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Chapter 1

General Introduction

Many important questions in macroeconomics, in particular policy-related ones, call for quantitative answers. Quantitative macroeconomists address such questions by applying their models to real world economies. They use calibrated models as laboratories and employ computational experiments to study the issue of interest. Kydland and Prescott (1996, p. 69) describe this approach as follows:

> *"In a computational experiment, the researcher starts by posing a well-defined quantitative question. Then the researcher uses both theory and measurement to construct a model economy that is a computer representation of a national economy. A model economy consists of households, firms and often a government. The people in the model economy make economic decisions that correspond to those of their counterparts in the real world. ... The researcher then calibrates the model economy so that it mimics the world along a carefully specified set of dimensions. Finally, the computer is used to run experiments that answer the question."*

This dissertation consists of three essays that deal with macroeconomic topics and are linked by a common method, the computational experiment. The essays give answers to quantitative questions on the post-war U.S. macroeconomy. Two essays evaluate episodes of contemporary economic policy: namely, the role of the Ford/Carter deregulation for the productivity growth resurgence in the early 1990s and the contribution of the Taxpayer Relief Act of 1997 to the housing boom of the 2000s. Another essay deals with the connection between business cycle fluctuations and economic growth during the post-war period. The essay also contributes to a discussion about policy proposals of countercyclical R&D subsidies. In the remainder, I provide a brief summary of each essay.

In Chapter 2, which is co-authored with Georg Dürnecker, we study macroeconomic effects of the Ford/Carter deregulation of U.S. product markets. This essay is motivated by the fact that the U.S. economy experienced a significant and persistent rise in the rate of investment-specific technical change (ISTC) in the early 1980s. This acceleration which was mainly due to the intensified adoption and usage of new information and communication technologies has boosted economic growth in recent decades. The macroeconomic consequences of faster ISTC are well understood. However, little is known about its origins. In this essay, we argue that the U.S. product market deregulation, as initiated by the Ford/Carter Administrations in the late 1970s, contributed to the acceleration of ISTC. We document that this acceleration is especially pronounced for deregulated industries which also show faster labor productivity growth. We develop a multi-sector general equilibrium model of endogenous ISTC that features imperfect competition and a technology choice by firms. The framework is used to study industry and macroeconomic effects of competition policy and to quantitatively assess to what extent the Ford/Carter regulatory reforms can account for the observed acceleration of ISTC and the subsequent divergence of labor productivity across U.S. industries. The quantitative experiment generates more than two thirds of the acceleration in ISTC for the deregulated industries and about a quarter of the divergence of labor productivities across industries.

In Chapter 3, I investigate the effects of business cycle fluctuations on R&D activities and long-run growth. The question is whether recessions really foster economic growth. On the one hand, an opportunity cost argument suggests that recessions are ideal times to undergo R&D aimed at enhancing productivity. On the other hand, empirical measures of U.S. R&D activity are procyclical. To resolve this discrepancy, I propose a calibrated real business cycle model featuring R&D-based growth through horizontal innovations. The model is used to quantitatively analyze growth implications of business cycle shocks under various specifications of the R&D process. I find that the specification of R&D inputs is essential for the cyclicality of R&D activities. First, the popular knowledge-driven specification of R&D has a hard time to generate both procyclical R&D investment and procyclical R&D labor at the same time. Second, the calibrated multi-input specification generates procyclical R&D investment as well as procyclical employment of scientists and engineers. In addition, the endogenous growth mechanism gives rise to amplification of business cycle shocks. Thus, booms promote productivity growth.

In Chapter 4, which is joint work with Tom Krebs and Mark Wright, we ask to what extent government policy, namely the U.S. tax reform of 1997, has contributed to the recent boom in the U.S. residential housing market. In the period 1997-2007, the following developments took place in the U.S.: first, house prices and mortgage volume increased strongly, but mortgage volume increased faster than house prices so that the loan-to-value ratio increased. Second, delinquency rates fell. In this essay, we develop a macro model with a housing sector to conduct a quantitative analysis of the 1997 tax reform. First, using a calibrated version of the model economy, we argue that the Taxpayer Relief Act of 1997, which eliminated taxes on capital gains from the sale of residential housing for most households, can account for a substantial part of these developments in the U.S. housing market. With higher after-tax gains from the purchase of housing, agents are less likely to default on their mortgages which increases both the demand and supply of credit for housing and hence helps us understand the simultaneous increase in the loan-to-value ratio and decline in mortgage default rates observed over the period 1997-2007. Second, we consider a hypothetical tax reform that taxes capital gains on home sales at the same rate that all other capital gains are taxed without any exemptions. We find that this tax reform would have reduced house prices, mortgage debt, and the loan-to-value ratio. Altogether, implementing this repeal of housing tax-breaks instead of the Taxpayer Relief Act of 1997 would have dampened the observed rise in house prices by about 20 percent.

Lastly, let me remark that all chapters of this Ph.D. thesis are written as independent essays. Each chapter contains its own introduction and appendices that provide supplementary materials such as additional graphs and tables as well as data sources. Hence, the essays can be read in any order. References from all three chapters can be found in one bibliography at the end of this dissertation.

Chapter 2

Macroeconomic Effects of the U.S. Product Market Deregulation[1]

2.1 Introduction

In the early 1980s the U.S. economy experienced a substantial and persistent rise in the rate of investment-specific technical change (ISTC). Evidence provided by Cummins and Violante (2002); Krusell, Ohanian, Ríos-Rull, and Violante (2000); Pakko (2002b,c); and others suggests that until the 1970s investment-specific technical change was fairly stable between 3% and 4% but it started to accelerate in the early 1980s leading to annual rates of more than 6% in the subsequent decades.[2] This acceleration in ISTC was the main driver of the U.S. growth resurgence in the 1990s.[3] However, little is known about its origins.

At about the same time, labor productivity across U.S. industries started to diverge: industries of the communications, energy, finance, and transportation sectors experienced a considerable hike in productivity growth. On average, their growth rate rose by more than 3% percentage points in the 1980s and 1990s while other private industries continued to grow at an annual rate of 1%. Consequently, those industries contributed substantially to the U.S. growth resurgence. Remarkably, communications, energy, finance, and transportation were prime target of the regulatory reforms of the

[1]This chapter is joint work with Georg Dürnecker.

[2]Structural-break tests by Pakko (2005) provide overwhelming evidence for a breakpoint in 1983.

[3]E.g., Cummins and Violante (2002); Martínez, Rodríguez, and Torres (2010); Pakko (2002c, 2005).

Ford and Carter Administrations.

This observation suggests the question whether a change in competition policy is able to explain a such rise in productivity growth. To this end, we propose a general equilibrium multi-sector model of endogenous investment-specific technical change and study industry and macroeconomic effects of competition policy. We use a version of the model economy calibrated to U.S. data to assess quantitatively to which extent the Ford/Carter regulatory reforms can account for the observed acceleration of ISTC and the subsequent divergence of labor productivity in the U.S.

The present study contributes in three respects: first, we empirically document that those industries that were deregulated in the late 1970s performed fundamentally differently in the subsequent decades than those not directly affected by the Ford/Carter reforms. In particular, deregulated industries experienced faster investment-specific technical change and substantially higher labor productivity growth than the rest of the U.S. economy. One reason is that they reduced their technological backwardness by replacing old capital with state-of-the-art equipment.

Second, we provide a general equilibrium multi-sector model framework to investigate industry and macroeconomic effects of competition policy. In the model, deregulation of entry restrictions encourages new competitors to enter the products market. Intensified competition leads to lower prices and expanding production. Firms install additional capital which fosters R&D activities to improve investment goods. Investment-specific technical change accelerates and, hence, labor productivity grows at a higher rate.

Third, our quantitative experiment finds that about 70% of the observed acceleration in ISTC for the deregulated industries and almost a fifth of the overall acceleration for the U.S. economy can be explained by the Ford/Carter reforms. Furthermore, deregulation leads to a divergence of labor productivities across industries, as in the data.

In a seminal paper, Greenwood, Hercowitz, and Krusell (1997) find that the introduction of new, more efficient capital goods is the major source of U.S. post-war growth. Besides, the observed acceleration in ISTC called forth vivid interest. A large literature discusses its consequences for various macroeconomic outcomes. Among the more recent contributions are Krusell, Ohanian, Ríos-Rull, and Violante (2000) studying the rise in the skill premium; Hornstein, Krusell, and Violante (2007) focusing on policy outcomes; Duernecker (2013) studying the divergence of unemployment rates; and Marimon and Zilibotti (1999) addressing the rise in labor market frictions. This essay proposes a cause.[4]

In addition, the current study contributes to the literature investigating the macroeconomic effects of deregulation such as Blanchard and Giavazzi (2003) examining the interaction of product market and labor market regulations, Bertinelli, Cardi, and Sen (2013); Ebell and Haefke (2009); Fang and Rogerson (2011) studying effects of deregulation on labor market outcomes, and Alesina, Ardagna, Nicoletti, and Schiantarelli (2005); Barone and Cingano (2011); Dawson and Seater (2013); Nicoletti and Scarpetta (2003) estimating growth effects. One of the main differences is that our essay considers a multi-industry framework similar to Ngai and Samaniego (2009) which allows us to model industry-specific deregulation and investigate inter-industry input-output linkages.

It is also related to the large literature on the relationship between competition and innovation (e.g. Klette and Griliches (2000); Vives (2008) in partial equilibrium, and Aghion, Bloom, Blundell, Griffith, and Howitt (2005); Aghion, Harris, Howitt, and Vickers (2001) in general equilibrium). However, these papers focus on in-house R&D and process innovation by product market firms while this essay considers R&D activities that are outsourced and lead to investment-specific technical change.

The rest of this essay is organized as follows: Section 2 gives a summary of the regulatory reforms under presidents Ford and Carter. Section 3 presents a set of macroeconomic developments of the U.S. economy during the 1980s and 1990s. Section 4 sets up the model. Section 5 calibrates the model, describes our policy experiment, and reports the findings. Section 6 summarizes the essay and offers some concluding comments.

[4]So far, little is known about the origins of this acceleration in ISTC. Boucekkine, del Río, and Licandro (2003), who a study two-sector learning-by-doing model, find that an exogenous change in learning efficiency favoring investment goods over consumption goods could explain faster ISTC. However, they do not provide an explanation for such an ”technological reassignment” in the late 1970s.

2.2 U.S. Product Market Deregulation

In the late 1970s and early 1980s a wave of regulatory reforms affected the U.S. economy. Within less than a decade presidents Ford, Carter, and – to a lesser extent – Reagan liberalized virtually every previously regulated sector of the American economy. Originating from a novel attitude towards economic regulation, this regulatory reform movement marked an extraordinary turning point in U.S. economic policy.[5]

The reforms addressed both the nature and extent of regulation. Output restrictions were given up, rate-of-return regulation came to an end, price controls were abolished, licensing was replaced by free entry, and regulatory agencies like the Civil Aeronautics Board or the Federal Power Commission were closed down (Joskow and Noll, 1994; Weiss and Klass, 1986). Most affected by this liberalization of regulatory restrictions are the following industries: communications, energy, finance, and transportation. Table 2.1 provides an overview of those regulatory reforms by industry. Joskow and Noll (1994); Weiss and Klass (1986); Winston (1993, 1998) portray the regulatory changes in detail. Distilling their accounts of deregulation, we conclude that in the 1970s entry restrictions were an omnipresent measure of regulation. Subsequently, groundbreaking regulatory changes have altered industry structures, operation practices, and pricing conditions.

Basically, the market conditions under which about one sixth of U.S. GDP were produced changed completely. But these industries did not only produce 16% of GDP and employ 12% of the labor force before the reforms took place. Rather, about 55% of their output was input to other U.S. industries, making up 22% of total intermediate inputs. This suggests that deregulated industries were well connected to the whole U.S. economy. Hence, input-output relationships might be an important channel for spillover effects.

The fact that liberalizing operations, pricing, entry and exit has permeated broad fields of the American economy is also reflected in the OECD regulatory indicators. Consisting of five sub-indicators, the OECD constructs a measure for the intensity of

[5] Winston (1993, p. 1263) assesses the economic deregulation of American industry as *"one of the most important experiments in economic policy of our time"*.

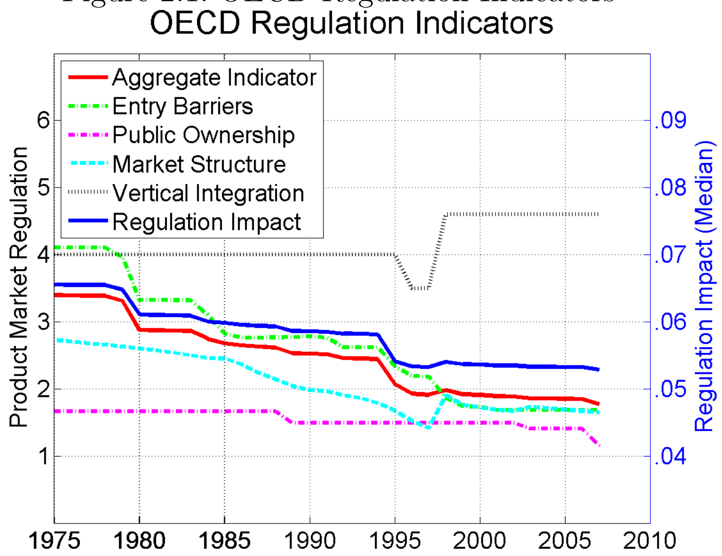
Table 2.1: Regulatory reform

Industry	Regulatory Agencies[a]	Regulatory Changes	Major Initiatives
Airlines	Civil Aeronautics Board (1985)	phased out route regulation, eliminated regulations on fares	CAB initiatives (mid 1970s), Airline Deregulation Act (1978)
Passenger Transit	Interstate Commerce Commission (1996)	relaxed entry controls, freed up rates, abolished some types of collective rate making	Federal Bus Regulatory Reform Act (1982)
Shipping	Federal Maritime Commission	permitted independent rate making	Ocean Shipping Act (1984)
Road transport	Interstate Commerce Commission (1996), state agencies	rates could be set independently but had to be filed, entry restrictions were eliminated	ICC initiatives (late 1970s), Motor Carrier Reform Act (1980)
Railroads	Interstate Commerce Commission (1996)	liberalization of rates and contracting, permission to abandon routes and of mergers	ICC initiatives (late 1970s), Railroad Revitalization and Regulatory Reform Act (1976), Staggers Rail Act (1980)
Telecommunications	Federal Communications Commission, state agencies	industry restructuring, deregulation of equipment prices and long distance rates, open entry	Agency initiatives, Court Decisions (by mid 1970s), Execunet Decision (1977), AT&T Settlement (1982)
Cable Television	Federal Communications Commission, municipalities	price deregulation	FCC initiatives (late 1970s), Cable Television Deregulation Act (1984)
Brokerage	Securities and Exchange Commission	outlawed fixed brokerage rates	Securities Acts Amendments (1975)
Banking	Federal Savings and Loan Insurance Corporation (1989), Federal Deposit Insurance Corporation, Federal Reserve Board, Comptroller of the Currency	eliminated interest rate ceilings, deregulated deposit services, liberalized investment portfolios, permitted interstate bank branching and commercial bank ownership of subsidiaries in investment banking	Depository Institutions Deregulation and Monetary Control Act (1980), Garn-St. Germain Act (1982), Financial Institutions Reform, Recovery, and Enforcement Act (1989)
Petroleum	Federal Energy Administration	phased out controls on domestic crude oil prices	executive orders (beginning in 1979)
Natural Gas	Federal Power Commission (1977), Federal Energy Regulatory Commission, state agencies	deregulation of field prices, created open access to interconnected grid, unbundling of gas supplies, contractual revisions	Agency initiatives, Natural Gas Policy Act (1978), Fuel Use Act (1978)
Electric power	Federal Energy Regulatory Commission, state agencies	deregulation of field prices, created open access to interconnected grid, unbundling of gas supplies, contractual revisions	Public Utility Regulatory Act (1982)

[a] Year of dissolution in parentheses.

Sources: Joskow and Noll (1994); OECD (1999); Weiss and Klass (1986); Winston (1993, 1998)

Figure 2.1: OECD Regulation Indicators



NOTES: The Regulation Impact Indicator is computed at the industry level. We illustrate the median value of the Regulation Impact Indicator for every year.
DATA SOURCE: OECD, Product Market Regulation Database.

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product market regulation in the energy, communications, and transportation sector (Conway and Nicoletti, 2006).[6] Furthermore, the OECD provides a Regulation Impact Indicator measuring how other industries are affected by regulation in the energy, communications, and transportation sector through input-output relations.

Figure 2.1 illustrates these indicators. Both the aggregate Product Market Regulation Indicator and the Regulation Impact Indicator show a declining trend with two pronounced drops: the Ford/Carter/Reagan and the Clinton deregulation. The three sub-indicators for public ownership, market structure, and entry barriers show a similar evolution. In particular, entry barriers were substantially reduced, most notably around 1979 and 1984.

Ebell and Haefke (2009), for example, estimate hat entry costs in the late 1970s were about the ninefold of their late-1990s level.[7] Finally, an international comparison of the OECD indicators reveals that the U.S. were in the vanguard of the deregulation

[6]The scale from 0 to 6 reflects increasing restrictiveness of regulatory provisions. The sub-indicators are: entry barriers, public ownership, market structure, vertical integration, and price controls.

[7]Following a similar approach, Bertinelli, Cardi, and Sen (2013) estimate a relationship between the aggregate PMR indicator and price-cost margins. Their results suggest that the average price-cost margin in U.S. declined by 5.3 percentage points since the late 1970s to about 1.5.

movement.

2.3 Macroeconomic Developments

This section documents the long-run development of several macroeconomic outcomes in the U.S. The main message is that those industries that were deregulated in the late 1970s experienced a fundamentally different evolution subsequently than those not directly affected by the Ford/Carter reforms.

One development which has attracted a lot of attention in the literature is the acceleration of investment-specific technical change in the U.S.[8] It is a well-documented fact that there was a substantial and persistent rise in the rate of ISTC by about 2.5 percentage points in the early 1980s (Cummins and Violante, 2002; Pakko, 2002c, 2005).[9] Reporting the Cummins and Violante (2002) data, the first row of Table 2.2.A illustrates this acceleration.

In addition, we establish that the acceleration of ISTC was more powerful in deregulated industries than in the rest of the U.S. economy. To this end, we construct measures of ISTC at the industry level which aggregate asset-specific ISTC rates into industry-level rates (Table 2.2).[10] Between 1960 and 1975 the ISTC rate for deregulated industries (3.8% p.a.) was lower than for all other private industries (4.4% p.a.). However, during the 1980s and 1990s deregulated industries experienced an acceleration by 3.5 percentage points to 7.3% per year, while all other industries increased their ISTC rate by 2.1 percentage points.[11]

Interestingly, the sources of this acceleration differ as well, as the decomposition in Table 2.2.B reveals. Deregulated industries attained high rates of ISTC mainly by replacing their old equipment capital with state-of-the-art vintages while keeping their

[8] Cummins and Violante (2002); Greenwood, Hercowitz, and Krusell (1997), for example, find that investment-specific technical change is one of the major determinants of U.S. productivity growth. They quantify the contribution of ISTC to post-war growth to approximately 60%.

[9] Table 2.9 in the Appendix gives a broad overview of the literature documenting this rise in ISTC.

[10] The aggregation method, a Tornqvist procedure, is described in Appendix 2.C.1.

[11] We run panel-data regressions to estimate the causal effect of the Ford/Carter deregulation on the industry rate of ISTC (see Appendix 2.A). The difference-in-difference estimate attributes an acceleration of 1.3 percentage points to the regulatory reforms. However, we regard this estimate to be a lower bound since the regression analysis does not allow for spillover effects. Nevertheless, the regression analysis confirms that deregulated industries experienced a faster acceleration of ISTC than the rest of the U.S. economy.

Table 2.2: Average annual rate of ISTC

	A: current investment shares[a]				B: 1975 investment shares[b]		
	1960-75	1980-89	1990-2000	Δ	1980-89	1990-2000	Δ
aggregate	4.1	5.0	6.9	+2.8	3.7	4.9	+0.8
de/regulated	3.8	5.2	7.3	+3.5	4.9	6.8	+3.0
others	4.4	4.7	6.5	+2.1	3.1	4.0	-0.4

Aggregate refers to Private industries; de/regulated does not only include de/regulated industries (Energy and utilities, Communications, Transportation, and Brokers) but also industries "severely affected by deregulative reform" according to the OECD Regulatory Impact indicator; other industries are all remaining private industries.

[a] We follow the Tornqvist procedure employed by Cummins and Violante (2002) to aggregate asset-level ISTC rates into industry-level ISTC rates. To compute the asset's share in industry investment we use the detailed estimates from BEA's Fixed Asset Accounts.

[b] Panel B is computed using a Tornqvist procedure but holding the investment composition fixed at its 1975 shares. That way, we decompose the acceleration of ISTC into two origins: first, an acceleration due to a shift in investment from low-ISTC to high-ISTC assets. Second, an acceleration purely due to an acceleration of ISTC in underlying assets. The latter is reported here.

Sources: Cummins and Violante (2002); Bureau of Economic Analysis, Fixed Asset Accounts.

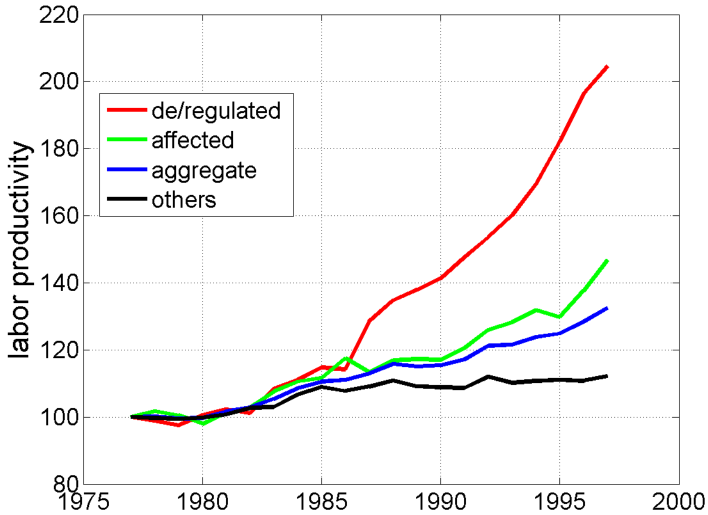
composition of investment stable.[12] This way, deregulated industries took advantage of the acceleration in ISTC of capital assets they use intensively, especially new information and communication technologies. In contrast, the remaining industries shifted their investment to high-ISTC assets. This composition effect contributes about 2 percentage points to their ISTC rate (Table 2.2).

At the same time, labor productivity across U.S. industries started to diverge as Figure 2.2 shows. Average U.S. labor productivity growth was about 1% per year during the period 1965-1980 and increased to 1.4% p.a. in 1980-1995. This increase was mainly driven by deregulated industries: their labor productivity growth amounted to 4% p.a. during the post-deregulation period while other private industries continued to grow at an annual rate of 1%. Those private industries that obtained more than 20% of their intermediate inputs from de/regulated industries, in contrast, have grown faster. This finding suggests that these industries may have benefited from the faster productivity growth of deregulated industries through input-output linkages.

The simultaneity of this growth acceleration and the Ford/Carter reforms might point to a causal link such as competitive pressures inducing a battle for technological

[12] Documenting a reduction their technological gap, Figure 2.3 supports this view.

Figure 2.2: Labor productivity diverges



Notes: Labor productivity is computed as real value-added per full-time equivalent employee. Aggregate refers to Private industries; de/regulated industries are Energy and utilities, Communications, Transportation, and Brokers; affected industries are those private industries that obtained more than 20 % of their intermediate inputs from de/regulated industries; other industries are all remaining Private industries.
Data Source: Bureau of Economic Analysis, NIPA.

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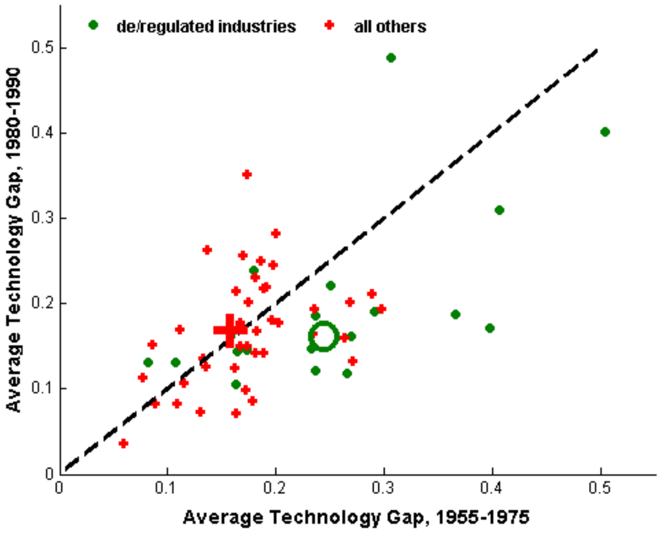
leadership. The following pieces of evidence tend to be in line with such a view.

Figure 2.3 compares the technological gaps of U.S. industries for two periods. The technological gap measures how much more productive new capital goods are compared to the average vintage.[13] The figure reveals that during the pre-deregulation period the technological gap of deregulated industries was higher than for other industries. This means, deregulated industries initially operated with technologies more distant from the technology frontier, leaving scope for technological catch-up. While for all other industries the technological gap remained stable, the gap closed for deregulated industries subsequent deregulation, matching the rest of the U.S. economy.

Figure 2.4 suggests that competitive pressures have increased in the U.S. ensuing the Ford/Carter deregulation. The figure displays estimates of the gross markup for two periods: 1961-77 and 1983-1994 (see Appendix 2.B). Each bullet depicts a

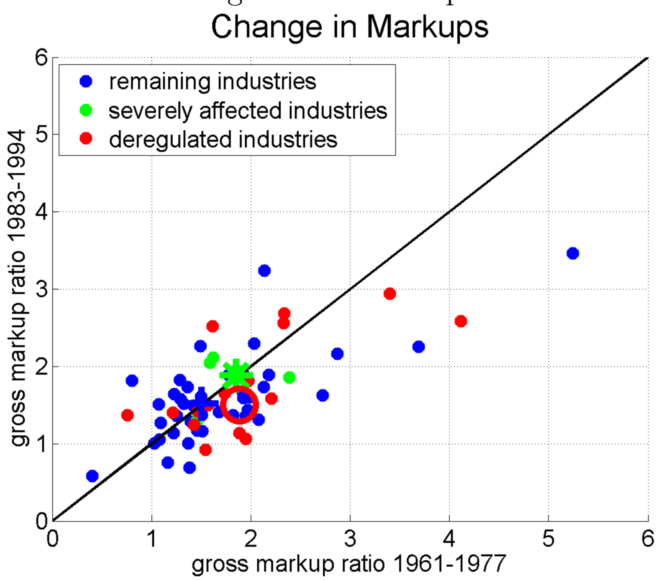
[13]Cummins and Violante (2002) define the technology gap Γ between a new machine and the average machine as the efficiency gap between the leading-edge technology q and average practice Q relative to the average efficiency level of the corresponding capital stock: $\Gamma = (q - Q)/Q$.

Figure 2.3: Technology gap closes



Notes: Following Cummins and Violante (2002) the technology gap for an industry Γ is computed as the efficiency gap between the leading-edge technology q and average practice Q relative to the average efficiency level of the industry's capital stock: $\Gamma = (q - Q)/Q$.
Data Source: Cummins and Violante (2002).

Figure 2.4: Markups



Notes: The figure displays estimates of industry gross markups for two periods: 1961-77 and 1983-1994 (for details see Appendix 2.B). Bullets below the 45°-line indicate industries that experienced a decline in markup, while bullets above suggest an increase in markups.
Data Source: Bureau of Economic Analysis, GDP-by-Industry Accounts & Fixed Asset Accounts.

single industry. Most bullets are below the 45°-line which means that these industries experienced a decline in the markup after the regulatory reforms. This is particularly true for the majority of deregulated industries. For them, the gross markup decreased, on average, by 22 percentage points from 1.92 to 1.71 (Table 2.7 in the Appendix). Similarly, markups in severely affected industries decline on average by 35 percentage points, while for the remaining private industries there is essentially no change. However, these estimates should be treated with caution as the number of observations is small and standard errors are high.

2.4 The Model

This section develops a multi-sector general equilibrium model of endogenous technical change. The economy is populated by an infinitely-lived representative household. The production side of the economy consists of a final good sector, a products sector, and a R&D sector. The final goods sector competitively assembles an all-purpose numeraire good from intermediate products.

The products sector consists of a large number of industries. Each industry produces its own output good using capital, labor, and intermediate inputs. In the model, governmental regulation raises barriers to entry and leads to imperfect competition in product markets. We focus on legal and administrative restrictions to entry. The reason is that only those deregulative measures that decrease the rents required to enter and stay in the market will permanently be effective in spurring competition, as Blanchard and Giavazzi (2003) find.

R&D activities improve the quality of capital goods in the spirit of Aghion and Howitt (1992); Grossman and Helpman (1991). However, the precise formulation of the R&D sector is close to Krusell (1998)'s model of endogenous ISTC in which innovations are embodied in investment goods. This is a simple way to model productivity growth which is driven by the ongoing development of better equipment.

2.4.1 Economic Environment

Final good composite. In the economy there is a final good Y which can be used for consumption purposes C, investment X as well as R&D activities S. Furthermore, entry costs that might be paid arise in terms of the final good. This final good is a composite of products which are assembled under perfect competition according to a Cobb-Douglas aggregator

$$Y = \prod_{i=1}^{I} \left(y_i^f\right)^{\theta_i^Y}, \quad \theta_i^Y \geq 0 \; \forall i, \quad \sum_{i=1}^{I} \theta_i^Y = 1 \tag{2.1}$$

where y_i^f is final demand of the product produced by industry i. The price index corresponding to the final good is $P^Y = \prod_{i=1}^{I} \left(p_i/\theta_i^Y\right)^{\theta_i^Y}$ where p_i is the price of industry i's output. We choose the final good as the numeraire and normalize $P^Y = 1$. Hence, the aggregate resource constraint reads as $Y = C + X + S + E$ where E denotes aggregate entry costs paid.

