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ESSAYS IN QUANTITATIVE MACROECONOMICS

By

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ABSTRACT

ESSAYS IN QUANTITATIVE MACROECONOMICS

By

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This dissertation contains three essays in quantitative macroeconomics.

The first chapter, "Precautionary savings in general equilibrium", uses a calibrated stochastic OLG model to address three questions about US savings and wealth accumulation: first, does an equilibrium display buffer stock savings by agents? Second, is this equilibrium consistent with savings behavior of US households? And finally, what level of precautionary savings arises when general equilibrium effects are accounted for? I find that given observed earnings risk, the rates of time preference that are consistent with the equilibrium are very close to the interest rate, so no buffer stock behavior is observed. Moreover, the equilibrium reproduces important facts about savings behavior of US households. Finally, accounting for general equilibrium effects lowers the size of precautionary wealth to about 35% of aggregate wealth, or 30 to 50% less than partial equilibrium estimates.

The second chapter, "Green taxes and double dividends in a dynamic economy", asks whether a tax recycling experiment would deliver a double dividend in the US economy. According to the double dividend hypothesis, environmental taxes may raise revenue that can be used to lower other (pre-existing) tax distortions apart from decreasing pollution externalities. This hypothesis is evaluated using a dynamic general equilibrium model of capital accumulation. I find that, although in the long run pollution may worsen, the green dividend -higher discounted utility from a cleaner environment- would be obtained under all tax changes, due to a better environment during most of the transition. The efficiency dividend however -higher discounted utility from consumption of traded goods- will obtain only for target levels of the green tax below a critical number.

In the third chapter, "Training and business cycles", I examine the behavior of skill

acquisition through training at business cycles frequencies. First, a time series of training is constructed using individual data from the NLSY79 database. After documenting the cyclical properties of the series, I discuss what features are needed for a RBC model to successfully reproduce them. I find that training is weakly countercyclical, leads the cycle, and has a standard deviation of about ten times output. A model where employment, but not weekly hours, is costly to adjust, is able to account for most of the documented regularities.

To Carolina, my wife,

and Sebastian, my brother.

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Chapter 1

Precautionary saving in general equilibrium

1.1 Introduction

It is now understood that precautionary motives for accumulating wealth play a key role in the consumption/savings decisions of households. At least since the work of Skinner [1988], Hubbard and Judd [1987], and Summers and Carroll [1987], precautionary savings behavior has been extensively studied, primarily as a candidate solution to problems in the consumption literature, such as the excess sensitivity puzzle (Zeldes [1989], Caballero [1991]), and the failure of standard finite horizon models to explain the observed pattern of consumption growth over the life cycle (Skinner [1988]). Alternatively, precautionary motives have been advanced to link the decline in the personal savings rate over the last 20 years to the extension of social insurance programs such as Medicare and Social Security (Summers and Carroll [1987]).

This paper is concerned with a research agenda fostered by Skinner [1988], Carroll and Samwick [1998, 1997], Hubbard et al. [1994] (HSZ), Huggett [1996] and others. The objective is to study whether a model with realistic lifespans, income paths, and risk exposure can account for the savings/consumption behavior of US households. In this line of work, Hubbard et al. [1994] showed that in a calibrated model where the interest rate is close to the rate of time preference, agents would desire to accumulate levels of wealth similar to those found in the data. Moreover, evidence was reported that other model statistics such as the age-consumption profile, and the response of consumption to innovations in income could also reproduce their data counterparts. In a companion paper (Hubbard et al. [1995]) these authors focus on the importance of asset tested programs to explain the low accumulation of assets by the lowest quintile of the wealth distribution.

The calibration of these models was criticized by Carroll and Samwick (Carroll and Samwick [1998, 1997]), on the grounds that it produces a level of sensitivity to changes in income risk so high that it was impossible to reconcile with their empirical findings. Instead, they propose a calibration where agents have very high levels of impatience, so that the rate of time preference is well above of the interest rate. In such model, agents find it optimal to achieve a target level of wealth over (expected) income, which they keep until late in their life cycle. Carroll and Samwick report that this model displays a sensitivity to changes in income risk more in line with their empirical results.

One common finding of this literature is that wealth that is held for precautionary motives accounts for at least 50% of total wealth. However, these estimates are partial equilibrium in nature, as prices do not respond to changes in aggregate wealth [1]. As shown by Hubbard and Judd [1987] in a model with longevity risk only, and by Aiyagari [1994] in the context of an infinite horizon model, general equilibrium effects can be sizable and tend to increase wealth holding, therefore reducing the estimated share of wealth that is precautionary.

This paper contributes to the literature by taking an alternative path: imposing the discipline of general equilibrium, we compute the levels of discount rates consistent with observed levels of interest rates, savings rates, and income/longevity risk. We show that the resulting equilibrium produces interest and discount rates that are very close to each other, so that agents are not buffer stock savers. Moreover, the age specific saving behavior that emerges is consistent with average asset accumulation by US households,

[1] An exception is Huggett [1996] who carries a general equilibrium analysis and reports a lower estimate. However, his focus is on wealth distribution, so there is no discussion of this result.

and displays levels of sensitivity to income risk in line with those reported by Carroll and Samwick. Finally, we compute the level of precautionary savings that arise in this model, and show that properly accounting for general equilibrium effects considerably lowers previous estimates.

This chapter has four other sections. In section 1.2 the model is presented. Section 1.3 discusses the calibration procedure. Section 1.4 presents the results, and Section 1.5 concludes.

1.2 The model

We present a large scale OLG model in the tradition of İmrohoroğlu et al. [1995], Huggett [1996] and Rios-Rull [1996]. In this model, a large number of agents of size 1 live for a maximum of T periods, are endowed with a level of assets a_1 at the beginning of their life ($t = 1$) and face uncertainty regarding labor earnings and lifespan. Each period, agents take the interest rate and the realization for labor income as given and must allocate their earnings between consumption and saving, subject to a borrowing constraint.

Agents take prices as given and maximize a utility function of the form:

$$\max_{c_t, a_{t+1}} E_1 \sum_{t=1}^{T} [\prod_{j=1}^{t} \eta_j] \beta^t u(c_t)$$

$$\begin{aligned} s.t. \quad a_{t+1} + c_t &= (1+r)a_t + w\phi_t l_t + q \\ a_{t+1} &\geq 0, \end{aligned}$$

where l_t, is a random variable with bounded support that represents a shock to labor endowment, and ϕ_t is a nonstochastic variable that indexes labor productivity for an agent of age t. Therefore, $w\phi_t$, is the unconditional mean of labor earnings at age t, that can be thought of as the life cycle component of earnings, and l_t, is labor endowment of an agent at age t.

An agent of age t survives to $t+1$ with probability η_t. With probability $1-\eta_t$, he dies and leaves bequests that are evenly distributed among all living agents, each agent receives q in bequests every period. Survival probabilities $\{\eta_t\}_{t=1}^{T}$, in turn define the cohort shares $\{\mu_t\}_{t=1}^{T}$ by $\mu_t = (1-\eta_t)\mu_{t-1}$ and $\sum_{t=1}^{T}\mu_t = 1$.

The household problem can be expressed in recursive form. Let $V_t(a,l)$ be the maximum value of the objective function for an agent of age t with a level of asset holdings and labor endowment shock $\{a,l\}$. Then, $V_t(a,l)$ is given by:

$$\begin{aligned} V_t(a,l) &= \max_{a',c}\{u(c) + \beta\eta_t E[V_{t+1}(a',l'|l)]\} \\ s.t. \quad a' + c &= (1+r)a + w\phi_t l + q \\ a' &\geq 0 \qquad (P1), \end{aligned}$$

where a' is asset holdings for next period. Moreover, since an agent lives at most for T periods, we have:

$$\begin{aligned} V_T(a,l) &= \max_{C}\{u(c)\} \\ s.t. \quad c &= (1+r)a + w\phi_t l + q \end{aligned}$$

The solution to this problem are the optimal policy functions $C_t(a,l)$ and $A_t(a,l)$, for $t = 1,...,T$, that map the state $\{a,l\}$ at age t to consumption at age t and assets at the beginning of age $t+1$ respectively.

The representative firm chooses $\{L,K\}$ to solve:

$$\max_{K,L} F(K,L) - RK - wL \qquad (P2).$$

To complete the description of the economy, we define the capital accumulation technology in a standard way: $K_{t+1} = (1-\delta)K_t + I_t$, where I is aggregate investment and δ is the depreciation rate.

We are interested in a steady state equilibrium where the aggregate capital stock is constant, and although there is a large amount of dynamics at the individual level, the distribution of assets and other endogenous variables is time invariant. Since a meaningful equilibrium concept needs to be expressed in terms of these distributions, we proceed to define them.

Let $(X, \mathcal{B}, \Psi_t)$ be a probability space. If Z is the support for the stochastic shock l_t and asset holdings are restricted to lie in $[0, \infty)$, then an individual state $x = \{a, l\}$ lies in the state space $X = Z \times [0, \infty)$. Let B be the Borel sets in X. Then, for each t from 1 to T a distribution Ψ_t can be defined such that, for each $B \in \mathcal{B}, \Psi_t(B)$ is the probability that an agent of age t will be in a state $x \in B$. Together with the stochastic process for l, the optimal policy function $A_t(a, l)$ defines a transition function $P(B, t) = Prob(x_{t+1} \in B | x_t)$ that links current and future distributions. The function Ψ_t is then derived recursively by:

$$\Psi_t(B) = \int_X P(B, t-1) d\Psi_{t-1} \quad B \in \mathcal{B}.$$

Equilibrium Definition: A steady state equilibrium for this economy is a collection of value functions $V_t(.)$, policy functions $C_t(.)$ and $A_t(.)$, $t = 1, ..., T$; prices for labor and capital services $\{w, r\}$; aggregate values for $\{K, L\}$; a level of per capita bequests q; and distributions $\{\Psi_t, P_t\}$ for $t = 1, , T$ such that,

1. Households maximize utility: given q and prices $\{w, r\}$, the policy functions $C_t(.)$ and $A_t(.)$ solve $(P1)$ for all t.

2. Firms maximize profits:

   $F_K = R = r + \delta$

   $F_L = w.$

3. Markets clear:

   (i) $\sum_t \mu_t \int (C_t + A_t) d\Psi_t + q = (1 - \delta)K + F(K, L)$

   (ii) $\sum_t \mu_t \phi_t = L = 1$

(iii) $\sum_t \mu_t \int A_t d\Psi_t = K$

4. Cross section distributions are consistent with policy functions:

   $\Psi_{t+1} = \int P_t d\Psi_t$

5. All bequests are distributed:

   $q = \sum_t (1 - \eta_t) \int A_t d\Psi_t$

Aiyagari [1994] presents a characterization of this problem in the context of an infinite horizon model: agents will overaccumulate assets, with respect to a complete markets situation, as a way to partially insure themselves against the possibility of being effectively borrowing constrained in the future.

The pattern of wealth accumulation is studied by Carroll [1999] in a life cycle model, and Deaton [1991] in an infinite horizon economy. An important result is that, when the growth rate of income is sufficiently high for given levels of risk $\{\rho, \sigma_\epsilon^2\}$, prudence $\{\frac{\theta u_c'''}{u_c''}\}$, and patience $\{\beta\}$, agents optimally choose to achieve a target level of wealth over earnings, or "buffer stock" of assets [2].

Checking whether this condition is empirically plausible is difficult given the unobservable nature of the discount rate $\gamma = \frac{1-\beta}{\beta}$. The next section presents a calibration procedure where β is determined using the general equilibrium nature of the model.

1.3 Calibration.

The calibration exercise is designed so that the stochastic model economy displays relevant features of the US economy. In particular, the discount factor β is left as a free parameter that takes on the value needed for the model economy to display target levels of the interest rate and the savings rate.

[2]The condition in discrete time can be approximated by:

$$\frac{r-\gamma}{\theta} + \frac{(\theta+1)\sigma_\epsilon^2}{2} < g,$$

where g is the growth rate of income, γ is the rate of time preference, and θ is the coefficient of relative risk aversion.

To calibrate the model we need to define functional forms and parameters. The functional forms used are as follows:

- A Cobb-Douglas production function is used for all exercises:

$$F(K, L) = AK^{\alpha}L^{1-\alpha}$$

- Felicity functions are of the CRRA form:

$$u(c) = \frac{c^{1-\theta} - 1}{1 - \theta}$$

- The stochastic process for the labor endowment is $AR(1)$:

$$\ln(l_t) = \rho \ln(l_{t-1}) + \epsilon_t \qquad \epsilon_t \sim N(0, \sigma_{\epsilon}^2),\ i.i.d.$$

The parameter values are shown in table 1.1. For the earnings process we adopt the results for households with 12-15 years of education reported by Hubbard et al. [1994](table A.4) using PSID data. Figure 1.1 shows the unconditional means. The stochastic process associated implies values of .946 for ρ , and .025 for σ_{ϵ}^2. These values are roughly consistent with findings by MaCurdy [1982], as explained below, but imply a variance in the change of earnings lower than the values in Abowd and Card [1989], who use the same dataset.

The baseline economy is also calibrated so as to display the following ratios: an interest rate of 4% per annum, in line with the calculations reported by Kotlikoff and Summers [1981], and a savings rate of 19%, chosen to match the rate of investment over GDP of the US economy in the period 1980-1989. These ratios imply a depreciation rate of .045 per year.

A comment of the calibration choices is in order. Evidence from longitudinal studies of earnings and labor supply suggest that the process for (log) earnings can best be modelled as a near unit root process with autoregressive errors of order 2 (MaCurdy

[1982]. This leads Carroll and Samwick [1997] to calibrate their model using a unit root process with a variance of innovations equal to 0.01.

As suggested by Skinner [1988], we can summarize the risk to lifetime resources implied by a AR(l) stochastic process with the following statistic:

$$\pi_t = \sigma_\epsilon^2 [\sum_{j=1}^{T-t} \frac{\phi_{t+j-1}\rho^j}{(1+r)^j}]^2,$$

where ϕ_t indexes labor earnings at each age. We compute this statistic (the average over all ages) for our baseline parameters, and compare it with those for Carroll and Samwick and MaCurdy, properly accounting for the $ARMA$ specification. We find that the $AR(l)$ process chosen here implies a similar level of risk to lifetime resources (2.54) than the $ARMA(1,2)$ proposed by MaCurdy (2.81) and the specification used by Carroll and Samwick (3.13). Moreover, increasing the variance of innovations from our baseline of .025 to .031 would be enough to produce a value of 3.13 for this statistic.

With respect to the interest and savings rates, since the empirical equivalent of the model interest rate is a risk-free rate, we are tempted to use a number in the order of 1/2% per annum, consistent with the return on Treasury Bonds. On the other hand this rate is also the marginal product of capital, so the historical return on stocks, of the order of 7% annually but more volatile, may also be appropriate. We therefore experiment with different values of r.

The problem of interpreting the savings rate lies in the fact that households are not the only source of savings in the US economy. In fact, from 1980 to 1989 the personal savings rate averaged 6.7% of GDP[3], businesses contributed with 12.6 percentage points to the average savings rate, and the government dissaved .8% of GDP. Of these aggregates, businesses and government reported as capital consumption allowances 10.2 and 2.3% of GDP respectively. Aggregate gross saving was then in average 18.8% of GDP in this period, close to our benchmark, but the net saving rate was only 5.9% (ERP

[3]This is the contribution of private saving to aggregate saving, and is different from the Personal Saving Rate in the National Income and Product Accounts, which is calculated as saving as a percentage of disposable (after tax) income, and does not take into account changes in asset prices

[1999]).

A related issue is that, since we focus on a steady state equilibrium, savings net of capital consumption (depreciation) allowances is zero in the model. Since introducing growth considerations is beyond the scope of this paper, we check the robustness of our results to the choice of savings rate by doing some sensitivity analysis with values of S/Y from 15% to 24%.

Finally, note that Table1.1 show the levels of K/Y implied by each choice of $\{r, S/Y\}$. These levels are roughly consistent with the ratios of Assets/Income reported by Hubbard et al. [1994], but are in general higher than the capital-output ratios calculated for the US economy. Note that once the interest rate and savings rates are fixed, the depreciation rate and the capital output ratio are defined by the conditions $s = \delta K/Y$ and $r = F_K - \delta$. Table 1.7, with the capital output ratios that result from selected $\{r, S/Y\}$ pairs, show that a lower K/Y is associated with higher levels of saving rates and interest rates. While decreasing K/Y to 3 increases the estimated share of wealth that is precautionary (see table 1.3), it remains that this variation is small compared to the differences in precautionary wealth associated with different risk aversion coefficients.

1.4 Results

In this section, we begin by showing how the calibrated model reproduces important facts about wealth accumulation by US households. We then examine the implications of these results for the debate on whether US households are buffer stock savers or not. Finally, we compute the levels of precautionary wealth that emerge in this model and decompose it in partial and general equilibrium effects.

We evaluate the ability of the model to mimic US data along three dimensions: the age/wealth profile, the age-specific average propensities to save, and the sensitivity of wealth holdings with respect to income risk.

The paper focuses on age-specific aggregate statistics, rather than distributions, because we believe that most of the intra cohort heterogeneity cannot be explained by different histories of shocks that are mean-reverting. It is known that this model compresses the income distribution, generating too few very rich (see e.g. Carroll [2000]) and too few very poor agents. Realistic models of wealth distribution imply types of heterogeneity in agents that are absent here: in investment opportunities (for instance Quadrini [2000]), in time discounting (e.g. Krusell and Smith [1998]), or in productivity (e.g. Hubbard et al. [1994]. Considering these types of heterogeneity is beyond the scope of this work.

Figure 1.2 shows the predicted average profile of wealth holdings at each age (in thousands of 1984 dollars), compared to data reported by Radner [1989] using the 1984 Survey of Income and Program Participation (SIPP) database. The model generated data is normalized so that average income equals 1984 per capita GDP at current prices.

