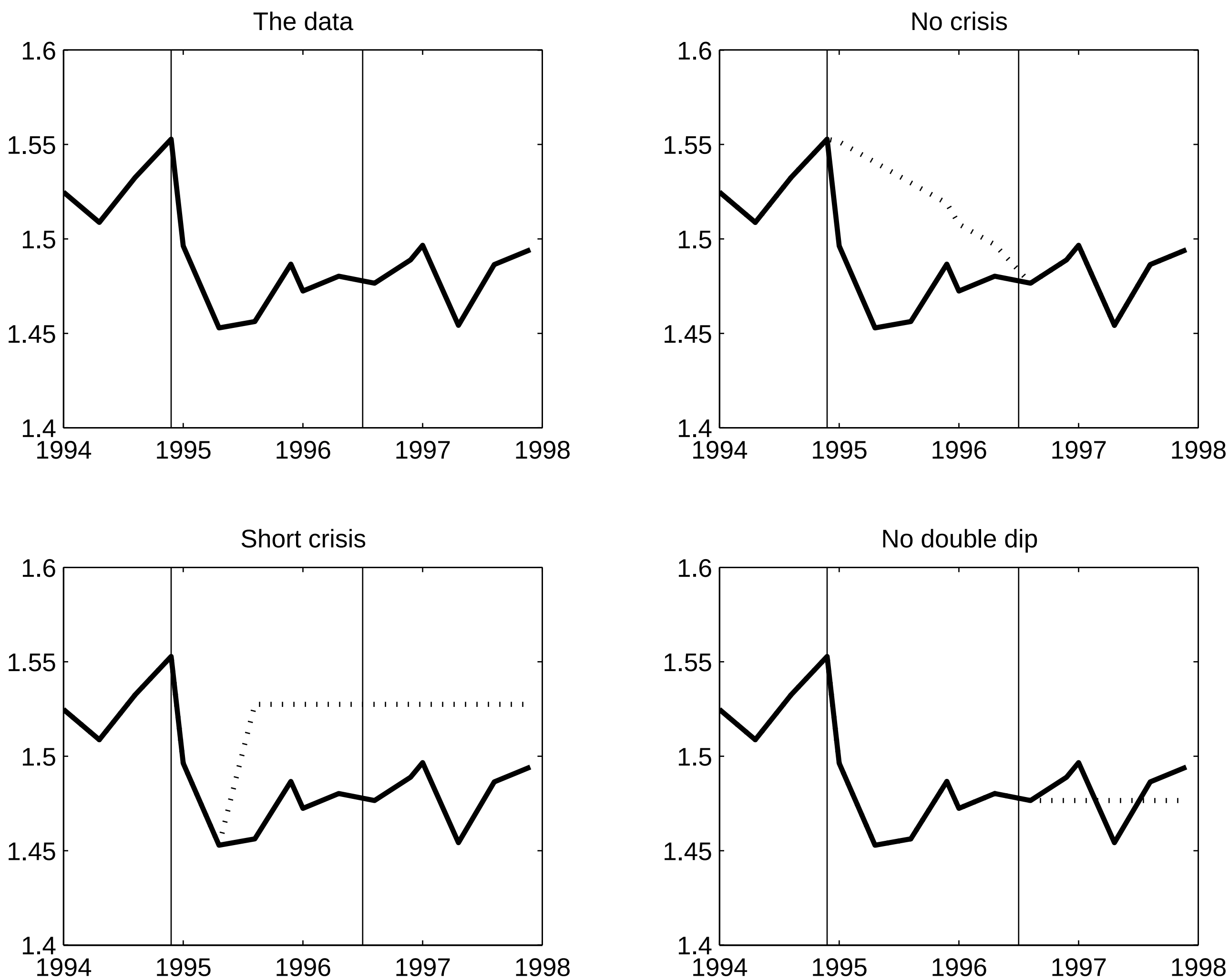


Figure 6: Predictions of homogenous capital model