Products. The economy consists of a large but finite number of industries I. Each industry i is populated by a finite number of product market firms N_i which produce a perishable differentiated product $\mathbf{y}_i$. This product can be used for final demand y_i^f or as intermediate input y_i^z by other industries: $\mathbf{y}_i = y_i^f + y_i^z$.

It is produced from capital $\mathbf{k}$, labor h, and intermediate inputs $\mathbf{z}$. The main difference between intermediate inputs and capital is that the latter is accumulable and can be used for production for more than one period, whereas the former is non-storable and gets used up in production. All incumbent firms of an industry operate according to the same Cobb-Douglas technology

$$y_{ij} = A_i \mathbf{k}_{ij}^{\alpha_i^k} \mathbf{z}_{ij}^{\alpha_i^z} h_{ij}^{1-\alpha_i^k-\alpha_i^z} \qquad 0 < \alpha_i^k, \alpha_i^z, \quad \alpha_i^k + \alpha_i^z \leq 1, \; \forall i \tag{2.2}$$

where the subscript ij denotes firm j in industry i. $A_i > 0$ is an industry-specific productivity parameter. The firm uses intermediate inputs from other industries, each representing a different input variety. The firm's total input of intermediate goods is denoted by $\mathbf{z}_{ij}$. It is given by a Cobb-Douglas aggregator of the different input varieties:

$$\mathbf{z}_{ij} = \prod_{l \neq i}^{I} (z_{l,ij})^{\theta^{\mathbf{z}}_{l,i}}, \quad \theta^{\mathbf{z}}_{l,i} \geq 0 \; \forall l \neq i, \quad \sum_{l \neq i}^{I} \theta^{\mathbf{z}}_{l,i} = 1 \tag{2.3}$$

where z_l is the quantity of the intermediate input obtained from sector l.

The firm's capital stock is not homogeneous but it consists of different varieties of capital goods such as computers, machines, structures, etc. A particular variety is denoted by $\nu \in \{1, ..., \bar{\nu}\}$ where $\bar{\nu}$ denotes the total number of varieties available. Total capital input $\mathbf{k}$ is a Cobb-Douglas aggregator of the different varieties employed by the firm:

$$\mathbf{k}_{ij} = \prod_{\nu=1}^{\bar{\nu}} (k_{\nu,ij})^{\theta^{k}_{\nu,i}} \quad \theta^{k}_{\nu,i} \geq 0 \; \forall \nu, \quad \sum_{\nu=1}^{\bar{\nu}} \theta^{k}_{\nu,i} = 1 \tag{2.4}$$

where k_ν is the quantity of variety ν and $\theta^{k}_{\nu,i}$ is the associated weight. As there is investment-specific technical change, capital stocks are measured in efficiency units. This means, that $x_{\nu,t}$ units of investment contribute $\phi_{\nu,t} \cdot x_{\nu,t}$ effective units to the capital stock, where $\phi_{\nu,t}$ is the quality of period t investment goods. The capital stock depreciates at rate δ_ν. Hence, the law of motion of the firm's capital stock of variety ν reads:

$$k_{\nu,ij,t+1} = (1 - \delta_\nu) k_{\nu,ij,t} + \phi_{\nu,ij,t} \cdot x_{\nu,ij,t} \quad \forall \nu \tag{2.5}$$

Product market incumbents. Consider any product market incumbent in an industry. The incumbent's state consists of the capital stocks he owns: $\{k_{\nu,t}\}_{\nu=1}^{\bar{\nu}}$. However, his state is sufficiently characterized by the composite of capital services $\mathbf{k}_t$.

It is convenient to break the decision problem of a product market incumbent into two pieces: static and dynamic. The static part involves hiring labor and purchasing intermediate inputs in order to produce as well as competing in Cournot quantity competition for sales, taking the firm's state and input prices as given. The dynamic part deals with the decision whether to exit or to stay in the market and, conditional on staying, to choose investment for each capital variety.

The objective of the static problem is to maximize current period profits, given the firm and industry state which is denoted by $\omega_{it} \equiv (N_{it}, \{\mathbf{k}_{ijt}\}_{j=1}^{N_{it}})$:

$$\bar{\pi}(\mathbf{k}, \omega) = \max_{h, \{z_l\}_{l \neq i}^{I}} \left\{ p(\mathbf{y}_i) y_{ij} - w h_{ij} - \sum_{l \neq i}^{I} p_l z_{lij} \right\} \qquad \text{s.t. (2.2)},$$

where w is the economy-wide wage rate per unit of labor and $p(\mathbf{y_i})$ is the demand curve for the corresponding industry's total output produced by all incumbents: $\mathbf{y}_i = \sum_{j=1}^{N_i} y_{ij}$. The first-order conditions imply that the marginal revenue products equal factor costs

$$w = p_i \left[1 - \frac{1}{\epsilon_i(\mathbf{y}_i)} \frac{y_{ij}}{\mathbf{y}_i} \right] \cdot (1 - \alpha_i^k - \alpha_i^z) A_i \mathbf{k_{ij}}^{\alpha_i^k} \mathbf{z_{ij}}^{\alpha_i^z} h_{ij}^{-\alpha_i^k - \alpha_i^z} \tag{2.6}$$

$$P_i^{\mathbf{z}} = p_i \left[1 - \frac{1}{\epsilon_i(\mathbf{y}_i)} \frac{y_{ij}}{\mathbf{y}_i} \right] \cdot \alpha_z A_i \mathbf{k_{ij}}^{\alpha_i^k} \mathbf{z_{ij}}^{\alpha_i^z - 1} h_{ij}^{1-\alpha_i^k - \alpha_i^z} \tag{2.7}$$

and demand relations for each intermediate variety z_l (by firm j in sector i) are given by:

$$z_{ijl} = \theta_{l,i}^{\mathbf{z}} \cdot P_i^{\mathbf{z}} \mathbf{z}_{ij} / p_l \qquad \text{for all } l \neq i \tag{2.8}$$

where $\epsilon_i(\mathbf{y}_i) \equiv -\frac{\partial \mathbf{y}_i}{\partial p_i} \frac{p(\mathbf{y}_i)}{\mathbf{y}_i}$ is the price-elasticity of the industry demand curve and $P_i^{\mathbf{z}} = \prod_{l \neq i}^{I} \left(p_l / \theta_{l,i}^{\mathbf{z}} \right)^{\theta_{l,i}^{\mathbf{z}}}$ the price index for intermediate goods.

Since any industry's output is used as input by final good producers or as intermediate input by other industries, industry i's demand consists of final demand $y_i^f = \theta_i^Y \cdot Y / p_i$ and intermediate input demand $y_i^z = \sum_{l \neq i}^{I} \sum_{j=1}^{N_j} \theta_{l,i}^{\mathbf{z}} \cdot P_l^{\mathbf{z}} \mathbf{z}_{lj} / p_i$. Hence, the industry demand curves $p(\mathbf{y_i})$ are unit-elastic, i.e. $\epsilon_i(\mathbf{y}_i) = 1 \ \forall i = 1, ..., I$. As a result, maximized current period profits can be written as

$$\bar{\pi} = \left(1 - (1 - \alpha_i^k) \left[1 - \frac{y_{ij}}{\mathbf{y}_i} \right] \right) p_i(\mathbf{y}_i) y_{ij} \tag{2.9}$$

The dynamic optimization problem is to maximize the value of a firm which enters period t with capital $\mathbf{k}$. This value consists of current period profits and the discounted future value net of investment if the incumbent decides to continue operating or an outside option value of zero if the incumbent exits the market:

$$v(\mathbf{k},\omega) = \bar{\pi}(\mathbf{k},\omega) + \max\left(0, \max_{\{x_\nu\}_{\nu=1}^{\bar{\nu}}} \left\{ -\sum_{\nu=1}^{\bar{\nu}} q_\nu \cdot x_\nu + \frac{1}{1+r'} v(\mathbf{k}',\omega') \right\}\right) \tag{2.10}$$

subject to the capital accumulation equations (2.5) and law of motion for the industry state: $\omega' = h_\omega(\omega)$. Here r denotes the real interest rate. The first-order conditions is

$$k'_\nu = \theta^{\mathbf{k}}_{\nu,i} \cdot P^{\mathbf{k}}_i \mathbf{k}'_i / \frac{q_\nu}{\phi_\nu} \qquad \text{for all} \quad \nu = 1, 2, ..., \bar{\nu} \tag{2.11}$$

and the envelope condition implies

$$\frac{1}{1+r} \frac{\partial \bar{\pi}(\mathbf{k}',\omega')}{\partial \mathbf{k}'} = P^{\mathbf{k}}_i \tag{2.12}$$

where $P^{\mathbf{k}}_i = \prod_{\nu=1}^{\bar{\nu}} \left(\frac{q_\nu}{\phi_\nu \theta^{\mathbf{k}}_{\nu,i}}\right)^{\theta^{\mathbf{k}}_{\nu,i}}$ is the price index for the capital bundle. The incumbents' corresponding investment demand is derived from the capital accumulation equation (2.5):

$$x_{\nu,ij,t} = \theta^{\mathbf{k}}_{\nu,i} \cdot P^{\mathbf{k}}_i \mathbf{k}_{ij,t+1} / q_{\nu,t} - (1-\delta_\nu) \cdot k_{\nu,ij,t} / \phi_{\nu,t} \tag{2.13}$$

Investment demand is decreasing in the price q_ν and increasing in the quality level $\phi_{\nu,t}$. The latter effect reflects obsolescence of the existing capital stock.

Product market regulation and entry. Product industries are subject to governmental regulation raising barriers to entry. We focus on barriers to entry not only because they were common in the U.S. (e.g. licenses being a brute measure of entry regulation, red tape related to new business start-ups a more subtle one) but also because Blanchard and Giavazzi (2003) find them to be the regulatory measure crucial for the mode of industry competition. The reason is that entry regulation determines the number of firms operating in an industry and, thereby, their market power and profit margins. Entry costs are a convenient way of modeling entry regulation: a decrease in barriers to entry is a de-facto reduction of entry costs and it therefore mimics a deregulative measure. For example, cutbacks in regulations that require filing of reports and studies or stamps of approval will reduce the real resource cost of entry. A decline in license fees will have a similar effect from the entrant's perspective.[14]

We assume that there is free entry into the products market. Attempted entry is successful upon payment of entry costs which flow into the ocean. There is a pool of potential entrants which can choose to enter into any of the I industries upon paying a fixed setup cost. The cost of entry into industry i is denoted by $\kappa_{it} \geq 0$.[15] The process of entry takes a full period as investments need to be installed. The timing is as follows: an entering firm pays κ_{it} and purchases capital goods in period t; it starts operating in period $t+1$. Entry into a given industry takes place if:

$$-\kappa_{it} + \max_{x_{\nu,ie}} \left\{ -\sum_{\bar{\nu}} q_\nu \cdot x_{\nu,ie} + \frac{1}{1+r'} v(\mathbf{k}'_{ie}, \omega') \right\} \geq 0 \tag{2.14}$$

where

$$\mathbf{k}'_{ie} = \prod_{\nu=1}^{\bar{\nu}} (\phi_\nu \cdot x_{\nu,ie})^{\theta^k_{\nu,i}}$$

In case of entry, the optimal capital stock is given by (2.12) and investments are determined by:

$$x_{\nu,ie,t} = \theta^{\mathbf{k}}_{\nu,i} \cdot P^{\mathbf{k}}_i \mathbf{k}_{ie,t+1}/q_\nu \qquad \text{for all} \;\; \nu = 1, ..., \bar{\nu} \tag{2.15}$$

For future reference, we denote the number of entrants entering into industry i by N^E_i.

R&D firms. Each variety of capital ν is produced by a single R&D firm which is the sole producer of this variety. This firm can pursue R&D activities to increase the quality of its capital variety. These quality improvements result in endogenous investment-specific technical change: installing the current vintage of the capital good augments the corresponding capital stock by $\phi_{\nu,t}$ efficiency units.

More specifically, we assume a lab-equipment innovation possibilities frontier: quality $\phi_{\nu,t}$ is increasing in the firm's R&D spending $s_{\nu,t}$ (which is in terms of the final good).

$$\phi_{\nu,t} = \phi_{\nu,t-1} \cdot [1 + m_\nu \left(\frac{s_{\nu,t}}{\Omega_t} \right)^{\gamma_\nu}] \qquad m_\nu, \gamma_\nu > 0 \;\forall\; \nu \tag{2.16}$$

where γ_ν governs the returns to scale in R&D, m_ν scales the productivity of R&D, and

[14] If licence fees were refunded, a distinction might be sensible as Fang and Rogerson (2011) discuss.
[15] We assume that entry costs grow with the same rate as the economy does.

Ω_t is a growth trend that eliminates scale effects.

Capital goods are sold to product market firms. Let $q_\nu(X_\nu)$ denote the aggregate inverse demand function for capital goods of variety ν where

$$X_{\nu,t} \equiv \sum_{i=1}^{I} N_{it} \cdot x_{\nu,ij,t} + N_{it}^E \cdot x_{\nu,ie,t} = \sum_{i=1}^{I} (N_i + N_i^E) \cdot \theta_{\nu,i}^{\mathbf{k}} \cdot P_i^{\mathbf{k}} \mathbf{k}_{ij,t+1} / q_\nu - (1-\delta_\nu)/\phi_{\nu,t} \cdot \sum_{i=1}^{I} N_i \cdot k_{\nu,ij,t}$$

is total investment demand for variety ν. As every variety is produced by a single R&D firm, these firms possess monopoly power in their corresponding sales markets.

The decision problem of any R&D firm involves choosing R&D activities and capital goods production in order to maximize profits. As the R&D firm is short-lived and will be replaced next period by some other R&D firm, its decision problem is static but consists of two stages: the first stage is to choose the optimal R&D investment strategy in order to improve the quality of its capital good. In stage two, the firm chooses a production quantity to maximize profits taking the quality level $\phi_{\nu,t}$ as given. The production of one unit of capital requires one unit of the final good. Hence, the stage-2 optimization problem of the firm is the following:

$$\bar{\pi}_\nu^R(\phi_{\nu,t}) \equiv \max_{q_{\nu,t}} \ \{[q_{\nu,t}(X_{\nu,t}) - 1] \cdot X_{\nu,t}(\phi_{\nu,t})\} \tag{2.17}$$

The first-order condition can be written as the usual markup-pricing rule over marginal costs (which are equal to 1)

$$q_{\nu,t} = \frac{1}{1 - \frac{1}{\epsilon_\nu(X_{\nu,t})}} \tag{2.18}$$

where the price elasticity of investment demand $\epsilon_\nu(X_\nu) \equiv -\frac{\partial X_\nu}{\partial q_\nu(X_\nu)} \frac{q_\nu}{X_\nu} = \frac{\sum_{i=1}^{I} (N_i + N_i^E) \cdot \theta_{\nu,i}^{\mathbf{k}} \cdot P_i^{\mathbf{k}} \mathbf{k}_{ij,t+1}}{q_\nu X_\nu}$ is determined by the corresponding nominal capital-investment ratio.

In the first stage, the firm chooses R&D to maximize profits net of R&D investment

$$\max_{s_{\nu,t}} \ \left\{\bar{\pi}_\nu^R(\phi_{\nu,t}) - s_{\nu,t}\right\} \tag{2.19}$$

subject to the innovation possibility frontier (2.16) which governs the extent of quality improvement that is achieved by any chosen R&D level. The first-order condition can be written as

$$s_{\nu t} = [q_{\nu,t} - 1] X_{\nu,t}(\phi_{\nu,t}) \cdot \eta_{X_\nu,\phi_\nu} \cdot \eta_{\phi_\nu,s_\nu} \tag{2.20}$$

where $\eta_{X_\nu,\phi_\nu} \equiv \frac{\partial X_{\nu,t}(\phi_{\nu,t})}{\partial \phi_{\nu,t}} \frac{\phi_{\nu,t}}{X_{\nu,t}(\phi_{\nu,t})} = \frac{(1-\delta_\nu)\cdot\sum_{i=1}^{I} N_i \cdot k_{\nu,ij,t}}{\phi_{\nu,t} X_{\nu,t}}$ and $\eta_{\phi_\nu,s_\nu} \equiv \frac{\partial \phi_{\nu,t}}{\partial s_{\nu,t}} \frac{s_{\nu,t}}{\phi_{\nu,t}} = \gamma_\nu \frac{m_\nu (s_t/\Omega_t)^{\gamma_\nu}}{1+m_\nu (s_t/\Omega_t)_t^{\gamma_\nu}}$ Hence, net profits are

$$\bar{\pi}_\nu^R - s_{\nu,t} = [1 - \eta_{X_\nu,\phi_\nu} \cdot \eta_{\phi_\nu,s_\nu}] \left[\frac{\epsilon_\nu(X_{\nu,t})}{\epsilon_\nu(X_{\nu,t}) - 1} - 1 \right] X_{\nu,t} \tag{2.21}$$

which are payed out to the household every period.

Household. The economy is populated by a infinitely-lived representative household that values consumption of the final good C and inelastically supplies L units of labor to the market sector. Labor is employed in the products sector and it is perfectly mobile across firms and industries. The objective of an individual is to maximize lifetime utility. Preferences are described by the following time-separable CIES utility function:

$$U = \sum_{t=0}^{\infty} \beta^t u(C_t) \qquad u(C_t) = \frac{C_t^{1-\sigma} - 1}{1-\sigma} \tag{2.22}$$

where $\beta \in (0,1)$ is the personal discount factor and σ determines the intertemporal elasticity of substitution. The household earns wage and interest income. In addition, he receives a stream of distributed profits from R&D firms. The household chooses consumption to maximize his life-time utility (2.22) subject to his budget constraint:

$$C_t + A_{t+1} = w_t L + (1 + r_t) A_t + \Pi_t^R \tag{2.23}$$

where A denotes the household's asset holdings and $\Pi_t^R \equiv \sum_{\nu=1}^{\bar{\nu}} \bar{\pi}_{\nu,t}^R - s_{\nu,t}$ are the profits net of R&D spending of all R&D firms. The asset is a balanced portfolio of equity of all product market firms in all industries: $A_t = \sum_{i=1}^{I} N_{it} v_{ijt}$.

The household's optimality condition delivers the usual consumption-Euler equation:

$$\left(\frac{C_{t+1}}{C_t} \right)^\sigma = \beta \left(1 + r_{t+1}\right) \tag{2.24}$$

Having described the economic environment, we next turn to the equilibrium concept.

Beforehand we briefly characterize the model's balanced growth path.

2.4.2 Balanced Growth Path and Stationary Transformation

Along a balanced growth path all variables grow at constant rates. Obviously, hours worked will remain constant while capital and output will grow in the presence of investment-specific technological change. The aggregate resource constraint implies that final output, consumption, investment, and R&D expenditures all have to grow at the same (gross) rate, say g. Similarly, the resource constraints for each product mean that output, final demand, and intermediate input demand grow at a common rate $g_{\mathbf{y}_i}$.

As the final good is assembled from intermediate products according to a Cobb-Douglas production function, the economy's growth rate is a weighted geometric mean of the industry growth rates: $g = \prod_{i=1}^{I} (g_{y_i})^{\theta_i^Y}$. Industry growth, in turn, is related to growth in capital services and intermediate inputs, as described by each industry's production function: $g_{y_i} = g_{\mathbf{k_i}}^{\alpha_i^k} g_{\mathbf{z_i}}^{\alpha_i^z}$. Again, due to the Cobb-Douglas functional form, growth in intermediate inputs and capital services, respectively, is a geometric mean of the growth rates of the corresponding components: $g_{z_i} = \prod_{l \neq i}^{I} (g_{z_l})^{\theta_l^{z_i}} = \prod_{l \neq i}^{I} (g_{y_l})^{\theta_l^{z_i}}$ and $g_{\mathbf{k}_i} = \prod_{\nu=1}^{\bar{\nu}} (g_{k_{\nu,i}})^{\theta_{\nu,i}^k}$. Recall that $k_{\nu,i}$ is the capital stock of variety ν, measured in efficiency units. Hence, its growth rate does not only reflect growth in physical investment but also investment-specific technical change: $g_{k_\nu} = g_{\phi_\nu} g$, as implied by the accumulation equation (2.5). Here, g_{ϕ_ν} denotes the rate of investment-specific technical change in the corresponding capital good. Note that the BGP growth rate of capital of variety ν is the same for all firms in all industries because each firm's investment grows at the same rate, g. Nevertheless, capital growth may differ across industries due to a varying composition of the capital stock: $g_{\mathbf{k}_i} = g_Y \cdot \prod_{\nu=1}^{\bar{\nu}} (g_{\phi_\nu})^{\theta_{\nu,i}^k}$.

Given these BGP growth rates, detrending variables by their balanced growth path will render them stationary. In the following we use a tilde to denote the stationary transformation of any variable: the stationary transformation of capital, for example, is denoted by $\tilde{\mathbf{k}}_t \equiv \mathbf{k}_t / g_{\mathbf{k}}^t$.

2.4.3 Equilibrium

Next, we consider a stationary symmetric Markov-perfect equilibrium of the decentralized economy. In a symmetric equilibrium all firms within an industry choose the same level of capital. Stationarity requires all variables to grow at constant rates. In other words, the economy follows a balanced growth path.

Stationary symmetric Markov-perfect equilibrium. *A stationary symmetric Markov-perfect equilibrium of the decentralized economy is represented by an allocation* $(\tilde{C}, \tilde{A}, \{\tilde{\mathbf{y}}_i, \tilde{\mathbf{z}}_i, h_i, \{\tilde{k}_{\nu,i}\}_{\nu=1}^{\bar{\nu}}\}_{i=1}^{I})$*, the number of product market firms in each industry* $\{N_i\}_{i=1}^{I}$*, and prices* $(\tilde{w}, r, \{p_i\}_{i=1}^{I}, \{q_\nu\}_{\nu=1}^{\bar{\nu}})$ *such that*

1. *the household solves his utility maximization problem given prices;*
2. *the final good firm solves its profit maximization problem given prices;*
3. *product market firms solve their profit maximization problems given input prices, industry demand curve, and competitors' quantities;*
4. *R&D firms solve their profit maximization problem given input prices and investment demand curve;*
5. *the number of product market firms in each industry is determined by free entry;*
6. *the laws of motion for the industry state* $\{h_\omega(\omega)\}_{i=1}^{I}$ *are consistent with number of product market firms operating in each industry* $\{N_i\}_{i=1}^{I}$.
7. *all markets clear:*

   (a) *labor*

$$L = \sum_{i=1}^{I} N_{it} h_{ijt} \tag{2.25}$$

   (b) *final good*

$$Y_t = C_t + X_t + S_t + E_t \tag{2.26}$$

   where aggregate investment is $X_t = \sum_{\nu=1}^{\bar{\nu}} X_{\nu,t}$*, aggregate R&D spending is* $S_t = \sum_{\nu=1}^{\bar{\nu}} s_{\nu,t}$*, and total entry costs are* $E_t = \sum_{i=1}^{I} N_{it}^{E} \kappa_{it}$.

   (c) *products*

$$N_{it} y_{ijt} = \mathbf{y}_{it} = y_{it}^{f} + y_{it}^{z} \quad \forall\ i = 1, ..., I \tag{2.27}$$

(d) *capital goods*

$$X_{\nu,t} = \sum_{i=1}^{I} N_{it} \cdot x_{\nu,ij,t} + N_{it}^{E} \cdot x_{\nu,ie,t} \quad \forall\ \nu = 1, ..., \bar{\nu} \tag{2.28}$$

(e) *asset*

$$A_t = \sum_{i=1}^{I} N_{it} v_{ijt} \tag{2.29}$$

The model is solved numerically for its stationary equilibrium.

2.5 Quantitative Analysis

This section explores the model's ability to generate an acceleration of investment-specific technical change and a divergence in labor productivities as a result of product market deregulation. We begin with a discussion of our calibration strategy. Then, we introduce our quantitative experiment symbolizing the Ford/Carter deregulatory reforms and, finally, we present the findings.

2.5.1 Calibration

The model economy's balanced growth path is calibrated to match various stylized facts of the U.S. economy in the period 1960-75, that is, the pre-deregulation period. All parameters are listed in Table 4.1. Some parameters are set based upon a priori information from the literature. The intertemporal elasticity of substitution $1/\sigma$ is routinely set to 1/2 and the real interest rate to 4.5%. Both values are inserted into the Euler equation (2.24) to pin down the discount factor β.

Turning to the technology parameters, the elasticities of the Cobb-Douglas aggregators for the final good, the capital bundles, and the intermediate product bundles are pinned down by the corresponding cost shares in the data. The share of final demand in nominal output determines the elasticity of the final good aggregator: $\theta_i^Y = \frac{p_i y_i^f}{P^Y Y}$ for all 57 industries. We compute these shares of final demand in nominal output from the 1972 Input-Output tables published by the Bureau of Economic Analysis (Table 2.15). Furthermore, the Input-Output tables allow us to compute

Table 2.3: Calibration

Parameter name	Symbol	Dim	Target
Preferences			
discount factor	β	1	r
intertemp. elasticity of substitution	$1/\sigma$	1	1/2
Production Technology			
elasticity of final good aggregator Y	θ_i^Y	I	$\frac{p_i y_i^f}{P^Y Y}$
elasticity of capital aggregator $\mathbf{k}$	$\theta_{\nu,i}^k$	$I \cdot \bar{\nu}$	$\frac{q_{\nu t} \cdot k_{\nu t+1}/\phi_{\nu t}}{\mu_{k,t} \cdot \mathbf{k_{t+1}}}$
elasticity of intermediate input aggregator $\mathbf{z}$	$\theta_{l,i}^z$	$I \cdot I$	$\frac{p_l y_l^{z_i}}{P^{z_i} \mathbf{z_i}}$
output elasticity w.r.t. capital	α_i^k	I	$\frac{\mathbf{w} h_i}{p_i \mathbf{y_i}}$
output elasticity w.r.t. intermediates	α_i^z	I	$\frac{P^{\mathbf{z_i}} \mathbf{z_i}}{p_i \mathbf{y_i}}$
industry TFP	A_i	I	$\frac{p_i \mathbf{y}_i - P^{\mathbf{z_i}} \mathbf{z_i}}{\sum_i \mathbf{y}_i}$
depreciation rate	δ_ν	$\bar{\nu}$	$\frac{q_\nu \cdot x_\nu}{q_\nu \cdot k_{\nu,t}/\phi_{\nu,t-1}}$
R&D Technology			
R&D duplication parameter	γ_ν	$\bar{\nu}$	g_{ϕ_ν}
R&D productivity parameter	m_ν	$\bar{\nu}$	1
Policy			
entry cost	κ_i	I	

intermediate input shares $\theta_{l,i}^z = \frac{p_l y_l^{z_i}}{P^{z_i} \mathbf{z_i}}$. In the same way we compute the shares of all 27 capital goods we distinguish in the Current-Cost Net Stock of Private Fixed Assets by Industry from BEA's Fixed Asset Accounts $\theta_{\nu,i}^k = \frac{q_{\nu t} \cdot k_{\nu,i,t+1}/\phi_{\nu t}}{P_{i,t}^{\mathbf{k}} \cdot \mathbf{k_{i,t+1}}}$. Besides, we choose the depreciation rates δ_ν to target the investment-to-capital ratios $\frac{q_\nu \cdot x_\nu}{q_\nu \cdot k_{\nu,t}/\phi_{\nu,t-1}}$ for all 27 capital goods since both are related to each other through the capital accumulation equation (2.5).

The output elasticities of the production function have to be calibrated jointly with the number of firms by industry. In any industry all incumbent firms operate according the same production function. Hence, the incumbents' first-order conditions with respect to labor (2.6) and intermediate inputs (2.7) can be rearranged in order to target the industry's wage bill share and intermediate inputs share in industry's nominal gross output, respectively:

$$\left(1-\frac{1}{N_i}\right)(1-\alpha_i^k-\alpha_i^z)=\frac{wN_ih_{ij}}{N_ip_iy_{ij}}=\frac{wh_i}{p_i\mathbf{y}_i}$$

and

$$\left(1-\frac{1}{N_i}\right)\alpha_i^z=\frac{\sum_{l\neq i}^{I}N_ip_lz_{li}}{N_ip_iy_{ij}}=\frac{P^{\mathbf{z_i}}\mathbf{z_i}}{p_i\mathbf{y}_i}$$

We compute these targets from the BEA's GDP by Industry Accounts. Finally, the industry total factor productivity parameters A_i are calibrated to match the statistic $\frac{p_i\mathbf{y}_i-P^{\mathbf{z_i}}\mathbf{z_i}}{\sum_i \mathbf{y}_i}$.

The R&D technology parameter γ_ν is chosen to match the pre-deregulation ISTC rate of the corresponding capital good reported by Cummins and Violante (2002) (Table 2.14 in the Appendix).[16]

Finally, the policy parameter entry costs are calibrated in the following way. In equilibrium, the free entry condition (2.14) imposes a positive relationship between entry costs and the value of a product market incumbent firm and, hence, an incumbent's current period profit contribution (2.9) which is negatively related to the number of incumbent firms operating in that industry. Hence, we calibrate the pre-deregulation level of entry costs by targeting the number of firms in each industry. However, we do not observe these data directly. But the County Business Patterns published by U.S. Census provide an annual series of the number of establishments by industry. We use this establishment data for 1975 to construct a target of the number of firms by industry as follows: firstly, we assume that the number of firms in each industry is proportional to the number of establishments reported in the County Business Patterns. Secondly, we calibrate this factor of proportionality in order to match a markup of 12% for the aggregate economy.