The fit is extremely good given that the model was calibrated to savings and interest rates of the period only. The feature that deserves attention is the similarity of the shapes of the two curves, more than the fact that they overlap. In fact, since SIPP data comprises only private wealth, while the model's data is on aggregate wealth, and their measurement units (households in SIPP versus 'workers' in model) differ, there is little reason why they should overlap. The similarities however suggest that, on average, the model contains the right elements that shape life cycle savings behavior.

Figures1.3 and 1.4 present the age-wealth profiles for alternative parameterizations of the model, compared to Radner's data. Clearly, very high levels of aggregate wealth can be attained by this model with the appropriate discount rate.

We now turn to examine two direct measures of age-specific saving behavior. Figure 1.5 compares the life cycle profiles of average propensities to save (APS) generated by the model with their data counterparts, constructed by Gokhale et al. [1996] using the Consumer Expenditure Survey (CEX) for various years. The two series correspond to different definitions of disposable income. Conventional disposable income is the sum of labor income, capital income, and pension income minus net taxes, while in the alternative definition social security contributions are classified as loans (so that they are considered savings), and social security benefits are classified as the repayment of principal (not part of disposable income) plus interest on past social security loans.

It is important to note that, once again, it is the shape of the APS curve and not the level that matters the most. Data on household savings is data on net savings, since businesses make most of the allowances for consumption of capital. In a growing economy this measure of savings should be positive in the aggregate. In our model, since we are focusing on a Steady State equilibrium, net savings are zero.

The model prediction follows more closely the APS observed under the alternative definition, but it tends to overpredict savings rates at the beginning (until around age 32) of the life cycle. Overall, it displays the characteristic hump shape present in the data, with a 'plateau' from ages 35 to 60, and a drastic decrease after age 60.

Figure 1.6 allows an examination of the sensitivity of wealth holdings with respect to uncertainty, measured in this case by the conditional variance of earnings σ_ϵ^2 . The wealth/income profile for the baseline model is shown along with the average age-wealth profile of an agent facing the same prices as in the baseline model but with half of the variance (1.2% versus 2.4%). The results for two alternative parameterizations are shown in figures 1.7 and 1.8.

These simulated changes in the levels of wealth holdings are consistent with those predicted by the regression coefficients in Carroll and Samwick [1997]. Using differences in occupation specific income risk, Carroll and Samwick regress various measures of log net worth on the variance of permanent and transitory income shocks, permanent income, and life-cycle variables (age, married, etc). Using the approximation $[log(Wl)log(W2)]/[var1 - var2]$ suggested by the authors, where $W1$,$W2$, and $var1$, $var2$ are wealth holdings and income variances for the baseline and alternative paths respectively, we can approximate what the regression coefficients would be in the models. The results, presented in Table 1.2, indicate that reasonable parameterizations of the model can reproduce these coefficients without difficulty.

These levels of risk sensitivity are similar to those reported by Carroll and Samwick [1997], even though the levels of discount rates and other parameters are very close to those of Hubbard et al. [1994]. In fact, figures 1.6, 1.7, and 1.8 show that the ratio of wealth/income chosen by agents, increases from the beginning of the life cycle, instead of remaining constant for the first part of it -after a target level is reached- as would be the case in a buffer stock model.

Using the discount factors consistent with Steady State equilibria in the stochastic economies, we can predict how large would aggregate wealth be in a similar economy with no income uncertainty, and no income or lifespan uncertainty. We do so by using a certainty version of the program, described in the appendix.

The results are shown in Table 1.3. It is worth noting that the levels of precautionary wealth are significantly lower than those found in similar models. Table 1.4 shows that the difference can be entirely explained by not accounting for general equilibrium effects. In what follows, we examine this issue more closely.

Two exercises are carried out. First, we calibrate our model to interest rates, discount rates, and stochastic paths similar to those in Skinner [1988] and Hubbard et al. [1994]. Rather than attempting a detailed replication, we want to find if given these rough similarities, our model generates similar levels of precautionary wealth. Table 1.5 shows the results for two different levels of aggregate earnings, and confirms that in partial equilibrium this type of model generates high levels of precautionary wealth.

Next, we compare the levels of precautionary wealth generated by these models in general vs. partial equilibrium (Table 1.6). Given the parameters for the stochastic process and the interest rate chosen in the original papers, we find the discount factor consistent with a predetermined savings rate (S/Y=.19 for Skinner and .24 for Hubbard et al.). Next, we find the level of aggregate wealth in a deterministic economy where agents face the same factor prices (columns labelled P.E.), and finally we allow prices to change and compute the general equilibrium effects (columns labelled G.E.).

It is clear that the partial vs. general equilibrium nature of the exercise matters, as was already noted in Hubbard and Judd [1987] and Aiyagari [1994]. In our examples, a partial equilibrium estimation of the size of precautionary wealth overstates it by 20 to 50%, consistent with the differences between the findings in this paper and those reported by Skinner [1988] and Hubbard et al. [1994].

1.5 Conclusions

An important problem in the study of life cycle savings behavior is whether it can be characterized by a model of buffer stock versus 'life cycle' savings. This paper examines the issue using the discipline of general equilibrium to sort among alternative models.

We find that a model calibrated to the levels of aggregate savings, interest rates, and risk exposure found in the data displays life cycle patterns of asset accumulation and overall sensitivity to risk in line with empirical evidence. This model does not predict buffer stock behavior. Rather, agents find it optimal to increase their wealth/income ratios until shortly before retirement.

At the same time, the equilibrium allocation implied a level of precautionary wealth around 35% of total wealth, far below comparable estimates in the literature. The differences can clearly be traced to the partial/general equilibrium nature of the exercises.

Figure 1.1: Income profile (Hubbard et al. [1994], 12-15 years of education)

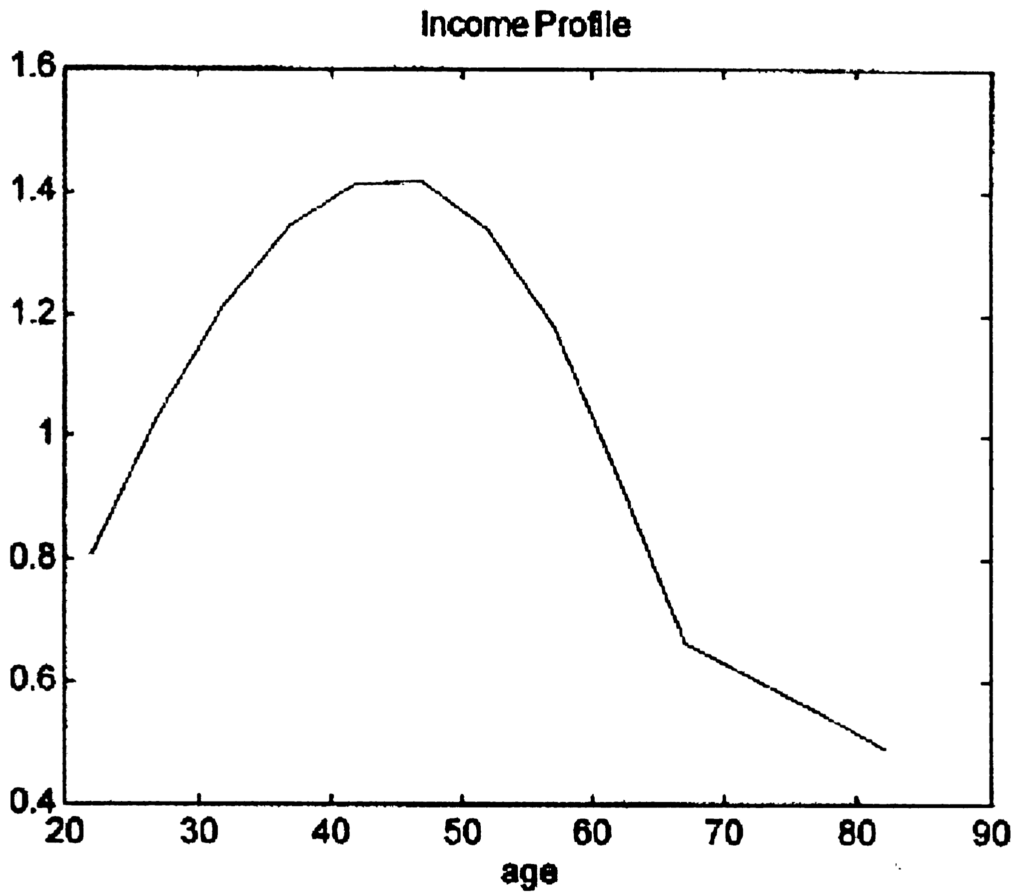


Table 1.1: Calibration

Model	Calibration Choices			Implied Parameters			Stochastic Process	
	S/Y	Interest R.	θ	β	δ	K/Y	ρ	σ_ϵ^2
Baseline	0.19	0.04	3	0.9815	0.0447	4.25	0.946	2.5%
Model 2	0.15	0.04	3	0.9983	0.0286	5.25	0.946	2.5%
Model 3	0.24	0.04	3	0.9556	0.08	3	0.946	2.5%
Model 4	0.19	0.03	3	1.011	0.0335	5.67	0.946	2.5%
Model 5	0.19	0.05	3	0.959	0.0559	3.4	0.946	2.5%
Model 6	0.19	0.04	5	0.9729	0.0447	4.25	0.946	2.5%
Model 7	0.19	0.04	1	0.9763	0.0447	4.25	0.946	2.5%

Figure 1.2: Age-wealth profile: Baseline model

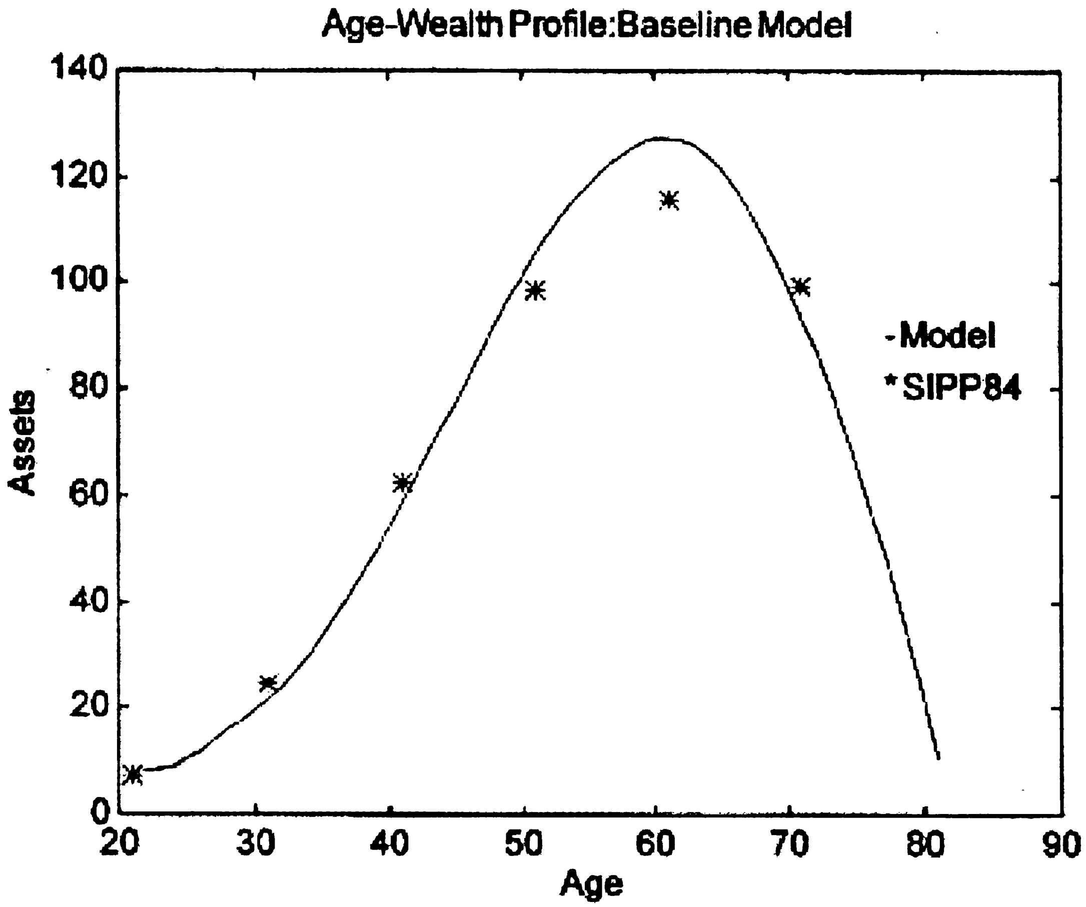


Table 1.2: Carroll-Samwick estimates for sensitivity of wealth holdings with respect to income risk

Model	Age<50	Age 1-82
C-S:Per. Var.	12.09	13.27
C-S:Tr. Var.	7.11	6.6
Baseline	23.76	18.69
Model 2	21.76	14.88
Model 6	8.61	3.99

Figure 1.3: Age-wealth profile: Models 2 to 4

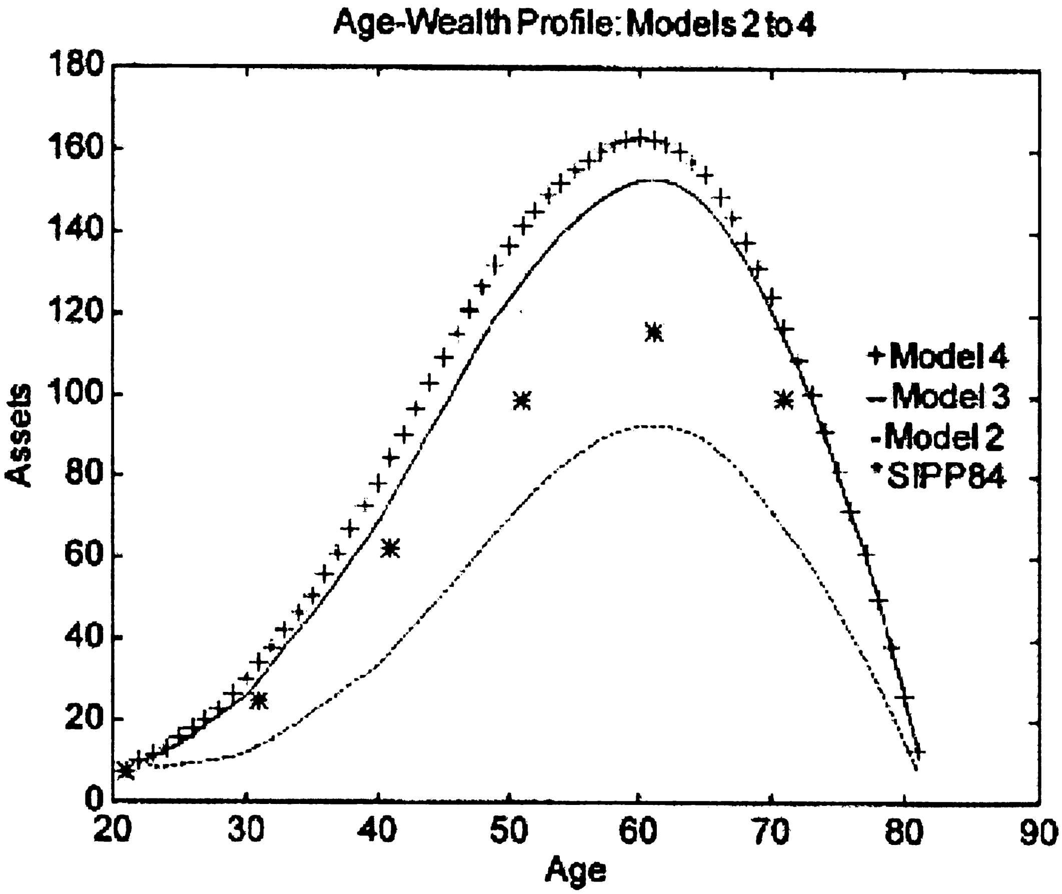


Table 1.3: General equilibrium estimates of precautionary wealth

Model	Calibration			Precautionary wealth (%)	
	S/Y	Interest R.	θ	Lifespan Uncertain	All Certain
Baseline	0.19	0.04	3	27.33	30.09
Model 2	0.15	0.04	3	23.42	26.75
Model 3	0.24	0.04	3	31.94	34.08
Model 4	0.19	0.03	3	22.38	25.63
Model 5	0.19	0.05	3	29.63	32.07
Model 6	0.19	0.04	5	49.63	50.71
Model 7	0.19	0.04	1	6.69	11.81

Figure 1.4: Age-wealth profile: Models 5 to 7

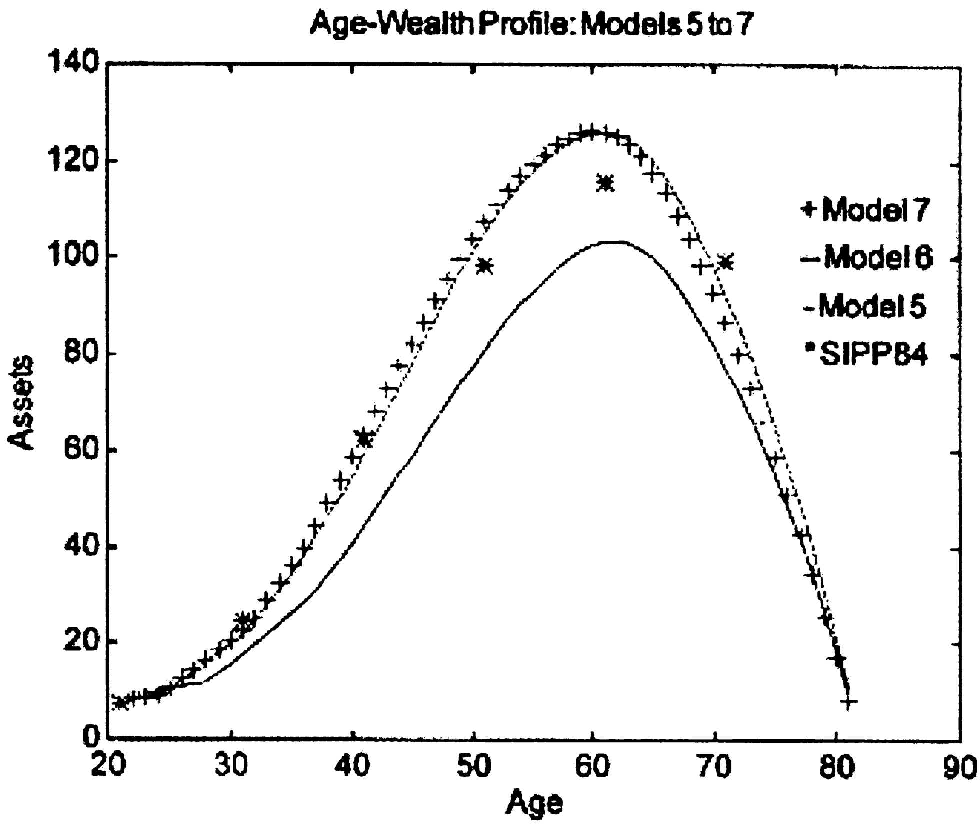


Table 1.4: Partial and general equilibrium estimates of precautionary wealth (%)