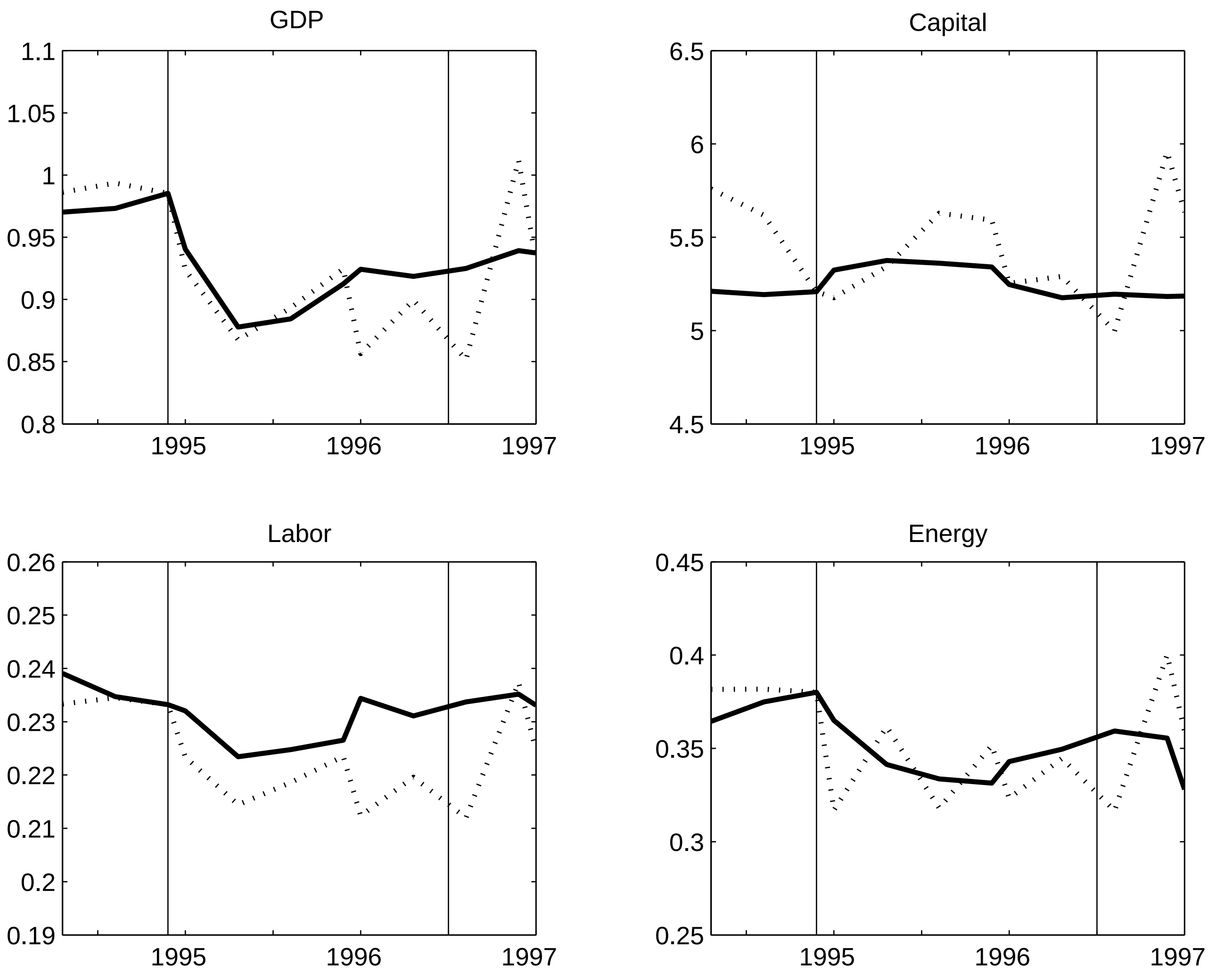


Figure 7: Energy-capital ratio predicted by the homogenous capital model