[16] Cummins and Violante (2002) provide ISTC rates for 26 capital goods covering equipment and software capital. For structures we follow the literature (e.g. Pakko, 2002c, 2005) and use the estimate of Gort, Greenwood, and Rupert (1999) who find an ISTC rate of 1% per year.

2.5.2 The Experiment

The purpose of the quantitative model is to answer the question "How much of the observed acceleration in investment-specific technical change is accounted for by U.S. product market deregulation?". We address this question by simulating two model economies. The first one matches important empirical facts of the U.S. economy in the pre-deregulation period (1960 - 1975), that is, before the Ford/Carter/Reagan reforms were implemented. The second model economy is a hypothetical one: how would the U.S. economy have looked like if product market regulations in the 1970s were at their post-deregulation levels. Comparing the change in ISTC rates of these model economies to the observed acceleration in actual U.S. data allows us to compute the fraction which is accounted for by deregulation in our model.

To this end, we decrease the entry costs for all 16 industries that have been deregulated under the Ford, Carter, and Reagan Administrations[17] by factor 5.[18] For all other industries which have not been subject to regulatory changes we assume that entry costs did not change.

2.5.3 Findings

The results of the deregulation experiment are reported in Table 2.4. In the model, deregulation leads to an increase in the aggregate rate of ISTC from 4.2% to 4.7% per year. Comparing this acceleration of 0.5 percentage points to the observed acceleration of 2.7 percentage points means that the considered regulatory relief is able to explain about 18.6% of the acceleration of ISTC in the aggregate economy. However, focusing on the 16 deregulated industries only, deregulation is an important explanation for the acceleration of ISTC in deregulated industries. For these industries the policy experiment generates an acceleration of 2.5 percentage points, compared to

[17]The deregulated industries are: Oil and gas extraction, Petroleum and coal products, Railroad transportation, Local and interurban passenger transit, Trucking and warehousing, Water transportation, Transportation by air, Pipelines, except natural gas, Transportation services, Telephone and telegraph, Radio and television, Electric services, Gas services, Depository institutions, Nondepository institutions, and Security and commodity brokers.

[18]On the one hand, Ebell and Haefke (2009) find that in the U.S. entry costs decreased by factor 9 between the late 1970s and late 1990s. On the other hand, our calibration of pre-deregulation entry costs suggests a factor of 2.5 between non-deregulated and deregulated industries. In the light of this evidence, factor 5 is an intermediate value for the extent of deregulation.

Table 2.4: Comparison of ISTC and labor productivity in the model and in the data

	U.S. economy			Model economy			Fraction accounted for
	pre- deregulation	post-	Δ	pre- deregulation	post-	Δ	
investment-specific technical change[a]							
aggregate	4.12	6.87	2.74	4.16	4.67	0.51	18.6%
de/regulated	3.78	7.32	3.54	4.20	6.70	2.50	70.6%
others	4.43	6.46	2.03	4.14	4.49	0.35	17.2%
labor productivity[b]							
aggregate	1.19	1.79	0.60	2.91	3.60	0.69	115.0%
de/regulated	1.55	5.07	3.52	2.92	4.04	1.12	31.8%
others	1.09	1.17	0.08	2.91	3.21	0.30	375.0%
Δ	0.46	3.90	3.44	0.01	0.83	0.82	23.8%

Pre-deregulation refers to the period 1960-75, post-deregulation to 1990-2000.
The model panel shows BGP growth rates, the data panel average growth rates for the corresponding periods. Both are reported in percentage points per year. The last column computes the fraction of the observed acceleration in ISTC and labor productivity growth, respectively, that is accounted for by the deregulation experiment in the quantitative model (column 7 divided by column 4).
[a] The pre-deregulation period excludes ISTC rates for 1975 which are known to be an outlier (cf. Cummins and Violante, 2002, p. 257).
[b] Due to lacking data availability, the pre-deregulation period for labor productivity is 1978-1984 and the post-deregulation period is 1990-1997.
Data sources: Cummins and Violante (2002); Bureau of Economic Analysis, Historical Industry Accounts and Fixed Assets Accounts.

3.5 percentage points in the data. This means, 70.6% of the acceleration are accounted for by the quantitative model. For other industries, however, the model explains about one sixth of the observed acceleration in ISTC. One explanation for this might be that the model does not allow for a changing composition of the capital stock (in nominal terms) while the data suggests that a shift in investment towards high-ISTC capital goods contributes substantially to the acceleration of ISTC in non-deregulated industries. For example, the experiment explains five eighths of the increase in aggregate ISTC that is due to a pure asset-specific acceleration (0.8 percentage points, Table 2.2.B).

The quantitative model performs well in predicting a moderate rise in aggregate labor productivity growth as well as an almost constant growth rate for the non-deregulated industries. The 16 deregulated industries grew about 3.5 percentage points faster in the 1990s than before the reforms. Thus, the gap in labor productivity growth between deregulated and non-deregulated industries increased to the same extent. The quantitative model, however, captures only about one third of the rise in labor productivity growth of the deregulated industries. This suggests that gains in total factor productivity, maybe due to a reorganization of the production process, might be another important outcome of product market deregulation. Despite neglecting other sources of productivity growth than ISTC, the model is able to generate diverging labor productivities ensuing deregulation: the quantitative experiment still accounts for about a quarter of the observed divergence.

2.6 Concluding Remarks

Documenting that deregulated industries have outperformed the remaining U.S. economy in terms of labor productivity growth and investment-specific technical change, this essay studies industry and macroeconomic effects of competition policy. In particular, we address a quantitative question: to what extent can the Ford/Carter regulatory reforms account for the observed acceleration of ISTC and the subsequent divergence of labor productivity in the U.S.?

To this end, we develop a multi-sector general equilibrium model of endogenous ISTC that features imperfect competition and a technology choice by firms. In the model, industries are subject to governmental regulations which constitute barriers to entry. Deregulation is modelled as a reduction in entry barriers which results in new competitors entering deregulated industries. Intensified competition, in turn, leads to lower markups, declining prices, and expanding production. In order to increase output firms install additional capital goods. This rise in investment demand fosters R&D activities to improve the efficiency of capital goods and, hence, accelerates investment-specific technical change. Consequently, labor productivity grows at a higher rate.

We employ our model framework for a quantitative experiment. The experiment investigates the effects of the Ford/Carter reforms by simulating model economies calibrated to the U.S. economy with and without deregulation. We find that the quantitative model explains 70% of the observed acceleration in ISTC for the deregulated industries and almost a fifth of the overall acceleration for the

U.S. economy. Furthermore, the deregulation experiment leads to a divergence of labor productivities across industries, as in the data. Deregulated industries grow substantially faster than the remaining U.S. economy. However, the simulations also suggest that a broad rise of asset-specific ISTC rates is not the only source. Rather, the figures leave some scope for investments being shifted towards high-ISTC assets, as the data for non-deregulated industries indicates. Beyond its role for ISTC, deregulation might have had important stimulating effects on total factor productivity, in addition. Both qualifications point to interesting directions of future research.

2.A Industry-level evidence on the acceleration of investment-specific technical change

2.A.1 Dataset

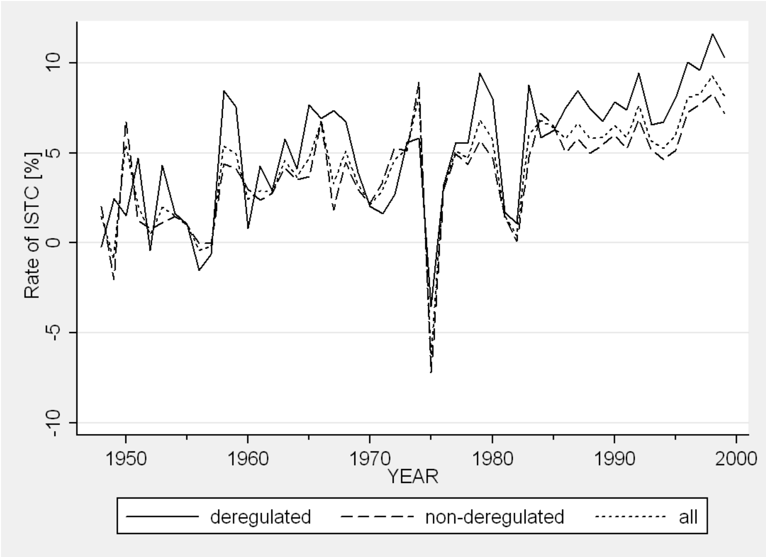
Our empirical analysis inspects whether deregulation has indeed accelerated the pace of investment-specific technical change. To identify the causal impact of deregulation, we compare a panel of U.S. industries; some of them being directly affected by the Ford/Carter/Reagan reforms. We use industry-level data on the rate of ISTC computed by Cummins and Violante (2002). Constructed from a Tornqvist aggregation of asset-specific technology indexes, the industry-level indexes measure *"the rate of technological improvement in the typical mix of investment goods used in production by each industry"* (Cummins and Violante, 2002, p. 260).[19]

We classify the 62 industries covered by the Cummins and Violante (2002) dataset into two groups: deregultated versus non-deregulated industries.[20] Figure 2.5 shows the investment-share weighted mean for both groups as well as for the whole economy and reveals faster ISTC for deregulated industries. Note that the cross-industry variation in the rate of ISTC stems from the different composition of investment goods installed by each industry. The figure reveals that ISTC rates increased in the late 1950s and in the 1980s again. As we focus our analysis on the consequences of the Ford/Carter/Reagan

[19] The Tornqvist aggregation method is described in Appendix 2.C.1.

[20] Our classification is based upon the information on legislative and regulatory changes provided by Joskow and Noll (1994); Winston (1993). See Table 2.8 for details.

Figure 2.5: Rate of investment-specific technical change by regulation status



deregulation, we restrict our estimation period to 1961-94 in order not to cover the Clinton deregulation period of the late 1990s.[21] As the vast majority of regulatory reforms was enacted in the years 1978 to 1982, we view this time span as the treatment epoch. Correspondingly, in our baseline specification the pre- and post-treatment period amount to 1961-77 and 1983-1994, respectively.

2.A.2 Empirical Strategy

The industry-level data allow us to compare the pace of technical change in deregulated industries with others not directly affected by the Ford/Carter/Reagan reforms. However, computing the causal effect of deregulation on the rate of ISTC would require data on an unobservable counterfactual situation: what would have been the pace of ISTC if deregulated industries had not been deregulated?

The econometric literature offers several estimators that make use of cross-sectional and/or longitudinal variation and employ different sets of assumptions to identify the

[21] The choice of 1961 as the first year under study is motivated by data issues: First, the underlying asset-specific ISTC rates are not available for computers and peripheral equipment and all three categories of software before 1960 in the Cummins and Violante (2002) dataset. Second, we regard the observations for 1959 and 1960 in the transportation by air industry with ISTC rates of more than 50% p.a. as outliers.

average treatment effect of the treated.

1. The cross-sectional estimator:
   The cross-sectional estimator compares the rates of ISTC for deregulated industries to those of non-deregulated industries assuming that in absence of deregulation ISTC were the same across all industries. But if ISTC were faster (slower) for deregulated industries, the estimator would be biased upward (downwards).

2. The before-after estimator:
   The before-after estimator compares the rates of ISTC for deregulated industries before and after the policy change. This comparison is a valid estimate of the true causal effect only if the pace of ISTC would not have changed over time, had there not been the deregulative reforms. In the presence of a positive time trend, however, the causal effect is overestimated by the before-after estimator.

3. The difference-in-difference estimator:
   The difference-in-difference estimator allows for a time trend that is common for both industry-groups by computing the difference of the before-after estimator between the deregulated and non-deregulated industries. The identifying assumption implicitly made here is that without any policy change, for both groups the change in ISTC rates would have been the same.

Of course, one can expect spillover effects from deregulated industries: even industries that were not directly affected by the regulatory reforms can benefit from higher quality equipment being available, although the R&D process has probably been more directed to the needs of the deregulated industries that increased their investment. In this case, both the cross-sectional and the difference-in-difference estimator underestimate the causal effect. Therefore, we regard them as a lower bound; and, hence, together with the before-after estimator the true causal effect of deregulation on investment-specific technical change is bracketed.

To implement these estimators on our (balanced) panel dataset, we estimate the average rate of ISTC in the period prior to and after the reforms for both groups. Thereto we regress the rate of ISTC, $q_{i,t}$, on dummy variables indicating the time period, $Post_t$, and regulatory status, $Dereg_i$, of industry i:

$$q_{i,t} = \alpha + \beta \cdot Post_t + \gamma \cdot Dereg_i + \delta \cdot (Post_t * Dereg_i) + \epsilon_{i,t}$$

where the coefficients β, γ and δ capture the before-after estimator, the cross-sectional estimator and the difference-in-difference estimator, respectively.

Given the panel structure of our dataset, independence of observations is unlikely: rather, the estimation strategy has to address the possibility of regression disturbances being correlated both over time and between industries. To the extent these correlations are due to unobservable common factors that are uncorrelated with the regressor, standard panel methods like pooled OLS or fixed effects still provide consistent coefficient estimates while standard error estimates are no longer valid. A popular remedy is to rely on "robust" standard errors, which are adjusted to be valid if certain assumptions regarding the model disturbances are violated: clustered standard errors, for instance, are valid if error terms can be assumed to be correlated only within the observational unit. The assumption of residuals being correlated within a cluster but independent across clusters is often inappropriate for panel models. Beck and Katz (1995) suggest panel corrected standard errors, which are robust to both contemporary cross-panel and serial correlation. Alternatively, one can apply a FGLS estimator with appropriate restrictions on the variance-covariance matrix.

2.A.3 Results

Table 2.5 reports the results for different specifications of pooled OLS and fixed effects regressions.[22] Among the pooled least squares estimates, we consider – besides a standard pooled OLS regression with clustered standard errors – a Prais-Winsten specification with panel-corrected standard errors as recommended by Beck and Katz (1995) as well as a feasible GLS model where the error process is allowed to be heteroskedastic across panels and assumed to follow a common AR(1) process. Finally, we employ a one-way error component regression model to allow for industry-specific fixed effects. While the first specification with clustered standard errors is equivalent

[22]Random effects specifications have most often been rejected by a Hausman test.

Table 2.5: Regression DiD: deregulated industries

	Pooled Least Squares			Industry Fixed Effects	
	OLS[a]	PRAIS-WINSTEN[b]	FGLS[c]	WITHIN[a, e]	WITHIN[d, e]
Explanatory	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)
dereg	1.342**	1.385***	0.842**		
	(0.592)	(0.415)	(0.420)		
d83	2.526***	2.697**	2.534***	2.526***	2.588***
	(0.536)	(1.059)	(0.511)	(0.536)	(0.413)
d83Xdereg	1.312**	1.345**	0.957*	1.312**	1.411***
	(0.580)	(0.551)	(0.557)	(0.579)	(0.465)
d7783	0.098	0.146	0.274	0.098	0.025
	(0.190)	(1.447)	(0.264)	(0.190)	(0.260)
d7783Xdereg	0.363	0.288	0.035	0.363	0.411
	(0.814)	(0.662)	(0.669)	(0.814)	(0.568)
_cons	6.694***	6.799***	6.224***	5.634***	5.663***
	(0.549)	(0.799)	(0.386)	(0.124)	(0.122)
R^2	0.038	0.027		0.046	0.037
χ^2		18.430	81.665		
F	11.858			14.710	19.186
p	0.0000	0.0025	0.0000	0.0000	0.0000
AC(1)			0.234		0.127
corr_fe				-0.109	-0.112
sigma_u				2.009	2.063
sigma_e				3.380	3.383
rho_fov				0.261	0.271
N_industries	62	62	62	62	62
Tbar		34	34	34	33
N	2108	2108	2108	2108	2046

[a] clustered standard errors reported
[b] Beck and Katz (1995) panel-corrected standard errors reported
[c] pooled FGLS with heteroskedastic errors following a common AR(1) process
[d] fixed effects model with common AR(1) error process
[e] within-R^2 reported
estimation period: 1961-1994
significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

---

to the pooled OLS estimator, the second within estimator explicitly models a common AR(1) error process.

The first column of Table 2.5, for instance, reports the results of the pooled OLS specification. In this case, the difference-in-difference estimator takes the value 1.312 percentage points p.a., the coefficient on the deregulation dummy estimates the cross-sectional estimator to be 1.342, and the before-after comparison yields an annual acceleration of 2.526 percentage points.[23]

To sum up, all specifications show a statistically significant and economically momentous increase of the ISTC rate. Except for the FGLS model, the difference-

[23]Note that the data is coded such that the coefficient on the interaction term of the post-treatment period with the deregulation dummy is identical to the difference-in-difference estimator, while the coefficients on the post-treatment period and the deregulation dummy are the before-after estimator and the cross-sectional estimator, respectively.

in-difference estimator, which yields a lower bound of the true causal effect, indicates an acceleration due to deregulation slightly above 1.3 percentage points p.a. The cross-sectional estimates are in line with the difference-in-difference results. On the other hand, the before-after estimator offers an upper bound in the range of 2.5 to 2.7 percentage points.

Overall, the Cummins and Violante (2002) industry-level data provide empirical evidence of a 1.3 to 2.5 percentage point acceleration of investment-specific technical change caused by the Ford/Carter/Reagan deregulative reforms. Finally, our robustness checks confirm this finding. Extending the estimation period to the full sample slightly increases the causal effect (Table 2.10), while additionally classifying industries that were severely but only indirectly affected by the reforms as "deregulated" reduces it by about 0.4 percentage points (Table 2.11). Moreover, the results are robust to different time frames of the interim, i.e. reform, period (Table 2.12).

Regulation Impact Regressions

The OECD indicator of regulation impact provides another way of robustness check: Instead of coding industries either as deregulated or not, the OECD indicator of regulation impact provides a measure of the extent of regulation impact. We regress the rate of ISTC on the OECD sectoral indicator of regulation impact. The dataset contains 27 industry groups for which the regulation impact (RI) indicator and the rate of ISTC can be matched.[24] Spanning from 1975 to 1999 it covers the Ford/Carter/Reagan and the Clinton deregulation.

Our hypothesis that deregulation has accelerated investment-specific technical change can be tested with a industry-fixed effects regression model. As the fixed-effects estimator relies solely on within variation, it captures only the impact of deviations of the regulation impact indicator from its time-mean on the rate of ISTC and discards the effect of cross-industry variation due to differing initial conditions. A negative relationship between the regulation impact indicator and the rate of ISTC will support our hypothesis, implying that more severe regulation is linked with lower technical

[24]As the OECD defines sectors according to the International Standard Industrial Classification (ISIC), concordance tables are used to match the industries. In this case, however, one has to considerably aggregate SIC industries to achieve correspondence.

Table 2.6: Regulation Impact Indicator Regression

	Industry Fixed Effects	
	WITHIN[a]	WITHIN[a]
Explanatory	Estimate (Std. Err.)	Estimate (Std. Err.)
regimp	-37.823*** (4.320)	
lnregimp		-8.812*** (1.041)
_cons	9.182*** (0.459)	-16.806*** (2.596)
within-R^2	0.066	0.096
F	76.646	71.613
corr	-0.919	-0.962
sigma_u	4.533	6.774
sigma_e	2.346	2.308
rho	0.789	0.896
N_industries	27	27
Tbar	24	24
N	648	648

[a] clustered standard errors reported
estimation period: 1975-1999
significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

change. As Table 2.6 shows for both the linear and the lin-log specification, the significantly negative coefficients confirm our hypothesis.

2.B Markup Estimation

2.B.1 Dataset

We use time-series data on value added and compensation of employees from the GDP-by-industry accounts published by the Bureau of Economic Analysis. The dataset is based on SIC industries and covers the period 1947 to 1997. Besides, we use the stock of private fixed assets and depreciation of private fixed assets from the BEA's Fixed Asset Accounts.[25] The literature computes the remuneration of capital as the product of a rental rate of capital and the capital stock. The rental rate of capital consists of an economic depreciation rate which is computed from FAA-data and the firms' real costs of funds rate. The latter is approximated by the nominal interest rate implied by Moody's AAA Corporate Bond index less inflation expectations. We follow Oliveira Martins, Scarpetta, and Pilat (1996) and construct our measure of inflation expectations as the HP-trend of the annual inflation rate, measured by a chain-type price-index for GDP.

2.B.2 Empirical Strategy

Roeger (1995) proposes to estimate the markup ratio of prices over marginal costs, $\mu \equiv \frac{P}{MC}$, indirectly via the Lerner index, $L \equiv \frac{P-MC}{P} \in [0,1]$. Employing primal and dual growth accounting, Roeger (1995) derives his estimation equation

$$\Delta y_t = L \cdot \Delta x_t + u_t \tag{2.30}$$

from a constant-returns-to-scale production function, $A_t \cdot F(N_t, K_t)$, for value added, Q_t, under imperfect competition. Here N_t and K_t denote labor and capital input, respectively, and A_t measures total factor productivity. Roeger (1995)'s dependent and explanatory variables are functions of these quantities and corresponding factor prices. Oliveira Martins, Scarpetta, and Pilat (1996) show that one can rearrange terms so

[25] Tables 3.1ES and 3.4ES as of September 25, 2002.

that Δy_t and Δx_t are defined only by nominal variables:

$$\Delta y_t \equiv \Delta(q_t + p_t) - \alpha_t \cdot \Delta(n_t + w_t) - (1 - \alpha_t) \cdot \Delta(k_t + r_t)$$

$$\Delta x_t \equiv \Delta(q_t + p_t) - \Delta(k_t + r_t)$$

where P_t is the price of value added, W_t the wage rate, R_t the rental rate of capital, and $\alpha_t \equiv \frac{W_t N_t}{P_t Q_t}$ the wage bill share in value added. Lower-case letters denote logs of the corresponding (upper-case) variables. However, this regression may suffer from endogeneity issues as nominal value added appears on both sides of the estimation equation. Boulhol (2008); Hindriks, Nieuwenhuijsen, and de Wit (2000) argue that rearranging terms in the following way mitigates this bias:

$$\Delta x_t = \mu \cdot \Delta z_t + e_t \tag{2.31}$$

where

$$\Delta z_t \equiv \alpha_t \cdot [\Delta(n_t + w_t) - \Delta(k_t + r_t)]$$

As this regression estimates the markup directly, it is called the μ-based version, while Roeger (1995)'s original regression equation is called L-based version. Note that the relationship between both measures is non-linear: $\mu = \frac{1}{1-L}$. Boulhol (2008) shows theoretically that L-based markups are higher than μ-based ones.

Eventually, Oliveira Martins, Scarpetta, and Pilat (1996) show that in the presence of decreasing (increasing) returns to scale the estimated markup is upward-biased (downward-biased). This finding is especially relevant in the case of fixed factors. As Boulhol (2008) points out, returns to scale on the variable factors matter. Hence, if capital, for example, were fixed in the short-run and returns to scale on the variable factors were decreasing, markups would be overestimated.

2.B.3 Results

We estimate markups by running μ-based regressions for 69 U.S. industries.[26] In order to bring out the impact of the Ford/Carter/Regan deregulation on market conduct, we split the sample into two estimation periods: a pre-deregulation period and a post-deregulation one. The regression results are illustrated in Figure 2.4 and condensed in Table 2.7.

Figure 2.4 compares the estimated gross markups for our benchmark period. Each bullet depicts a single industry. Bullets below the 45°-line indicate industries that experienced a decline in markup, while bullets above suggest an increase in markups. First of all, many estimates lie in the [1,2]-square. This means these markups are in a range of 0 to 100%, a very plausible order of magnitude. More importantly, most bullets are below the 45°-line which means that most U.S. industries experienced a decline in the markup after the Ford/Carter/Reagan deregulation. This is particularly true for the majority of deregulated industries (red bullets).

Table 2.7 reports these markup estimates for a few industry groups. For the aggregate of deregulated industries, the gross markup decreased, on average, by 22 percentage points from 1.92 to 1.71. This decrease comes mainly from the Energy and Utilities industry as well as Radio and Television, as the industry-group estimates show. Similarly, markups in severely affected industries decline on average by 35 percentage points, while for the remaining private industries there is essentially no change. Overall, these findings indicate that deregulation lead to more intense competition in the 1980s and 1990s that becomes visible in lower markups.

[26] Table 2.C.2 compares our μ-based and L-based estimates to Roeger (1995) as well as Oliveira Martins, Scarpetta, and Pilat (1996). By and large, our μ-based markups are close to Roeger (1995)'s estimates. Furthermore, for most of the industries that were not covered by Roeger (1995) or Oliveira Martins, Scarpetta, and Pilat (1996) our estimates seem to be plausible with respect to their order of magnitude.

Table 2.7: Estimation of Markup Ratios

Estimation Period	**1961 1977**	**1983 1994**	Δ	**1961 1974**	**1983 1997**	Δ
Private Industries	1.95	1.87	-0.08	2.06	1.87	-0.19
	(0.09)	(0.04)		(0.06)	80.04)	
Deregulated Industries	1.92	1.71	-0.22	1.95	1.76	-0.20
	(0.15)	(0.22)		(0.18)	(0.23)	
Energy and Utilities	3.00	1.07	-1.93	3.09	1.02	-2.06
	(0.35)	(0.90)		(0.38)	(0.88)	
Telecommunication	2.34	2.68	0.34	2.42	2.38	-0.04
	(0.19)	(0.57)		(0.19)	(0.56)	
Transportation	1.57	1.50	-0.06	1.52	1.51	-0.01
	(0.12)	(0.11)		(0.12)	(0.10)	
Radio and Television	1.95	1.06	-0.89	1.80	1.26	-0.55
	(0.21)	(0.77)		(0.21)	(0.66)	
Banking	1.57	1.70	0.14	1.58	1.75	0.17
	(0.10)	(0.18)		(0.11)	(0.18)	
Severely Affected Industries	2.35	2.00	-0.35	2.69	1.98	-0.70
	(0.22)	(0.33)		(0.20)	(0.32)	
Remaining Private Industries	1.92	1.90	-0.03	2.02	1.88	-0.13
	(0.10)	(0.05)		(0.06)	(0.05)	

Estimates for μ-based version of the regression equation.
White standard errors are reported in parentheses.

2.C Supplementary Materials

2.C.1 Data

Measuring Investment-specific Technical Change

The industry-level data on the rate of ISTC were constructed by Cummins and Violante (2002) from a Tornqvist aggregation of asset-specific technology indexes that are price-based measures of investment-specific technical change. To be precise, Cummins and Violante (2002) estimate for each of the 26 different categories of producers' durable equipment and software the quality bias implicit in the official NIPA price indexes. Correcting for this quality bias, they compute the (constant-quality) price of a investment good in terms of consumption, which the literature identifies with the inverse of the index of investment-specific technology. Then they aggregate for each of the 62 industries considered the asset-specific ISTC rates by weighting them according to their share in the industry's nominal investment expenditures. This yields a measure of *"the rate of technological improvement in the typical mix of investment goods used in production by each industry"* (Cummins and Violante, 2002, p. 260).

The investment data we use to aggregate the industry-specific ISTC rates into an index for deregulated and one for non-deregulated industries come from the U.S. Bureau of Economic Analysis' Fixed Asset Tables: Investment in Private Equipment and Software by Industry.

The OECD product market regulation index

Based on its International Regulation Database, the OECD compiles, among others, indicators of product market regulation at sectoral levels. According to Conway and Nicoletti (2006, p. 6) all indicators intend to *"quantify the degree to which regulatory settings in a given sector are anti-competitive."*

For sectors of the energy, transport and communication (ETCR) group, these indicators of sectoral regulation have been constructed for the years 1975 to 2007, while for retail distribution and business services (RBSR) sectors the indicators are only available for the years 1996, 1998, and 2003. Due to this data availability problem, we focus on the seven non-manufacturing sectors that have been under study since the mid-1970s, i.e. airlines, telecoms, electricity, gas, post, rail, and road freight.

Depending on the sector, some of the following low-level indicators have been computed: barriers to entry, public ownership, vertical integration, market structure, and price controls. Conway and Nicoletti (2006) claim that the coverage of the various regulatory areas is tailored to the structural characteristics of each industry.

These low-level indicators are constructed as weighted average of several items, each coded on a scale of 0 to 6, reflecting increasing restrictiveness of regulatory provisions to competition. Scores are awarded relative to theoretical best or worst practice situations. In order to obtain indicators by area of regulation, low-level indicators are aggregated across sectors using some weighting scheme.

The Barriers to Entry Indicator covers regulations that curb entry and/or distort market structure relative to a competitive outcome (Conway and Nicoletti, 2006, p. 7). It is therefore closest to our question at hand. The indicator consists of 2 to 4 equally weighted items and collects information on the extent to which the number of firms that are allowed to operate in a market is restricted and on the legal conditions of entry into the market; for the energy sector information on the terms and conditions of third party market access and on the extent of choice of supplier for consumers instead.

Classifying Deregulated Industries

For the classification of industries into deregulated or non-deregulated we collect information on legislative and regulatory changes during the Ford, Carter, and Reagan presidencies. Our classification is based upon Joskow and Noll (1994, tab. 6.2) and Winston (1993, tab. 1) and shown in the third column of Table 2.8.

Moreover, the OECD Indicators of Regulation Impact (Conway and Nicoletti, 2006) allow us to identify industries that were not directly hit by the deregulative reforms but were affected indirectly via economic linkages to deregulated ones.[27] We define an industry to be severely affected by deregulation if its Regulatory Impact indicator declined by more than 10% between 1978 and 1982. These industries are marked in the last column of Table 2.8.

[27]OECD Indicators of Regulation Impact are available from the OECD International Regulation Database at `http://www.oecd.org/document/1/0,3343,en_2649_34323_2367297_1_1_1_1,00.html`.