Model	Partial Eq. (1)	General Eq. (2)	$100 \times ((1) - (2))/(2)$
Baseline	44.92	30.09	49.29
Model 2	33.28	26.75	24.42
Model 3	76.03	34.08	123.11
Model 4	30.33	25.63	18.33
Model 5	60.36	32.07	88.25
Model 6	59.22	50.71	16.79
Model 7	39.34	11.81	233.19

Figure 1.5: Average propensities to save

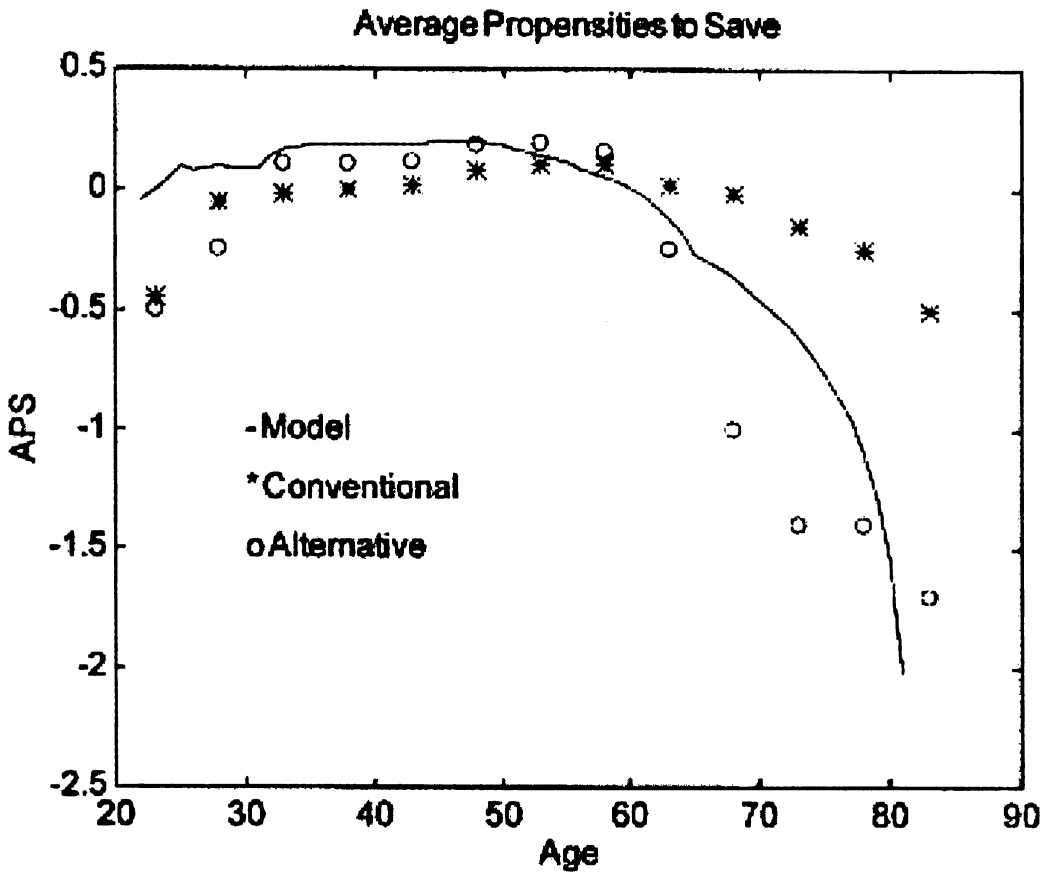


Table 1.5: Reproducing results: % of wealth that is precautionary

Model	Lifespan	All
	Uncertain	Certain
HSZ 1	68.29	71.93
HSZ 2	67.17	70.97
Skinner 1	47.86	50.87
Skinner 2	47.04	50.13

Figure 1.6: Wealth/income profile: Baseline model

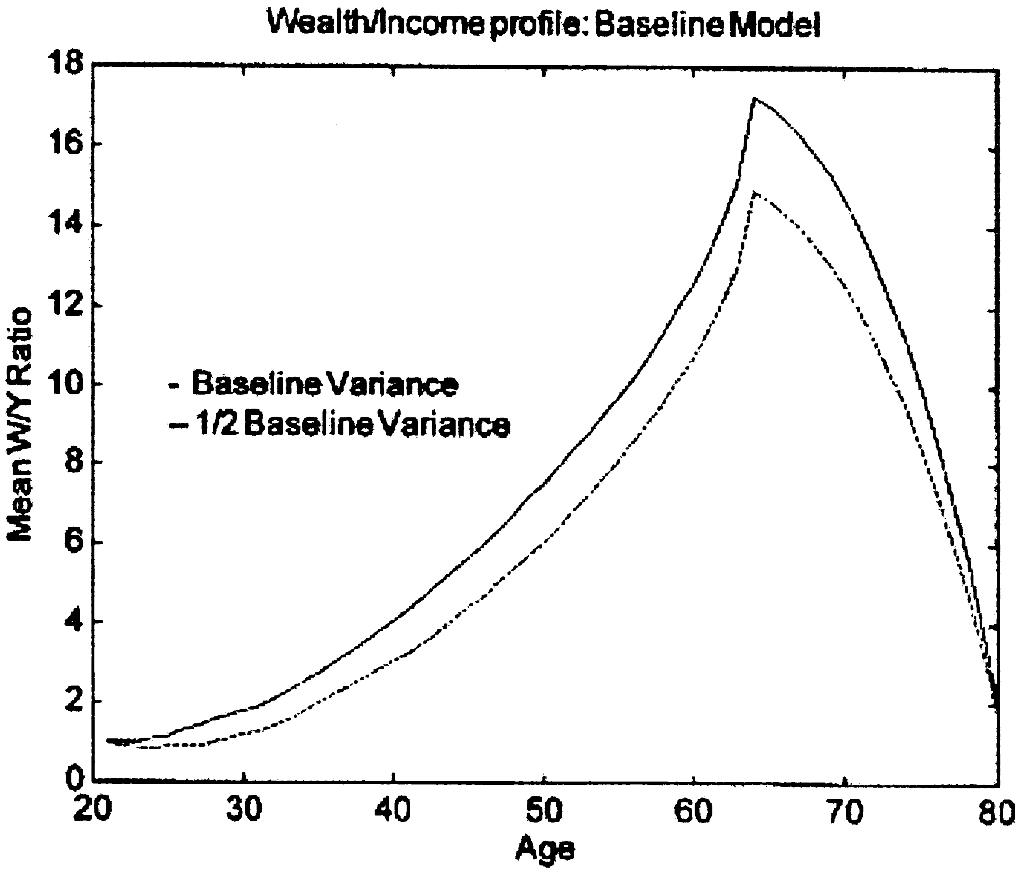


Table 1.6: Partial vs. general equilibrium effects

Model	% prec.	% Prec.	100 × ((1) − (2))/(2)	% prec.	% Prec.	100 × ((3) − (4))/(4)
	P.E. (1)	G.E. (2)		P.E. (3)	G.E. (4)	
HSZ	26.63	22.38	19	30.33	25.64	18.32
Skinner	41.62	27.63	50.67	44.6	31.06	43.59

Figure 1.7: Wealth/income profile: Model 2

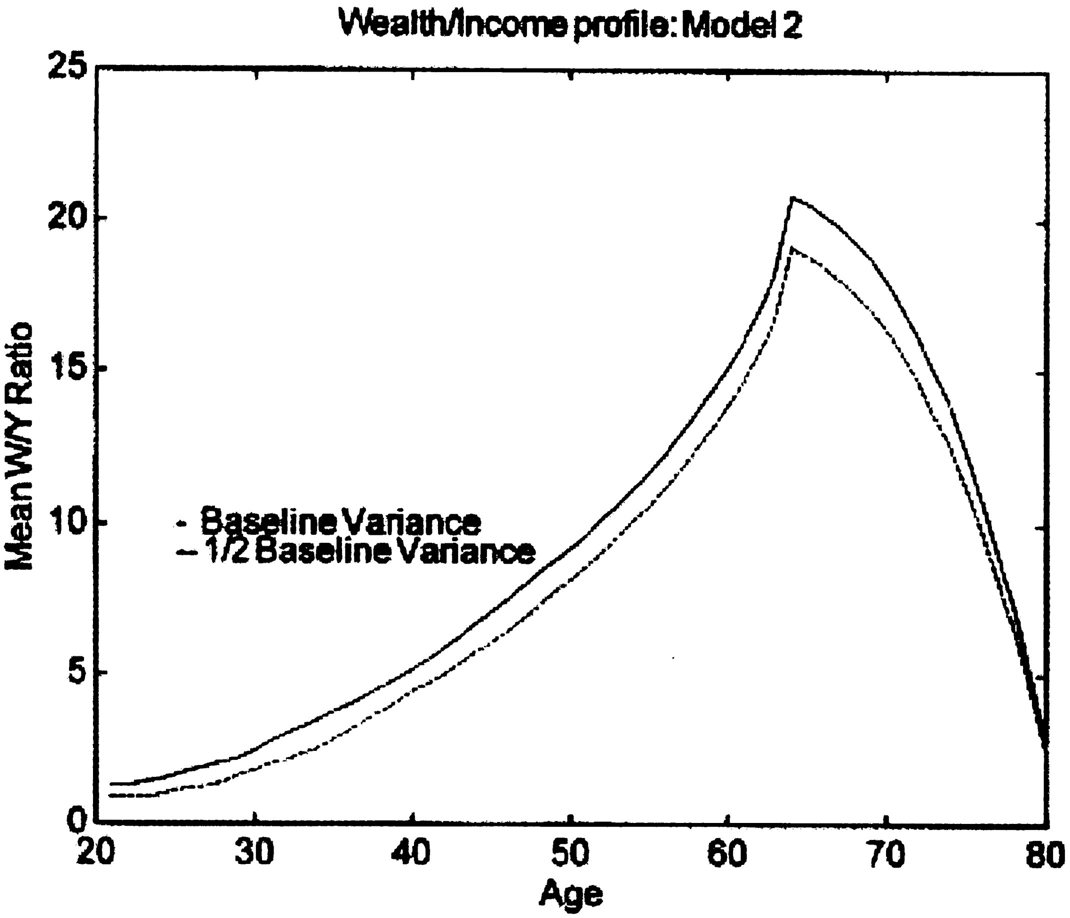


Table 1.7: Selected capital output ratios

	Interest Rate			
Saving Rate	.03	.04	.05	.06
.16	6.7	5	4	3.3
.18	6	4.5	3.6	3
.20	5.3	4	3.2	2.7
.22	4.7	3.5	2.8	2.3
.24	4	3	2.4	2

Figure 1.8: Wealth/income profile: Model 6

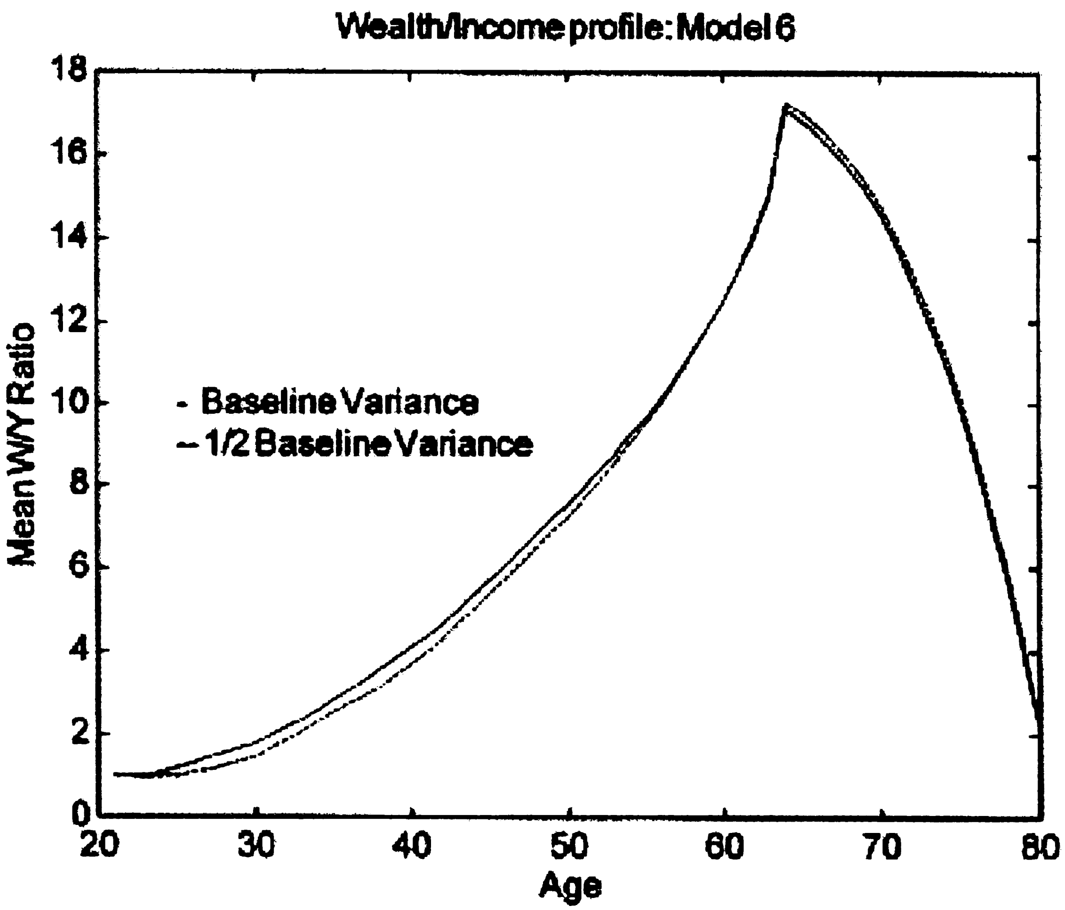
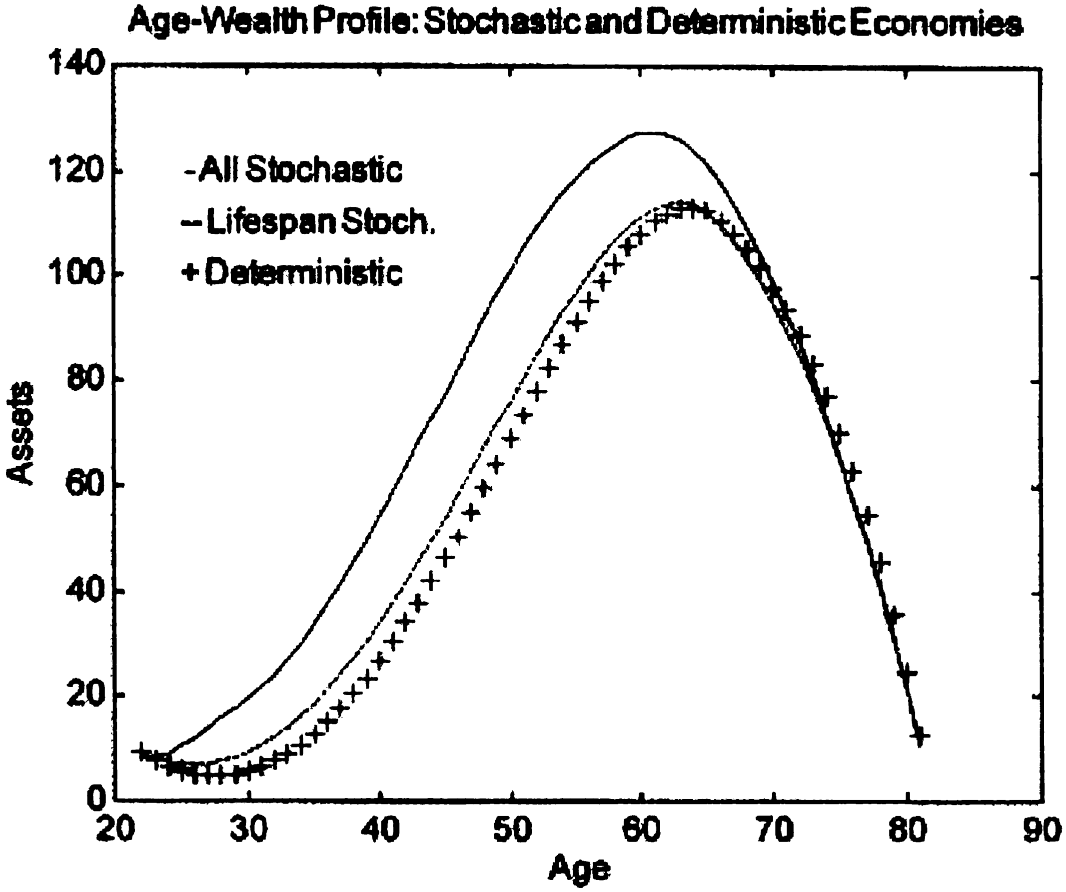


Figure 1.9: Age-wealth profile: Stochastic and deterministic economies



Chapter 2

Green taxes and double dividends in a dynamic economy

2.1 Introduction

The possibility that green tax reform may yield a double dividend has become a major issue in the environmental policy arena. The double dividend hypothesis is nicely exposited in Goulder [1995] and Bovenberg [1999]. Apart from decreasing pollution externalities, a 'green' dividend, environmental taxes raise revenue that can be used to lower other (pre-existing) tax distortions, resulting in a smaller deadweight loss from the tax system, or 'efficiency' dividend. Because of the appealing nature of such reform Bovenberg calls environmental taxes a 'no regret option'.