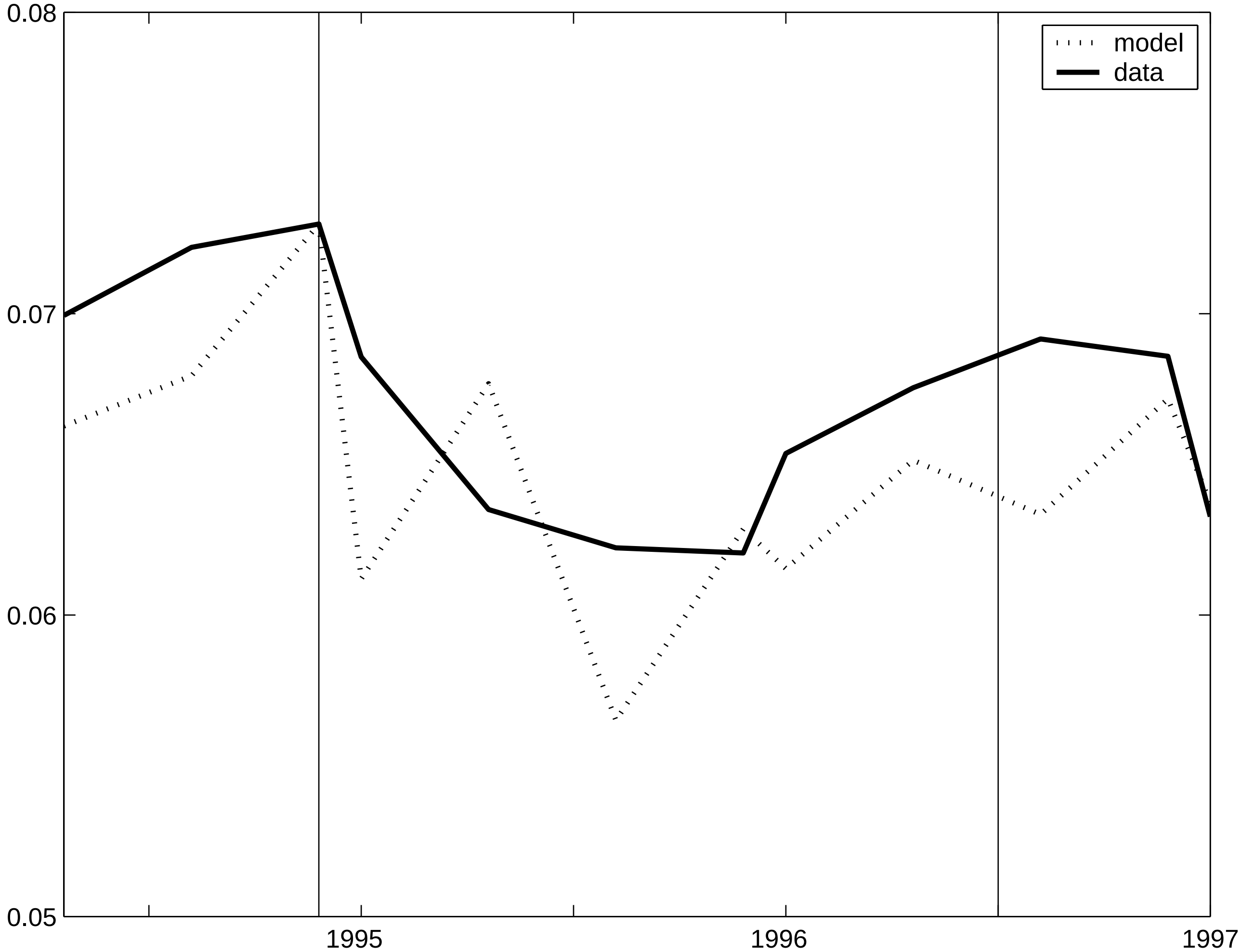


Figure 8: TFP accounting in heterogenous capital model