Table 2.8: Coding of deregulation dummy

US SIC	Industry	year of earliest deregulative reform	severely affected industries
1	Farms		x
7	Agricultural services, forestry, and fishing		x
10	Metal mining		
12	Coal mining		
13	Oil and gas extraction	1978	
14	Nonmetallic minerals, except fuels		
15	Construction		
20	Food and kindred products		
21	Tobacco products		
22	Textile mill products		
23	Apparel and other textile products		
24	Lumber and wood products		x
25	Furniture and fixtures		
26	Paper and allied products		
27	Printing and publishing		
28	Chemicals and allied products		
29	Petroleum and coal products	1981	
30	Rubber and miscellaneous plastics products		x
31	Leather and leather products		
32	Stone, clay, and glass products		x
33	Primary metal industries		x
34	Fabricated metal products		
35	Industrial machinery and equipment		
36	Electronic and other electric equipment		
371	Motor vehicles and equipment		
372	Other transportation equipment		
38	Instruments and related products		
39	Miscellaneous manufacturing industries		
40	Railroad transportation	1976	x
41	Local and interurban passenger transit	1982	x
42	Trucking and warehousing	1980	x
44	Water transportation	1984	x
45	Transportation by air	1978	x
46	Pipelines, except natural gas	1981	x
47	Transportation services	1980	x
481	Telephone and telegraph	1977	
483	Radio and television	1981	
491	Electric services	1978	
492	Gas services	1981	
495	Sanitary services		
50	Wholesale trade		

Continued on next page

Table 2.8: Coding of deregulation dummy

US SIC	**Industry**	**year of earliest deregulative reform**	**severely affected industries**
52	Retail trade		
60	Other depository institutions	1980	
6011	Federal reserve banks		
61	Nondepository institutions	1980	
62	Security and commodity brokers	1975	
63	Insurance carriers		
64	Insurance agents, brokers, and service		
65	Real estate		
671	Nonfinancial holding and investment offices		
672	Financial holding and investment offices		
70	Hotels and other lodging places		
72	Personal services		
73	Business services		
75	Auto repair, services, and parking		
76	Miscellaneous repair services		
78	Motion pictures		
79	Amusement and recreation services		
80	Health services		
81	Legal services		
82	Educational services		
83	Other services, n.e.c.		

Industries classified as ”severely affected by deregulative reform” are defined by a decline of the OECD Regulatory Impact indicator by more than 10% between 1978 and 1982.

Industries classified as ”deregulated” or ”highly affected by deregulative reform” are coded as 0, others as -1.

Table 2.9: Rise in Investment-Specific Technical Change

article	aggregation of investments	data source	growth in ISTC p.a. period 1	growth in ISTC p.a. period 2
GY (1997)	producers' durable equipment	Gordon, NIPA	1954-74: 3.3%	1975-1990: 4.0%
KORV (2000)	capital equipment	Gordon	1963-79: 3.6%	1980-1992: 6.0%
KORV (2000)	capital equipment	NIPA	1963-79: 0.3%	1980-1992: 2.6%
CV (2002)	equipment & software	CV	1960-79: 3.6%	1980-2000: 5.5%
Fisher (2006)	equipment & software	CV	1955-82: 3.2%	1983-2000: 5.8%
RT (2012)	equipment & software	CV, RT	1977-80: 2.6%	1980-1990: 5.5%
Pakko (2002c)	total private NFI[a]	Pakko	1950-82: 2.0%	1983-2000: 4.0%
Pakko (2005)	total private NFI[a]	Pakko	1951-87: 2.2%	1988-2001: 3.8%
JPT (2009)	consumer durables & PDI[b]	CV	1954-81: 1.2%	1982-2000: 3.1%
JPT (2009)	consumer durables & PDI[b]	NIPA	1954-81: 0.6%	1982-2000: 2.4%

[a] NFI: nonresidential fixed investment
[b] PDI : private domestic investment
GY (1997): Greenwood and Yorukoglu (1997)
KORV (2000): Krusell, Ohanian, Ríos-Rull, and Violante (2000)
CV (2002): Cummins and Violante (2002)
RT (2012): Rodríguez-López and Torres (2012)
JPT (2009): Justiniano, Primiceri, and Tambalotti (2009)

2.C.2 Tables and Figures Appendix

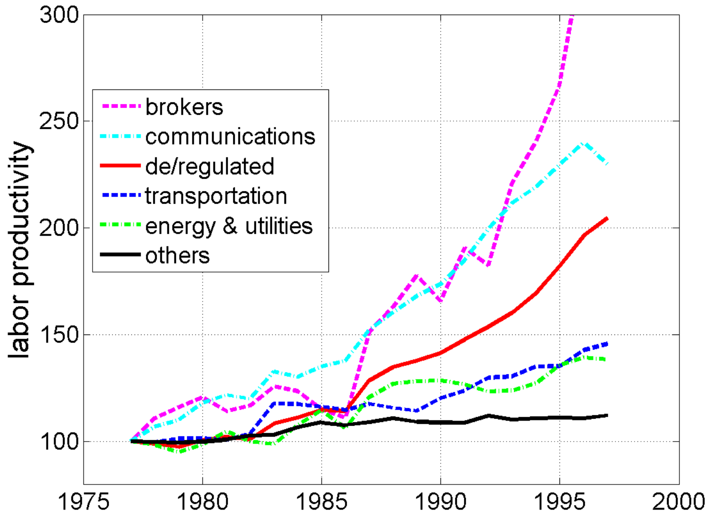
Acceleration of Investment-specific technical change

It is a well-documented fact that ISTC accelerated in the early 1980s. Table 2.9 provides an overview of the empirical evidence. Note that there exist, essentially, two different measures of the state of investment-specific technology: first, both Cummins and Violante (2002) and Pakko (2002b) provide time-series data on the development of investment-specific technology indices, which are derived from a constant-quality price index for investment goods based on Gordon (1990)'s "The Measurement of Durable Goods Prices". Second, the Bureau of Economic Analysis started to introduce hedonic methods only in the late 1980s and 1990s.[28]

As expected, both the growth rates of investment-specific technology and their increase show some variation, depending not only on the data source and periods considered but also the definition of investments employed. A closer look at the varieties of investments establishes the following pattern: ISTC is especially prominent in computers, communication equipment, and software – sometimes at two-digit rates

[28] see e.g. Pakko (2002a) or Pakko (2005, Appendix).

Figure 2.6: Labor productivity diverges



Notes: Labor productivity is computed as real value-added per full-time equivalent employee. De/regulated industries are Energy and utilities, Communications, Transportation, and Brokers; affected industries are those private industries that obtained more than 20 % of their intermediate inputs from de/regulated industries; other industries are all remaining private industries.

Data Source: Bureau of Economic Analysis, NIPA.

–, while other types of producers' durable equipment and structures show lower rates.[29] Nevertheless, all report an economically significant acceleration, mostly in the range between 1.5 to 2.5 percentage points p.a. . Regarding the timing of the acceleration, Pakko (2005, Tab. 1) conducts statistical structural-break tests and provides overwhelming evidence for a breakpoint in 1983 – just about the end of the deregulation phase.

Robustness of DiD results

[29]ISTC rates for different asset categories are reported by Cummins and Violante (2002) and Pakko (2002a, Web appendix). In order to evaluate their contribution to productivity growth, Martínez, Rodríguez, and Torres (2010); Rodríguez-López and Torres (2012) conduct decomposed growth accounting.

Table 2.10: Regression DiD: deregulated industries, all years

	Pooled Least Squares			Industry Fixed Effects	
	OLS[a]	PRAIS-WINSTEN[b]	FGLS[c]	WITHIN[a, e]	WITHIN[d, e]
Explanatory	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)
dereg	1.416**	1.454***	0.976***		
	(0.655)	(0.474)	(0.373)		
d83	3.935***	4.083***	3.667***	3.925***	3.897***
	(0.460)	(0.919)	(0.437)	(0.457)	(0.373)
d83Xdereg	1.352***	1.407**	1.003**	1.342***	1.258***
	(0.494)	(0.599)	(0.471)	(0.491)	(0.420)
d7783	1.104***	1.062	0.953***	1.104***	1.047***
	(0.246)	(1.330)	(0.246)	(0.246)	(0.270)
d7783Xdereg	0.329	0.282	0.235	0.319	0.157
	(0.767)	(0.837)	(0.659)	(0.772)	(0.589)
_cons	7.130***	7.239***	6.634***	6.010***	6.075***
	(0.607)	(0.728)	(0.346)	(0.106)	(0.105)
R^2	0.110	0.078		0.125	0.088
χ^2		25.154	302.724		
F	60.298			75.388	74.417
p	0.0000	0.0001	0.0000	0.0000	0.0000
AC(1)			0.240		0.215
corr_fe				-0.090	-0.084
sigma_u				1.624	1.641
sigma_e				3.547	3.479
rho_fov				0.173	0.182
N_industries	62	62	62	62	62
Tbar		51.97	51.97	51.97	50.97
N	3222	3222	3222	3222	3160

[a] clustered standard errors reported
[b] Beck and Katz (1995) panel-corrected standard errors reported
[c] pooled FGLS with heteroskedastic errors following a common AR(1) process
[d] fixed effects model with common AR(1) error process
[e] within-R^2 reported
estimation period: 1948-1999
significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.11: Regression DiD: deregulated and severely affected industries

	Pooled Least Squares			Industry Fixed Effects	
	OLS[a]	Prais-Winsten[b]	FGLS[c]	Within[a, e]	Within[d, e]
Explanatory	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)
dereg	0.018	0.036	-0.457		
	(0.517)	(0.359)	(0.329)		
d83	2.124***	2.269**	2.117***	2.124***	2.191***
	(0.365)	(1.121)	(0.365)	(0.365)	(0.325)
d83Xdereg	0.960**	0.971**	0.560	0.960**	1.085***
	(0.447)	(0.476)	(0.436)	(0.447)	(0.400)
d7783	0.157	0.187	0.298	0.157	0.055
	(0.210)	(1.428)	(0.288)	(0.210)	(0.285)
d7783Xdereg	0.052	0.052	-0.087	0.052	0.169
	(0.562)	(0.574)	(0.525)	(0.562)	(0.489)
_cons	5.646***	5.725***	5.198***	5.634***	5.663***
	(0.461)	(0.846)	(0.275)	(0.125)	(0.123)
R^2	0.039	0.028		0.045	0.037
χ^2		15.594	98.946		
F	13.268			15.215	18.767
p	0.0000	0.0081	0.0000	0.0000	0.0000
AC(1)			0.227		0.127
corr_fe				-0.002	-0.003
sigma_u				1.925	1.975
sigma_e				3.382	3.385
rho_fov				0.245	0.254
N_industries	62	62	62	62	62
Tbar		34	34	34	33
N	2108	2108	2108	2108	2046

[a] clustered standard errors reported
[b] Beck and Katz (1995) panel-corrected standard errors reported
[c] pooled FGLS with heteroskedastic errors following a common AR(1) process
[d] fixed effects model with common AR(1) error process
[e] within-R^2reported
estimation period: 1961-1994
significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.12: Regression DiD: deregulated industries, interim period

pre reform	1961 - 1979		1961 - 1976		1961 - 1974	
post reform	1980 - 1994		1983 - 1994		1985 - 1994	
	PRAIS-WINSTEN[b]	WITHIN[a, c]	PRAIS-WINSTEN[b]	WITHIN[a, c]	PRAIS-WINSTEN[b]	WITHIN[a, c]
Explanatory	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	Estimate (Std. Err.)	
dereg	1.068***		1.385***		1.363***	
	(0.398)		(0.415)		(0.466)	
d80	1.208	1.402***				
	(1.044)	(0.510)				
d80Xdereg	0.895*	1.037*				
	(0.527)	(0.548)				
d83			2.697**	2.526***		
			(1.059)	(0.536)		
d83Xdereg			1.345**	1.312**		
			(0.551)	(0.579)		
d7783			0.146	0.098		
			(1.447)	(0.190)		
d7783Xdereg			0.288	0.363		
			(0.662)	(0.814)		
d85					1.291	1.730***
					(1.180)	(0.593)
d85Xdereg					1.365**	1.310**
					(0.613)	(0.629)
d7585					-2.196*	-1.426***
					(1.259)	(0.188)
d7585Xdereg					0.567	0.367
					(0.601)	(0.780)
const	5.809***	5.027***	6.799***	5.634***	6.512***	5.588***
	(0.789)	(0.107)	(0.799)	(0.124)	(0.898)	(0.131)
R^2	0.002	0.011	0.027	0.046	0.047	0.059
χ^2	8.415		18.430		14.989	
F		5.449		14.710		27.369
p	0.0382	0.0229	0.0025	0.0000	0.0104	0.0000
corr_fe		-0.129		-0.109		-0.104
sigma_u		1.988		2.009		2.013
sigma_e		3.440		3.380		3.356
rho_fov		0.250		0.261		0.265
N_industries	62	62	62	62	62	62
Tbar	34	34	34	34	34	34
N	2108	2108	2108	2108	2108	2108

[a] clustered standard errors reported
[b] Beck and Katz (1995) panel-corrected standard errors reported
[c] within-R^2 reported
significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Markup Estimation

Table 2.13: Comparison of Markups for the U.S.

	Roeger (1995)	Oliveira Martins et al. (1996)	*L*-based			μ-based		
Period	1953 - 1984	1970 - 1992	1953 - 1984			1953 - 1984		
Industry	Markup	Markup	Markup	95% CI (White)		Markup	95% CI (White)	
Private industries			2.01	1.89	2.14	1.95	1.83	2.08
Agriculture, forestry, and fishing			15.85	9.78	41.82	4.59	1.03	8.15
Farms			23.80	12.55	231.27	4.81	0.74	8.89
Agricultural services, forestry, and fishing			2.66	2.38	3.03	2.36	2.15	2.57
Mining			6.42	3.47	42.47	1.78	0.43	3.13
Metal mining			4.74	3.46	7.52	2.30	1.25	3.34
Coal mining			3.14	1.77	13.77	1.33	1.03	1.62
Oil and gas extraction			12.41	6.64	94.63	3.81	1.75	5.87
Nonmetallic minerals, except fuels			3.09	2.54	3.95	2.42	1.96	2.87
Construction	1.44		1.55	1.40	1.73	1.50	1.35	1.64
Manufacturing			1.62	1.51	1.75	1.55	1.39	1.70
Durable goods	1.45		1.60	1.47	1.75	1.51	1.37	1.66
Lumber and wood products	1.75	1.22	2.06	1.89	2.26	1.94	1.77	2.11
Furniture and fixtures	1.28	1.06	1.34	1.18	1.56	1.23	1.03	1.43
Stone, clay, and glass products	1.59	1.09 - 1.18	1.90	1.68	2.18	1.76	1.53	1.99
Primary metal industries	1.58	1.10 - 1.14	1.99	1.74	2.33	1.70	1.47	1.93
Fabricated metal products	1.33	1.09	1.39	1.29	1.49	1.33	1.21	1.45
Machinery, except electrical	1.41	1.06 - 1.54	1.50	1.36	1.66	1.39	1.24	1.55
Electric and electronic equipment	1.34		1.49	1.31	1.73	1.33	1.10	1.56
Motor vehicles and equipment	2.06	1.09	2.48	2.09	3.04	2.00	1.63	2.37
Other transportation equipment	1.22	1.05 - 1.13	1.78	1.12	4.32	1.13	0.92	1.33
Instruments and related products	1.47	1.09	1.60	1.35	1.95	1.38	1.13	1.64
Miscellaneous manufacturing industries	1.62	1.08	1.75	1.42	2.30	1.19	0.81	1.56
Nondurable goods	1.48		1.72	1.57	1.89	1.61	1.41	1.82
Food and kindred products	1.50	1.05	2.25	1.71	3.27	1.51	1.13	1.90

	Roeger (1995)	Oliveira Martins et al. (1996)	L-based			μ-based		
	Markup	Markup	Markup	95% CI (White)		Markup	95% CI (White)	
Tobacco products	2.75	1.56	7.35	6.01	9.46	6.13	5.39	6.87
Textile mill products	1.34	1.08	1.43	1.31	1.56	1.36	1.26	1.46
Apparel and other textile products	1.15	1.10	1.25	1.13	1.38	1.15	1.02	1.27
Paper and allied products	1.57	1.13	1.77	1.59	2.00	1.65	1.48	1.82
Printing and publishing	1.40	1.19	1.66	1.48	1.89	1.52	1.32	1.72
Chemicals and allied products	2.11	1.18 - 1.44	2.67	2.27	3.25	2.06	1.71	2.41
Petroleum and coal products		1.11	9.63	5.28	54.31	2.27	0.84	3.70
Rubber and miscellaneous plastics products	1.36		1.61	1.42	1.85	1.46	1.22	1.70
Leather and leather products	1.19	1.08	1.30	1.14	1.50	1.12	0.96	1.28
Transportation and public utilities			2.16	1.89	2.51	1.99	1.77	2.22
Transportation			1.68	1.50	1.92	1.60	1.43	1.77
Railroad transportation			1.61	1.37	1.97	1.41	1.20	1.62
Local and interurban passenger transit			1.96	1.65	2.42	1.62	1.47	1.78
Trucking and warehousing			1.56	1.45	1.69	1.49	1.38	1.59
Water transportation			1.51	1.26	1.87	1.26	1.02	1.51
Transportation by air			2.14	1.85	2.55	1.82	1.58	2.07
Pipelines, except natural gas			10.90	8.05	16.88	4.97	3.09	6.85
Transportation services			4.46	2.96	9.03	1.89	1.08	2.71
Communications			2.55	2.14	3.16	2.11	1.83	2.39
Telephone and telegraph			2.69	2.21	3.44	2.14	1.82	2.46
Radio and television		1.40	2.10	1.83	2.47	1.78	1.55	2.01
Electric, gas, and sanitary services	3.14		3.84	3.36	4.48	3.22	2.68	3.76
Wholesale trade			2.19	1.98	2.44	2.01	1.85	2.17
Retail trade			1.91	1.77	2.08	1.82	1.66	1.98
Finance, insurance, and real estate			5.01	4.62	5.47	4.83	4.47	5.19
Banking			2.47	2.19	2.82	2.14	1.84	2.44
Credit agencies other than banks			9.18	3.76	∞	1.04	0.20	1.88
Security and commodity brokers			2.10	1.69	2.77	1.62	1.37	1.87

	Roeger (1995)	Oliveira Martins et al. (1996)	L-based			μ-based		
	Markup	Markup	Markup	95% CI (White)		Markup	95% CI (White)	
Insurance carriers			1.76	1.51	2.11	1.48	1.27	1.68
Insurance agents, brokers, and service			2.72	2.37	3.21	2.26	1.85	2.67
Real estate			23.02	18.81	29.64	17.12	14.95	19.30
Services			1.73	1.63	1.84	1.68	1.58	1.78
Hotels and other lodging places			2.01	1.84	2.22	1.88	1.68	2.08
Personal services			1.93	1.77	2.13	1.82	1.66	1.98
Business services			1.67	1.54	1.81	1.53	1.41	1.65
Auto repair, services, and parking			2.89	2.40	3.65	2.21	1.69	2.73
Miscellaneous repair services			2.77	2.22	3.67	1.98	1.54	2.43
Motion pictures			2.55	2.09	3.27	1.83	1.40	2.26
Amusement and recreation services			2.30	1.96	2.77	2.00	1.79	2.21
Health services			2.09	1.69	2.74	1.37	1.03	1.70
Legal services			3.47	2.89	4.35	2.37	1.74	3.00
Educational services			1.07	1.02	1.13	1.05	0.99	1.11
Other			1.19	1.13	1.25	1.17	1.11	1.23

2.C.3 Calibration

Table 2.14: Average annual rate of ISTC by capital good

	Capital Type	**ISTC rate**	
		1960-75	1965-75
1	Computers and peripheral equipment	26.083	23.475
2	Pre-Packaged software	17.146	15.767
3	Customized software	0.512	0.971
4	Own-account software	4.386	4.440
5	Communication equipment	3.234	3.766
6	Instruments, photocopy, and related equipment	6.957	9.332
7	Office and accounting equipment	2.667	3.349
8	Fabricated metal products	2.769	2.262
9	Engines and turbines	3.117	2.126
10	Metalworking machinery	1.260	1.644
11	Special industry machinery	3.874	4.040
12	General industrial equipment	2.430	2.150
13	Electrical transmission, distribution, and industrial apparatus	4.316	2.877
14	Trucks, buses, and truck trailers	4.057	4.252
15	Autos	4.031	5.472
16	Aircraft	10.752	10.893
17	Ships and boats	2.199	1.933
18	Railroad equipment	1.538	2.216
19	Furniture and fixtures	1.871	1.644
20	Tractors	1.808	2.420
21	Agricultural machinery	0.092	0.122
22	Construction machinery	2.196	1.900
23	Mining and oilfield machinery	2.196	1.900
24	Service industry machinery	5.451	5.221
25	Electrical equipment	1.746	1.839
26	Other equipment	2.424	2.355
27	Structures	1.000	1.000

Sources: For equipment and software capital the underlying data is taken from the web appendix to Cummins and Violante (2002). For structures we use the estimate of Gort, Greenwood, and Rupert (1999) which we assume to be valid for the whole post-war period.

Table 2.15: Calibrated share in final demand

	Industry	θ_i^Y [%]
1	FARMS	1.10419
2	AGRICULTURAL SERVICES, FORESTRY, FISHING	0.09339
3	METAL MINING	0.02490
4	COAL MINING	0.02205
5	OIL & GAS EXTRACTION	0.06561
6	NONMETALLIC MINERALS, EXCEPT FUELS	0.00291
7	CONSTRUCTION	10.59149
8	LUMBER AND WOOD PRODUCTS	0.11373
9	FURNITURE AND FIXTURES	0.99012
10	STONE, CLAY, AND GLASS PRODUCTS	0.17679
11	PRIMARY METAL INDUSTRIES	0.13412
12	FABRICATED METAL PRODUCTS	0.61937
13	INDUSTRIAL MACHINERY	3.24991
14	ELECTRICAL MACHINERY	2.33676
15	MOTOR VEHICLES AND EQUIPMENT	4.82430
16	OTHER TRANSPORTATION EQUIPMENT	1.38573
17	INSTRUMENTS AND RELATED PRODUCTS	0.78747
18	MISCELLANEOUS MANUFACTURING	0.87027
19	FOOD AND KINDRED PRODUCTS	7.79307
20	TOBACCO PRODUCTS	0.67382
21	TEXTILE MILL PRODUCTS	0.78039
22	APPAREL & OTHER TEXTILE PRODUCTS	2.36554
23	PAPER AND ALLIED PRODUCTS	0.30183
24	PRINTING AND PUBLISHING	0.65215
25	CHEMICALS AND ALLIED PRODUCTS	1.38040
26	PETROLEUM AND COAL PRODUCTS	1.40795
27	RUBBER AND PLASTIC PRODUCTS	0.54685
28	LEATHER AND LEATHER PRODUCTS	0.55120
29	RAILROAD TRANSPORTATION	0.33863
30	LOCAL AND INTERURBAN TRANSIT	0.44804
31	TRUCKING AND WAREHOUSING	0.80221
32	WATER TRANSPORTATION	0.13292
33	AIR TRANSPORTATION	0.60672
34	PIPELINES, EXCEPT NATURAL GAS	0.03127
35	TRANSPORTATION SERVICES	0.03540
36	TELEPHONE AND TELEGRAPH SERVICES	1.60874
37	RADIO & TV BROADCASTING	0.00778
38	ELECTRIC SERVICES	1.30755
39	GAS SERVICES	0.67403
40	SANITARY SERVICES	0.13031
41	WHOLESALE TRADE	4.89388
42	RETAIL TRADE	15.11415
43	DEPOSITORY INSTITUTIONS	1.33678
44	NONDEPOSITORY INSTITUTIONS	0.38531
45	SECURITY AND COMMODITY BROKERS	0.40867
46	INSURANCE CARRIERS	2.04622
47	INSURANCE AGENTS AND BROKERS	0.00000
48	REAL ESTATE	12.07569
49	HOTELS AND LODGING PLACES	0.51125
50	PERSONAL SERVICES	1.69478
51	BUSINESS SERVICES	0.40354
52	AUTO REPAIR, SERVICES, AND PARKING	1.46024
53	MOTION PICTURES	0.16037
54	AMUSEMENT AND RECREATION SERVICES	0.73559
55	HEALTH SERVICES	4.95109
56	LEGAL SERVICES	0.57186
57	EDUCATIONAL SERVICES	1.07725
58	OTHER SERVICES	2.20339

Chapter 3

On the Cyclicality of R&D Activities: Do Recessions Foster Economic Growth?

3.1 Introduction

Background. — Economists have recently revived the long-standing notion that cyclical fluctuations and productivity growth are closely interrelated.[1] Some economists argue that economic downturns may well be ideal times to enhance productivity. Their reasoning is based on an opportunity cost argument: during recessions R&D activities are relatively more profitable than goods production because forgone output, the opportunity cost of R&D, is comparatively low (Aghion and Saint-Paul, 1998; Saint-Paul, 1993). This is why in an endogenous growth framework short-run economic fluctuations have a persistent impact on the economy's output level, namely through their impact on the intertemporal allocation of R&D resources over the business cycle (Barlevy, 2007; Fatás, 2000a,b).

The facts. — Empirical evidence for the post-war U.S. economy shows that R&D activities are procyclical: both real R&D expenditures and employment of scientists and engineers tend to rise during booms and fall during recessions. This procyclicality

[1] See, among others, Aghion and Saint-Paul (1998); Barlevy (2004, 2007); Comin and Gertler (2006); Fatás (2000a,b); Francois and Lloyd-Ellis (2009); Nuño (2011); Posch and Wälde (2011); Wälde (2002, 2005).

is documented at the aggregate and the industry level, and for total as well as industry-funded R&D.[2]

The question. — Do recessions foster economic growth, as an opportunity cost argument predicts? Or is it booms, as empirical evidence on R&D activity suggests? First, the essay asks whether an endogenous growth framework is able to capture the cyclical properties of R&D activities – both procyclical R&D investment and procyclical employment of scientists and engineers. Then, the long-run consequences of business cycle shocks on productivity are explored.

The approach. — I propose a calibrated real business cycle model featuring R&D-based growth through horizontal innovations. The R&D process allows for multiple inputs into R&D: labor and goods. This novel, more realistic description of R&D is based on detailed evidence from the National Science Foundation. Then, I quantitatively study the relevance of goods inputs into R&D as well as endogenous labor supply for rendering R&D procyclical. To the best of my knowledge, this is the first quantitative investigation into the determinants of the procyclicality of R&D. Finally, I employ the calibrated model to investigate whether shocks enhance or weaken endogenous total factor productivity (TFP).

The contribution. — The contribution of this essay is twofold: first, the essay widens the perspective of the empirical literature on the cyclicality of R&D by employing the classical RBC approach. It documents a set of new business cycle facts related to R&D activities for the U.S. post-war economy. To compute these statistics, aggregate macroeconomic data that treat R&D as investment are constructed, based on the BEAs R&D Satellite Account (see Lee and Schmidt, 2010). As a consequence, R&D investment constitutes a component of GDP. This incorporation yields national accounts that are conceptually in line with the model.

Second, the essay contributes a new explanation for the observed procylicality of R&D activities. Since a bare opportunity cost argument predicts countercyclical R&D, the literature aims at resolving this discrepancy. While recent theoretical studies find that market frictions such as dynamic R&D externalities may cause this discrepancy between empirical evidence and the opportunity cost hypothesis, the current results

[2]See Barlevy (2007); Comin and Gertler (2006); Fatás (2000a); Nuño (2011); Ouyang (2011).

suggest that complementarity among R&D inputs may play a vital role. Besides, welfare-improving policy interventions are studied in the literature. Some authors (e.g. Barlevy, 2007; Nuño, 2011) argue that an optimal intervention should reverse the timing of R&D, e.g. by subsidizing R&D activities in recessions. I critically discuss such proposals. Finally, the quantitative analysis contributes to settle the dispute about role of labor supply (Barlevy, 2007; Fatás, 2000a; Nuño, 2011).

Findings. — The specification of the R&D process with respect to factor inputs is essential for both the cyclicality of R&D activities and the importance of endogenous labor supply for these cyclical properties. First, I show that the popular knowledge-driven specification of the R&D process has a hard time to generate both procyclical R&D investment and procyclical R&D labor at the same time. Rather, R&D labor tends to be countercyclical due to the opportunity cost effect unless labor supply is very elastic or innovations earn a very small markup.[3] Thus, R&D output and, hence, endogenous TFP is typically countercyclical so that economic downturns foster TFP. Moreover, due to its simplicity, the knowledge-driven model cannot match the empirical values of the share of R&D investment in GDP and the number of scientists and engineers simultaneously.

Second, I show that the calibrated multi-input specification generates procyclical R&D investment as well as procyclical employment of scientists and engineers. Intersectoral reallocation of workers seems to be much less relevant when the R&D process involves multiple inputs. This might be due to complementarities between R&D inputs. Besides, the endogenous growth mechanism amplifies business cycle shocks. Therefore, the calibrated multi-input specification implies that booms promote productivity growth. Finally, I conclude that a sound assessment of welfare-improving policy interventions requires a careful modeling of the R&D process and results may crucially depend on the underlying assumptions.

Sectioning. — The rest of this essay is organized as follows: Section 2 presents empirical evidence on the cyclicality of R&D activities. Section 3 sets up the model.

[3]Note that in a knowledge-driven model with exogenous labor supply R&D labor is countercyclical while R&D investment is ambiguous. In contrast, R&D investment is clearly procyclical under a lab-equipment specification of R&D. These results follow immediately from Aghion and Saint-Paul (1998). However, the lab-equipment model does not allow for R&D labor and, hence, is not well suited to study the implications of business cycle shocks for R&D activities.