Most of the work on the double dividend problem addresses the question from a normative perspective and in a static framework. Examples include Bovenberg and van der Ploeg [1998], Carraro and Soubeyran [1996], Holmlund and Kolm [1995], and Koskela et al. [1998]. In an influential paper, Bovenberg and de Mooij [1994] use a model with two goods (one clean, one 'dirty'), and labor as the only input, to examine whether increasing the tax rate on the polluting good above its Pigovian level, and reducing labor taxes in a revenue neutral fashion will deliver a welfare gain. In this version of the double dividend question, the distortionary effect of increasing green taxes above the level at which the marginal pollution damage is internalized should be compared to the efficiency gains from reducing other taxes. Bovenberg and De Mooij find that the efficiency dividend does not materialize, since green taxes turn out to be more distortionary than the labor tax by virtue of their effect on the composition of the production bundle.

The previous result relies heavily on the static nature of the model. A few papers have extended the discussion to a dynamic setting. Bovenberg and de Mooij [1997] study the impact of environmental tax reform on long run growth. In their model, where production externalities decrease the productivity of capital, a tax shift from output taxes to pollution taxes always achieves a green dividend, and an efficiency dividend is obtained only under certain parametric conditions. Perhaps the closest paper to ours is Bovenberg and Smulders [1996]. In this paper, the transitional dynamics of a growth model are examined after a tightening of environmental standards occur. Starting from a situation where green taxes are below their Pigovian levels, the authors study the conditions under which the efficiency dividend is obtained.

This paper departs from previous literature on the double dividend hypothesis in that it examines a policy rather than a normative question. We are interested in the environmental and efficiency effects of green tax reform in the U.S. As Bovenberg and Smulders, we compute the transitional path after a policy change, but unlike their paper, the policy change in our experiment is a revenue-neutral tax reform, intended to address the double dividend question, and involves an actual calibration to the U.S. economy.

Unlike previous work, this paper focuses on the effects that the higher levels of capital accumulation resulting from a more efficient tax system may have on environmental quality. After Lucas [1990], and Hall and Jorgenson [1967], a large body of evidence suggests that tax changes have a first order effect on the level of the capital stock. Moreover, this effect is important enough that we would expect it to overshadow the effects of pollution on productivity emphasized in previous work. Our focus on capital taxes is in part dictated by the mechanism we want to examine. By choosing to reduce capital taxes, as opposed to labor or consumption taxes, we are maximizing the efficiency dividend and therefore, by promoting capital accumulation, betting against better environmental quality. If it turns out that the green dividend is also achieved by decreasing capital taxes, then it will most likely be achieved by shifting the tax burden from any preexisting tax to green taxes.

In our model, which is described in section 2.2, there are a large number of identical infinitely lived households. Households value clean consumption goods, dirty consumption goods, like gasoline, and their stock of health. Final goods and services are produced using capital, which is clean, and a dirty input, fuel. Fuel is produced with capital as the only input. Health is a function of the stock of pollution. Pollution is augmented by current fuel use, both in consumption and in production and depreciates like the other capital stock. The government collects taxes on fuel and on capital income. In the main policy exercise considered, increased revenue from green taxes is used to reduce the tax rate on capital earnings. As noted above, by choosing to reduce the highly distortionary capital taxes, we all but ensure that the efficiency dividend will obtain, and we focus on the environmental effects of the policy change.

We find that, because a more efficient tax system encourages capital accumulation, the environment may worsen in the new steady state. However, in all the cases we consider, a double dividend is obtained during a very long period of time at the beginning of the transition. We conclude that a tax reform experiment of the nature explored in this paper is most likely to be Pareto improving.

This chapter has four other sections. In section 2.2 the model is presented. In section 2.3 functional forms and parameter values are chosen, then section 2.4 presents the results, and section 2.5 concludes.

2.2 The model

The economy is populated by a large number of infinitely lived individuals. We abstract from population growth and normalize population size to unity. Preferences of the representative individual are given by

$$\sum_{t=0}^{\infty} \beta^t u(c_t, m_{ct}; h_t), \tag{2.1}$$

where c_t is consumption of the single perishable consumption good at time t, m_{ct} is the amount of fuel consumed at time t and h_t is the state of health at time t, β is discount factor which is a real number between zero and one, and u is felicity. We find it useful here to disaggregate consumption goods into two types: one good, which is associated with negative pollution externalities, we call fuel, m_{ct}, and the other good, which is not associated with such externalities we refer to as the consumption good, c_t. The elasticity of substitution between these two (consumption) goods will play an important role in the following analysis. In the utility function specified in equation (2.1) the state of health, h_t, enters as a separate variable. Health here is a capital stock, which is taken as given by each individual, but which depends upon the aggregate amount of pollution in the economy.

The relationship between health and the aggregate amount of pollution, z_t, is given by

$$h_t = h(z_t). \tag{2.2}$$

The consumption good is produced via a constant returns to scale technology using two inputs, capital k_{pt} and fuel m_{pt}. The production function is given by

$$y_t = f(k_{pt}, m_{pt}). \tag{2.3}$$

Fuel is produced using capital k_{mt} only. The production function for fuel is given by

$$m_t = g(k_{mt}). \tag{2.4}$$

There are two capital stocks in this economy, physical capital (k_t) that can be used in the production of the consumption good (k_{pt}) or fuel (k_{mt}), and the stock of pollution (z_t). These two types of capital evolve according to

$$k_{t+1} = (1 - \delta)k_t + i_t, \tag{2.5}$$

$$z_{t+1} = (1 - \delta_z)z_t + m_t, \tag{2.6}$$

where i_t is investment in physical capital at time t. In this economy, fuel m_t can be used as an input in the final goods sector, m_{pt}, or consumed, m_{ct}. The initial endowments in this economy are k_0 and z_0.

The government in this economy collects taxes on capital income at the uniform rate τ_k, and taxes on household fuel consumption and fuel use by firms at the rate τ_m. All tax revenue is rebated in a lump sum fashion to the households.

The representative household in this economy solves the problem

$$\max_{(c_t, k_{t+1}, m_{ct})_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t u(c_t, m_{ct}; h_t), \tag{2.7}$$

subject to

$$\sum_{t=0}^{\infty} p_t(c_t + i_t + (1+\tau_m)w_t m_{ct}) = \sum_{t=0}^{\infty} p_t((1-\tau_k)q_t k_t + \pi_{mt} + T_t),$$

$$k_{t+1} = (1-\delta)k_t + i_t,$$

given

$$k_0, \{p_t, q_t, w_t, h_t\}_{t=0}^{\infty},$$

where p_t is the price of final goods at time t, w_t is relative price of fuel compared with final goods at time t, q_t is return to capital at time t. Here π_{mt} are profits from producing fuel and T_t are the lump sum transfers from the government. The final goods producing firm solves the problem

$$\max_{\{k_{pt}, m_{pt}\}} f(k_{pt}, m_{pt}) - q_t k_{pt} - (1+\tau_m)w_t m_{pt}. \tag{2.8}$$

The fuel producing firm solves the problem

$$\max_{\{k_{mt}\}} w_t g(k_{mt}) - q_t k_{mt}, \tag{2.9}$$

We do not allow the government to run a deficit or surplus, so the government budget constraint each period is

$$\tau_m w_t(m_{ct} + m_{pt}) + \tau_k q_t k_t = T_t. \tag{2.10}$$

An equilibrium for this economy is an allocation for the representative household $\{c_t, m_{ct}, k_{pt+1}, k_{mt+1}\}_{t=0}^{\infty}$, an allocation for the final goods producing firm $\{k_{pt}, m_{pt}\}_{t=0}^{\infty}$, an allocation for the fuel-producing firm $\{k_{mt}\}_{t=0}^{\infty}$ and prices $\{w_t, q_{pt}, q_{mt}\}_{t=0}^{\infty}$ satisfying

1. the household's allocation solves the maximization problem in (2.7),

2. the final goods producing firm solves the maximization in problem (2.8),

3. the fuel-producing firm solves the problem in (2.9),

4. the fuel and capital markets clear, and

5. the government budget constraint (2.10) is satisfied.

2.3 Calibration

In this section we restrict numerically the model by choosing functional forms and parameter values. For the utility function, we need to choose a functional form that allows us to match the observed income elasticities for household fuel demand. In most standard utility functions, such as Cobb-Douglas or CES, the implied income elasticity is unity. Schmalensee and Stoker [1999] find an estimate of this elasticity of 0.2. Other estimates of this elasticity are in a neighborhood of 0.2 (Puller and Greening [1999]). To allow for varying income elasticities we pick the following utility function:

$$u(c_t, m_{ct}; h_t) = \frac{1}{1-\sigma}(h_t^{\eta}(\theta c_t^{\xi} + (1-\theta)m_{ct}^{\rho})^{1-\eta})^{1-\sigma},$$

$$\xi > 0,\ \rho > 0,\ 0 < \theta < 1,\ 0 < \eta < 1,\ \sigma \geq 1. \tag{2.11}$$

We also choose a CES production function, that allows for a response of input use to changes in relative prices in accordance with microevidence.

$$f(k_{pt}, m_{pt}) = A[\chi k_{pt}^{\alpha} + (1-\chi) m_{pt}^{\alpha}]^{1/\alpha}, \ A > 0, \alpha < 1, \ 0 < \chi < 1. \tag{2.12}$$

The production function for fuel is Cobb-Douglas in one input capital, so that

$$g(k_{mt}) = E k_{mt}^{\psi} \ 0 < \psi < 1. \tag{2.13}$$

Finally, the health production function is of the form,

$$h(z_t) = 1/z_t. \tag{2.14}$$

We calibrate our model to the US economy. The benchmark parameters we use are illustrated in Table 2.1. Calibrating the utility function to long-run data is a bit tricky since preferences are not homothetic and expenditure shares do depend upon the level of income. We thus pick preference parameters ξ and ρ that match observed income elasticities at the steady state. Most estimates of this income elasticity are in the neighborhood of 0.2 (See Schmalensee and Stoker [1999]). But we experiment with higher and lower values for this elasticity. The elasticity of substitution parameter, α, in the CES production function is set equal to -0.5, making substitution between fuel and capital slightly more difficult than in the Cobb-Douglas case. The case of $\alpha = -10$ was also considered with no substantive change in the results.

We choose a value for the preference parameter η that places a relatively small weight on health. Since health is not a choice variable for the household, the choice of η has an effect on the allocation only through the effect of fuel consumption m_c on future health levels.

The preference and technology parameters $\{A, \theta, \chi\}$ are chosen so that fuel usage by household out of total usage is 30% [1] and fuel share of GNP is 7% [2], and the

[1]The Statistical Abstract of the United States 1999, table 955 contains data on fuel use which is broken down into the following categories: residential and commercial, industrial, and transportation. We assign 50 percent of fuel use in the residential and commercial category to fuel use in consumption. Over the period from 1970 - 1997, households used 30.75 percent of all fuel.

[2]According to the Statistical Abstract of the United States table 958 and table 727, expenditure on fuel as a fraction of GDP in the US for 1995 is about 7%.

household's expenditure share for fuel is about 3.5 percent [3]. We know very little about the technology parameter ψ. We execute some sensitivity analysis and find that our qualitative results are robust to changes in ψ. We assume that the depreciation rate for capital is 10%, and we choose δ_p to be consistent with the steady state conditions.

The Statistical Abstract of the United States 1999, table 793 contains data on the state tax rates for gasoline in 1997. Together with a federal gasoline tax of about 18 cents for a gallon, the average tax rate for gasoline is around 50%

2.4 Results

To solve this model, we first obtain the steady state using a Newton-Raphson procedure, then we linearize the first-order conditions around the steady state and solve the resulting difference equations. The approximation errors that result are very small, as evidenced by the Euler residuals:

$$\frac{u_c(t)}{u_c(t+1)\beta(1+r_{t+1}-\delta)} - 1$$

shown in Table 2.2.

We now report the results of our main experiment, a revenue neutral tax change. In this experiment, we raise the fuel tax and adjust the capital tax to keep the government share of GDP constant at 35%. For ease of exposition, we concentrate first on steady-state comparisons, and examine the transition path later.

Figure 2.1 shows fuel usage in steady state as the tax on fuel increases for the baseline parametrization. It is clear from this figure that the steady state level of aggregate fuel consumption is not monotonic in the tax rate on fuel. In fact, fuel use by household is monotonically declining in the tax rate, as the substitution effect dominates the income effect because of the small income elasticity. Fuel use by firms, however, increases in the tax rate. This is an expected result, since higher tax rates on fuel are accompanied

[3]This is slightly lower than the average share of household income allocated to fuel estimated by Chernick and Reschovsky [1997].

by lower capital tax rates, and therefore higher steady state levels of the capital stock. When the fuel tax rate is low (high), the former (latter) effect tends to dominate, giving a hump shaped relationship between tax rates and aggregate fuel usage.

The steady state levels of the capital stock as τ_m changes are depicted in figure 2.2. While the amount of capital devoted to fuel production stays roughly constant, capital in the final goods producing sector increases as the tax on capital income is reduced and the tax system becomes more efficient.

Figures 2.3 to 2.5 show the transition path from period 11 (time 1), when the policy change occurs. At time 1, the higher tax rate on fuel generates, via a substitution effect, a sharp decrease in fuel consumption (figure 2.3). The lower tax rate on capital earnings, however, creates incentives to accumulate capital (figure 2.4). Since capital and fuel are complements in the production of the capital good, fuel consumption by firms increases monotonically from time 1 (period 11).

Figure 2.5 shows the evolution of GDP and consumption of the final good. At the time the policy change takes place and the rate of return to capital jumps, more capital is devoted to produce final goods k_p, and the relative price of fuel must fall to avoid arbitrage opportunities. As capital is accumulated however, the relative price of fuel increases reducing the share of capital used in final goods production. This composition effect operates to reduce final goods consumption after period 11, but eventually the growth of the capital stock takes over the dynamics of this variable. Note that for a period of about 25 years (period 15-40 in figure 5) the household has a lower level of consumption of both fuel and the final good.

We now turn to the welfare effects of this policy experiment. To disentangle welfare changes from different consumption paths and different health stock paths, we first compute the level of discounted utility during the transition to the new steady state, assuming that households enjoy the levels of health of the original steady state. We then calculate by what percentage should consumption (of both fuel and the final good) increase for both discounted utilities (original steady state and transition) to be equal, and call this number the efficiency dividend. Next, we do the same exercise but now holding consumption at the level of the original steady state, and comparing discounted utilities where only the stock of health changes. We call this second number the green dividend.

Table 2.3 shows both dividends for the baseline case, where τ_m increases from .5 to .55, as well as for alternative tax changes. Note that the green dividend is obtained in all cases, but the efficiency dividend obtains only for target levels of the green tax below a critical level, around .5. Above this level, we conjecture, the green tax becomes more distortionary than the capital earnings tax, and the results mimic those in most of the green tax literature. Below this level, however, both dividends are realized. With the caveat that we know little about how health enters into the utility function, we can appeal to linearity and add both columns of table 2.3 to get the aggregate welfare effect. This effect is always positive, since the green dividend is always larger -by as much as two orders of magnitude in the baseline case- than the efficiency dividend.

Summarizing, even though in steady state comparisons the efficiency dividend always holds, and the green dividend is in doubt, the transition path shows that the a lower level of pollution will be enjoyed for a very long period during the transition. In order to build a larger capital stock however, a lower level of consumption must be endured for some years near the beginning of the transition. The green dividend, or higher discounted utility from a cleaner environment, will then always obtain, while the efficiency dividend, or higher utility from consumption of market goods, obtains under most, but not all tax changes.

2.5 Conclusion

In this paper we have studied whether a green tax reform actually does deliver a double dividend in a model calibrated to the U.S. economy. Our answer is a timid yes. In our model, raising a green tax does indeed allow a pre-existing tax to be decreased, here a tax on capital income. Cutting capital taxes stimulates investment and growth, so green taxation does yield one dividend. If capital and fuel are complementary inputs, however, increasing the capital stock raises the demand for fuel which can, depending on the degree of complementarity, offset any decline in fuel use due to higher fuel taxes. While this offsetting effect is important in steady state comparisons, it is dwarfed by substitution effects that decrease the consumption of fuel and thus deliver a better environmental quality for a very long period along the transition path. A green dividend is then always achieved, but the growth dividend is achieved only when the target level of the environmental tax is below a critical level.