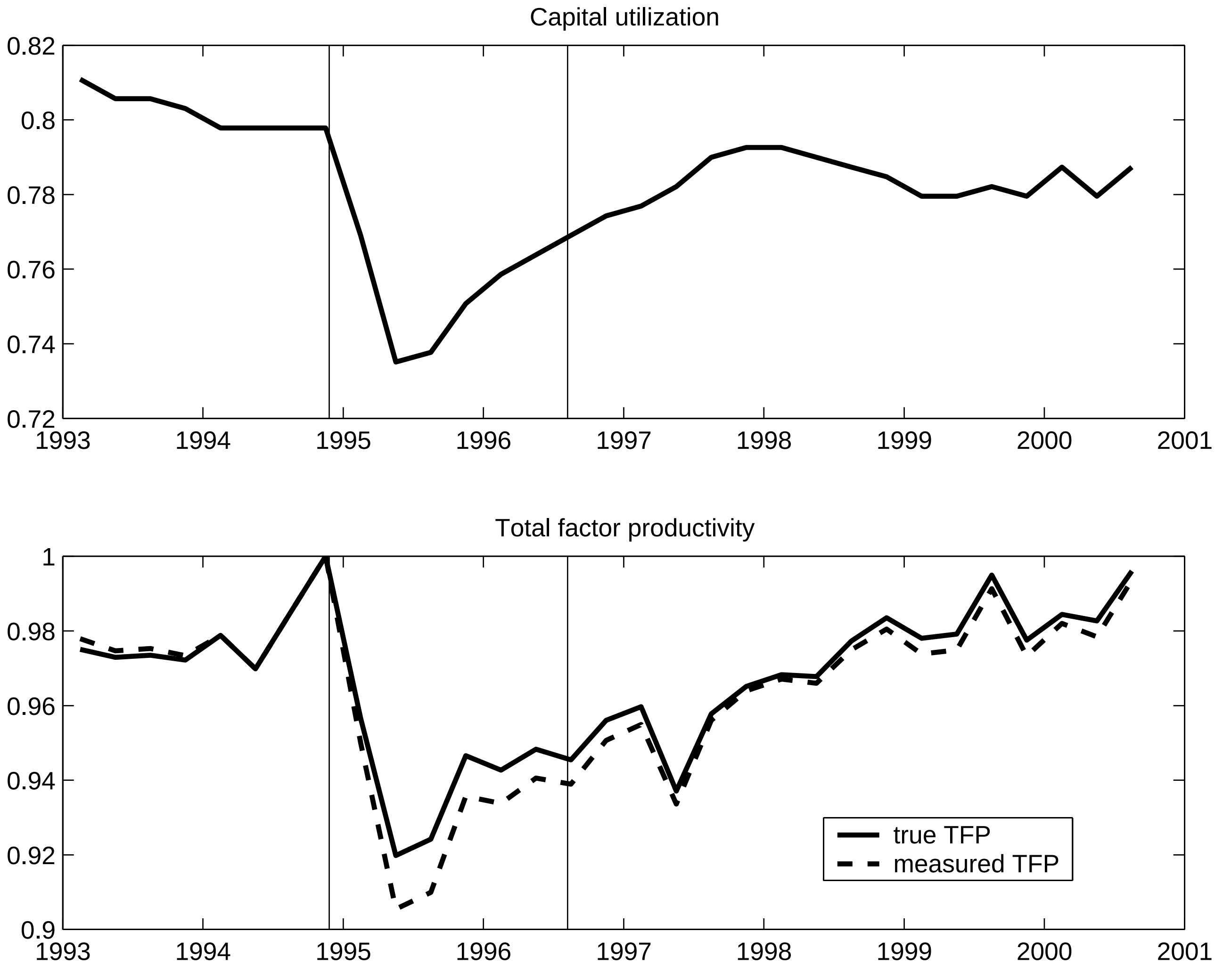


Figure 9: Predictions of heterogenous capital model