Section 4 calibrates the model, reports the findings on the business cycle properties of R&D activities, and quantifies the importance of the endogenous growth channel. Section 5 summarizes the essay and offers some concluding comments.

3.2 Empirical Evidence

Most recent empirical studies for the U.S. find that real R&D expenditures are procyclical.[4] This procyclicality is documented at both the aggregate (Barlevy, 2007; Comin and Gertler, 2006; Fatás, 2000a; Nuño, 2011) and the industry (Barlevy, 2007; Ouyang, 2011) level, for total as well as industry-funded R&D, and for both National Science Foundation (NSF) and S&P Compustat data. However, these results are based on NIPA national accounting standards which treat R&D as expense while from an economic point of view R&D is seen as investment.

The present study considers a new data source: the BEAs R&D Satellite Account (henceforth R&DSA) which extends the NSF-scope of R&D and incorporates it into national accounting by treating R&D as investment (Lee and Schmidt, 2010).[5] As a consequence, the R&DSA do not only include R&D investment into GDP but also provide a measure of the stock of R&D capital. During the post-war period, R&D investment contributed on average 2.7% to GDP. R&D capital made up about 4.5% of produced assets (cf. Figure 3.9 in Appendix 3.B).

Figure 3.1 compares the growth rates of private R&D investment and total funds for industrial R&D from NSF. Both measures of R&D activity covary positively with GDP growth and tend to move through troughs during NBER-recessions.[6] This confirms the procyclicality-result of previous literature for R&DSA data.

Employment of scientists and engineers (henceforth S&E) is weakly procyclical. As is evident from Figure 3.2, the growth rate of scientists and engineers shows a pattern similar to the growth rate in R&D investment. Barlevy (2007) reports that

[4]Wälde and Woitek (2004) document procyclical contemporaneous correlations of R&D expenditures with GDP for six out of seven G7 countries.

[5]Both R&D investment from R&DSA and total funds for industrial R&D from NSF grew in parallel during the last 50 years, as Figure 3.10 in Appendix 3.C shows.

[6]As in Barlevy (2007), for the NSF time series the recessions of the early 1980s and 1990s are an exception. The R&DSA data, however, show a trough for the recession of 1981/82.

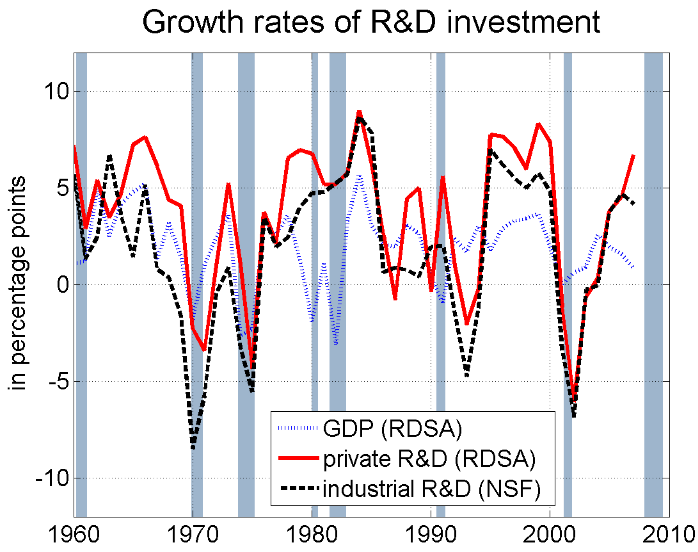


Figure 3.1: Procyclicality of R&D

Notes: All variables are defined as real per-capita measures. The shaded regions correspond to NBER-recessions.

Sources: Bureau of Economic Analysis, R&D Satellite Account; National Science Foundation

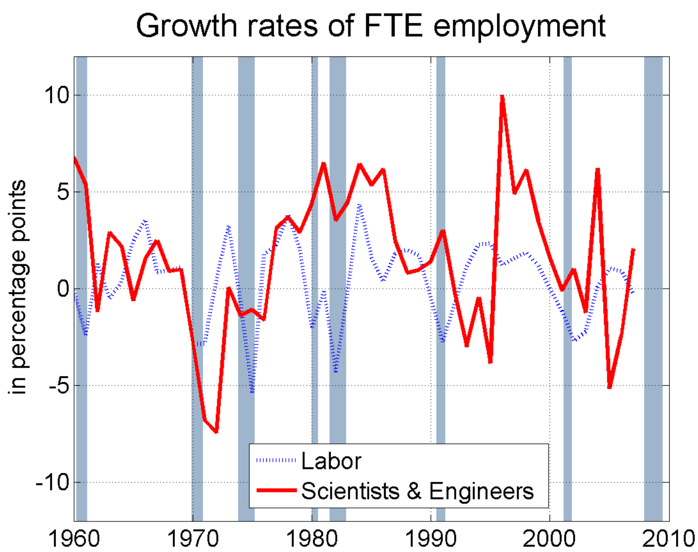


Figure 3.2: Cyclicality of employment

Notes: All variables are defined as real per-capita measures. The shaded regions correspond to NBER-recessions.

Sources: Bureau of Economic Analysis, NIPA; National Science Foundation

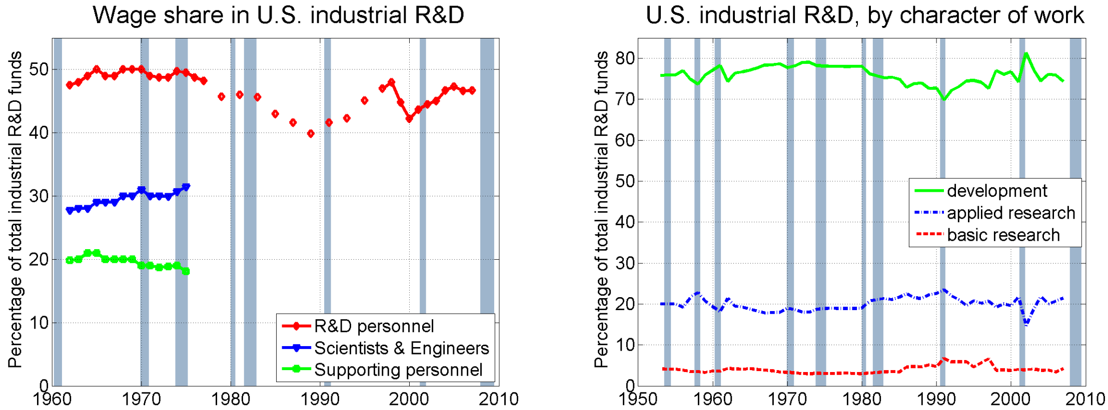


Figure 3.3: Composition of industrial R&D
NOTES: The shaded regions correspond to NBER-recessions.
SOURCE: National Science Foundation, Survey of Industrial Research and Development

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the correlation between these two time series is about 0.6 which suggests that S&E employment captures R&D activity only partially.

Indeed, the NSF data in Figure 3.3, left panel, reveal that only 46% of industrial R&D funds are wages. Interestingly, expenditures for materials and supplies (17%) and other costs (37%) comprise the majority of industrial R&D funds. Besides, the R&D wage bill is split 3:2 between scientists and engineers, on the one hand, and supporting personnel on the other hand. Both wage bill shares in industrial R&D funds remained quite stable during the period under observation. Note that the share of R&D supporting personnel in R&D funds is less than 20%.

Lastly, industrial performers spend on average 76% of R&D funds on development activities, 20% on applied research, and 4% on basic research (Figure 3.3, right panel). This means, industrial R&D activities are mainly directed towards *"translating research findings or other scientific knowledge into products or processes"* (Wolfe, 1997, p. 113) as development is defined.

Next, turn to standard business cycle measures of R&D activities. Following the RBC literature, I consider logs of actual time series and extract trends using the HP-filter. This yields cyclical components – percentage deviations from the trend – for which first-order autocorrelations, standard deviations, and cross-correlations with cyclical output are computed. Table 3.1 reports these summary statistics for R&D

related series.[7] Several features of the data are worth noting:

- Comovement: The cyclicality of R&D has attracted most attention. Recently, there has emerged a consensus that total and private R&D expenditures are procyclical: Barlevy (2007) reports a correlation of 0.39 between R&D expenditure growth and GDP growth, while Nuño (2011) computes 0.27. Comin and Gertler (2006) decompose R&D expenditures into trend, medium-frequency oscillation, and high-frequency fluctuation and find a contemporaneous correlation of 0.3 at both frequencies. Following the RBC approach, Cahn (2012) finds a contemporaneous correlation coefficient of 0.48. Wälde and Woitek (2004) provide similar evidence for most G7 countries.

  The findings for both industrial R&D expenditures (from NSF) and R&D investment (from the R&DSA) confirm this procyclicality result and extend it to several components of R&D. The facts are as follows.

  1. Both industrial R&D expenditures and total R&D investment are procyclical.
  2. Private R&D investment is procyclical too, while federal government's R&D investments are only weakly correlated with contemporaneous GDP.
  3. Development expenditures are procyclical, while basic and applied research are essentially acyclical in the sense that their correlation with contemporaneous output is close to zero.
  4. The three R&D cost types – wages, materials & supplies, other costs – show almost the same degree of comovement with output as private R&D investment.
  5. Their shares in industrial R&D expenditures are essentially acyclical.
  6. R&D capital is essentially acyclical, as is the R&D investment share in GDP.
  7. Scientist & Engineer's labor is weakly procyclical and lags output.

- Volatility

[7] Business cycle summary statistics for standard series based on annual data are provided in Table 3.8 in Appendix 3.C.

Table 3.1: Business Cycle Statistics of the U.S. Economy, 1959-2007

National Science Foundation

	SD[a]	AR(1)	GDP_{-2}	GDP_{-1}	GDP	GDP_{+1}	GDP_{+2}
GDP (NIPA)	1.98	0.57	0.04	0.57	1.00	0.57	0.04
Industrial R&D exp.	5.01	0.79	0.08	0.42	0.52	0.43	0.30
basic	10.28	0.19	0.04	0.06	0.11	0.25	0.33
applied	7.98	0.30	0.01	0.20	0.26	0.20	0.20
development	5.19	0.73	0.08	0.44	0.55	0.45	0.27
wage cost[1]	4.94	0.51	0.01	0.26	0.43	0.39	0.25
materials & supplies[1]	7.41	0.38	-0.18	0.20	0.42	0.27	0.14
other cost[1]	6.61	0.50	0.34	0.50	0.48	0.27	-0.03
R&D exp/GDP	4.33	0.75	0.08	0.22	0.15	0.24	0.33
R&D wage cost share[1]	2.34	0.34	-0.25	-0.34	-0.22	0.04	0.26
R&D materials share[1]	5.06	0.42	-0.39	-0.11	0.09	0.03	0.08
R&D other cost share[1]	4.03	0.40	0.40	0.32	0.14	-0.01	-0.21
wage cost ratio S to L^R[2]	2.76	-0.01	0.69	0.13	-0.37	-0.15	-0.14
S&E labor	4.14	0.74	0.35	0.40	0.33	0.27	0.22

BEA R&D Satellite Account

	SD[a]	AR(1)	GDP_{-2}	GDP_{-1}	GDP	GDP_{+1}	GDP_{+2}
GDP	1.99	0.58	0.06	0.58	1.00	0.58	0.06
R&D investment, total	4.27	0.85	0.13	0.48	0.61	0.52	0.33
private	4.57	0.75	0.26	0.53	0.52	0.26	0.06
wage cost[1]	4.37	0.53	0.16	0.37	0.43	0.25	0.09
materials & supplies[1]	6.73	0.39	-0.11	0.26	0.43	0.18	0.03
other cost[1]	6.60	0.53	0.44	0.56	0.45	0.14	-0.17
fed. gov. extramural	5.98	0.82	-0.05	0.23	0.45	0.51	0.41
fed. gov. intramural	4.81	0.80	0.06	0.21	0.31	0.32	0.22
private + extramural	4.59	0.83	0.12	0.47	0.59	0.50	0.31
R&D capital, total	2.65	0.86	0.17	0.04	0.05	0.25	0.36
private	2.19	0.79	0.21	-0.04	-0.09	0.07	0.20
fed. gov. extramural	4.11	0.87	0.07	0.04	0.08	0.29	0.38
fed. gov. intramural	2.74	0.84	-0.01	-0.09	-0.03	0.13	0.20
private + extramural	2.11	0.79	0.21	-0.01	-0.05	0.11	0.22
R&D inv/GDP	3.93	0.70	0.28	0.32	0.09	0.01	0.04
S&E labor (NSF)	4.14	0.74	0.36	0.42	0.35	0.28	0.23

All variables are defined as logarithms of real per-capita measures which are computed by normalizing with the price index for GDP and the civilian noninstitutional population, aged 16 years and over. The business cycle component is calculated as deviation from trend, using the HP-filter with smoothing parameter $\lambda = 100$. According to these transformations, one can interpret the cyclical components as percentage deviations from the trend.

[a] Standard deviations are reported in percentage terms.

[1] Period 1962-2007; between 1977 and 1997 data were collected only at biannual frequency. HP-filtering is conducted with Schlicht (2008)'s MEND-code.

[2] Period 1962-1975.

1. While physical investment is almost four times as volatile as GDP, R&D investment is only more than twice as volatile as GDP. This is in line with Nuño (2011) and Comin and Gertler (2006)'s finding for the medium-term, whereas Cahn (2012) finds a volatility that is only 15% higher than of GDP.
2. The share of R&D investment in GDP is about twice as volatile as GDP while the share of physical investment is about three times as volatile.
3. Expenditures for industrial basic research are about 5 times, applied research is 4 times, and development expenditures are about 2.5 times as volatile as GDP.
4. Federal government's extramural R&D investment is more volatile than are federal intramural or private R&D investment.
5. R&D wage costs are about as volatile as industrial R&D expenditures while materials & supplies costs and other costs are more volatile.
6. Their shares in industrial R&D expenditures are less volatile than the costs itself.
7. Just as physical capital, R&D capital has about the same volatility as output.
8. Scientist & Engineer's labor is more than twice as volatile as GDP while production labor has about the same volatility as output.

- Persistence

1. Both R&D investment and R&D capital are extremely persistent. Their serial correlation is in the order of 0.8 to 0.9 at annual frequency which is substantially higher than for output, consumption, or physical capital.
2. Basic and applied research are less persistent than development expenditures.
3. Scientist & Engineer's labor is more persistent than production labor.

The rest of this essay focuses mainly on the business cycle facts regarding the cyclicality – i.e., the cross-correlation with GDP – and volatility of private R&D investment.

3.3 Model

The aim of the analysis is to investigate how relevant the opportunity cost hypothesis is quantitatively for the business cycle patterns of R&D activities in the light of endogenous labor supply. To the best of my knowledge, this is the first time assessing quantitatively the contribution of different determinants to the procyclicality of R&D. For this, I incorporate endogenous growth into an otherwise standard RBC model which allows comparing the business cycle properties of the model to the RBC literature. This will facilitate the calibration of the model's parameters. The building blocks of the model are:

- a competitive final goods sector that benefits from an increasing division of labor,
- a monopolistically competitive machine production sector,
- a R&D sector employing both goods and labor inputs,
- a representative household that takes a consumption-savings decision, labor-leisure decision, and a portfolio choice decision.

The model focuses on the R&D sector which generates economic growth endogenously through horizontal innovations à la Romer (1990). Guided by detailed evidence from the National Science Foundation, the model considers a more realistic framework of the R&D process that allows for multiple inputs. This is a novelty to the literature which has so far either studied the knowledge-driven specification or the lab-equipment specification of R&D. The substitution possibilities and complementarities between R&D inputs, which are introduced by the multi-input specification, will also be crucial for the cyclical properties of R&D investment.

The model enables an examination of how the cyclicality of R&D investment depends on the relative importance of labor inputs in R&D activities. By successively switching on features like endogenous labor supply or R&D labor, their importance for the cyclical properties of equilibrium R&D are assessed. Then the main question of the essay is addressed: how does the cyclicality of R&D activities influence long-run productivity growth?

3.3.1 Economy

Final goods production

Final goods Y are produced by competitive firms that hire production workers l^Y and rent a set of machines, $X(m), m \in [0, M_t]$. The final goods sector as an aggregate can be described by a representative firm with constant-returns-to-scale production function that benefits from technological progress resulting in an increasing division of labor:

$$Y_t = \eta_t {l_t^Y}^{1-\alpha} \left(M_t^{\phi\rho+\rho-1} \int_0^{M_t} X_t(m)^\rho dm \right)^{\frac{\alpha}{\rho}} \tag{3.1}$$

where M_t denotes the number of machines that have already been discovered, $\phi > 0$ measures returns to specialization, and $\rho > 0$ determines the elasticity of substitution between machine varieties $1/(1-\rho)$.[8] η_t denotes a RBC shock; its log follows an AR(1)-process with autocorrelation $AR1$ whose innovation ϵ is white noise, $\epsilon \sim i.i.d.\ N(0; Std.\ dev.^2)$:

$$\ln \eta_{t+1} = AR1 \cdot \ln \eta_t + \epsilon_{t+1} \tag{3.2}$$

The representative firm chooses its labor l^Y and machine $X(m)$ inputs in order to maximize its profit

$$\Pi_t^Y = Y_t - W_t l_t^Y - \int_0^{M_t} p_t(m) X_t(m) dm \tag{3.3}$$

subject to this production function while it takes the wage rate W and rental rates for machines $p(m)$ as given. The first-order conditions determine labor demand

$$W_t = (1-\alpha)\eta_t {l_t^Y}^{-\alpha} \left(M_t^{\phi\rho+\rho-1} \int_0^{M_t} X_t(m)^\rho dm \right)^{\frac{\alpha}{\rho}} = (1-\alpha)\frac{Y_t}{l_t^Y} \tag{3.4}$$

and demand for each machine variety i:

$$X_t(i) = \left(\frac{\alpha \eta_t {l_t^Y}^{1-\alpha} \left(M_t^{\phi\rho+\rho-1} \int_0^{M_t} X_t(m)^\rho dm \right)^{\frac{\alpha}{\rho}-1}}{p_t(i)} \right)^{\frac{1}{1-\rho}} \tag{3.5}$$

[8] Such a CES-aggregator has been proposed by Benassy (1998); Ethier (1982). For $\phi = 1/\rho - 1$ the well-known Dixit-Stiglitz-aggregator is nested.

Machine production

Machines are protected by patents. Each producer of a machine variety has to buy the corresponding patent first which grants him the exclusive right to produce machines of this variety. Thus, the machine production sector operates under monopolistic competition. The production technology for machines is linear and allows the producer to transform physical capital – which he rents at the market price r^K – into machines at a 1:1 rate. Each machine producer i is assumed to set a price $p(i)$ that maximizes his static profit contribution

$$\Pi_t^X(i) = (p_t(i) - r_t^K)X_t(i) \tag{3.6}$$

This price follows the standard monopoly pricing rule, i.e. is just a markup over marginal costs

$$p_t(i) = \frac{1}{\rho} \cdot r_t^K \tag{3.7}$$

which is the same for all machine producers.

R&D activities

There is a large number of identical innovators that can decide to hire scientists and engineers s^R, R&D supporting workers l^R, and goods inputs Z in order to conduct R&D activities. Research results in discoveries of new machine varieties D. They are immediately patented and can be sold at the price V. The R&D sector can be described by an representative innovator that conducts research according to the following constant-returns-to-scale innovation possibilities frontier (IPF)

$$D_t = \nu_t \cdot s_t^{R\omega} l_t^{R\psi} Z_t^{1-\psi-\omega} \tag{3.8}$$

and takes the productivity of R&D effort ν_t as given. The parameters $\omega, \psi \in [0;1]$ control the wage shares of scientists and R&D supporting workers, respectively.

Note that allowing for three different input factors is a novelty. The proposed IPF, which I call multi-input specification, is more general than the literature. While the endogenous growth literature has focussed on single input specifications so far, the multi-input IPF nests both well-known special cases: the lab-equipment specification for $\omega = \psi = 0$ and the knowledge-driven specification for $\psi = 1, \omega = 0$. Besides, the literature usually considers only one type of labor which is split up between production and R&D, whereas the present model distinguishes between two types: scientists & engineers who can be employed only in the R&D sector and workers who can be employed in both producing goods and supporting R&D. This distinction is motivated by the objection that production workers may be a poor substitute for scientists and engineers in undertaking research and vice versa.[9] Rather, S&E labor is found to be quite inelastic at business cycle frequencies (Goolsbee, 1998; Romer, 2001). For this reason, I believe that separating scientists and engineers from R&D supporting workers is essential when assessing the quantitative relevance of the opportunity costs hypothesis.

The choice of a Cobb-Douglas functional form is motivated by NSF evidence (shown in Figure 3.3) that the wage bill shares of both scientists & engineers and supporting R&D personnel in industrial R&D funds remained quite stable during the postwar period. Besides, Table 3.1 reveals that the cyclical properties of private R&D investment by cost type are very similar.

Profits of the representative R&D firm are sales revenues net of R&D costs which consist of the wage bill of scientists and engineers $W^S s^R$, the wage bill of supporting R&D personnel Wl^R, and goods costs Z.

$$\Pi_t^R = V_t \cdot D_t - \left(W_t^S s_t^R + W_t l_t^R + Z_t \right) \tag{3.9}$$

Profit maximization implies the following optimal relative factor demand functions

$$\frac{l_t^R}{Z_t} = \frac{\psi}{1 - \psi - \omega} \frac{1}{W_t} \tag{3.10}$$

$$\frac{s_t^R}{Z_t} = \frac{\omega}{1 - \psi - \omega} \frac{1}{W_t^S} \tag{3.11}$$

which display substitution possibilities among R&D inputs. The third first-order

[9] Barlevy (2007) discusses this objection but sticks to the classical approach of the knowledge-driven endogenous growth literature.

condition determines the value of an innovation as

$$V_t = \frac{1}{1-\psi-\omega} \cdot \frac{Z_t}{D_t} = \frac{E_t}{D_t} \tag{3.12}$$

implying the zero-profit condition that the value of discoveries VD is equal to R&D costs:

$$E_t \equiv W_t^S s_t^R + W_t l_t^R + Z_t = \frac{1}{1-\psi-\omega} Z_t \tag{3.13}$$

Last but not least, discoveries D accumulate according to the following law of motion

$$M_{t+1} = M_t + D_t \tag{3.14}$$

The aggregate number of machines discovered M, in turn, determines the productivity of R&D effort as follows

$$\nu_t = \bar{\nu} \cdot M_t^{\upsilon} \tag{3.15}$$

where $\upsilon \leq 1$ controls the knowledge spillover. Individual innovators, however, ignore this standing-on-the-shoulders externality at the aggregate level.

Household sector

The household sector is modeled as a representative family that takes three decisions:

- a consumption-savings decision.
- a labor-leisure decision. The household elastically supplies two types of labor: workers l^H and scientists & engineers s^H. While workers can be employed both in producing goods and in supporting R&D, scientists & engineers are assumed to be employable only in the R&D sector.
- a portfolio choice decision. The household may invest in two assets: physical capital and R&D capital.

Lifetime utility is assumed to be separable between consumption and hours worked with constant Frisch labor supply elasticities of $1/\gamma$ and $1/\theta$, respectively

$$U = \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\log C_t - (1-\varsigma) \cdot \zeta \frac{l_t^{H^{1+\gamma}}}{1+\gamma} - \varsigma \cdot \chi \frac{s_t^{H^{1+\theta}}}{1+\theta} \right) \right] \tag{3.16}$$

where the parameters ζ and χ measure the disutility of working and ς denotes the fraction of scientists and engineers in the representative family. When maximizing lifetime utility, the household faces a sequential budget constraint

$$C_t + V_t H_{t+1} + K_{t+1} = \left(V_t + \Pi_t^X \right) H_t + (1 + r_t^K - \delta^K) K_t + W_t l_t^H + W_t^S s_t^H \tag{3.17}$$

where H denotes the holdings in machine producers equity at the beginning of each period and K the beginning-of-period capital stock.

The first-order conditions give rise to the labor supply functions

$$l_t^H = \left(\frac{1}{(1-\varsigma) \cdot \zeta} \frac{W_t}{C_t} \right)^{\frac{1}{\gamma}} \tag{3.18}$$

$$s_t^H = \left(\frac{1}{\varsigma \cdot \chi} \frac{W_t^S}{C_t} \right)^{\frac{1}{\theta}} \tag{3.19}$$

the Euler equation

$$C_t^{-1} = \beta \mathbb{E}_t \left[C_{t+1}^{-1} (1 + r_{t+1}^K - \delta^K)) \right] \tag{3.20}$$

and an equality-of-expected-returns condition

$$\mathbb{E}_t \left[C_{t+1}^{-1} \left(1 + r_{t+1}^K - \delta^K - \frac{V_{t+1} + \Pi_{t+1}^X}{V_t} \right) \right] = 0 \tag{3.21}$$

The corresponding transversality condition reads as

$$\lim_{t \to \infty} \beta^t \ \mathbb{E}_0 \left[C_t^{-1} \left((1 + r_t^K - \delta^K) K_t + \left(V_t + \Pi_t^X \right) H_t \right) \right] = 0 \tag{3.22}$$

3.3.2 Characterization of equilibrium

The economy is defined by a vector of endowments $< \varsigma, K_0, M_0 >$ and a vector of parameters $< \beta, \zeta, \gamma, \chi, \theta; \alpha, \rho, \phi, \delta^K, \omega, \psi, \bar{\nu} >$.

Definition 1. *An equilibrium for this economy is an allocation such that*

1. *households choose* $\{C_t, l_t^H, s_t^H, H_{t+1}, K_{t+1}\}_{t=0}^{\infty}$ *to maximize expected lifetime utility*

(i.e. satisfy (3.17) - (3.21)),

2. *final good firms choose* $\{l_t^Y, \{X_t(m)\}_{m\in[0,M_t]}\}_{t=0}^{\infty}$ *to maximize profits under perfect competition (i.e. satisfy (3.4), (3.5)),*

3. *R&D firms choose* $\{l_t^R, s_t^R, Z_t\}_{t=0}^{\infty}$ *to maximize profits under perfect competition (i.e. satisfy (3.10) - (3.12)),*

4. *all machine producers* $m \in [0, M_t]$ *choose* $\{p_t(m), X_t(m)\}_{t=0}^{\infty}$ *to maximize the discounted value of profits under monopolistic competition (i.e. satisfy (3.7)),*

5. *the time path of available machine varieties* $\{M_t\}_{t=1}^{\infty}$ *is determined by free entry (i.e. follows (3.14)),*

6. *and the evolution of prices* $\{W_t, W_t^S, r_t^K, p_t, V_t\}_{t=0}^{\infty}$ *is consistent with market clearing, i.e.*

   capital market

   physical capital:

$$K_t = \int_0^{M_t} X_t(m)dm \tag{3.23}$$

   stocks of machine producers:

$$H_t = M_t \tag{3.24}$$

   labor market

   workers:

$$l_t^H = l_t^Y + l_t^R \tag{3.25}$$

   scientists and engineers:

$$s_t^H = s_t^R \tag{3.26}$$

   goods market

$$K_{t+1} = (1-\delta^K)K_t + Y_t - C_t - Z_t \tag{3.27}$$

The set of equilibrium conditions consists of 18 equations in 3 state variables $< K_t, M_t, \eta_t >$, 12 endogenous variables $< Y_t, C_t, Z_t, l_t^H, l_t^Y, l_t^R, s_t^H, s_t^R, D_t, H_t, X_t, \Pi_t^x >$, and 5 prices $< W_t, W_t^S, r_t^K, p_t, V_t >$.

First, it is shown that in equilibrium the economy operates under the familiar Cobb-Douglas production technology. Second, both the physical and the R&D capital-output ratio are computed. Finally, expressions for the allocation of workers between final goods production and supporting R&D are derived.

Consider the machine production sector. Due to symmetry, all machine producers charge the same price

$$p_t = \frac{r_t^K}{\rho} \tag{3.28}$$

and sell the same quantity of their variety

$$X_t = \left(\frac{\rho\alpha}{r_t^K}\eta_t M_t^{\alpha\phi-(1-\alpha)}\right)^{\frac{1}{1-\alpha}} l_t^Y = \frac{\rho\alpha}{r_t^K}\frac{Y_t}{M_t} \tag{3.29}$$

Thus, under symmetry the market clearing condition for physical capital (3.23) becomes $K_t = M_t X_t$ which gives rise to a Cobb-Douglas final goods production function

$$Y_t = \eta_t \cdot A_t {l_t^Y}^{1-\alpha} K_t^\alpha \tag{3.30}$$

where total factor productivity consists of a RBC shock η and an endogenous productivity component $A \equiv M^{\alpha\phi}$ arising from an expansion in machine varieties.

Now, consider the capital-output ratios. Under symmetry the physical-capital-output ratio can be written as (from (3.29)):

$$\frac{K_t}{Y_t} = \frac{\rho\alpha}{r_t^K} \tag{3.31}$$

And the machine producer's static profit contribution

$$\Pi_t^X = \left(\frac{r_t^K}{\rho} - r_t^K\right) X_t = \alpha(1-\rho)\frac{Y_t}{M_t} \tag{3.32}$$

determines the R&D-capital-output ratio as:

$$\frac{V_t M_t}{Y_t} = \alpha(1-\rho)\frac{V_t}{\Pi_t^X} \tag{3.33}$$

The intersectoral allocation of workers depends on the share of R&D investment in

GDP

$$\frac{l_t^R}{l_t^Y} = \frac{1}{1-\alpha}\frac{\psi}{1-\omega-\psi}\frac{Z_t}{Y_t} = \frac{\psi}{1-\alpha}\frac{E_t}{Y_t} \tag{3.34}$$

This follows immediately from intersectoral labor mobility and the competitive firm behavior. The relationship implies that relatively more workers are allocated to support R&D activities when the share of R&D investment in GDP is high. This link gives birth to a channel allocating relatively more labor to the R&D sector which may counteract the opportunity cost argument. Note that this channel goes back to the multi-input specification of the R&D process, namely the fact that R&D input factors are complementing each other.