Table 2.1: Benchmark parameters and data

Preference parameters	
β	0.979
σ	3
θ	0.925
η	0.9
ξ	0.83
ρ	0.17
Technology parameters	
Final good production	
A	.111
α	-0.5
χ	0.983
Fuel production	
E	1
ψ	0.5
Depreciation rate	
δ	0.041
δ_p	0.1
Data	
$\frac{m_c}{m_c+m_p}$	0.3
wm/GNP	0.07

Table 2.2: Euler residuals (er)

Change of tax rate on fuel	max $\lvert er \rvert$
.5 to .55	4.9×10^{-6}
.65 to .7	3×10^{-6}
.5 to .6	1.8×10^{-5}
.35 to .4	8×10^{-6}
.3 to .35	9.4×10^{-6}

Table 2.3: Welfare analysis: Compensating variation (%)

Change of tax rate on fuel	Growth dividend	Green dividend
.5 to .55	-.008	.16
.65 to .7	-.026	.15
.5 to .6	-.0084	.33
.35 to .4	.038	.18
.3 to .35	.056	.19

Figure 2.1: Steady state comparisons: fuel

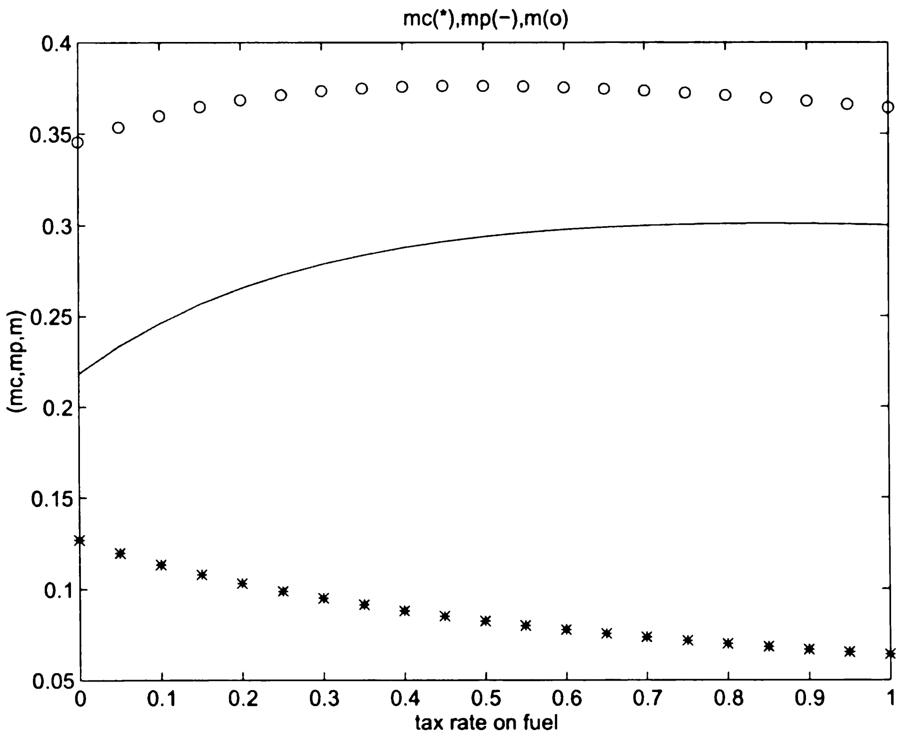


Figure 2.2: Steady state comparisons: capital

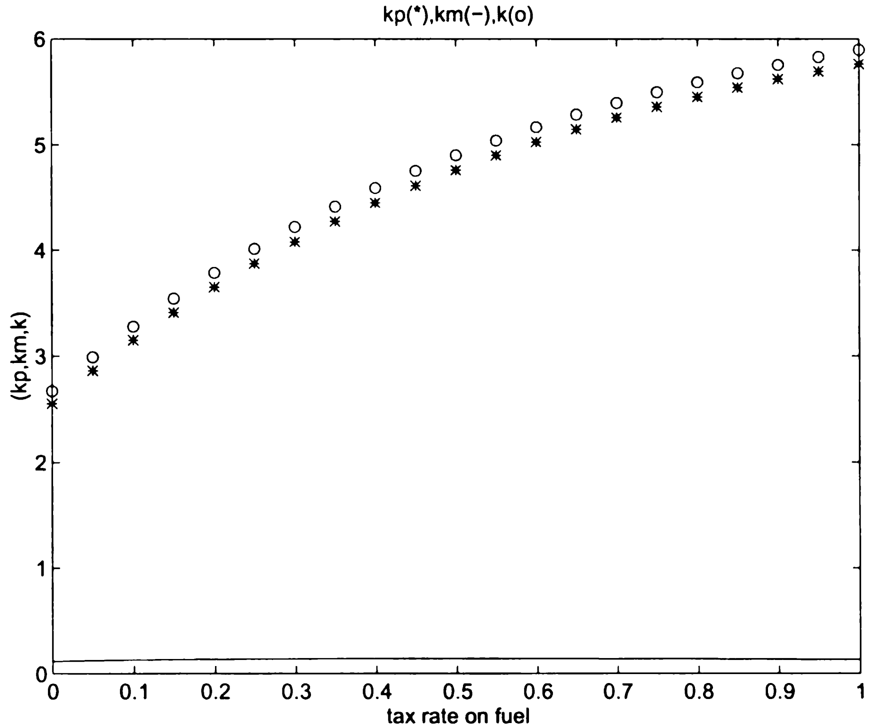


Figure 2.3: Transition path: capital

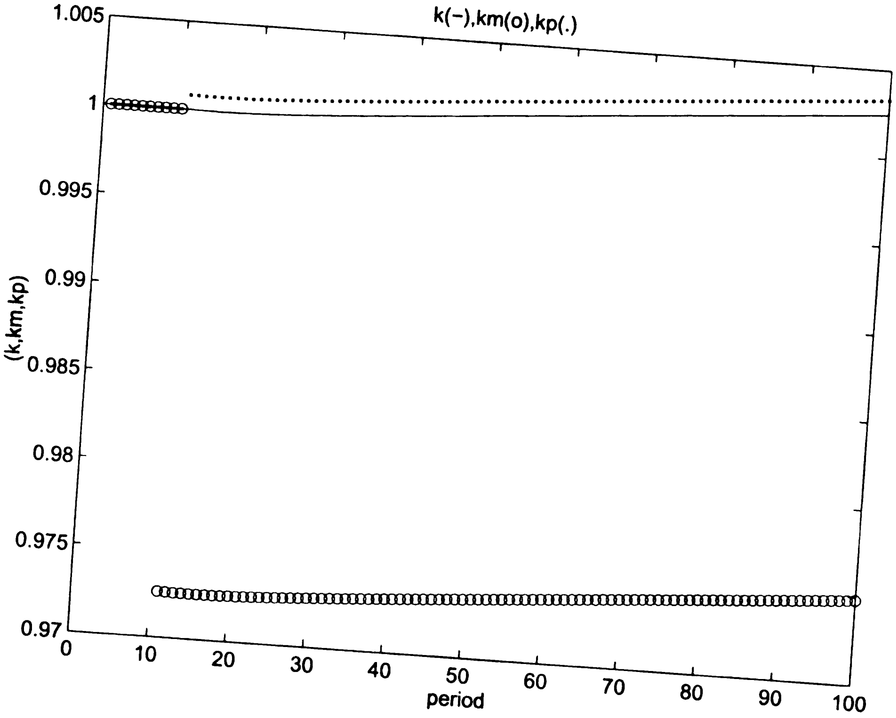


Figure 2.4: Transition path: fuel

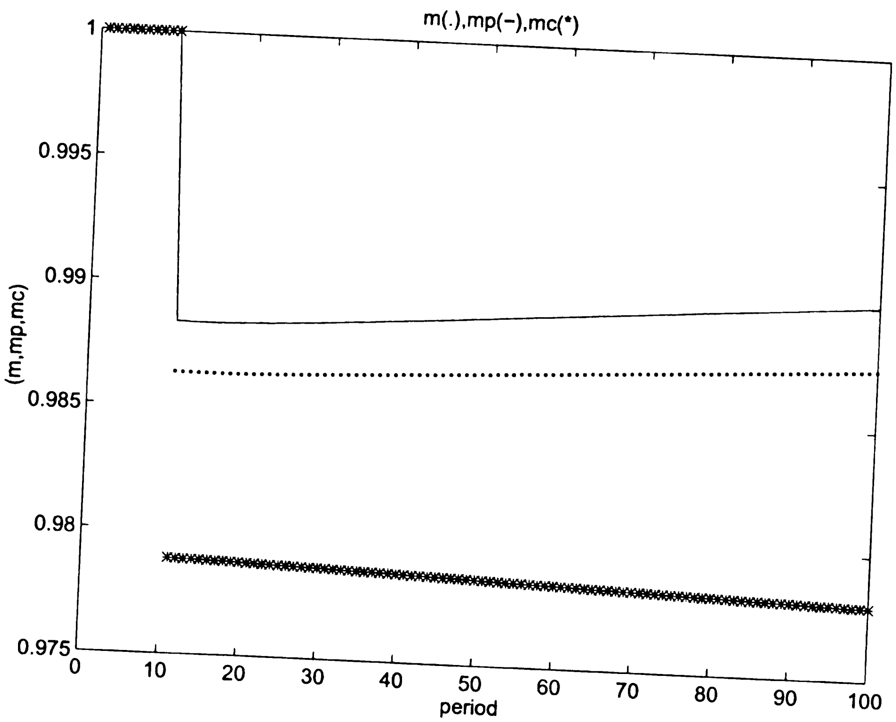
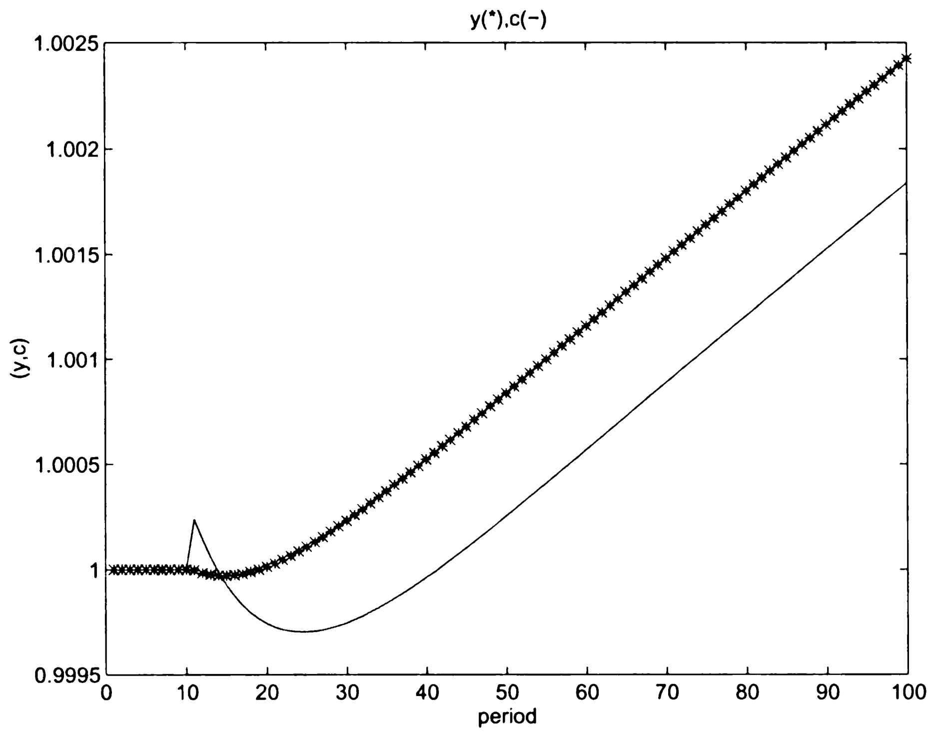


Figure 2.5: Transition path: GDP and final goods consumption



Chapter 3

Training and business cycles

3.1 Introduction

This paper studies the behavior of skill acquisition through training at business cycles frequencies. Beginning with Mincer [1974] and Porath [1967], human capital accumulation has been extensively studied as one of the main determinants of productivity growth along a worker's life cycle. Human capital investment also plays an important role in accounting for cross country differences in growth rates in the empirical literature spanned by Barro [1991] and Mankiw et al. [1992]. In an influential paper, Lucas [1988] suggests that human capital investment is the main force driving long run growth. While the literature on human capital accumulation on both the life cycle and aggregate growth dimensions is vast, we still have a limited understanding of the mechanics of skill acquisition over the cycle. This paper contributes to bridging this gap.

Understanding the behavior of skill acquisition during the cycle has potentially important implications. From a policy perspective, firms implement training programs -and workers engage in them- after deciding that future benefits in terms of higher productivity offset current opportunity costs. If training turns out to have a strong cyclical component, then the rate of return on the large number of government-sponsored training programs might be affected by the time at which they are implemented. Moreover, the cyclical behavior of training may help explain both the phenomenon of procyclical productivity, and the empirical finding that recessions tend to be followed by periods of higher than average productivity growth (see Bean [1990] and Saint-Paul [1996]). In both cases, it has been conjectured that training occurs in downturns and the economy starts a new cycle with higher levels of human capital. Finally, we will argue that the behavior of skill acquisition is strongly linked with the ease with which firms can adjust their factors of production, so that the analysis in this paper will shed light on the cyclical behavior of employment, hours, and labor productivity.

Our empirical knowledge of human capital investments during the cycle is limited to Dellas and Sakellaris [1996], who study skill acquisition activities through formal schooling. In that paper, a database of college enrollments is constructed and the cyclical properties of the series examined. The authors report that college enrollments are countercyclical, and strongly tied to local labor market conditions.

The theoretical implications of skill acquisition activities are explored in a limited number of papers. DeJong and Ingram [2001] estimate a real business cycle (RBC) model with human capital production, investment goods and final goods sectors, and a rich stochastic specification. In their paper, the authors note that there is a lack of usable data on skill acquisition at high frequencies, and address this issue by using their model to infer what the behavior of skill acquisition should be given the realization of the remaining variables. Using a maximum likelihood procedure, they find that a countercyclical and highly volatile behavior of skill acquisition time provides the best fit of their model to existing data.

Einarsson and Marquis [1998] show that adding human capital accumulation can improve the capacity of a model to match the low observed correlation between hours and productivity. A second paper, by Perli and Sakellaris [1998], shows that the countercyclical allocation of resources from a goods producing sector to a sector producing human capital adds a strong propagation mechanism to the standard model. While these results are important, we believe that the ability to assess their empirical relevance is hampered by lack of reliable data [1].

This paper is closer in scope to DeJong and Ingram [2001] in that we are interested in the cyclical behavior of the types of skill acquisition that occur after workers leave formal schooling. In so doing, our study complements the work by Dellas and Sakellaris [1996], who focus on skill acquisition through formal schooling. This paper contributes to the literature in two ways. One, it is the first paper to construct a time series of training activities, and to document its cyclical properties. Two, it highlights the role of labor adjustment costs in explaining the cyclical behavior of skill acquisition.

Our results show that training, both on and off-the-job, is weakly countercyclical, leads the cycle, and has a standard deviation of more than ten times that of output. We show that a standard RBC model with human capital accumulation is unable to reproduce this volatility, but a model with empirically plausible adjustment costs of employment can.

The rest of this chapter is organized as follows. Section 3.2 describes the data used and documents the regularities to be explained by a business cycle model. Section 3.3 presents the model. Section 3.4 calibrates the model, and section 3.5 presents the results. The last section concludes.

3.2 Data

3.2.1 Data description

In this study we use the National Longitudinal Survey of Youth 1979 (NLSY79) as the source of training data. The NLSY79 is a longitudinal survey of 12686 individuals who are interviewed every year from 1979 to 1994, and every two years since until 1998. The

[1] The data on human capital used in Einarsson and Marquis [1998] and Perli and Sakellaris [1998] is a series constructed by Jorgenson et al. [1987]. To construct this series, at every period classes of workers are aggregated using both their wage levels (which are intended to measure the level of human capital) and relative weights in the workforce. While wages are at best weakly procyclical, it is well known that low wage workers drop out of the workforce in higher proportions during recessions, and return during booms. The resulting index shows a clear countercyclical pattern, but this is influenced by the effects of the cycle on the composition of the workforce, and it is unclear to what extent it measures skill acquisition activities.

same respondents are followed every interview year without replacement, so that the age distribution of the sample ranges from 14 to 22 years in 1979 and from 34 to 44 in 1998.

With this dataset we first construct a quarterly panel from 1978Q1 to 1998Q4, using questions on the incidence and time spent in training, the type of training provider, working status (working/not working), industry code, and education level (less than high school, high school and some college, college graduate). The questions on training, however, are not consistent across time. From 1979 to 1986, the survey registers information on up to three training programs in which the respondent enrolled for more than one month since the date of last interview, and up to two programs in which the respondent was enrolled at the time of the last interview. In 1987 no training questions were fielded, and in 1988 no information is recorded about training programs in which the respondent was enrolled at the time of last interview. From 1988, information is recorded on up to four training programs started since the date of last interview, regardless of the duration of the program [2].

The questions on the type of training provider are used to separate training into On-The-Job (OJT) and Off-The-Job (OFFJT) training, a distinction that intends to separate firm-specific skill acquisition (OJT) from investments in general skills (OFFJT). The assignment of training programs to either OJT or OFFJT is done according to whether the program took place at the workplace or not. Table 3.1 details how the different NLSY training categories are aggregated in On-The-Job and Off-The-Job training.

Once the panel is constructed, there are 12,686 individuals, with each being observed for up to 84 quarters, or 1,065,624 observations in total. The NLSY79 oversamples the military population, and this subsample is dropped (107,520 observations). Further,

[2] To construct this panel, we consider a respondent to be in a training program in any quarter if he was enrolled in training for more than one of the three months. For consistency between time periods, we use a maximum of three training programs per year for each respondent, which has negligible effects on the resulting series.

all observations prior to the respondent last being enrolled in school, and posterior to the respondent's last interview are also dropped (414,976 observations) [3]. Finally, we divide the sample into two subperiods to address the problem of data inconsistency, as explained below.

A total of 543,128 observations remain, and are matched with business cycle indicators: GDP and Investment from the Bureau of Economic Analysis, and industrial production by 2-digit industry from the Board of Governors of the Federal Reserve System, for respondents who report working in manufacturing industries (SIC 20-39).[4] Table 3.2 shows descriptive statistics for this data, and Table 3.3 describes the nomenclature. This panel is then used to produce time series at different levels of aggregation: by education groups, working status, etc.

The NLSY79 data has the natural advantages of a panel dataset over aggregated data, and for the purpose of this study it contains extremely detailed information on training at the individual level. There are also two potential problems associated with it when used to construct an aggregate time series. The first problem, as explained above, is that the data collection criteria for training questions previous to 1986 and posterior to 1988 are not entirely consistent. The second potentially important problem is that we observe the same individuals at every time period, so we must be careful to filter out life cycle effects. We discuss these questions in turn.