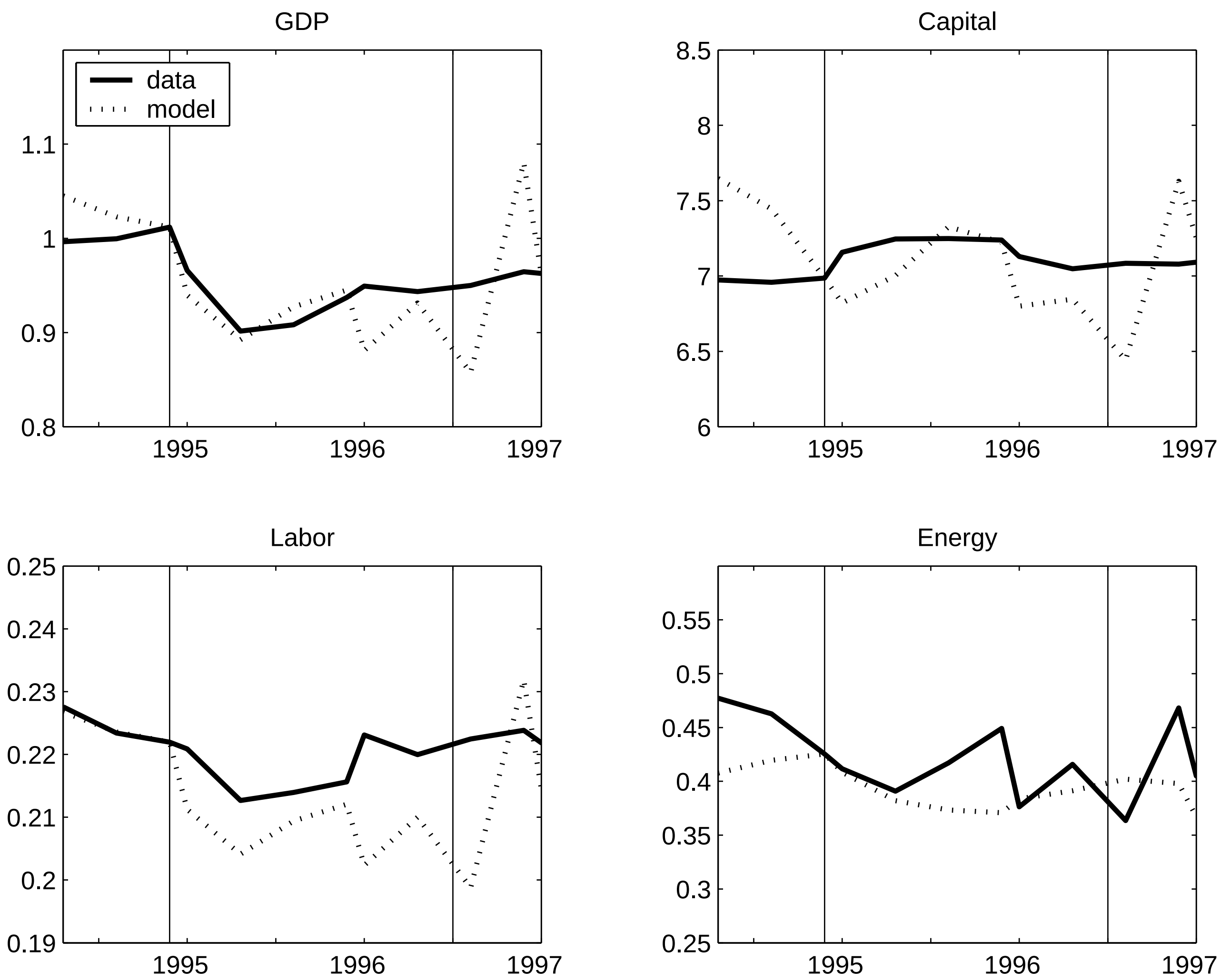


Figure 10: Energy-capital ratio predicted by the