3.3.3 Balanced Growth Path

In this section, the balanced growth path for a deterministic version of the above economy will be characterized. To this purpose, restrictions on the BGP growth rate are derived. Appendix 3.A.2 discusses how the great ratios depend on the BGP growth rate and model parameters. In addition, analytical results for a few boundary cases are provided.

The national accounting identity $Y = C + I + Z$ implies that output, consumption, physical investment, and R&D investment grow at the same (gross) rate: $g_Y = g_C = g_I = g_Z \equiv g$. The final goods production function under symmetry implies $g_Y = g_M^{\alpha\phi} \cdot g_K^{\alpha}$ and the capital accumulation equation $g_K = g_I$. Therefore,

$$g = g_M^{\frac{\alpha\phi}{1-\alpha}} \Leftrightarrow g_M = g^{\frac{1-\alpha}{\alpha\phi}} \tag{3.35}$$

The innovation possibilities frontier (3.8) determines the growth rate of machines varieties

$$g_M = \bar{\nu} M^{\upsilon-1} s^{R\omega} l^{R\psi} Z^{1-\psi-\omega} \tag{3.36}$$

which is constant if $g_M^{1-\upsilon} = g_Z^{(1-\psi-\omega)}$. This restricts the knowledge spillover to be $\upsilon = 1-(1-\psi-\omega)\frac{\alpha\phi}{1-\alpha}$.[10] Note that for sustaining productivity growth in the long-run the

[10]Growiec (2010) discusses the necessity of such a knife-edge condition for any model generating exponential growth.

economy must sustain the fraction of resources allocated to R&D; anything that raises this fraction will increase the TFP growth rate on BGP. That is, the productivity-growth function belongs to the class of second-generation fully endogenous models (Ha and Howitt, 2007).

3.4 Quantitative Analysis

3.4.1 Solution Method

The purpose of solving the model is to determine whether, at the calibrated parameter values, the model can deliver procyclical R&D activities and what role the specification of the R&D process as well as endogenous labor supply play in accounting for these patterns. Like for many DSGE models, it is not possible to solve the present model analytically for an equilibrium. Actually, except for special cases (see Appendix 3.A.2) one cannot even derive a closed-form solution of the stationary equilibrium for the corresponding non-stochastic economy.

Therefore, the equations that define an equilibrium must be solved numerically. To this end, a log-transformation of the set of stationary equilibriums conditions reported in Appendix 3.A.1 is used. The solution describes the balanced growth path of the corresponding deterministic model economy at the calibrated parameter values. Transitional dynamics are computed by a first-order approximation around the deterministic balanced growth path, applying code provided by Gomme and Klein (2011).[11] Then, the approximated laws of motion are exploited to simulate endogenous variables. Finally, business cycle statistics are computed from the simulated time series by a standard Monte Carlo method.

3.4.2 Calibration

The calibration exercise deals with assigning particular values to the 14 parameters of the model. The model is calibrated to match key empirical evidence for the U.S. economy during the period 1959-2007. Whenever possible, I rely on long-run growth

[11] The Gomme and Klein (2011) code provides numerical solutions for systems of second-order expectational difference equations and, hence, can be applied to a variety of dynamic economic models.

Table 3.2: Growth statistics for the U.S. and model economies

	Data	**Model**	
growth statistic	**U.S. economy[1]**	**knowledge-driven**	**multi-input**
GDP growth rate	1.9	1.9[T]	1.9[T]
K/GDP	279.8	279.8[T]	279.8[T]
I/GDP	15.7	15.7[T]	15.7[T]
VM/GDP	10.3	132.3	329.2
E/GDP	2.3	7.9	2.3[T]
Y/GDP	98.9	92.1	98.9
portfolio $VM/(K+VM)$	3.5	32.1	54.1
total wage bill / GDP	64.0[a]	64.0[T]	64.0[T]
R&D wage bill share	46.1	100.0	46.1[T]
Ratio $W^S * s^R$ **to** $W * l^R$	151.2	–	151.2[T]
labor supply s^H **[FTE]**	0.3	–	0.3[T]
labor supply l^H **[FTE]**	42.8	43.2[T]	42.8[T]
l^R		5.3	0.3
Π/V		9.1	3.6
g_V		-3.9	1.2
W^S/W		–	127.2
net return $r^K - \delta^K$		4.9	4.9
net markup $1/\rho - 1$		50.0[T]	50.0[T]

in per cent.
[1] R&DSA data, period 1959-2007.
[a] Source: Kydland and Prescott (1982)
[T] Calibration target.

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facts. Otherwise, calibration is based on micro-evidence reported in the literature. I regard the calibration presented here as a benchmark; an alternative one will be discussed later on.

There are data on the economy's wage bill $Wl + W^S s$, total employment $l + s$, employment of scientists and engineers s, GDP, output Y, physical investment I, R&D investment E by funder, capital stock K, R&D capital VM, and growth rate g as well as wage payments to R&D supporting personnel Wl^R and scientists and engineers $W^S s$.

I use these data to compute several growth statistics (Table 3.2, column 1), in particular the great ratios, which serve as calibration targets. In other words, parameter values are set such that the model economy matches features of actual U.S. data that characterize economic growth in the long run. As a consequence, the model economies will display these prescribed properties by construction (cf. Table 3.2, columns 2 and

3).[12] The following discusses for the multi-input model how these growth statistics reported in Table 3.2 uniquely pin down its parameter values which are summarized in Table 3.3.

RBC shock parameters. In the RBC literature, the shock process is well characterized. However, RBC models are usually calibrated to quarterly data, while I have to calibrate an annual model due to data availability. Therefore, I follow King and Rebelo (1999, p. 952) to estimate the stochastic process of the RBC shock for an exogenous growth model based on annual data. In particular, they assume an AR(1) RBC shock process and estimate the persistence and standard deviation of the innovation from the residuals of a regression of the log-Solow residual on a linear trend. The results which are reported in Table 3.9 in the Appendix suggest to assign an autocorrelation of 0.85 and a standard deviation of 1.5%.

R&D technology parameters. The IPF share parameters ψ, ω can be set directly from NSF data on R&D costs by type (using (3.10) and (3.11)):

$$\psi + \omega = \frac{Wl^R + W^S s}{E} \tag{3.37}$$

$$\frac{\omega}{\psi} = \frac{W^S s}{Wl^R} \tag{3.38}$$

and R&D productivity is determined by the innovation possibilities frontier[13]

$$\bar{\nu} = \frac{g^{\frac{1-\alpha}{\alpha\phi}} - 1}{s^{\omega}\left(\frac{l^R}{l^H} l^H\right)^{\psi}\left((1-\omega-\psi)\frac{E}{GDP}\left(\frac{Y}{GDP}\right)^{-1}\frac{Y}{M^{\frac{\alpha\phi}{1-\alpha}}}\right)^{1-\omega-\psi}} \tag{3.39}$$

with (using (3.10), (3.11), and (3.13))

$$\frac{l^R}{l^H} = \frac{Wl^R}{(Wl + W^S s) - W^S s} = \frac{\psi\frac{E}{GDP}}{\frac{(Wl+W^S s)}{GDP} - \omega\frac{E}{GDP}} \tag{3.40}$$

[12]Hence, such an accordance does not test the theory. Rather, a test of the theory is whether these parameter values give rise to business cycle properties of the model economy that are quantitatively consistent with the observed behavior of the U.S. economy. Moreover, selected parameters should be plausible in light of micro evidence.

[13]This requires a measure of detrended output $y = \frac{Y}{M^{\frac{\alpha\phi}{1-\alpha}}}$. In the numerical part, I will normalize BGP output $y^* = 1$. Note that this dependence of $\bar{\nu}$ is needed to kill the scale effect.

Table 3.3: Multi-input model economy: calibrated parameter values (markup-calibration)

Preferences					Shock	
β	$(1-\varsigma)\zeta$	γ	$\varsigma\chi$	θ	$AR(1)$	*Std. dev.*
0.972	4.21	1	0.0666	1	0.85	0.015
Technology						
α	ρ	ϕ	δ^K	ω	ψ	$\bar{\nu}$
0.364	0.667	4.6	0.0372	0.277	0.183	1.05

Preference parameters. The disutility of work parameters ζ, χ are calibrated according to the household's intratemporal first-order conditions (3.18) and (3.19)

$$(1-\varsigma)\zeta = \frac{Wl}{GDP}\cdot\left(\frac{C}{GDP}\cdot l^{H^{1+\gamma}}\right)^{-1} = \left(\frac{Wl+W^S s}{GDP} - \omega\frac{E}{GDP}\right)\cdot\left(\frac{GDP-I-E}{GDP}\cdot l^{H^{1+\gamma}}\right)^{-1} \tag{3.41}$$

$$\varsigma\chi = \frac{W^S s}{GDP}\cdot\left(\frac{C}{GDP}\cdot s^{1+\theta}\right)^{-1} = \omega\frac{E}{GDP}\cdot\left(\frac{GDP-I-E}{GDP}\cdot s^{1+\theta}\right)^{-1} \tag{3.42}$$

for given Frisch labor supply elasticities which remain free parameters.[14]

Then I follow Comin and Gertler (2006); Nuño (2011); Trabandt and Uhlig (2011) who choose a Frisch elasticity of 1 which represents an intermediate value for the range of estimates across micro and macro literature.[15] Consequently, I set both labor supply elasticities to 1.[16]

The discount factor is calibrated from the Euler equation to match the physical-capital-output ratio.

$$\beta = \frac{g}{1+\rho\alpha\left(\frac{K}{GDP}\right)^{-1}\frac{Y}{GDP}-\delta^K} \tag{3.43}$$

Production technology parameters. The capital share parameter α of the production function is indirectly determined by the economy's wage bill share via

[14]Note that $\varsigma\chi \equiv \hat{\chi}$ and $(1-\varsigma)\zeta \equiv \hat{\zeta}$, respectively, are only jointly identified.

[15]Regarding the Frisch elasticity see survey on estimates by Chetty, Guren, Manoli, and Weber (2011) and discussion by Ríos-Rull, Schorfheide, Fuentes-Albero, Kryshko, and Santaeulàlia-Llopis (2012).

[16]The choice of the Frisch elasticity for scientists and engineers is based on ignorance. On the one hand, Goolsbee (1998) argues that labor supply of scientists and engineers is quite inelastic in the short run, estimating elasticities of supply between 0.1 and 0.2. On the other hand, the business cycle statistics reported in Table 3.1 reveal that labor supply of scientists and engineers is about twice as volatile as labor supply of workers. To match this business cycle fact the model, however, requires a high Frisch elasticity.

Table 3.4: Knowledge-driven model economy: calibrated parameter values (markup-calibration)

Preferences			Technology					Shock	
β	$(1-\varsigma)\zeta$	γ	α	ρ	ϕ	δ^K	$\bar{\nu}$	$AR(1)$	*Std. dev.*
0.972	4.49	1	0.391	0.667	0.5	0.0372	1.12	0.85	0.015

equation (3.4).

$$1-\alpha = \frac{Wl^Y}{Y} = \left(\frac{Wl + W^S s}{GDP} - \frac{Wl^R + W^S s}{E} \cdot \frac{E}{GDP}\right) \cdot \left(\frac{Y}{GDP}\right)^{-1} \tag{3.44}$$

where $GDP = C + I + E = Y + Wl^R + W^S s$. Depreciation of physical capital is calibrated from the law of motion:

$$\delta^K = \frac{I}{GDP} \cdot \left(\frac{K}{GDP}\right)^{-1} - (g-1) \tag{3.45}$$

Following the endogenous growth literature (e.g. Comin, 2004; Jones and Williams, 2000), the substitution parameter for machine varieties ρ is calibrated to match the value of the gross markup

$$\rho = \frac{1}{markup}. \tag{3.46}$$

Hence, I call this calibration variant the markup-calibration. According to Comin (2004) the markups innovators can charge should be higher than typical estimates for the average markup in the U.S. economy due to patent protection and up front fixed costs. Therefore, I regard a markup of 50% – as proposed by Comin (2004) – to be more appropriate for equipment investment goods.

Then, the gains-from-variety-expansion parameter ϕ is determined by

$$g^{\frac{1-\alpha}{\alpha\phi}} = 1 + \frac{E}{Y} \cdot \frac{g^{\frac{1-\alpha}{\alpha\phi}}/\beta - 1}{(1-\rho)\alpha} \tag{3.47}$$

Knowledge-driven model. The knowledge-driven model is calibrated analogously. However, since its R&D specification just employs workers while scientists and engineers are not modeled, the model is calibrated to the U.S. economy's total labor supply of 43.2% (Table 3.2, column 2). Moreover, the classical knowledge-driven model

Table 3.5: Business cycle statistics for the U.S. and model economies (markup-calibration)

	Data		**Model**			
	US Economy		**Knowledge-driven**		**Multi-input**	
	rel. SD	**Corr.**	**rel. SD**	**Corr.**	**rel. SD**	**Corr.**
GDP	1.00	1.00	1.00	1.00	1.00	1.00
Consumption	0.87	0.93	0.44	0.92	0.47	0.94
Phys. investment	3.81	0.81	4.58	0.98	4.00	0.97
R&D investment	2.30	0.52	0.19	-0.16	1.44	0.93
Phys. capital	0.67	-0.13	0.43	0.56	0.37	0.59
R&D capital	1.10	-0.09	0.68	0.99	0.40	0.95
Labor	1.13	0.85	0.43	0.96	0.28	0.98
S&E labor	2.08	0.35	0.72	-0.99	0.50	0.89
R&D inv./GDP	1.97	0.09	1.05	-0.99	0.66	0.49

All variables are defined as logarithms of real per-capita measures. The business cycle component is calculated as deviation from trend, using the HP-filter with smoothing parameter $\lambda = 100$. According to these transformations, one can interpret the cyclical components as percentage deviations from the trend.

Reported figures for the model economies are sample means of statistics computed for each of 67600 simulations, each of which was 49 periods long as is the U.S. time series.

assumes $\phi = \frac{1}{\rho} - 1$. Hence, returns to specialization are implicitly pinned down by the calibrated value of the markup.[17] The resulting parameter values are reported in Table 3.4.

3.4.3 Findings: cyclical behavior of the model economies

This section quantitatively analyzes the cyclical properties of R&D activities in both the knowledge-driven model economy and the multi-input economy. First, I show that the knowledge-driven model fails to match the empirical cyclicality patterns of R&D in the U.S. economy for plausibly calibrated parameters. Second, I demonstrate that the multi-input specification of the R&D process improves in matching business cycle moments of the U.S. economy and that in the calibrated model economy booms foster TFP through the endogenous growth channel.

[17] For a critical discussion see Benassy (1998).

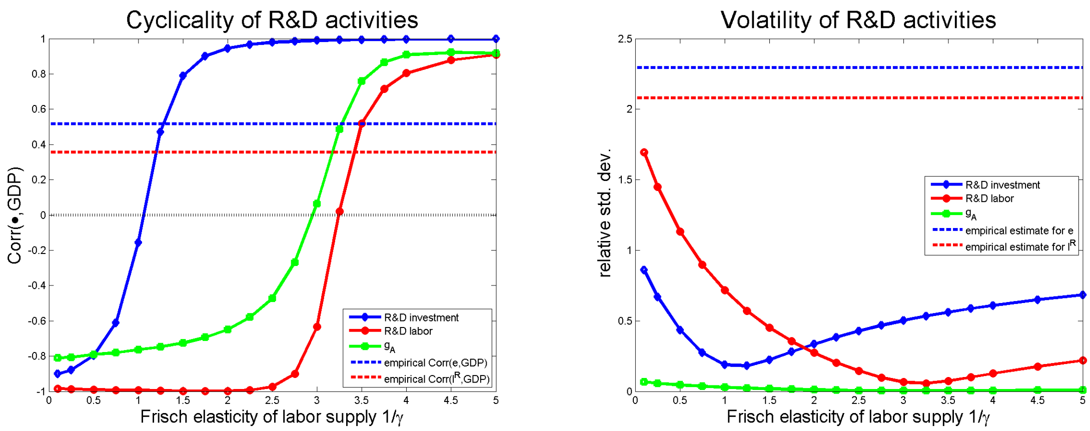

Figure 3.4: Knowledge-driven model economy: Sensitivity w.r.t. labor supply elasticity

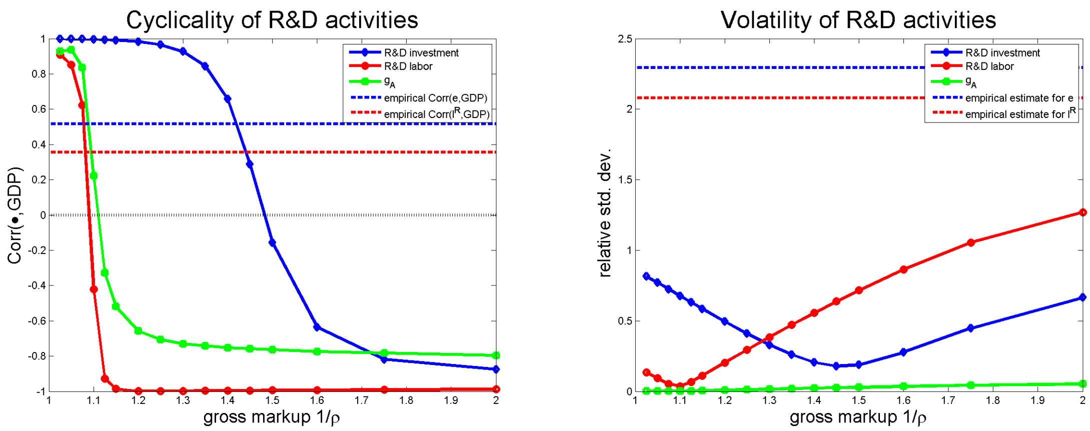

Figure 3.5: Knowledge-driven model economy: Sensitivity w.r.t. markup

Business cycle moments of the knowledge-driven model

While for the U.S. economy both R&D investment and R&D labor are procyclical, the calibrated knowledge-driven model predicts countercyclical employment in the research sector as well as weakly countercyclical R&D investment (Table 3.5). Figures 3.4 and 3.5 investigate how these cyclicality results depend on the calibrated parameter values of the labor supply elasticity and the markup, respectively. The sensitivity analysis reveals that the knowledge-driven model may generate procyclical R&D investment for reasonable parameter values: labor supply needs to be a bit more elastic than in the benchmark calibration or the markup a little lower.

In order to render R&D labor procyclical, however, either labor supply has to be very elastic (with values of the Frisch elasticity $1/\gamma$ exceeding 3; see Figure 3.4) or

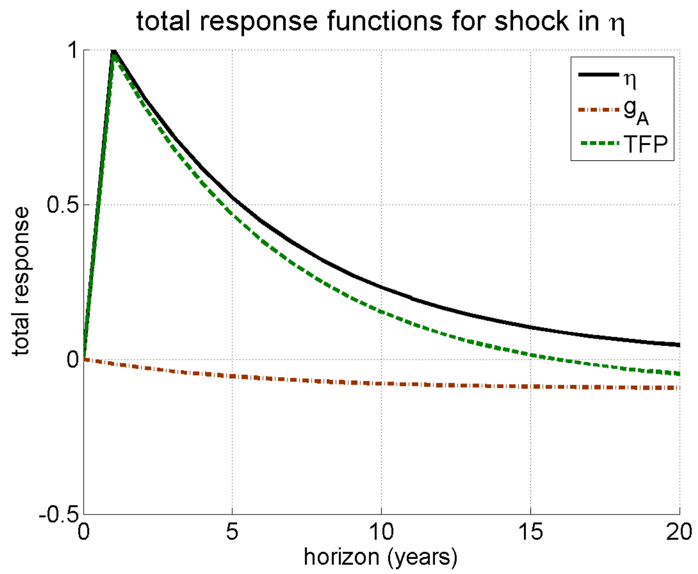

Figure 3.6: Knowledge-driven model economy: growth effects

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machine producers can earn only low margins of less than 10% (Figure 3.5). The reason is that for high values of the labor supply elasticity procyclicality of total labor supply dominates the opportunity cost effect which reallocates labor from R&D activities to goods production during a boom. However, such calibrations are at odds with the literature. Recently there has emerged a consensus that advocates an aggregate Frisch elasticity of around 1 (cf. Chetty, Guren, Manoli, and Weber, 2011; Ríos-Rull, Schorfheide, Fuentes-Albero, Kryshko, and Santaeulàlia-Llopis, 2012; Trabandt and Uhlig, 2011, and the literature discussed therein). Moreover, the literature seems to agree that a markup of 20% constitutes a lower bound for capital goods (Barlevy, 2007; Comin, 2004; Comin and Gertler, 2006).

Rather for a large range of standard parameterizations, the knowledge-driven model results in countercyclical R&D labor which is counterfactual. Countercyclical employment in the R&D sector, in turn, implies that R&D output is countercyclical, too. Consequently, the model predicts booms to weaken TFP growth: A 1% positive RBC shock entails a 0.079% lower TFP level after 10 years (Figure 3.6). Note that these endogenous growth repercussions of RBC shocks are valid for a broad range of plausible parameter values as figures 3.4 and 3.5 show.

In conclusion, the popular knowledge-driven specification of the R&D process has a

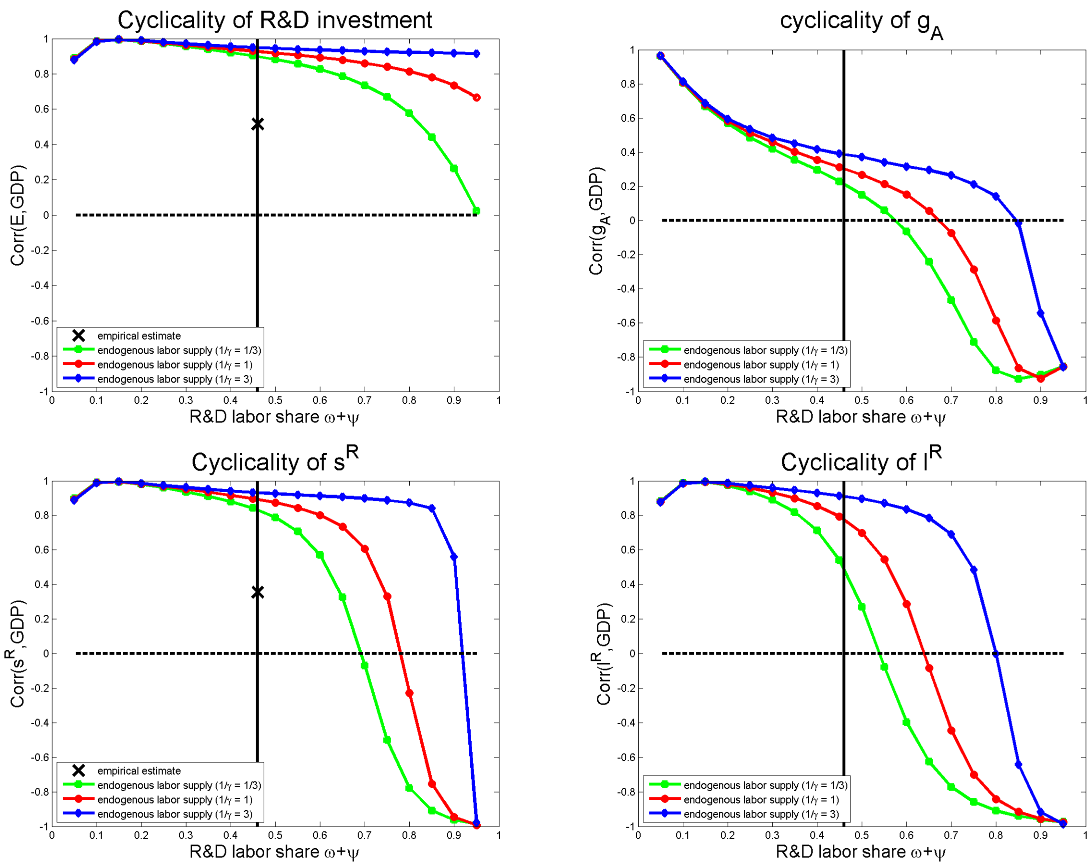

Figure 3.7: Multi-input model economy: cyclicality of R&D activities

NOTES: The experiment is conducted by varying the combined R&D labor share $\omega + \psi$ while holding the ratio ω/ψ constant at the calibrated value.

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hard time to generate procyclical R&D: while R&D investments – which are identical to the wage bill of scientists and engineers under the knowledge-driven specification – may plausibly be procyclical due to procyclical wage rates, the opportunity cost argument constitutes a strong incentive for R&D labor and R&D output to be countercyclical. This is clearly at odds with the empirical evidence. Moreover, the knowledge-driven model tends to predict that R&D activities are less volatile than GDP whereas the empirical measures are more than twice as volatile (Figures 3.4 and 3.5).

Business cycle moments of the multi-input model

In contrast to the knowledge-driven specification, the multi-input specification of the R&D process is capable to generate procyclical R&D investment, procyclical employment of scientists and engineers as well as procyclical employment of R&D

supporting personnel. Therefore, it can replicate the data. Due to this procyclicality of inputs, the endogenous growth mechanism gives rise to amplification of business cycle shocks. In other words, booms promote productivity growth. In the following, I study the calibrated model and show that this is indeed the case.

The calibrated multi-input model predicts that both employment of scientists and engineers and R&D investment are procyclical (Table 3.5). This is true independently of the parameter values for both Frisch elasticities and the markup as the sensitivity analysis in Appendix 3.C.4 shows. Interestingly, even for low values of the labor supply elasticity employment of R&D workers is not countercyclical (Figure 3.12 in the Appendix). This suggests that intersectoral reallocation of labor is much less attractive when the R&D process involves multiple inputs, a substantial share of them being supplied procyclically, and substitution possibilities among inputs are not perfect.

Figure 3.7 sheds light on the role the innovation possibility frontier plays for the cyclicality of R&D activities. The experiment underlying these graphs is to vary the combined share of labor inputs in R&D $\omega + \psi$, simulate the corresponding model economy, and compute the cross-correlation of R&D activities with GDP. This exercise is motivated by the finding of Aghion and Saint-Paul (1998) that the cyclical pattern of R&D differs completely whether a lab-equipment or a knowledge-driven specification of R&D – the boundary cases of the multi-input specification – is employed. In contrast to Aghion and Saint-Paul (1998), I allow for endogenous labor supply and consider different values of the Frisch elasticity because endogenous labor supply and intersectoral reallocation of labor work in opposite directions. To this purpose, I pick three values of the elasticity that cover the range of plausible parameter values.

Figure 3.7 reveals that for low R&D labor shares R&D activities are clearly procyclical, independent of the labor supply elasticity. In this case goods – which are supplied procyclically – are the main ingredient of R&D and impose their cyclical pattern upon both labor inputs. Consequently, booms foster TFP growth which is in line with Aghion and Saint-Paul (1998)'s finding for a lab-equipment model. However, if labor were dominant in R&D activities (with the combined R&D labor share exceeding 50 per cent), R&D supporting personnel as well as S&E employment could become countercyclical. Note that the turning point depends on the Frisch elasticity: the less elastic labor supply is, the sooner the opportunity cost effect dominates and R&D

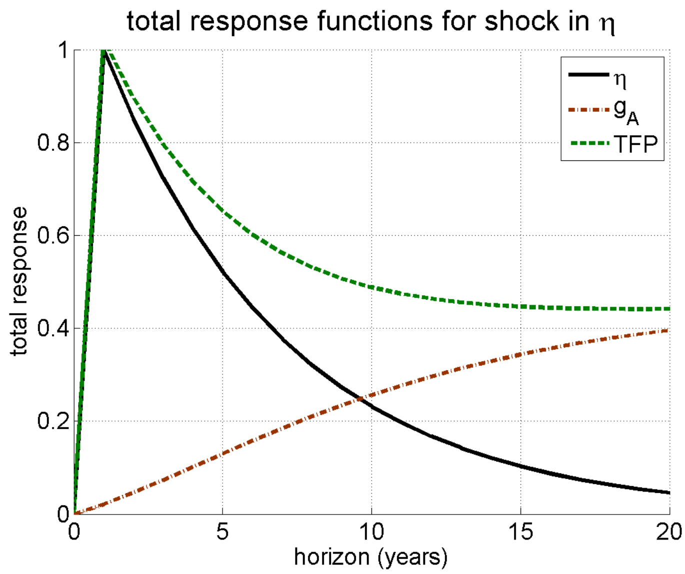

Figure 3.8: Multi-input model economy: growth effects

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labor becomes countercyclical. Finally, R&D output becomes countercyclical in this case despite R&D investment remains procyclical. Again, this is in line with Aghion and Saint-Paul (1998)'s finding that in a knowledge-driven economy recessions enhance productivity.

To sum up, procyclical R&D inputs – as observed in U.S. data – imply that endogenous TFP, i.e. R&D output, is procyclical, too. The sensitivity analysis shows that this outcome is largely independent of parameter values for both Frisch elasticities and the markup (Appendix 3.C.4), while large R&D labor shares may overturn this finding. However, the latter does not seem to be the case for the U.S. economy as its R&D labor share is moderate. Rather, the calibrated multi-input specification implies that a 1% positive RBC shock raises endogenous TFP A by additional 0.257% within 10 years (Figure 3.8). That is, RBC shocks are amplified through the endogenous growth mechanism. Hence, booms enhance economic growth.