To address the question of data consistency, we choose to divide our sample in two subperiods, and report our results separately for both. Additionally, we choose to keep in our time series only the periods with more than 3500 observations. Since about 3 to 4 percent of the respondents are enrolled in a training program in each period, this procedure mitigates sampling errors to be amplified in the time series. With these

[3]There is also an oversampling of the economically disadvantaged groups, and this subsample is kept, but weighted accordingly in the calculations of means, etc

[4]GDP and Investment downloaded from www.Economagic.com on November 10,2001. Two-digit industrial production downloaded from the Board of Governors of the Federal Reserve System's web site (www.federalreserve.gov) on October 25,2001.

adjustments, we have two periods of valid data, one from 1979Q2 to 1985Q4 (Period 1), and 1989Q1 to 1997Q1 (Period 2).

For the life cycle problem, we begin by noting that at any period a 9 year window of the age distribution is observed, and this cross sectional variation can be exploited in order to separate life cycle effects from business cycle effects. To do this we run a pooled regression of training variables (incidence and hours) on time dummies, that capture business cycle effects, and *age* and *age squared*, that capture life cycle effects. While we find, using an F test, significant coefficients for OFFJT that suggest declining investments in general human capital, we find no such effects for OJT programs. With these results in hand, we choose to use the time series data without applying any transformation, other than logging the hours variables, and we will report the results for both types of training programs.

3.2.2 Stylized facts

We now document the cyclical properties of the variables. The correlations with output (Table 3.4) of hours in production, investment and productivity display well known regularities: all variables are strongly procyclical, with the exception of labor productivity in period 2. The correlations between the training series and other business cycle variables are shown in Table 3.5. The results are consistent for both time periods, and suggest that both OJT and OFFJT are countercyclical. Table 3.5b, computed using pooled data, shows that these correlations are statistically significant when estimated taking advantage of individual variation in the data. [5]

A disaggregated analysis (not reported) reveals that this pattern is broadly consistent across education groups, with hours in training of higher educated workers showing stronger (larger in absolute value) negative correlations with output and investment. Only hours in off-the-job training (*hoff*) in period 2 shows a weakly procyclical pattern.

[5] Note that the results from tables 3.5a and 3.5b are not comparable: table 3.5a uses log aggregate hours in training at time t as the training variable, while table 3.5b uses hours in training at time t for each individual.

These results suggest that skill acquisition activities that would tend to make hours in on-the-job training (*hojt*) procyclical, such as those associated with the acquisition of new capital goods, are unimportant in the aggregate and are small compared to training activities driven by opportunity cost considerations.

Cross correlations of output with investment, hours and productivity (Table 3.6), and training variables (Table 3.7) are discussed now. In our sample, hours are not a leading indicator, but show the strongest correlation with contemporaneous output. This is also true for investment and productivity, with the noted exception of output per hour (*prodh*) in period 2. Table 3.7 indicates that, while training incidence does not show a clear pattern (it lags output by 2 quarters in period 1, and seems to lead in period 2), the response of hours in training clearly leads output by as much as 3 quarters ($HOJT$, period 1).

Finally, table 3.8 shows the volatility of aggregated variables. The standard deviation of the (log) hours in training variables is extremely high, as much as 17 times that of output and hours (see figures 3.3 and 3.4) . Note that this is not an artifact of training having a growth or life cycle trend. When detrended using a Hodrick-Prescott filter, the volatility of $HAGG$ decreases to .137 and .174 for periods 1 and 2 respectively, and a regression of $HAGG$ on *year* and *year squared* show insignificant (at 5%) coefficients for both subperiods.

At any quarter, note that only about 4% of workers are enrolled in training programs, and in average about 1.58% of aggregate hours are spent in training, so the proportionally large cyclical variations observed in training hours and incidence need to be weighted by these scaling factors. But even with this caveat, the high volatility of training hours makes training a margin with an importance of the same order of magnitude as employment in adjusting aggregate hours.

3.3 Model

In section 3.2 we presented a description of the high frequency regularities of the training series. Some of these regularities, such as the high volatility and moderate correlation with the main cycle indicators, are stark and defy obvious explanations, hence providing a test of high power that can be used to discriminate among competing models.

A natural place to start is the model by Lucas [1988], where human capital accumulation is the driving force of long-run growth. A close examination of this model, or a RBC version of it (see Appendix B), shows that it fails along important dimensions. In particular, it cannot reproduce the high volatility of skill acquisition hours, it tends to produce too high degrees of countercyclicality, and fails to match the observation that training leads the cycle.

The standard RBC model with human capital fails to reproduce these facts because, we believe, it does not incorporate the frictions that make some dimensions of labor input, such as employment or weeks worked, much costlier to adjust than others, such as hours per week. In this vein, we will explore the hypothesis that this high volatility of the training variables is driven by the difficulty in adjusting employment at business cycles frequencies due, for instance, to the existence of hiring and firing costs. This difficulty creates a labor hoarding effect, so that the marginal product of labor is adjusted partially on the extensive margin -employment or weeks worked- but mainly on the intensive margin of hours devoted to work/skill acquisition.

To examine this hypothesis, we construct a model where it is costly to adjust the number of weeks worked every year, while marginal adjustments in hours per week can be done at the prevailing wage. We do this in the spirit of Bils and Cho [1994], who examine the behavior of employment, hours and effort over the cycle. In this model, firms produce a single good using a Cobb-Douglas production function

$$Y_t = A_t K_t^{\alpha} (l_t N_t H_t)^{1-\alpha}. \tag{3.1}$$

Here Y is output, K is capital, N is weeks worked per quarter, l is hours per week devoted to work, and H is human capital. A, a measure of total factor productivity, is a random variable that follows an $AR(1)$ process:

$$A_{t+1} = \rho A_t + \epsilon_t \qquad \epsilon_t \sim N(0, \sigma_\epsilon^2). \tag{3.2}$$

To produce, firms hire capital and efficiency units of labor lNH, and pay the costs of adjusting weeks. These costs take the quadratic form:

$$C(\Delta N_t) = B\frac{[N_t - N_{t-1}]^2}{2}. \tag{3.3}$$

The existence of adjustment costs implies that the firm faces a dynamic problem when it chooses employment, and it may incur negative profits at time t. While this cost structure is standard in studies of aggregate employment dynamics (see Hamermesh and Pfann [1996] for a survey), there is strong evidence that it is a poor approximation of the structure of labor adjustment costs at the firm level. At least two features of such a structure are absent in (3.3): *(a)* a fixed cost of adjusting, that drives a pattern of lumpy adjustment at the firm level [6], and *(b)* asymmetric costs of positive (net hirings) versus negative (net layoffs) changes.

The lumpiness in adjusting employment, however, disappears once data is aggregated over firms (see Hamermesh [1989]). Since we do not have a panel of firms that would allow for modelling the firm's decisions when facing fixed costs of adjustment, and then aggregating over firms, the approach in this paper is to use "reduced form"-equation 3.3- to interpret aggregate labor market observations. We believe that this approach is useful, in that the main mechanism that drive our results, namely the relative difficulty of adjusting employment versus hours, is explicitly modelled.

The second feature of the firm-level structure of adjustment costs that is missing in our framework is the asymmetric nature of these costs. The evidence surveyed by

[6] This first point is most clearly made in Hamermesh [1989]. In a study of seven large plants, employment was found to adjust only after deviations of actual output from expected output reached 60%. Using a flexible parametric specification, the author reports significant fixed and marginal costs of adjusting employment. The same qualitative results were found in a study of airline technicians (Hamermesh [1992]).

Hamermesh and Pfann [1996] suggests that firing costs are larger than hiring costs, and that this asymmetry might still be present in aggregate data. We believe that, although the question is important, it goes beyond the scope of this paper, given that our dataset does not allow for observing firm-level data.

If we let r_t be the interest rate net of depreciation, and using the conventions $r_0 = 0$ and $R_t = r_t + \delta$, the firm's problem can be stated as:

$$\max_{\{K_t, H_t, l_t, N_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} (\prod_{\tau=0}^{t} \frac{1}{1+r_\tau}) \quad (A_t K_t^{\alpha}(l_t N_t H_t)^{1-\alpha} - w_t l_t N_t H_t \qquad [P1]$$
$$-R_t K_t - B\frac{[N_t - N_{t-1}]^2}{2}).$$

Households have preferences defined over consumption $\{c_t\}_{t=1}^{\infty}$, weeks worked $\{N_t\}_{t=1}^{\infty}$, and hours per week devoted to on the job activities: work plus skill acquisition activities $\{l_t + n_t\}_{t=1}^{\infty}$. The distinction between weeks and hours per week allow for the study of two margins of labor input with different cost structures. From the perspective of individual preferences, casual observation indicates that most workers choose an internal solution to their problem of allocating time resources on both margins. Moreover, data on the behavior of weeks and hours per week are available to restrict these preferences. The utility function is similar to that proposed by Bils and Cho:

$$U = E_0 \sum_{t=1}^{\infty} \beta^t (\log c_t + m N_t \frac{(n_t + l_t)^{1+\varphi}}{1+\varphi} + f \frac{N_t^{1+\phi}}{1+\phi}). \qquad (3.4)$$

Equation 3.5 shows the law of motion for human capital. Human capital depreciates at a rate δ_H, and is accumulated by devoting time to learning activities. The technology for producing it is in the spirit of Lucas [1988], although human capital is not used to produce more human capital, and the specification in 3.5 does not allow for unbounded growth. Given our focus on business cycles, these simplifications are sensible. Allowing for the level of human capital to influence the efficiency of training hours ($N_t n_t$) would only tend to increase volatility, via a feedback effect from human capital to training.

$$H_{t+1} = H_t(1 - \delta_H) + e\frac{(n_t N_t)^{1+\theta}}{1+\theta}. \qquad (3.5)$$

The household problem is then to maximize 3.4 subject to 3.5 and the budget constraint 3.6:

$$\max_{\{c_t, N_t, l_t, n_t, K_{t+1}, H_{t+1}\}_{t=0}^{\infty}} \quad \Sigma_{t=0}^{\infty} \quad \beta^t (\log c_t + mN_t \frac{(n_t + l_t)^{1+\varphi}}{1+\varphi} + f \frac{N_t^{1+\phi}}{1+\phi}) \qquad [P2]$$

$$\begin{aligned} s.t. \quad 0 &= \quad -H_{t+1} + H_t(1 - \delta_H) + e\frac{(n_t N_t)^{1+\theta}}{1+\theta} \\ 0 &= \quad w_t H_t N_t l_t + (1 + r_t)k_t - c_t - k_{t+1}. \end{aligned} \qquad (3.6)$$

The description of this economy is completed by making explicit the law of motion for capital:

$$K_{t+1} = (1 - \delta)K_t + i_t - B\frac{[N_t - N_{t-1}]^2}{2}. \qquad (3.7)$$

Equations 3.1- 3.7 provide a complete description of this economy. We are now ready to define an equilibrium.

Definition 1 *An equilibrium for this economy is a collection of sequences for allocations* $\{N_t, c_t, K_t, H_t, n_t, l_t\}_{t=1}^{\infty}$, *prices* $\{R_t, r_t, w_t\}_{t=1}^{\infty}$, *and shocks* $\{A_t\}_{t=1}^{\infty}$ *such that:*

1. *Given sequences for prices and shocks, the sequence for* $\{N_t, c_t, K_t, H_t, n_t, l_t\}_{t=1}^{\infty}$ *solve the household problem [P2].*

2. *The allocation for* $\{N_t, K_t, H_t, l_t\}_{t=1}^{\infty}$*solve the firm problem [P1], given sequences for prices and shocks.*

3. *Markets clear, in particular:*

   - *Goods market:* $C_t + I_t + B\frac{[N_t - N_{t-1}]^2}{2} = A_t K_t^{\alpha}(l_t N_t H_t)^{1-\alpha}$.

   - *Labor markets:*

$$\begin{aligned} w_t &= (1 - \alpha)A_t K_t^{\alpha}(l_t N_t H_t)^{-\alpha} \\ w_t &= (1 - \alpha)A_t K_t^{\alpha}(N_t)^{-\alpha}(l_t H_t)^{1-\alpha} - B(N_t - N_{t-1}) \end{aligned}$$

   - *Capital market:* $r_t = \alpha A_t K_t^{\alpha-1}(l_t N_t H_t)^{1-\alpha} - \delta$

Since this is an economy without distortions, the second welfare theorem holds. The above arrangement is then one in a class of alternatives that would yield the same equilibrium allocation. We could, for instance, have the firm hire $l_t + n_t$ and decide how much to invest in human capital accumulation. The resulting wage rate would then reflect a lower marginal product of labor of the aggregated training and working hours. This motivates the interpretation of the equilibrium allocation as the solution to the social planner's problem. This problem is:

$$\max_{\{c_t, N_t, l_t, n_t, K_{t+1}, H_{t+1}\}_{t=0}^{\infty}} \quad \sum_{t=0}^{\infty} \beta^t (\log c_t + mN_t \frac{(n_t + l_t)^{1+\varphi}}{1+\varphi} + f\frac{N_t^{1+\phi}}{1+\phi}) \qquad [P3]$$

$$\begin{aligned} s.t. \quad 0 =& \ -H_{t+1} + H_t(1-\delta_H) + e\frac{(n_t N_t)^{1+\theta}}{1+\theta} \qquad (a) \\ 0 =& \ A_t K_t^{\alpha}(l_t N_t H_t)^{1-\alpha} + (1-\delta)K_t - K_{t+1} \qquad (b) \\ & -c_t - B\frac{[N_t - N_{t-1}]^2}{2} \end{aligned}$$

Let λ and μ be the Langrange multipliers for restrictions (b) and (a) respectively. Then the first order conditions are:

$$(c_t) \quad 0 = \frac{1}{c_t} - \lambda_t \qquad (3.8)$$

$$\begin{aligned} (N_t) \quad 0 =& \ -fN_t^{\phi} - m\frac{(n_t + l_t)^{1+\varphi}}{1+\varphi} + \lambda_t(1-\alpha)\frac{A_t K_t^{\alpha}(l_t N_t H_t)^{1-\alpha}}{N_t} \qquad (3.9) \\ & -\lambda_t B[N_t - N_{t-1}] + E_t\lambda_{t+1}B[N_{t+1} - N_t] + \mu_t e N_t^{\theta} n_t^{1+\theta} \end{aligned}$$

$$(l_t) \quad 0 = -mN_t(l_t + n_t)^{\varphi} + \lambda_t(1-\alpha)\frac{A_t K_t^{\alpha}(l_t N_t H_t)^{1-\alpha}}{l_t} \qquad (3.10)$$

$$(n_t) \quad 0 = -mN_t(l_t + n_t)^{\varphi} + \mu_t e N_t^{\theta+1} n_t^{\theta} \qquad (3.11)$$

$$(K_{t+1}) \quad 0 = -\lambda_t + \beta E_t\lambda_{t+1}\{\alpha\frac{A_{t+1}K_{t+1}^{\alpha}(l_{t+1}N_{t+1}H_{t+1})^{1-\alpha}}{K_{t+1}} + (1-\delta)\} \qquad (3.12)$$

$$\begin{aligned} (H_{t+1}) \quad 0 =& \ -\mu_t + \beta(1-\delta_H)E_t\mu_{t+1} \qquad (3.13) \\ & +\beta E_t\lambda_{t+1}(1-\alpha)\frac{A_{t+1}K_{t+1}^{\alpha}(l_{t+1}N_{t+1}H_{t+1})^{1-\alpha}}{H_{t+1}} \end{aligned}$$

$$\begin{aligned} (\lambda_t) \quad 0 =& \ A_t K_t^{\alpha}(l_t N_t H_t)^{1-\alpha} + (1-\delta)K_t - K_{t+1} - c_t \qquad (3.14) \\ & -B\frac{[N_t - N_{t-1}]^2}{2} \end{aligned}$$

$$(\mu_t) \quad 0 = \quad -H_{t+1} + H_t(1-\delta_H) + e\frac{(n_t N_t)^{1+\theta}}{1+\theta} \tag{3.15}$$

Equations 3.8- 3.15, along with standard transversality conditions for physical and human capital, define the equilibrium allocation.

3.4 Calibration

In this section we restrict this model quantitatively by choosing values for the four types of parameters:

- Preferences $\{\phi, \varphi, \beta\}$.
- Final good technology $\{\delta, \alpha, B\}$.
- Human capital technology $\{\delta_H, \theta\}$.
- Stochastic process for A $\{\rho, \sigma_\epsilon^2\}$.

These choices are summarized in table 3.9 [7].

We start with the preference parameters. In steady state, given a quarterly interest rate of 1% (see Kotlikoff and Summers [1981]), the discount factor β equals .99. In choosing values for the parameters $\{\varphi, \phi\}$ that govern the labor supply elasticities, we follow the discussion in Bils and Cho [1994]. In our model, the responses of labor input to changes in the wage rate have two components: changes in weeks worked and changes in hours per week. From the optimality condition on l in the household problem (see appendix C), the Frisch elasticity of hours per week is $1/\varphi$. Evidence from studies using microdata, reviewed by Pencavel [1986], indicates that this elasticity is no higher than .5, which gives a value of 2 for φ. The optimality condition on weeks N in the household problem provides an expression for the elasticity of weeks with respect to hours per week worked. Using Canadian data, Reilly [1994], calculates this elasticity at .6, so we set ϕ accordingly.

[7] The parameters $\{m, f, e\}$ are purely normalization parameters, and therefore not considered in the discussion that follows.

For the technology parameters (α, δ), we follow the literature in choosing $\alpha = .36$, equal to the share of capital in aggregate income, and $\delta = .018$, which together with a quarterly interest rate of 1% is consistent with a yearly capital-output ratio equal to 3 (Prescott [1986]). To determine a value for the parameter B, we use evidence on the size of labor adjustment costs. Burgess and Dolado [1989] report that, for firms in the UK, these costs amount to .25% of the quarterly payroll, which in our model translate to .17% of output. We set the parameter B so that $\frac{EB[N_t - N_{t-1}]^2}{EY_t} = .0017$.