heterogenous capital model

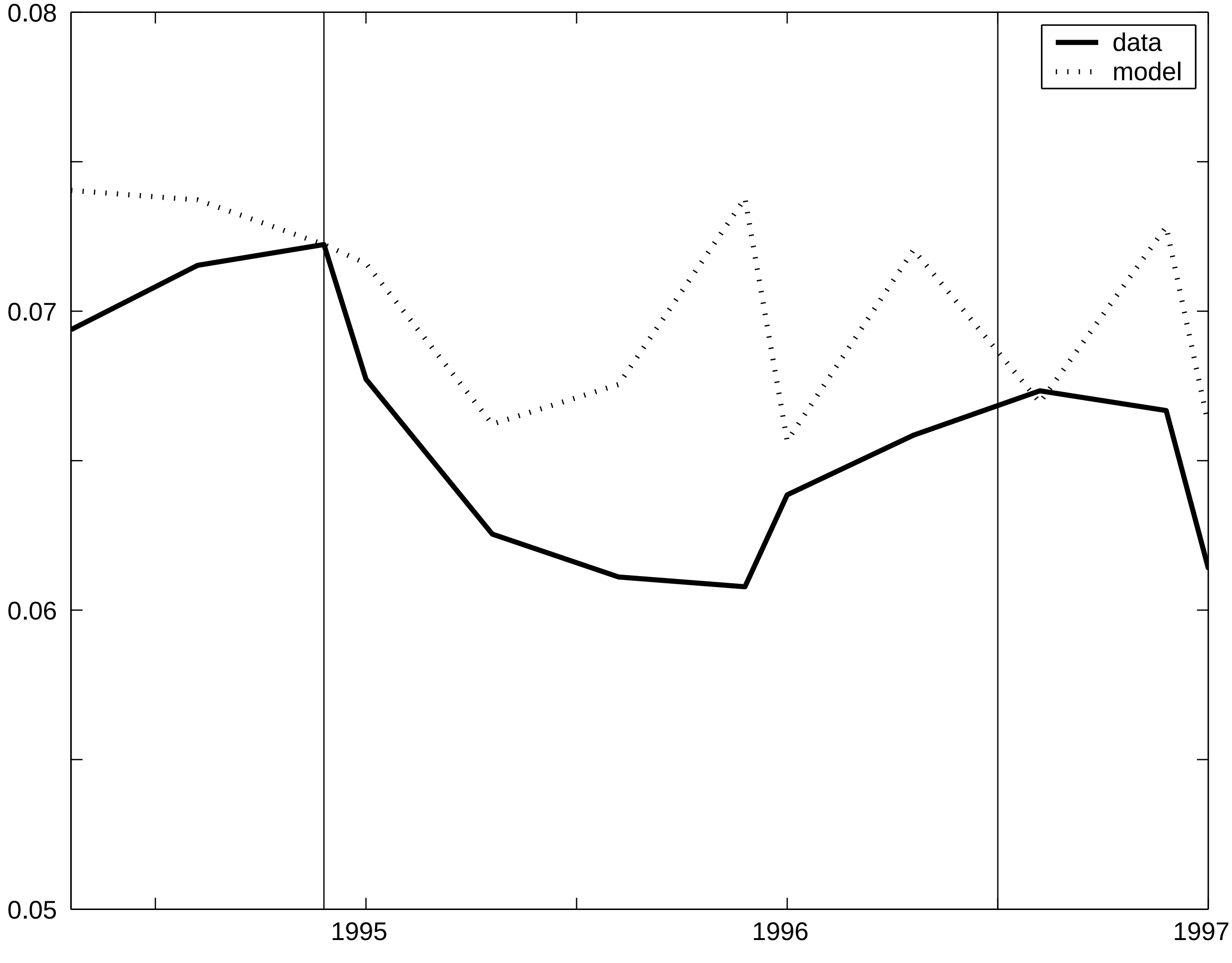


Figure 11: Sensitivity analysis