3.4.4 Robustness: targeting R&D capital

This section considers an alternative calibration exercise and discusses the robustness of previous findings. The R&D Satellite Accounts allow for another plausible way of identifying model parameters: as these accounts provide data on R&D capital, the

Table 3.6: Growth statistics for the U.S. and model economies (R&D-stock-calibration)

	Data	**Model**	
growth statistic	**U.S. economy**[1]	**knowledge-driven**	**multi-input**
GDP growth rate	1.9	1.9[T]	1.9[T]
K/GDP	279.8	279.8[T]	279.8[T]
I/GDP	15.7	15.7[T]	15.7[T]
VM/GDP	10.3	10.3[T]	10.3[T]
E/GDP	2.3	3.1	2.3[T]
Y/GDP	98.9	96.9	98.9
portfolio $VM/(K+VM)$	3.5	3.5	3.5
total wage bill / GDP	64.0[a]	64.0[T]	64.0[T]
R&D wage bill share	46.1	100.0	46.1[T]
Ratio $W^S * s^R$ **to** $W * l^R$	151.2	–	151.2[T]
labor supply s^H **[FTE]**	0.3	–	0.3[T]
labor supply l^H **[FTE]**	42.8	43.2[T]	42.8[T]
l^R		2.1	0.3
Π/V		37.6	30.2
g_V		-21.7	-17.0
W^S/W		–	127.2
net return $r^K - \delta^K$		7.8	8.0
net markup $1/\rho - 1$		12.0	9.4

in per cent.
[1] R&DSA data, period 1959-2007.
[a] Source: Kydland and Prescott (1982)
[T] Calibration target.

R&D-capital-output-ratio can be targeted instead of the markup. Hence, I call this new identification scheme the R&D-stock-calibration.

The law of motion for machine varieties is used to calibrate the gains-from-variety-expansion parameter ϕ in order to target the investment share and capital-output-ratio for R&D capital:

$$g^{\frac{1-\alpha}{\alpha\phi}} = 1 + \frac{E}{GDP} \cdot \left(\frac{VM}{GDP}\right)^{-1} \tag{3.48}$$

Then, the substitution parameter ρ which determines the markup is pinned down by

$$\frac{1}{\rho} = 1 + \frac{VM}{K} \cdot \frac{g^{\frac{1-\alpha}{\alpha\phi}}/\beta - 1}{g/\beta - (1-\delta^K)} \tag{3.49}$$

The calibrated parameter values are relegated to Appendix 3.C.5, Tables 3.10 and 3.11, respectively, while the underlying calibration targets and corresponding growth

Table 3.7: Business cycle statistics for the U.S. and model economies (R&D-stock-calibration)

	Data		**Model**			
	US Economy		**Knowledge-driven**		**Multi-input**	
	rel. SD	**Corr.**	**rel. SD**	**Corr.**	**rel. SD**	**Corr.**
GDP	1.00	1.00	1.00	1.00	1.00	1.00
Consumption	0.87	0.93	0.43	0.90	0.44	0.91
Phys. investment	3.81	0.81	4.42	0.97	4.34	0.97
R&D investment	2.30	0.52	0.64	0.99	0.75	0.99
Phys. capital	0.67	-0.13	0.40	0.58	0.40	0.59
R&D capital	1.10	-0.09	0.70	0.99	0.29	0.97
Labor	1.13	0.85	0.34	0.96	0.31	0.97
S&E labor	2.08	0.35	0.06	-0.89	0.18	0.99
R&D inv./GDP	1.97	0.09	0.37	-0.98	0.29	-0.88

All variables are defined as logarithms of real per-capita measures. The business cycle component is calculated as deviation from trend, using the HP-filter with smoothing parameter $\lambda = 100$. According to these transformations, one can interpret the cyclical components as percentage deviations from the trend.

Reported figures for the model economies are sample means of statistics computed for each of 67600 simulations, each of which was 49 periods long as is the U.S. time series.

statistics are reported in Table 3.6. Two statistics are worth to mention: First, the loss in value of patents implied by the multi-input model is 17%. Interestingly, this is close to the range of 13% to 16% estimated by Bessen (2008). Second, implied markups of 9% and 12% are very low – probably too low to be plausible.

Under the current calibration, the knowledge-driven specification generates procyclical R&D investment, while R&D labor remains countercyclical as already predicted by the markup-calibration (Table 3.7, column 2). For the multi-input model (Table 3.7, column 3) both calibrations yield, by and large, the same cross-correlations of R&D inputs with GDP. However, the markup-calibration slightly outperforms the R&D-stock-calibration with respect to volatilities.

In conclusion, the robustness analysis confirms that knowledge-driven models fail to explain procyclical R&D labor while multi-input economies perform reasonably well in quantitatively characterizing the cyclical properties of R&D activities.

3.5 Concluding Remarks

Employing a calibrated real business cycle model featuring R&D-based growth, I quantitatively study the implications of business cycle shocks for productivity growth. First, the essay may settle the discussion on the role of endogenous labor supply for procyclical R&D activities in knowledge-driven model economies. I show that for reasonable calibrations of the labor supply elasticity the opportunity cost effect dominates and, hence, the knowledge-driven specification is not capable to generate procyclical R&D labor as observed in the data. Second, I propose a multi-input specification of the R&D process which is able to generate both procyclical R&D investment and procyclical employment of scientists and engineers at the same time. The main finding is that for a broad range of plausible parameter values booms promote productivity growth. The reason is that business cycle shocks are amplified by the endogenous growth mechanism. This result stands in contrast to the prediction of the simple knowledge-driven model.

This highlights that the specification of the R&D process is crucial for the cyclical properties of R&D activities. Therefore, normative statements derived from knowledge-driven models should be treated with caution: for example, recessions may not be ideal times to conduct R&D. Moreover, findings regarding optimal policies in classical knowledge-driven or lab-equipment models might not be robust to a generalization of the innovation possibility frontier. Rather, my findings call policy recommendations on cyclical R&D subsidies or stabilization policies into question. Nonetheless, optimal policies under a general R&D specification like the multi-input model should be studied to settle this question.

Another promising avenue for future work would be a business cycle accounting exercise à la Chari, Kehoe, and McGrattan (2007). In particular, identifying a shock process to the R&D productivity could help to increase the volatility of R&D activities and, maybe, give rise to considerable propagation.

3.A Model Appendix

3.A.1 The set of stationary equilibrium equations

Let $b_t \equiv B_t/M_t^{\frac{\alpha\phi}{1-\alpha}}$ denote the detrended version of a variable B_t, $B \in \{Y, C, Z, K, X, W, W^S\}$ and $\pi_t^X \equiv \Pi_t^X/M_t^{\frac{\alpha\phi}{1-\alpha}-1}$, $v_t \equiv V_t/M_t^{\frac{\alpha\phi}{1-\alpha}-1}$, $d_t \equiv D_t/M_t$. The set of equilibrium conditions to a reduced form of the model in terms of stationary variables is given by:

Households[18]

$$\frac{w_t}{c_t} = (1-\varsigma) \cdot \zeta l_t^{H\gamma} \tag{3.50}$$

for $\gamma \to \infty$: $l_t^H = \bar{L}$ instead.

$$\frac{w_t^S}{c_t} = \varsigma \cdot \chi s_t^{H\theta} \tag{3.51}$$

for $\theta \to \infty$: $s_t^H = \bar{S}$ instead.

$$c_t^{-1} = \beta \mathbb{E}_t \left[g_{M,t+1}^{-\frac{\alpha\phi}{1-\alpha}} c_{t+1}^{-1} (1 + r_{t+1}^K - \delta^K) \right] \tag{3.52}$$

$$c_t^{-1} = \beta \mathbb{E}_t \left[g_{M,t+1}^{-1} c_{t+1}^{-1} \frac{v_{t+1} + \pi_{t+1}^X}{v_t} \right] \tag{3.53}$$

Production

$$y_t = \eta_t \cdot l_t^{Y\,1-\alpha} k_t^{\alpha} \tag{3.54}$$

$$w_t = (1-\alpha) \frac{y_t}{l_t^Y} \tag{3.55}$$

$$r_t^K = \rho \cdot \alpha \frac{y_t}{k_t} \tag{3.56}$$

[18] The household's budget constraint which is redundant with the aggregate resource constraint becomes: $c_t + v_t g_M h_{t+1} + g_M^{\frac{\alpha\phi}{1-\alpha}} k_{t+1} = (v_t + \pi_t^x) h_t + (1 + r_t^K - \delta^K) k_t + w_t l_t^H + w_t^S s_t^H$ where h is defined as $h_t = H_t/M_t$.

$$\pi_t^X = \alpha(1-\rho)y_t \tag{3.57}$$

R&D sector

$$g_{M,t+1} - 1 = \bar{\nu} s_t^{R\omega} l_t^{R\psi} z_t^{1-\psi-\omega} \tag{3.58}$$

$$\frac{w_t}{v_t} = \psi \cdot \frac{g_{M,t+1} - 1}{l_t^R} \tag{3.59}$$

for $\psi = 0$: $l_t^R = 0$ instead.

$$\frac{w_t^S}{v_t} = \omega \cdot \frac{g_{M,t+1} - 1}{s_t^R} \tag{3.60}$$

for $\omega = 0$: $s_t^R = 0$ instead.

$$\frac{1}{v_t} = (1-\psi-\omega) \cdot \frac{g_{M,t+1} - 1}{z_t} \tag{3.61}$$

for $1-\psi-\omega = 0$: $z_t = 0$ instead.

Market clearing

$$l_t^H = l_t^Y + l_t^R \tag{3.62}$$

$$s_t^H = s_t^R \tag{3.63}$$

$$y_t = c_t + z_t + g_{M,t+1}^{\frac{\alpha\phi}{1-\alpha}} \cdot k_{t+1} - (1-\delta^K)k_t \tag{3.64}$$

TFP shock

$$\ln \eta_{t+1} = AR1 \cdot \ln \eta_t + \epsilon_{t+1} \tag{3.65}$$

3.A.2 BGP equilibrium and the great ratios

This section discusses how the great ratios depend on model parameters and the BGP growth rate and compute the latter for a few special cases that constitute well-known boundary cases of the R&D specification.

On BGP, the Euler equation (3.20) becomes

$$g_C = \beta(1 + r^K - \delta^K) \tag{3.66}$$

determining the real rate of return on physical capital as a function of the BGP growth rate and model parameters.

In a deterministic environment, equation (3.21) becomes a no-arbitrage condition

$$1 + r^K - \delta^K = g_V \cdot \left(1 + \frac{\Pi^X}{V}\right) \tag{3.67}$$

where the price-dividend ratio has to be constant on BGP, i.e. $g_V = g_\Pi = g_Y/g_M = g^{1-\frac{1-\alpha}{\alpha\phi}}$

On BGP, the free entry condition (3.12) becomes

$$V(g_M - 1)M = \frac{1}{1 - \psi - \omega}Z \tag{3.68}$$

From the equilibrium laws of motion one gets equation (3.36) for the measure of varieties and the following for capital:

$$g_K = (1 - \delta^K) + \frac{Y}{K} - \frac{C}{K} - \frac{Z}{K} \tag{3.69}$$

The latter 5 equations determine the great ratios as a function of the BGP growth rate and model parameters. As usual, the physical-capital-output ratio is governed by the Euler equation via the real rate of return on physical capital

$$\frac{K}{Y} = \frac{\rho\alpha}{g/\beta - (1 - \delta^K)} \tag{3.70}$$

and pins down the BGP capital intensity, defined as capital per efficiency unit of labor: $\kappa \equiv K/(M^{\frac{\alpha\phi}{1-\alpha}} l^Y)$, via the production function (3.30)

$$\kappa = \left(\frac{K}{Y}\right)^{1-\alpha} = \left(\frac{\rho\alpha}{g/\beta - (1 - \delta^K)}\right)^{1-\alpha} \tag{3.71}$$

The no-arbitrage condition (3.67) implies that stocks of machine producers are priced according to

$$V = \frac{\Pi^X}{(1 + r^K - \delta^K)/g_V - 1} \tag{3.72}$$

Inserting the profit contribution (3.32) yields the R&D capital-output ratio on BGP

$$\frac{VM}{Y} = \frac{\alpha(1-\rho)}{g_M/\beta - 1} \tag{3.73}$$

Therefore, the BGP portfolio choice is characterized by

$$\frac{VM}{K} = \frac{1-\rho}{\rho} \frac{g/\beta - (1-\delta^K)}{g_M/\beta - 1} \tag{3.74}$$

Moreover, the free-entry zero-profit condition pin downs the BGP value of the R&D capital stock so that the share of final goods invested in R&D activities can be expressed as:

$$\frac{Z}{Y} = (1 - \psi - \omega)\alpha(1-\rho)\frac{g_M - 1}{g_M/\beta - 1} \tag{3.75}$$

Finally, the capital accumulation equation determines the consumption share

$$\frac{C}{Y} = 1 - \frac{Z}{Y} - [g - (1-\delta^K)]\frac{K}{Y} \tag{3.76}$$

Given Z/Y and C/Y, the BGP values for equilibrium labor inputs are also known:

$$s = \left(\frac{\omega}{(1-\omega-\psi)(\varsigma\chi)}\frac{Z}{C}\right)^{\frac{1}{1+\theta}} \tag{3.77}$$

$$l = \left(\frac{(1-\alpha)Y + \frac{\psi}{1-\omega-\psi}Z}{(1-\varsigma)\zeta C}\right)^{\frac{1}{1+\gamma}} \tag{3.78}$$

Then, the innovation possibilities frontier together with the R&D productivity function yields a nonlinear equation determining the BGP growth rate g. In the following I consider three special cases which give rise to analytical solutions, well-known from growth textbooks (e.g. Acemoglu, 2009; Arnold, 1997; Barro and Sala-i-Martin, 2004).

Boundary case 1: lab-equipment model

Consider a special case of the model in which the only input into R&D activities is final output Z, i.e. $\psi = \omega = 0$, and the household is endowed only with workers' labor, i.e. $\varsigma = 0$, which he supplies inelastically ($\gamma \to \infty$) in quantity $\bar{L}$. Moreover, $\phi = \frac{1-\alpha}{\alpha}$ and $\delta^K = 0$.

In this case, the innovation possibilities frontier (3.36) is linear in R&D expenditures Z so that the system can be solved analytically. The BGP growth rate of machine varieties becomes

$$g_M = \beta\left(1 + \alpha\rho \cdot \left(\bar{\nu}\frac{1-\rho}{\rho} \cdot \bar{L}\right)^{1-\alpha}\right) \tag{3.79}$$

which is increasing in the labor endowment $\bar{L}$, the productivity of R&D $\bar{\nu}$, the capital share α, the discount factor β, and if $1/\rho - 1 > \frac{\alpha}{1-\alpha}$ increasing in the markup $1/\rho - 1$.[19]

Boundary case 2: knowledge-driven model

Consider a special case of the model in which the only input into R&D activities are workers l^R, i.e. $\psi = 1$ and $\omega = 0$. Moreover, assume that the household is endowed only with workers' labor, i.e. $\varsigma = 0$, which he supplies inelastically ($\gamma \to \infty$) in quantity $\bar{L}$. In this case, the innovation possibilities frontier (3.36) is linear in the labor input l^R so that the system can be solved analytically. The BGP growth rate of machine varieties becomes

$$g_M = 1 + \frac{\frac{\alpha}{1-\alpha}(1-\rho)}{\frac{\alpha}{1-\alpha}(1-\rho) + 1 + \frac{1-\beta}{\beta}} \cdot \left(\bar{\nu}\bar{L} - \frac{1}{\frac{\alpha}{1-\alpha}(1-\rho)} \cdot \frac{1-\beta}{\beta}\right) \tag{3.80}$$

which is increasing in the productivity of R&D $\bar{\nu}$ and the discount factor β. The BGP labor input into R&D is[20]

$$l^R = \frac{1}{\bar{\nu}} \cdot \frac{\frac{\alpha}{1-\alpha}(1-\rho)}{\frac{\alpha}{1-\alpha}(1-\rho) + 1 + \frac{1-\beta}{\beta}} \cdot \left(\bar{\nu}\bar{L} - \frac{1}{\frac{\alpha}{1-\alpha}(1-\rho)} \cdot \frac{1-\beta}{\beta}\right) \tag{3.81}$$

[19] R&D activities have to be sufficiently productive for the economy to grow, i.e. $g_M \geq 1 \Leftrightarrow \bar{\nu} > \frac{\rho}{1-\rho}\left(\frac{1/\beta - 1}{\alpha\rho}\right)^{\frac{1}{1-\alpha}} \bar{L}^{-1}$.

[20] Employment in the R&D sector l^R is positive and, hence, the economy is growing iff $\bar{\nu} > \frac{1}{\frac{\alpha}{1-\alpha}(1-\rho)} \cdot \frac{1-\beta}{\beta}\bar{L}^{-1}$, i.e. R&D activities are sufficiently productive.

Boundary case 3: exogenous growth RBC model

Consider a special case of the model in which the only input into R&D activities is S&E labor s^R, i.e. $\psi = 0$ and $\omega = 1$. Moreover, assume that the household supplies workers' labor elastically while he supplies S&E labor inelastically ($\theta \to \infty$) in quantity $\bar{S}$. In this case, innovative activities are predetermined and the BGP growth rate of machine varieties is exogenously given by

$$g_M = 1 + \bar{\nu}\bar{S} \tag{3.82}$$

Hence, the R&D sector is determined exogenously and the production sector is equivalent to the classical RBC model.

3.B Data Appendix

3.B.1 Data Sources

Data on macroeconomic aggregates are taken from the Bureau of Economic Analysis (BEA), its NIPAs and its 2010 R&D Satellite Account (R&DSA). Data on the civilian noninstitutional population aged 16 and older stem from the FRED database of the Federal Reserve Bank of St. Louis. Besides, the National Science Foundation (NSF) publishes various data on research and development activities.

Data on funds for industrial R&D are reported in Table 55 of the NSF report "Research and Development in Industry: 2006-07". Data on distribution of costs are taken from NSF's Industrial Research and Development Information System, Table H-27 for 1962-1998, and from various issues of its "Research and Development in Industry" reports for later years. Data on full-time equivalent R&D scientists and engineers are published in the NSF's Industrial Research and Development Information System, Tables B-25 (1957-1970) and H-19 (1971-1999), and for later years in various issues of its "Research and Development in Industry" reports.

3.B.2 Adjustments to NIPA data to be in line with R&DSA definitions

Currently, BEAs national economic accounts treat spending on R&D as expenses or consumption rather than investment. The 2013 NIPA Comprehensive Revision will capitalize R&D. By then, BEAs R&D Satellite Account provides data on U.S. R&D activity and shows the impact of treating R&D spending as investment on GDP and investment (Aizcorbe, Moylan, and Robbins, 2009; Mataloni and Moylan, 2007).

Mataloni and Moylan (2007) illustrate in detail how R&DSA R&D investment is derived from NSF data on R&D[21] and how the incorporation of R&D investment into the NIPAs will affect the definition of core measures such as GDP, investment, government consumption etc. Table A of Mataloni and Moylan (2007) provides a brief overview of the revisions. Alas, BEA does not publish a R&DSA dataset comparable to the NIPAs. However, the data published in Lee and Schmidt (2010), the current version of the R&DSA, allows me to reconstruct R&DSA-conform aggregates as follows:

$$PCE_{R\&DSA} = PCE_{NIPA} - RDI^{NPI} + CSRD^{NPI} \tag{3.83}$$

$$I_{R\&DSA} = I_{NIPA} - SDC \tag{3.84}$$

$$G_{R\&DSA} = G_{NIPA} - RDI^{Gov} + CSRD^{Gov} \tag{3.85}$$

where

$$CSRD^i = depreciation^i + net\ returns^i$$

and PCE denotes personal consumption expenditures, G government consumption, I physical investment, RDI R&D investment, SDC the R&D software double-count, and $CSRD$ Capital Services generated by R&D. Superscripts NPI and Gov indicate non-profit institutions and the government, respectively. According to Mataloni and Moylan (2007), the R&DSA removes double-counted R&D software development from NIPA software investment and retains it in R&D investment. For the period 1978 - 2001, I back out SDC from Table 1.2 of Robbins and Moylan (2007); prior to 1978 no

[21] Most importantly, the R&DSA measure is extended to R&D in social sciences and the humanities.

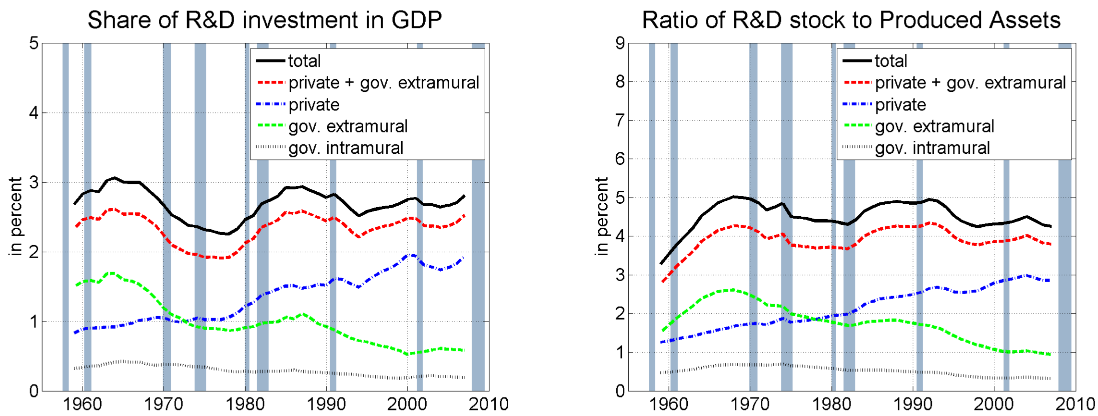

Figure 3.9: R&D investment/capital by source of funding
NOTES: The shaded regions correspond to NBER-recessions.
SOURCE: Bureau of Economic Analysis, R&D Satellite Account

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adjustment is made in the R&DSA; for recent years which have been revised in Lee and Schmidt (2010) I calculate the residual $SDC = GDP_{NIPA} + total\ adjustments - GDP_{R\&DSA}$ from Table C.

In principle, one would have to correct the NIPA software capital stock measures for the double-count of R&D software development. However, BEA does not publish corresponding corrections for the fixed asset account. Given a software-fraction of at max 1.5% in private fixed assets, the R&D software double-count issue seems to be negligible for the capital stock.

Figure 3.9 displays R&D investment and R&D capital from the R&DSA. The left panel shows the share of R&D investment in GDP. The total R&D share displays some medium-run fluctuations around its mean of 2.7%. These fluctuations stem from the phased decline in federal government's funding of extramural R&D combined with subsequent rise in private R&D funding. Adding both time series up, yields a stable share of 2.3% on average. The right panel shows illustrates that since the mid-1960s R&D capital has amounted to a constant fraction of the physical capital stock, namely 4.5% for total R&D capital and about 4% for private plus extramural R&D. In the analysis of business cycle patterns I consider the sum of private and federal government's extramural R&D investment (capital) as the appropriate measure of R&D investment (capital) as they reflect industrially performed R&D best.

3.C Tables and Figures Appendix

3.C.1 More Empirical Evidence

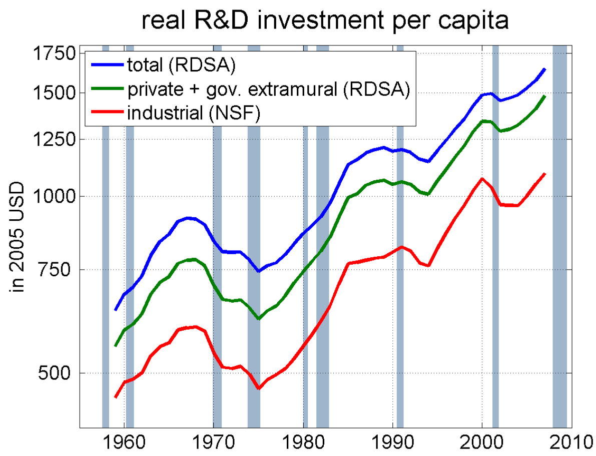

Figure 3.10: per-capita R&D investment
NOTES: The shaded regions correspond to NBER-recessions.
SOURCES: Bureau of Economic Analysis, R&D Satellite Account; National Science Foundation

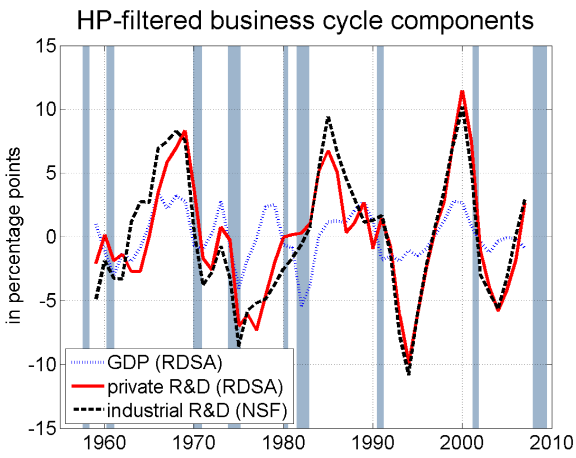

Figure 3.11: Business cycle components of R&D
NOTES: The business cycle component is calculated as deviation from trend, using the HP-filter with $\lambda = 100$. The shaded regions correspond to NBER-recessions.
SOURCES: Bureau of Economic Analysis, R&D Satellite Account; National Science Foundation

3.C.2 More Business Cycle Statistics

Table 3.8: Business Cycle Statistics of the U.S. Economy, 1959-2007

	SD[a]	AR(1)	GDP_{-2}	GDP_{-1}	GDP	GDP_{+1}	GDP_{+2}
TFP	1.41	0.56	-0.28	-0.01	0.61	0.64	0.34
GDP	1.99	0.58	0.06	0.58	1.00	0.58	0.06
Consumption	1.73	0.66	0.14	0.58	0.93	0.60	0.07
Investment	7.59	0.41	-0.36	0.25	0.81	0.49	0.10
R&D investment	4.57	0.75	0.26	0.53	0.52	0.26	0.06
Capital	1.34	0.54	0.44	0.26	-0.13	-0.27	-0.27
R&D capital	2.19	0.79	0.21	-0.04	-0.09	0.07	0.20
Wage bill	2.59	0.70	0.34	0.77	0.88	0.38	-0.10
Labor	2.24	0.60	0.20	0.74	0.85	0.28	-0.16
S&E labor	4.14	0.74	0.36	0.42	0.35	0.28	0.23
R&D wage costs[1]	4.37	0.53	0.16	0.37	0.43	0.25	0.09
R&D materials & supplies[1]	6.73	0.39	-0.11	0.26	0.43	0.18	0.03
R&D other[1]	6.60	0.53	0.44	0.56	0.45	0.14	-0.17
Cons/GDP	0.75	0.41	0.18	-0.21	-0.51	-0.17	-0.00
Inv/GDP	6.09	0.40	-0.47	0.12	0.69	0.42	0.11
R&D inv/GDP	3.93	0.70	0.28	0.32	0.09	0.01	0.04
Capital/GDP	2.54	0.51	0.19	-0.32	-0.85	-0.60	-0.18
R&D capital/GDP	3.09	0.62	0.11	-0.40	-0.71	-0.33	0.11
R&D inv./Inv	7.48	0.42	0.53	0.08	-0.51	-0.34	-0.06
S&E/Labor	4.14	0.64	0.25	0.01	-0.10	0.13	0.32
S&E/R&D inv.	3.35	0.40	0.07	-0.23	-0.26	-0.01	0.21
Labor/R&D inv.	3.76	0.74	-0.20	-0.21	-0.12	-0.15	-0.17
R&D wage cost share[1]	2.34	0.34	-0.26	-0.35	-0.22	0.05	0.27
wage cost ratio S to L^R[2]	2.76	-0.01	0.69	0.14	-0.37	-0.15	-0.14
R&D materials share[1]	5.06	0.42	-0.40	-0.12	0.10	0.05	0.09
R&D other cost share[1]	4.03	0.40	0.41	0.32	0.14	-0.02	-0.22
avg. wage W	1.24	0.73	0.35	0.28	0.30	0.29	0.07
avg. wage for S&E W^S[2]	2.48	0.12	-0.04	0.69	0.70	0.09	-0.43

All variables are defined as logarithms of real per-capita measures which are computed by normalizing with the price index for GDP and the civilian noninstitutional population, aged 16 years and over. The business cycle component is calculated as deviation from trend, using the HP-filter with smoothing parameter $\lambda = 100$. According to these transformations, one can interpret the cyclical components as percentage deviations from the trend.

[a] Standard deviations are reported in percentage terms.

[1] Period 1962-2007; between 1977 and 1997 data were collected only at biannual frequency. HP-filtering is conducted with Schlicht (2008)'s MEND-code.

[2] Period 1962-1975.

3.C.3 Estimates of the RBC shock process

Table 3.9: RBC shock process, U.S. economy, 1959-2007

data source	growth rate	AR(1) coeff.	std. dev. (ϵ)
Bureau of Labor Statistics	1.01 %	0.845	1.54 %
Fernald (2012)	0.97 %	0.832	1.52 %
Jorgenson and Landefeld (2006)	0.41 %	0.845	1.03 %
Kydland and Prescott (1991)		$0.95^4 = 0.815$	$1.858 \cdot 0.76\% = 1.41\%$
Gomme and Rupert (2007)[1]	1.72 %	$0.964^4 = 0.864$	$1.896 \cdot 0.82\% = 1.55\%$

The data underlying the estimation are multifactor productivity for the private non-farm business sector from Table 4 of the BLS' historical multifactor productivity measures and Fernald (2012)'s business sector TFP measure, both for the period 1959-2007, as well as the multifactor productivity measure of Jorgenson and Landefeld (2006, Tab. 1.25) for 1959-2002.

[1] Estimation period is 1954Q1 - 2000Q4. Results refer to the one-capital-stock specification reported in Table 2.