To pick values for the human capital production technology, we can use results from the growing literature on the productivity effects of training. A number of papers attempt to identify the effect of different measures of training on labor productivity. While most of these papers use discrete measures of training, such as participation dummies (Bartel [1994], Black and Lynch [1996]), at least two papers use a quantitative right hand side variable: hours in training (Schonewille [2001]), and training days (Barrett and O'Connell [1999]); these results can be more readily interpreted in terms of the parameters of the model.

In our model, the elasticity of human capital with respect to training time (nN) is $\delta_H(1+\theta)$. Since the share of human capital augmented labor (lNH) in income is $(1-\alpha)$,, a 1% increase in training time translates into a $(1-\alpha)\delta_H(1+\theta)$ percent increase in labor productivity (Y/lN). since α has been picked, we need to choose values for δ_H and θ. Using British data (UK Labor Force Survey), Schonewille [2001] reports significant estimates of .04 for $\delta_H(1+\theta)$ with a measure of *hours in training* as the right hand side variable. Barrett and O'Connell [1999], using data on a nationally representative sample of 1000 Irish firms, find a point estimate of .014 for the elasticity of labor productivity with respect to the variable *training days/total employment* (table 2 in their paper). With $\alpha = .36$, this implies that $\delta_H(1+\theta) = .021$. These estimates are clearly an upper bound for the value of $\delta_H(1+\theta)$, since most estimates are not different from zero. We choose a small value of .0005 for $\delta_H(1+\theta)$, which implies $\delta_H = 0.0005$

and $\theta = -0.0095$. In the next section we will discuss how sensitive the results are to this choice.

It is unfortunate that we have no useful results that rely on US data. A survey of the evidence based on US data highlights the difficulty of estimating precisely the training parameters. Bartel [1994] finds that implementing a new training program increases firms productivity by as much as 41% over a 3 year span, but old training programs seem to have no effect. Bishop [1994] reports that new workers enrolled in formal OJT programs at their previous jobs were more productive by an amount equivalent to 9.5% of their wage, and that this effect disappears after six months. Black and Lynch [1996] are unable to find significant effects of their main training variables on firm sales.

We interpret the evidence as indicating that the elasticity of human capital with respect to training $\xi_{HC,training} = \delta_H(1+\theta)$ lies between zero and the estimate by Schonewille [2001], 0.04. Besides ensuring that $\{\delta_H, \theta\}$ satisfy this elasticity, we need to impose that these parameters are consistent with the steady state condition:

$$\delta_H = \frac{\frac{n}{l}(1-\beta)}{\beta(1+\theta) - \frac{n}{l}}.$$

We will choose two values for $\xi_{HC,training}$: $\{0.0002, 0.01\}$ and discuss the importance of choosing $\xi_{HC,training}$ accurately in the next section.

Finally, we set $\rho = .95$ and $\sigma_\epsilon^2 = .007$, borrowing these values from Bils and Cho [1994].

3.5 Results

We solve the model by linearizing the optimality conditions 3.8- 3.15 around the deterministic steady state, and solving for the recursive law of motion. We begin by describing the main mechanisms at work in the model, using the beginning of a boom as the starting point. As the economy takes off, driven by positive TFP shocks, the marginal product of labor increases, and firms adjust largely by increasing hours and only gradually adjusting weeks, a process that entails direct costs to firms. Moreover, given that the marginal disutility of working activities ($n_t + l_t$) has increased, households choose to devote less time to acquiring human capital. The response of n_t is large because the increase in hours of work l_t had to be large enough to compensate the slow adjustment of weeks (we may think employment). Since preferences are convex in hours-per-week of leisure ($1 - l_t - n_t$), the large increase in n_t implied a sharp increase in the marginal utility of this dimension of leisure. Figure 3.1, with impulse responses to a shock in A_t for weeks N_t, hours at work l_t and in training n_t, illustrates this process. Training has a large negative response to a TFP shock, and hours-at-work show a larger response to shocks than weeks, even though the elasticity of labor supply for hours-at-work (.5) is smaller than that for weeks (.6).

In the goods market, a positive shock increases output, consumption and investment (figure 3.2). As the effects of the shock on TFP die out, and capital is accumulated above its steady state level, the interest rate increases, reducing the incentives to invest and fostering the consumption of the now large capital stock.

The model cross correlations with output are shown in table 3.10. It is clear that, although the signs are all correct, this model fails to reproduce both the weak level of countercyclicality of training, and its leading indicator characteristics.

Table 3.11 shows the volatility of selected variables. With the calibration of table 3.9, the model successfully reproduces the extremely high levels of volatility of time in training, and its relative volatility with respect to output and investment, but not hours.

We now study the sensitivity of our results to changes in the parameter values. Table 3.12 shows the effects of changing one by one the parameter values of table 3.9, and guides us as to which are the important calibration choices in this model. We see that the model fails both in reproducing the correlation between training and gdp, and in leading gdp. We thus concentrate on the volatility of training.

Row 2 of table 3.12 show the effects of increasing $\xi_{HC,training}$ from the (arbitrary) baseline level of .00016. Calibrating this elasticity to values reported by Schonewille [2001] and Barrett and O'Connell [1999] (.04 and .02 respectively) would imply a depreciation factor δ_H higher than 1, but even with $\xi_{HC,training} = .01$ consistency with the steady state requires the factor $(1+\theta)$ to drop to .016 from .977 in the baseline. In this case, the standard deviation of training is lower than that of output, and training displays a *positive* correlation with output. Figure 3.5 shows the pairs $\{\theta, \xi_{HC,training}\}$ consistent with the steady state in a neighborhood of the baseline; it shows that θ, and therefore $\sigma_{training}$, is extremely sensitive to very small changes in $\xi_{HC,training}$ around the baseline: decreasing $\xi_{HC,training}$ to .00016 increases $\sigma_{training}$ to 177 (!), while increasing it to .0003 brings $\sigma_{training}$ down to .43.

It is clear that the choice of $\{\delta_H, \theta\}$, that determines how efficiently training time is converted into new human capital, is crucial for our results. To understand this point, it is useful to decompose $\xi_{HC,training}$ into $(1+\theta)$ and δ_H. While the first term indicates that a 1% change in the time spent in training translates into a $(1+\theta)$% change in human capital *investment*, δ_H is a scale factor that indicates how large is human capital investment with respect to the stock of human capital[8]. Even if a high $(1+\theta)$ can drive human capital investment to display large fluctuations with respect to its level, as it does in our simulations, this level is so small with respect to the stock of human capital that the ultimate effect of training on human capital and labor productivity is barely distinguishable from zero[9].

Changing the size of adjustment costs has predictable effects on the second moments of training (rows 3 and 4): increasing these costs to one percent of *gdp* increases the standard deviation of training by 22%, while bringing B to zero has a small negative impact on σ^2_{nN}.

While formal training programs of the type considered in this paper are an important

[8]Investment in human capital is $e\frac{(n_t N_t)^{1+\theta}}{1+\theta}$, and in steady state we have $\delta_H H = e\frac{(nN)^{1+\theta}}{1+\theta}$.

[9]A stochastic depreciation factor δ_H is a possible avenue to improve on the results of this model, as noted by Einarsson and Marquis [1998]. However, as we know of no procedure to directly estimate the series $\{\delta_H\}$, we believe that examining this possibility is of limited use at this point

source of human capital accumulation, learning by doing and other informal means to acquire skills are also available but difficult to measure. We examine in row 5 whether increasing the time devoted to skill acquisition has significant effects on the results, and find that increasing the share of time devoted to skill acquisition from .0158 to .02 increases the volatility of training time by 12%.

Varying the size of the labor elasticities (rows 6 and 7) has also quantitatively minor effects on σ^2_{nN}. While increasing $\xi_{N,wage}$ makes it less costly to adjust weeks than hours per week, increasing $\xi_{(n+l),wage}$ has the opposite effect. As explained in section 3.3, σ^2_{nN} increases in this model when weeks become costly to adjust with respect to hours per week.

3.6 Conclusion

In this paper we have first characterized the behavior of training at business cycles frequencies, and proposed a model to reproduce this behavior. We find that training has a clear countercyclical behavior, leads the cycle, and is extremely volatile, making it an important margin in allocating time at the frequencies considered. We also found that our model shows the potential to reproduce the volatility of training, but does not fare as well in reproducing the remaining stylized facts. Moreover, our calibration exercise has identified the elasticity of human capital with respect to training as the key parameter to reproduce this volatility. We now believe that studying the technology used to convert training into new human capital is of great importance in understanding human capital accumulation, and plan to work on this issue in the future.

Figure 3.1: Impulse responses: Time allocations.

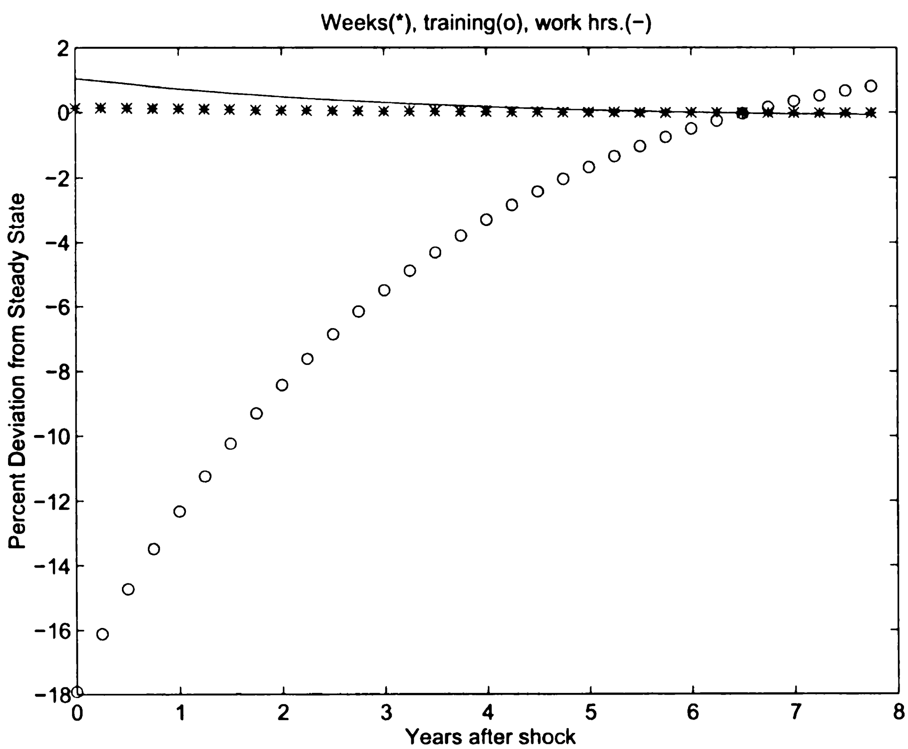


Figure 3.2: Impulse responses: GDP, C, I.

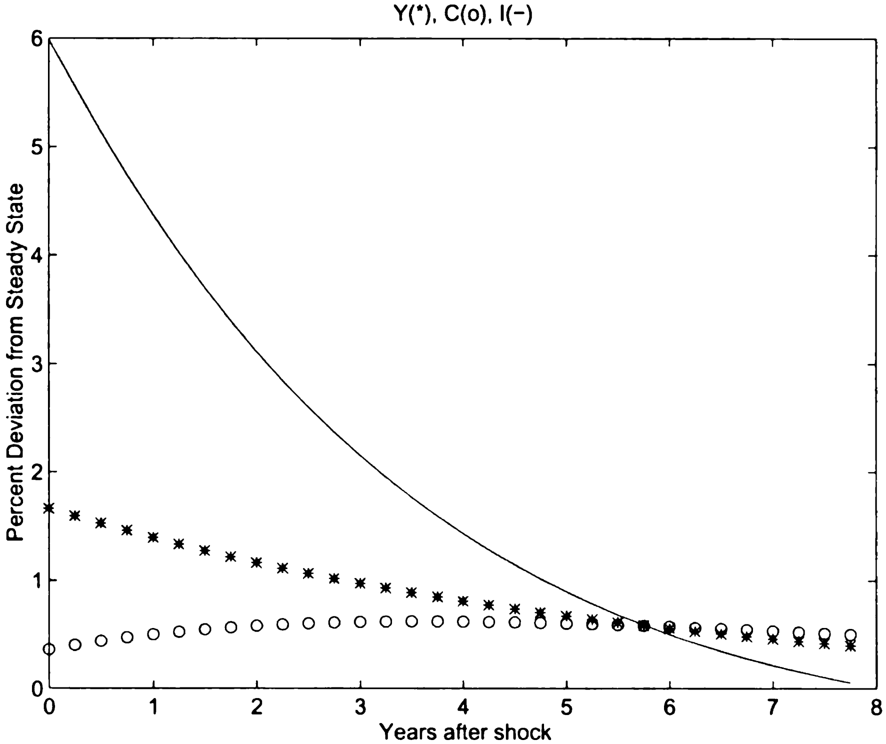
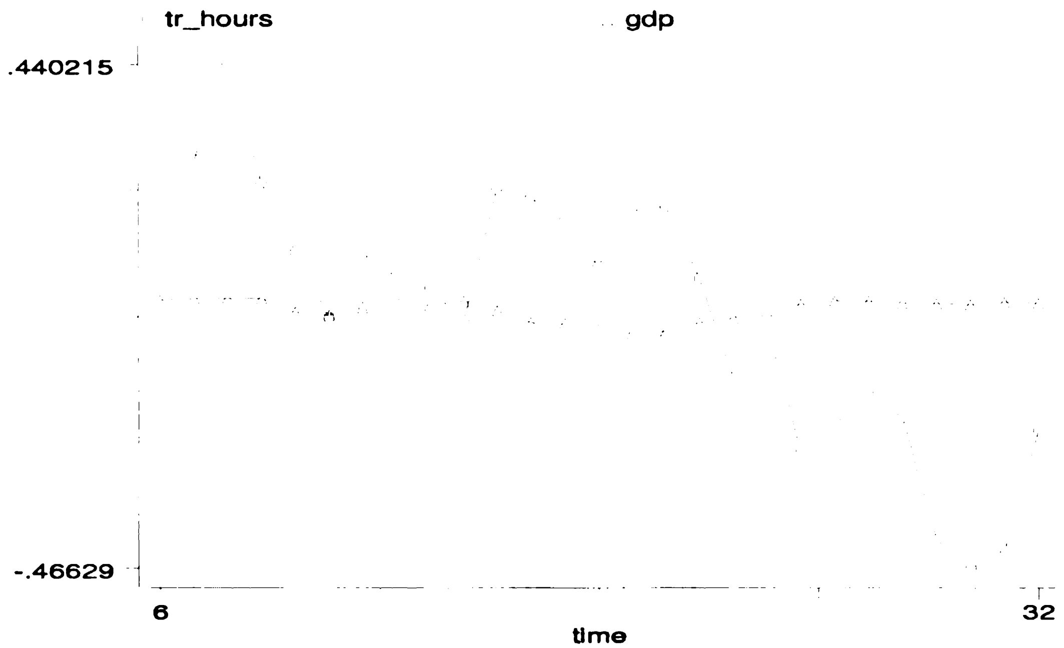
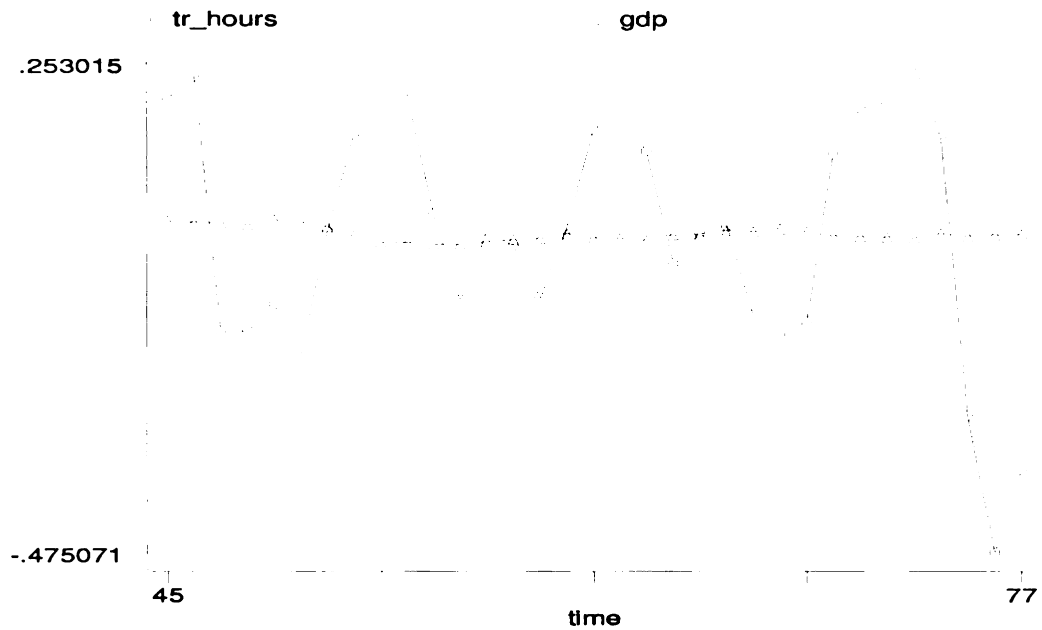


Figure 3.3: Training and GDP, period 1.



Agg. Training hours and gdp (centered), 1st period

Figure 3.4: Training and GDP, period 2.



Agg. Training hours and gdp (centered), 2nd period

Figure 3.5: $\{\theta, \xi_{HC,training}\}$ pairs consistent with the steady state

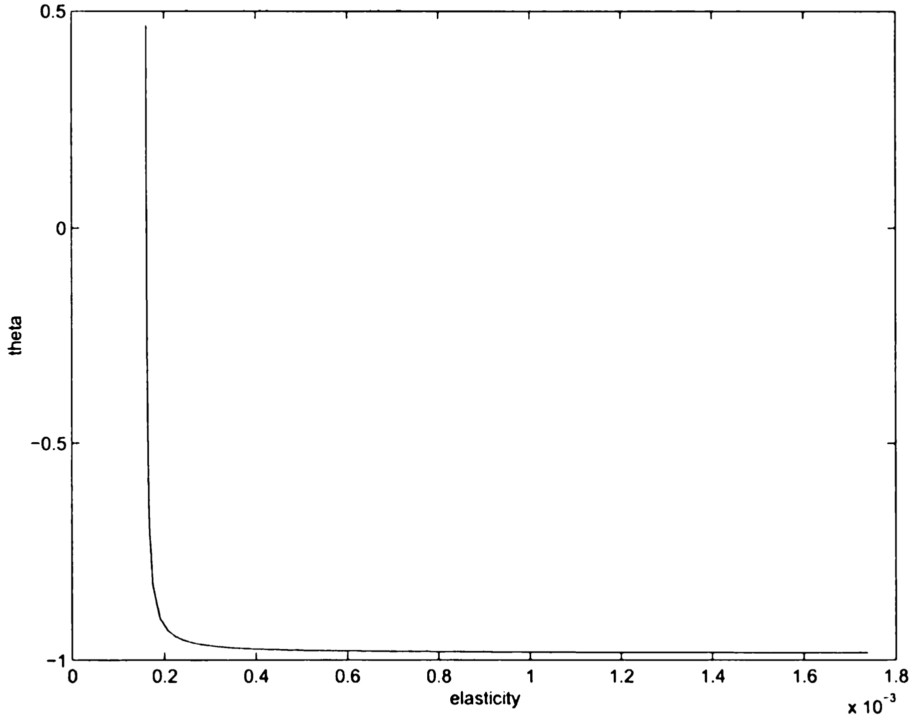


Table 3.1: Assignment of training program

	NLSY Classification	
	Years 1978-1986	Years 1988-1998
On The Job Training	Company Training	Formal Company Training run by Employer Seminars at work not run by employer
Off The Job Training	Business College Nurses Program Vocational Technical Institute Barber-Beauty Flight School Correspondence Other	Business School Vocational Technical Institute Correspondence Course Seminar or training program outside of work Vocational Rehabilitation Center Other
Dropped Observations	Apprenticeship	Apprenticeship Program Government Training Program

Table 3.2: Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
age	543128	28.236	5.379	14	41
hoff	542836	3.343	33.210	0	1248
hojt	542778	2.379	30.167	0	2496
job	543128	0.750	0.433	0	1
toff	543128	0.020	0.140	0	1
tojt	543128	0.016	0.126	0	1

Table 3.3: Description of variables

Variable	Description
age	age, in years
hoff	hours spent in off the job training programs
hojt	hours spent in on the job training programs
hagg	Hours spent in either off or on the job training
toff	Binary training variable, =1 if enrolled in a off the job training program
tojt	Binary training variable, =1 if enrolled in a on the job training program
tagg	Binary training variable, =1 if enrolled in either type of training program
HOJT	Natural log of time t aggregated hojt
HOFF	Natural log of time t aggregated hoff
HAGG	Natural log of time t aggregated hagg
TOJT	Time t mean tojt
TOFF	Time t mean toff
TAGG	Time t mean tagg
H	Index of total hours worked in the business sector, hp filtered
gdp	Log real gdp, hp filtered
I	Log real investment, hp filtered
prodh	Log real gdp per hour, hp filtered
prodp	Log real gdp per person, hp filtered

Table 3.4: Contemporaneous correlation of I, hours and productivity with GDP-Data

	Period 1	Period 2
I	0.91	0.86
H	0.97	0.87
Prodh	0.77	0.01
Prodp	0.79	0.39

Table 3.5: Contemporaneous correlations of training with GDP, I-Data

Table a. Correlations using time series

	Period 1		Period 2	
	gdp	I	gdp	I
TOFF	0.0026 (0.9898)	-0.2246 (0.2599)	-0.1307 (0.4684)	-0.0073 (0.9678)
TOJT	-0.3919* (0.0432)	-0.1924 (0.3364)	-0.3564* (0.0417)	-0.1957 (0.2750)
TAGG	-0.1033 (0.6083)	-0.2746 (0.1657)	-0.2622 (0.1405)	-0.1124 (0.5335)
HOFF	-0.2338 (0.2405)	-0.3992* (0.0391)	0.2555 (0.1512)	0.2577 (0.1477)
HOJT	-0.2020 (0.3124)	-0.1104 (0.5837)	-0.3860* (0.0265)	-0.4668* (0.0062)
HAGG	-0.2511 (0.2065)	-0.3912* (0.0436)	-0.2079 (0.2457)	-0.2766 (0.1191)

Table b. Correlations using pooled data

	Period 1		Period 2	
	gdp	I	gdp	I
toff	-0.0027 (0.2772)	-0.0072* (0.0039)	-0.0070* (0.0003)	-0.0011 (0.5871)
tojt	-0.0036 (0.1471)	-0.0022 (0.3713)	-0.0151* (0.0000)	-0.0074* (0.0001)
tagg	-0.0038 (0.1232)	-0.0074* (0.0031)	-0.0157* (0.0000)	-0.0060* (0.0019)
hoff	-0.0063* (0.0113)	-0.0092* (0.0002)	0.0013 (0.5184)	0.0039* (0.0421)
hojt	-0.0018 (0.4766)	-0.0018 (0.4788)	-0.0114* (0.0000)	-0.0110* (0.0000)
hagg	-0.0064* (0.0103)	-0.0089* (0.0003)	-0.0077* (0.0001)	-0.0055* (0.0043)

Table 3.6: Cross correlations of I, H and productivity with GDP-Data ($corr(x_t, gdp_{t+j})$)

Period 1

Lags	I	H	prodh	prodp
-6	-0.40	-0.18	-0.26	-0.39
-5	-0.34	-0.03	-0.38	-0.44
-4	-0.11	0.19	-0.37	-0.38
-3	0.2	0.46	-0.18	-0.18
-2	0.47	0.69	0.08	0.09
-1	0.76	0.89	0.41	0.45
0	0.91	0.97	0.77	0.79
1	0.74	0.80	0.72	0.78
2	0.49	0.53	0.60	0.68
3	0.27	0.25	0.48	0.53
4	0.02	0.00	0.27	0.34
5	-0.10	-0.14	0.11	0.20
6	-0.10	-0.21	0.04	0.12

Period 2

Lags	I	H	prodh	prodp
-6	-0.47	0.03	-0.46	-0.70
-5	-0.34	0.24	-0.62	-0.75
-4	-0.15	0.46	-0.67	-0.65
-3	0.06	0.64	-0.67	-0.51
-2	0.38	0.78	-0.52	-0.25
-1	0.68	0.86	-0.30	0.04
0	0.86	0.87	0.01	0.39
1	0.77	0.71	0.06	0.42
2	0.64	0.53	0.09	0.42
3	0.44	0.32	0.08	0.32
4	0.29	0.13	0.09	0.25
5	0.10	-0.05	0.07	0.14
6	-0.05	-0.22	0.14	0.11

Table 3.7: Cross correlations of training with GDP-Data ($corr(x_t, gdp_{t+j})$)

Period1

Lags	TOJT	TOFF	TAGG	HOJT	HOFF	HAGG
-6	-0.04	0.28	0.26	0.24	0.26	0.32
-5	-0.29	0.27	0.19	0.05	0.18	0.19
-4	-0.41	0.22	0.11	-0.09	0.08	0.07
-3	-0.35	0.16	0.06	-0.18	-0.01	-0.03
-2	-0.37	0.11	0.01	-0.23	-0.07	-0.10
-1	-0.36	0.05	-0.05	-0.23	-0.13	-0.16
0	-0.39	0.00	-0.10	-0.20	-0.23	-0.25
1	-0.51	-0.05	-0.18	-0.27	-0.27	-0.32
2	-0.50	-0.14	-0.28	-0.38	-0.30	-0.37
3	-0.40	-0.22	-0.32	-0.45	-0.26	-0.35
4	-0.25	-0.14	-0.21	-0.44	-0.16	-0.25
5	-0.09	-0.06	-0.08	-0.26	-0.04	-0.10
6	0.19	-0.05	0.00	0.00	-0.01	-0.01

Period 2

Lags	TOJT	TOFF	TAGG	HOJT	HOFF	HAGG
-6	-0.23	-0.33	-0.29	0.30	-0.22	0.16
-5	-0.27	-0.24	-0.27	0.28	-0.07	0.19
-4	-0.30	-0.17	-0.25	0.21	0.09	0.19
-3	-0.37	-0.21	-0.31	0.05	0.15	0.09
-2	-0.41	-0.20	-0.32	-0.18	0.16	-0.09
-1	-0.35	-0.16	-0.27	-0.30	0.19	-0.18
0	-0.36	-0.13	-0.26	-0.39	0.26	-0.21
1	-0.33	-0.13	-0.25	-0.42	0.23	-0.24
2	-0.23	-0.08	-0.16	-0.36	0.28	-0.17
3	-0.03	0.04	0.00	-0.19	0.36	0.01
4	0.12	0.14	0.13	-0.07	0.44	0.14
5	0.24	0.21	0.23	0.05	0.39	0.21
6	0.31	0.23	0.29	0.10	0.29	0.19

Table 3.8: Standard deviations-Data

	Period 1	Period 2
gdp	0.020	0.010
I	0.096	0.048
H	0.019	0.015
prodh	0.009	0.008
prodp	0.014	0.009
TOFF	0.006	0.005
TOJT	0.002	0.006
TAGG	0.006	0.010
HOFF	0.270	0.168
HOJT	0.274	0.257
HAGG	0.230	0.177

Table 3.9: Baseline parameter values

ϕ	2.46
φ	2
β	.99
δ	.018
α	.36
B	13,450
δ_H	.0002
θ	-.0228
ρ	.95
σ_ϵ^2	.00712

Table 3.10: Cross correlations with output-Model ($corr(x_t, gdp_{t+j})$)

Lags	I	Hours	Training hrs.	Labor Prod.
-5	-.05	.01	.11	.1
-4	.05	.11	.01	.19
-3	.26	.32	-.2	.38
-2	.43	.49	-.38	.54
-1	.66	.70	-.62	.73
0	.99	.99	-.98	.99
1	.72	.73	-.72	.68
2	.54	.54	-.55	.46
3	.39	.38	-.41	.29
4	.20	.19	-.22	.08
5	.10	.09	-.13	-.01

Table 3.11: Standard deviations-Model

Var.	σ
Y	.012
I	.043
Hours	.0024
Training hrs.	.159
Labor prod.	.01

Table 3.12: Sensitivity analysis

Calibration	σ_{nN}	$corr(gdp_t, nN_t)$	$argmax_j\{corr(nN_t, gdp_{t+j})\}$
Baseline	.159	-.98	0
$\xi_{HC,training} = .01$	.0016	1	0
Adjustment costs are 1% of gdp	.194	-.98	0
No adjustment costs	.153	-.99	0
$\frac{n}{l} = .02$	.179	-.99	0
$\xi_{N,wage} = .7$	.137	-.98	0
$\xi_{(n+l),wage} = .6$	.175	-.99	0

Appendix A

Numerical methods.

To simulate the stochastic OLG economy we use a standard dynamic programming method. To use this method we discretize the state space. In particular, a seven-state discrete approximation to the labor endowment process is used. This approximation is done with the method described in Tauchen [1986] to find a markov transition matrix for continuous stochastic processes.

A.1 Solution method for the stochastic OLG model

The stochastic OLG model is solved using a variation of the İmrohoroğlu et al. [1995] algorithm to compute the policy functions. Then a Monte Carlo simulation is performed to compute some of the statistics. The algorithm to compute the policy functions can be summarized as follows,

1. Make an initial guess for the discount factor β and the level of bequests q_0. For β define $b = [b_1, b_2]$ (with $b1 < b2$), and let $\beta = (b_1 + b_2)/2$.

2. Starting from age J, and given prices consistent with the calibration, compute the value functions and associated policy functions that solve $(P1)$ by a single backward recursion.

3. Define the distribution of assets and shocks for the first cohort $j = 1$), and using the policy functions and the transition matrix for the shock, compute recursively

the distribution of assets and shocks for ages $2, 3 \ldots J$.

4. Using the distribution of assets for all cohorts, calculate the implied levels of aggregate capital and bequests K_1, and q_1.

5. Compare K_1 with the level implied by the calibration $K*$. If convergence fails, adjust bequests with $q_0 = q_1$,and β by letting $b_1 = \beta$ if $K_1 < K*$, and $b_2 = \beta$ if $K_1 > K*$.

For both solution methods the grid size for assets is set to 5 -10% of average asset holdings, and the convergence criterion is set to .003. Convergence occurs generally in 7-9 iterations. Using the policy functions, we then simulate paths for 10.000 agents and compute the statistics. The original version of this algorithm is discussed in İmrohoroğlu et al. [1999].

A.2 Solution method for the deterministic OLG model

We solve the deterministic version of the OLG model by a method presented in Rios-Rull [1999]. It is a 'shooting' method that uses the fact that the Euler equation can be expressed as:

$$\begin{aligned} a_t = \quad & \{\frac{1 + (1+r)(\beta(1+r))^{-1/\theta}}{1+r}\}a_{t+1} + \{-\frac{(\beta(1+r))^{-1/\theta}}{1+r}\}a_{t+2} \\ & +\{\frac{(w_{t+1}+q)(\beta(1+r))^{-1/\theta} - (w_t + q)}{1+r}\} \end{aligned}$$

1. Set technology and preference parameters, $\{a1 = a, \alpha, \beta, \theta, \delta\}$ and guess levels of aggregate capital K_0 and per capita bequests q_0.

2. Using K_0, and given the production function $F(K, L) = AK^{\alpha}L^{1-\alpha}$, find prices $\{r, w\}$.

3. Using the fact that $a_{t+1} = 0$, guess a value for a_T, and compute $\{a_t\}_{t=1}^{T}$ backwards using the Euler equation.

4. Check whether $a_1 = a$, otherwise go back to 3 and modify guess for a_T.

5. Calculate aggregate capital K_1 and per capita bequests q_1 using $\{a_t\}_{t=1}^{T}$. If convergence fails, set $q_0 = q$ and $K_0 = K_1$, and go back to 1.

Appendix B

Standard RBC model with human capital

Model

Utility

$$U = E_t \sum_{t=0}^{\infty} \beta^t (\log c_t - m \frac{(1 - l_t - n_t)^{1-\theta}}{1-\theta})$$

Resource constraint

$$0 = A_t K_t^{\alpha} (H_t l_t)^{1-\alpha} - c_t - K_{t+1} + (1-\delta) K_t$$

Law of motion for human capital

$$0 = -H_{t+1} + H_t(1 - \delta_H) + e \frac{(n_t)^{\gamma}}{\gamma}$$

Stochastic process for A

$$A_{t+1} = \rho A_t + \epsilon_t \qquad \epsilon_t \sim N(0, \sigma_{\epsilon}^2).$$

Table B.1: Variable description

H	Human Capital
K	Capital
β	Discount factor
c	Consumption
l	Hours at work
n	Hours in skill acquisition
A	TFP shock
δ	Rate of depreciation of K
δ_H	Rate of depreciation of H

Appendix C

First order conditions in the household problem [P2]

Problem:

$$\max_{\{c_t, N_t, l_t, n_t, K_{t+1}, H_{t+1}\}_{t=0}^{\infty}} \quad \sum_{t=0}^{\infty} \beta^t (\log c_t + mN_t \frac{(n_t + l_t)^{1+\varphi}}{1+\varphi} + f\frac{N_t^{1+\phi}}{1+\phi}) \qquad [P2]$$

$$\begin{aligned} s.t. \quad 0 = & \quad -H_{t+1} + H_t(1-\delta_H) + e\frac{(n_t N_t)^{1+\theta}}{1+\theta} \\ 0 = & \quad w_t H_t N_t l_t + (1+r_t)k_t - c_t - k_{t+1}. \end{aligned}$$

Lagrangian:

$$\begin{aligned} \mathcal{L} = \quad E_t \sum_{t=0}^{\infty} \beta^t \{ & \quad \log c_t + mN_t \frac{(n_t + l_t)^{1+\varphi}}{1+\varphi} + f\frac{N_t^{1+\phi}}{1+\phi} \\ & + \mu_t[H_{t+1} - H_t(1-\delta_H) - e\frac{(n_t N_t)^{1+\theta}}{1+\theta}] \\ & + \lambda_t[w_t H_t N_t l_t + (1+r_t)k_t - c_t - k_{t+1}]\} \end{aligned}$$

First Order Conditions:

$$\begin{aligned} (c_t) \quad 0 = & \quad \frac{1}{c_t} - \lambda_t \\ (N_t) \quad 0 = & \quad -fN_t^{\phi} - m\frac{(n_t + l_t)^{1+\varphi}}{1+\varphi} - \lambda_t w_t H_t l_t + \mu_t e N_t^{\theta} n_t^{1+\theta} \\ (l_t) \quad 0 = & \quad mN_t(l_t + n_t)^{\varphi} + \lambda_t w_t H_t N_t \\ (n_t) \quad 0 = & \quad -mN_t(l_t + n_t)^{\varphi} + \mu_t e N_t^{\theta+1} n_t^{\theta} \\ (K_{t+1}) \quad 0 = & \quad -\lambda_t + \beta E_t \lambda_{t+1}(1 + r_{t+1}) \end{aligned}$$

$$
\begin{aligned}
(H_{t+1}) \quad 0 = &\quad -\mu_t + \beta(1-\delta_H)E_t\mu_{t+1} - E_t\lambda_{t+1}w_{t+1}N_{t+1}l_{t+1} \\
(\lambda_t) \quad 0 = &\quad w_t H_t N_t l_t + (1+r_t)k_t - c_t - k_{t+1} \\
(\mu_t) \quad 0 = &\quad -H_{t+1} + H_t(1-\delta_H) + e\frac{(n_t N_t)^{1+\theta}}{1+\theta}
\end{aligned}
$$

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