3.C.4 Sensitivity analysis for the multi-input model (markup-calibration)

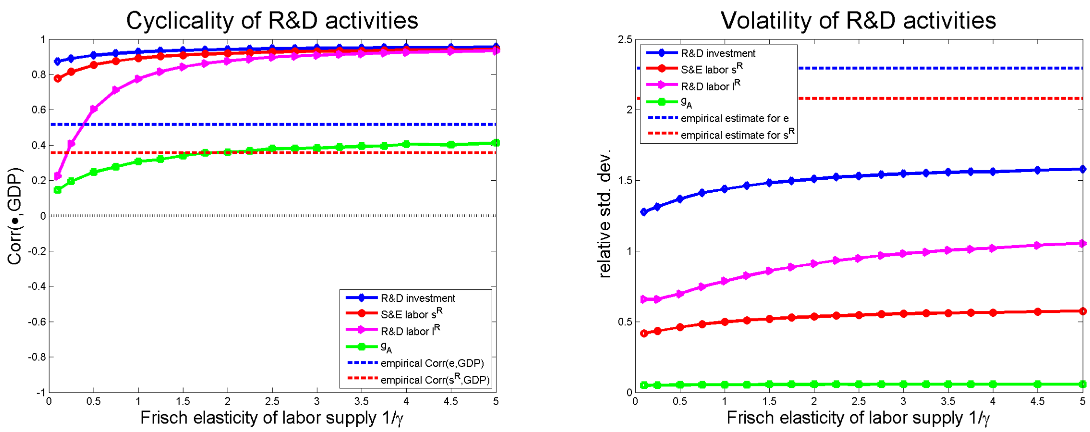

Figure 3.12: Multi-input model economy: sensitivity w.r.t. labor supply elasticity

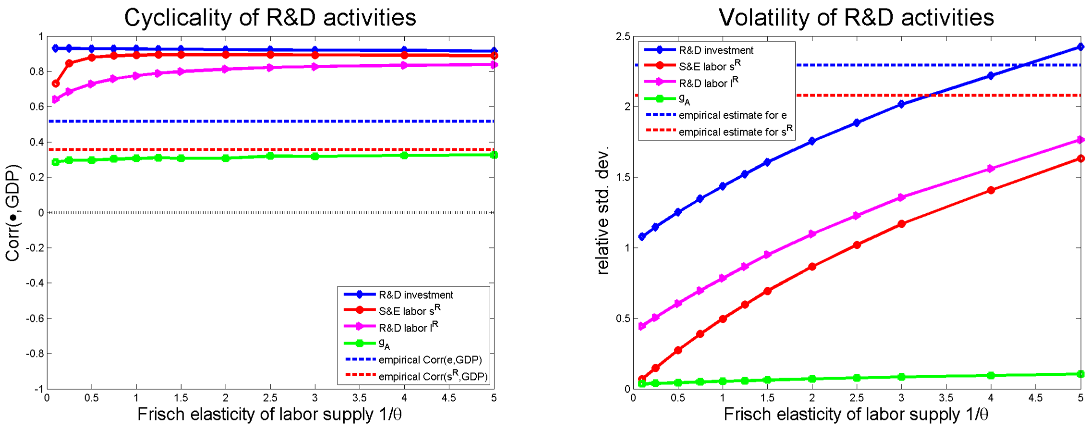

Figure 3.13: Multi-input model economy: sensitivity w.r.t. S&E labor supply elasticity

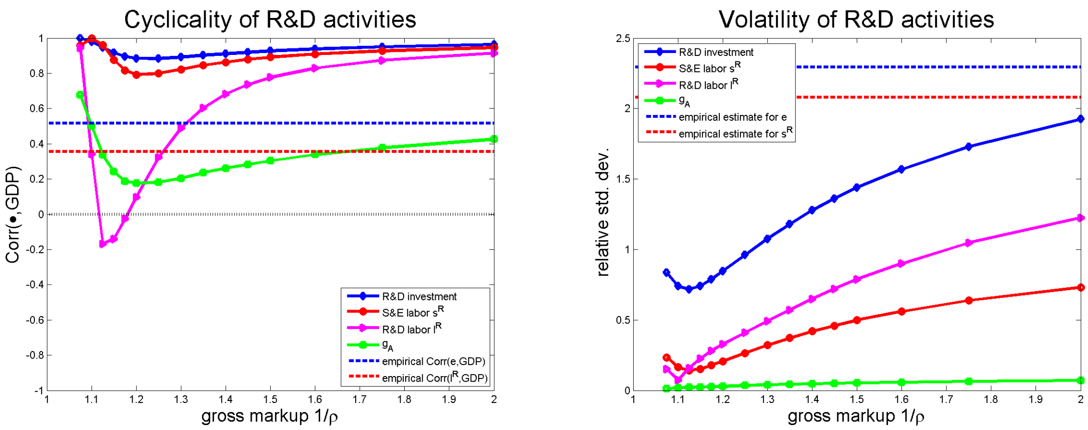

Figure 3.14: Multi-input model economy: sensitivity w.r.t. markup

3.C.5 R&D-stock-calibration

Table 3.10: Knowledge-driven model economy: calibrated parameter values (R&D-stock-calibration)

Preferences			**Technology**					**Shock**	
β	$(1-\varsigma)\zeta$	γ	α	ρ	ϕ	δ^K	$\bar{\nu}$	$AR(1)$	*Std. dev.*
0.945	4.22	1	0.371	0.893	0.12	0.0372	14.4	0.85	0.015

Table 3.11: Multi-input model economy: calibrated parameter values (R&D-stock-calibration)

Preferences					**Shock**	
β	$(1-\varsigma)\zeta$	γ	$\varsigma\chi$	θ	$AR(1)$	*Std. dev.*
0.943	4.21	1	0.0666	1	0.85	0.015
Technology						
α	ρ	ϕ	δ^K	ω	ψ	$\bar{\nu}$
0.364	0.914	0.159	0.0372	0.277	0.183	33.7

Chapter 4

The Taxpayer Relief Act of 1997 and the U.S. Housing Boom[1]

4.1 Introduction

In the period from the mid 1990s until the beginning of the housing crisis, the U.S. housing market experienced a number of remarkable developments. First, house prices and mortgage volume increased strongly, but mortgage volume grew faster than house prices so that the aggregate loan-to-value ratio increased. Specifically, between 1997 and 2007, real house prices went up by 55% percent (see Figure 4.1.A), the mortgage-to-GDP ratio went up from 44% to 74% (see Figure 4.2.A), and the loan-to-value ratio increased from 55% to 70% (see Figure 4.2.B). Second, in the same period delinquency rates dropped significantly (see Figure 4.3). In this essay, we ask two questions. First, did the U.S. Taxpayer Relief Act of 1997 contribute to these developments? Second, to what extent could some of these developments have been dampened by a different type of tax reform?

To address these questions, we develop a macro model with a housing sector and conduct a quantitative analysis of the tax reform based on a calibrated version of the model economy. In the model, households can buy consumption goods, save in a risk-free asset, rent or invest in housing space, and invest in human capital. Housing investment and human capital investment are subject to uninsurable idiosyncratic

[1]This chapter is joint work with Tom Krebs and Mark L. J. Wright.

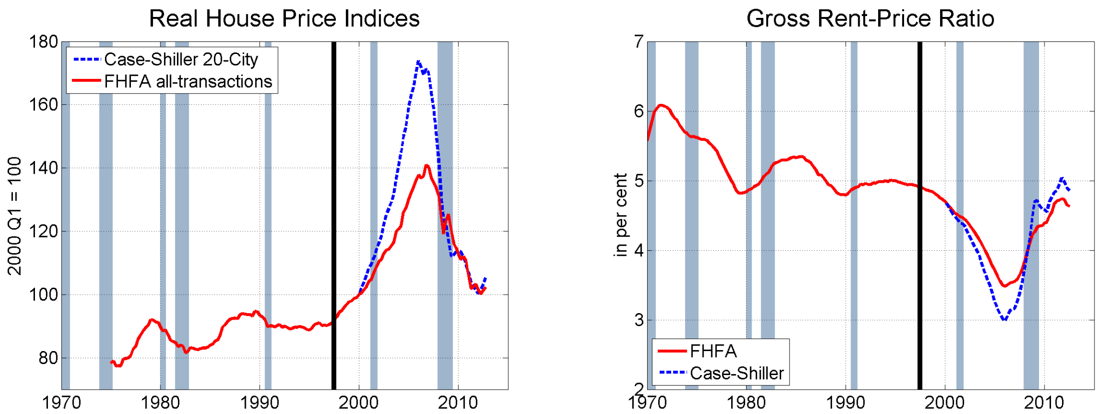

Figure 4.1: House prices and rent-price ratio for the U.S.

NOTES: Nominal values are deflated using the CPI for All Urban Consumers: All items less shelter. The shaded regions correspond to NBER-recessions.

SOURCE: FRED / FHFA; Davis, Lehnert, and Martin (2008), updated data:

`http://www.lincolninst.edu/subcenters/land-values/rent-price-ratio.asp`

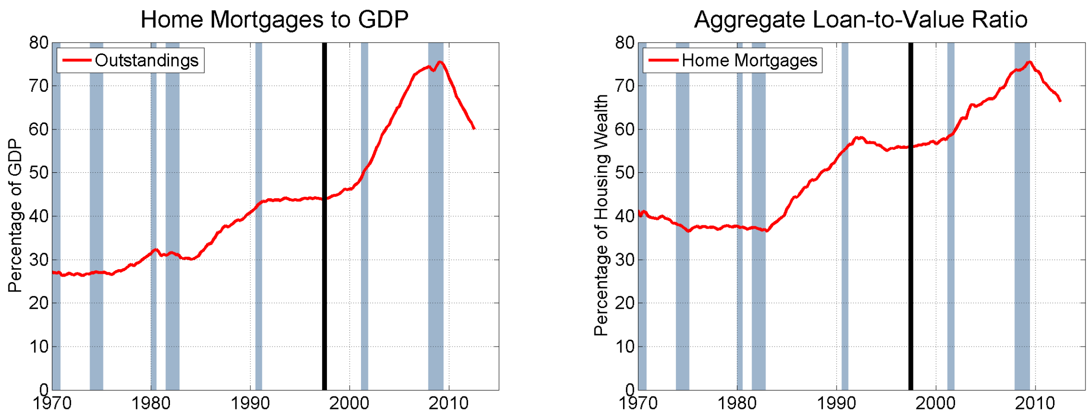

Figure 4.2: Home Mortgage Debt

NOTES: The shaded regions correspond to NBER-recessions.

SOURCE: FRED, Flow-of-Funds and NIPAs

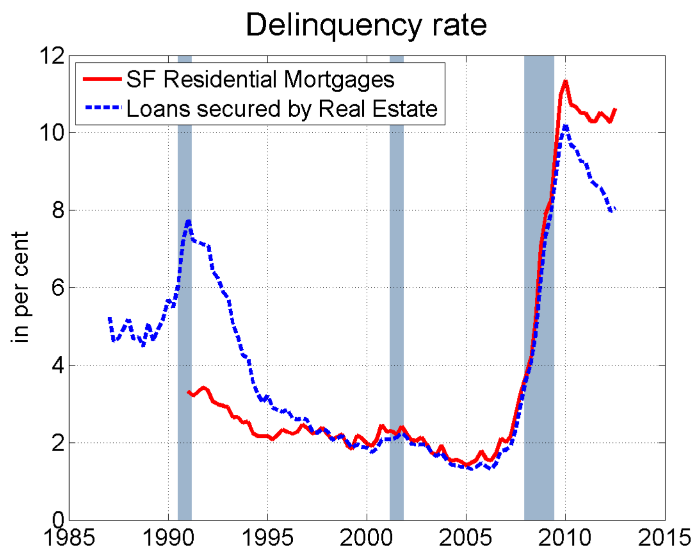

Figure 4.3: Mortgage Delinquencies
NOTES: The shaded regions correspond to NBER-recessions.
SOURCE: FRED

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risk. Households can also borrow and default on their debt, in which case they lose their housing investment and are excluded from borrowing for a number of periods (mortgage default with foreclosure and limited access to mortgage markets in the future). Household are ex-ante heterogeneous with respect to age (life-cycle) and their preferences for housing. We close the model assuming a fixed supply of housing (land) and an aggregate production function that displays constant returns to scale with respect to physical capital and human capital. The second assumption implies that the model generates endogenous growth.

The U.S. Taxpayer Relief Act of 1997 eliminated the capital gains tax on housing sales for all households if the gains did not exceed $500,000 (for single households $250,000). In contrast, before the tax reform in 1997 households could only avoid the capital gains tax if they re-invested the gains in larger homes. In other words, before the tax reform the capital gains tax had to be paid in all cases in which households do not want to increase their housing investment, which are most likely cases of job loss, divorce, or illness. Thus, the U.S. Taxpayer Relief Act of 1997 not only increased the after-tax expected return to housing investment, but also reduced the risk associated with housing investment. When we feed the tax changes associated with the U.S.

Taxpayer Relief Act of 1997 into the calibrated model economy, we find the following results.

First, the model predictions are qualitatively in line with the main developments in the U.S. housing market: house prices and mortgage volume rise, but mortgage volume rises faster than house prices so that loan-to-value ratios (leverage) increase. Second, the effects are quantitatively important, but the predicted changes are substantially less than the changes observed in the period 1997-2007. Specifically, according to our simulations the U.S. Taxpayer Relief Act of 1997 increased real house prices by 6.4 percent, increased the mortgage-to-GDP ratio from 44.0% to 49.0%, and increased the loan-to-value ratio from 55.7% to 58.2%. Thus, our conclusion from this analysis is that the U.S. Taxpayer Relief Act of 1997 can account for some part of the U.S. housing boom, but the larger part, in particular the strong increase in house prices, has to be explained by other factors (i.e. low interest rates and/or financial innovation).

We also find that the U.S. Taxpayer Relief Act of 1997 reduced mortgage default rates. In our model economy, a reduction in the housing tax has two opposing effects on equilibrium default rates. On the one hand, the tax reduction leads to higher housing leverage and therefore higher mortgage default rates. On the other hand, the tax reduction also makes mortgage default more costly since exclusion from mortgage markets becomes more costly. In our calibrated model economy, the second effect dominates and we therefore find that the U.S. Taxpayer Relief Act of 1997 decreased mortgage default rates. The prediction of a simultaneous rise in loan-to-value ratios and decline mortgage default rates distinguishes our work from previous macro work on housing, which assumes that the only consequence of default is the loss of the housing investment (foreclosure) and therefore necessarily predicts that leverage and default rates are positively correlated.

We also consider the effect of a hypothetical tax reform that taxes capital gains on housing sales at the same rate that all other capital gains are taxed without any exemptions. We find that this tax reform would have reduced real house prices by 4.1 percent, the mortgage-to-GDP ratio from 44.0% to 41.5%, the loan-to-value ratio from 55.7% to 54.7%. Thus, if this tax reform had been implemented in 1997, instead of the Taxpayer Relief Act of 1997, our analysis suggests that real house prices would have been 10.5 percent lower than their actual value. In other words, implementing a tax reform that treats capital gains of housing sales as ordinary capital gains as opposed to the Taxpayer Relief Act of 1997 would have dampened the observed house price rise during the U.S. housing boom by about 20 percent.

4.1.1 Related Literature

We build on the growing macro literature that uses calibrated model economies to conduct a quantitative analysis of the housing sector. We make two contributions to this literature. First, on the substantive side we contribute to the literature that studies the positive (and normative) consequences of government housing policy. In this respect our essay is closely related to the work of Gervais (2002), who studies the effects of preferential tax treatment of housing, Jeske, Krueger, and Mitman (2013), who evaluate the effects of the government bailout guarantees for Government Sponsored Enterprises, and Nakajima (2010), who studies the optimal income tax rate when residential capital is treated preferentially in the tax code. Chambers, Garriga, and Schlagenhauf (2014) analyze to what extent U.S. housing policy caused the postwar boom in homeownership. We contribute to this literature by analyzing a major tax reform, namely the Taxpayer Relief Act of 1997, which has so far not been studied by the macro literature.

Our second contribution is to develop a model with mortgage debt and default in which mortgage interest rates reflect equilibrium default probabilities and the consequences of default are twofold: mortgage default leads to loss of housing investment (foreclosure) and limited access to mortgage markets in the future. In this regard, our work is a natural extension of the literature on uncollateralized debt and equilibrium default (Chatterjee, Corbae, Nakajima, and Ríos-Rull, 2007; Livshits, MacGee, and Tertilt, 2010). In contrast, the existing housing literature has incorporated equilibrium mortgage rates that fully reflect default probabilities (Chatterjee and Eyigungor, 2011; Corbae and Quintin, 2013; Jeske, Krueger, and Mitman, 2013), but has so far confined attention to the case in which mortgage default has no repercussions on the ability of households to borrow in the future (however, see also Mitman (2012) for a noteworthy exception). As we have argued above, this extension is important to understand any historical episode in which leverage rises and default rates are either constant or declining.

Finally, our essay is related to empirical work evaluating the effects of the Taxpayer Relief Act of 1997. Consistent with our results, this literature has found that during the pre-reform period many homeowners were prevented from selling their homes due to capital gains taxation, and that the Taxpayer Relief Act of 1997 has released these lock-in effects (Biehl and Hoyt, 2014; Cunningham and Engelhardt, 2008; Heuson and Painter, 2014; Shan, 2011). Indeed, we use the estimates of this literature to calibrate our model economy along one important dimension. We complement this literature by analyzing the effects on aggregate house prices, mortgage volume, and default rates in an equilibrium model.

4.2 Model

4.2.1 Economy

Household sector

The economy is populated by a unit mass of households. Households age stochastically according to a Markov process with transition probability $\pi(j'|j)$. We consider three age-groups j: young, middle-aged, and old. Old people stochastically die and are immediately replaced by newborns. For each age group there are two subgroups with low and high housing return, respectively. Households move from housing return state L to H – i.e. become first-time buyers – with probability b_j. In addition, we distinguish middle-aged households with high human capital return (type $m1$) and middle-aged with low human capital return (type $m2$). In sum, there are 2*4 types of households denoted by $\{y, m1, m2, o\} \times \{H, L\}$, with type transitions specified by transition matrix Π^T (for details see Appendix 4.A.1). We assume that the demographic structure of the population is stationary.

Households derive utility from consumption of two goods: a standard good and housing services. We assume that households have identical time-separable preferences which can be represented by the discount factor β and the following one-period utility function

$$u(c_1, c_2) = \begin{cases} \ln c_1 + \nu \ln c_2 & if\ no\ default \\ \ln c_{d1} + \nu \ln c_{d2} - u_d & if\ in\ default \end{cases} \tag{4.1}$$

where c_1 is consumption of the standard good, c_2 is consumption of the housing service, and u_d is a utility cost of being in default. Households can invest in human capital h, physical capital k, and housing x. We assume that households do not care whether they live in a rented home or owner-occupied home. Besides, they can take out an one-period mortgage m. Actually, they choose mortgages from a menu that states loan-to-value ratios $\ell' = \frac{p_m m'}{\tilde{p}_x x'}$ and corresponding mortgage prices p_m. The standard consumption good can be transformed one-to-one into physical capital or human capital, whereas the housing stock is in fixed supply. Thus, the sequential budget constraint for a household who is not in default reads

$$\begin{aligned} & c_1 + \tilde{p}_l c_2 + k' + h' + p_m m' + \tilde{p}_x x' \ = (1 + tr) \cdot \\ & [(1 + \tilde{r}_k - \delta_k)k + (1 + \tilde{r}_h(j) - \delta_h + \eta(s))h + m + [\tilde{p}_l + (1 + \epsilon(s))\tilde{p}_x - \tau(s)\tilde{p}_x]\, x] \\ & h' \geq 0 \ , k' \geq 0 \ , \ x' \geq 0 \ , \ m' \leq 0 \end{aligned} \tag{4.2}$$

where we used the following variable definition:

h, k, x: stock of human capital, physical capital, and housing owned by household

$\tilde{r}_h(j)$, $\tilde{r}_k$: rental rate of human capital, physical capital

$\tilde{p}_x$: aggregate price of housing

$\tilde{p}_l(j)$: price of housing services

$\epsilon(s)$: idiosyncratic shock to the price of housing

$\tau(s)$: capital gains tax on the sale of housing

m: mortgage (quantity)

p_m: price of mortgage

$\eta(s)$: idiosyncratic human capital shock

tr: transfer rate

s: exogenous state

We assume that the human capital shock η to is normally distributed with zero mean. In the following, however, we consider a discrete-state approximation. In contrast, the individual house price shock ϵ is uniformly distributed on the support $[\epsilon_{min}; \epsilon_{max}]$.

In addition to the choice of $(k', h', m', x', c_1, c_2)$ households also make a default decision, which in general depends on the entire state (k, h, m, x, s). However, in our setting, the current default decision depends only on the current stock of housing x and mortgage debt m as well as current shocks s. Thus, a default policy is a function $d = d(x, m, s, j)$ mapping current shocks into $\{0, 1\}$ where 1 stands for default.

We model the consequences of default as follows. All debt is canceled and the housing collateral is seized.[2] However, there is no garnishment of wage income. Besides, the household who defaults is excluded from the mortgage market in future. By this, we mean the household can neither take on any debt nor buy a house. Nevertheless, he can invest into physical and human capital. In sum, the budget constraint for households in default is given by (4.2) with $m = x = 0$ and the restriction $m' = x' = 0$. We assume that the period of exclusion ends stochastically with probability $1 - p$. As long as the household is in default, he suffers a utility cost of u_d.

Financial intermediaries

Financial intermediaries borrow at the risk-free rate $r_f = \tilde{r}_k - \delta_k$ and incur a real resource cost of financial intermediation $\Delta \geq 0$ per unit of the mortgage. We assume that financial intermediaries can observe the loan-to-value ratio ℓ of the mortgages they offer. However, they do not observe default policies and, hence, cannot condition the mortgage price p_m on it. Hence, a mortgage is represented by the pair (p_m, ℓ'). In case of default the mortgage claim m' is written off and the housing collateral x' is liquidated. We assume that financial intermediaries possess a foreclosure technology according to which they recover a fraction $\gamma \leq 1$ of the current market value of the foreclosed home $(1 + \epsilon')p'_x x'$.[3] Besides, we assume for simplicity that there are no capital gains taxes on foreclosed homes.

Financial intermediaries offer various types of mortgages, i.e. combinations of loan-to-value ratios and mortgage prices. We assume that financial intermediaries can fully diversify idiosyncratic risk for each mortgage type (p_m, ℓ') and all mortgage markets are perfectly competitive so that they earn zero profits on each mortgage type. Zero profit per mortgage type requires that the intermediary exactly earns its costs of funding

[2]If the household decides to default, he loses, by assumption, all his housing assets in foreclosure, even if he is not under water.

[3]If the net revenue from foreclosure exceeds the size of the mortgage m', the bank is repaid and the excess amount vanishes by assumption.

$1 + r_f + \Delta$. Hence, the mortgage pricing schedule $p_m(\ell')$ is given by

$$1/p_m = max\left\{\frac{1 + r_f + \Delta - \gamma \cdot \frac{\tilde{p}'_x}{\tilde{p}_x}\frac{1}{\ell'}(1 + E[\epsilon'|d_{max} = 1])}{1 - E[d_{max} = 1]},\ 1 + r_f + \Delta\right\} \tag{4.3}$$

where $E[d_{max} = 1]$ is the expected default rate for this mortgage contract.

Production and Housing Supply

We assume that the non-housing good is produced under the production function $Y = AK^\alpha H^{1-\alpha}$, where K is the aggregate stock of physical capital, H the aggregate stock of human capital, and A a productivity parameter. Markets for physical and human capital are perfectly competitive so that the rental rates satisfy

$$\begin{aligned} \tilde{r}_k &= \alpha A\tilde{K}^{\alpha-1} \\ \tilde{r}_h &= (1-\alpha)A\tilde{K}^{\alpha} \end{aligned} \tag{4.4}$$

where $\tilde{K} = K/H$ denotes the capital-to-labor ratio. While the non-housing consumption good can be transformed one-to-one into physical capital or human capital, the housing stock is in fixed supply, normalized to one. We assume that one unit of the housing stock generates one unit of housing consumption services. We further assume that mortgages are financed through savings from abroad. Thus, we have three market clearing conditions that read:

$$\begin{aligned} \tilde{K} &= \frac{\sum_i E[k^i|j=i]\pi(i)}{\sum_i E[h^i|j=i]\pi(i)} \\ 1 &= \sum_i E[x^i|j=i]\pi(i) \\ 1 &= \sum_i E[c_2^i|j=i]\pi(i) \end{aligned} \tag{4.5}$$

where $\pi(i)$ is the population share of household type i. Note that the first market clearing condition in (4.5) follows from combining the market clearing conditions for physical capital and human capital. The second condition is market clearing for the housing stock and the third is for housing services. Finally, goods market clearing is implied by Walras' law and the aggregate stock of mortgage debt amounts to $M =$

$\sum_i E[m^i|j = i]\pi(i)$.

Government

The government collects income taxes. The U.S. law of taxation distinguishes ordinary income, which includes wage income, from long-term capital gains. However, in the U.S. there have been several tax breaks for owner-occupied housing.[4]

This essay focuses on special provisions for the recognition of capital gains from the sale of a primary residence and studies the changes that were implemented by the Taxpayer Relief Act of 1997 (TRA97). Consequently, we model the taxation of capital gains from the sale of housing in detail and abstract from ordinary income taxes and standard capital gains taxes.[5] Before the TRA97, the recognition of capital gains from the sale of a primary residence could be deferred in case the taxpayer bought a new residence of at least equal value. In this case, the capital gain would have been rolled-over into the new home. Otherwise, the gain was subject to capital gains taxation. The Taxpayer Relief Act of 1997 replaced this roll-over rule by an exemption of $500'000 per married couple. As a consequence, since 1997 capital gains on housing have been de facto tax-exempt for the vast majority of U.S. households.[6]

We model the pre-TRA97 tax law as follows: first, we assume that a household sells his home with exogenous probability $Prob(\chi = 1) = \varsigma$. Second, capital gains from the sale of housing are taxed only if the house is downsized. In our model, this corresponds to a negative realization of the labor shock η. The following tax function which specifies the tax liability per unit of housing in case of a sale captures this interpretation of roll-over:

$$\tau(s) = \begin{cases} \bar{\tau} \cdot \max\left\{\frac{(1+\epsilon)\tilde{p}_x}{\tilde{p}_{x0}} - 1 \ ; \ 0\right\} & if\ \chi = 1 \ \ and\, \eta < 0 \\ 0 & otherwise \end{cases} \tag{4.6}$$

[4] For a brief history of the U.S. law of taxation focussing on owner-occupied housing see Appendix 4.B.

[5] However, in the quantitative analysis we calibrate the model to after-tax returns.

[6] According to the Office of Management and Budget (1997, p. 46) *"the proposal would exempt over 99 percent of home sales from the capital gains tax and would dramatically simplify taxes and record keeping for over 60 million homeowners."* Evidence by Shan (2011) supports this claim: using transaction data for the Boston metropolitan area, Shan (2011) imputes accumulated housing capital gains and finds that prior to the TRA97 only 1% of transactions have imputed capital gains over $500'000.

where $(1+\epsilon)\tilde{p}_x$ is the individual sales price and $\tilde{p}_{x0}$ denotes the purchase price of the home. For simplicity, we assume that the house-buying took place $1/\varsigma$ periods ago so that the the individual purchase price was $\tilde{p}_{x0} = \tilde{p}_x/(1+g)^{1/\varsigma}$. For future reference, denote the threshold level of the house price shock that implies zero capital gains on housing by $\bar{\epsilon}$, i.e. $(1+\bar{\epsilon})\tilde{p}_x/\tilde{p}_{x0} - 1 = 0$.

In equilibrium housing tax revenues amount to

$$\begin{aligned} Tax &= \varsigma \cdot \sum_i E[\tau(s) \cdot \tilde{p}_x x^i | j = i]\pi(i) \\ &= \varsigma\bar{\tau} \cdot Prob(\eta < 0) \cdot \left(\int_{\bar{\epsilon}}^{\epsilon_{max}} \frac{(1+\epsilon)\tilde{p}_x}{\tilde{p}_{x0}} d\pi(\epsilon) - 1 \right) \cdot \tilde{p}_x \end{aligned} \quad (4.7)$$

where the last line uses the market clearing condition for the housing stock (4.5) and the tax function (4.6). The government rebates its tax revenues as transfers to households in order to run a balanced budget. Suppose these transfers are proportional to household wealth after all assets have paid off $(1+\tilde{r}_k-\delta_k)k + (1+\tilde{r}_h-\delta_h+\eta(s))h + m + [\tilde{p}_l + (1+\epsilon(s))\tilde{p}_x - \tau(s)\tilde{p}_x]\,x$ and denote the transfer rate by tr. Then the government's budget constraint reads

$$Tax = tr \cdot [(1+\tilde{r}_k-\delta_k)\cdot K + (1+\tilde{r}_h-\delta_h)\cdot H + M + (\tilde{p}_l+\tilde{p}_x)\cdot 1 - Tax] \quad (4.8)$$

where we again use the market clearing conditions (4.5). Hence, the balanced budget policy determines the equilibrium transfer rate.

4.2.2 Theoretical Results

In this section, we derive the main theoretical results. Proposition 1 characterizes the optimal decision rules of the household. Proposition 2 decribes the stationary competitive equilibrium of the model economy.

Characterization of Household Problem

First, note that optimality requires that consumption expenditures on goods and housing services are proportional so that the demand for housing consumption is $c_2 = \frac{\nu}{\tilde{p}_l}c_1$. This implies that total consumption expenditures are $c = c_1 + \tilde{p}_l c_2 = (1+\nu)c_1$.

Second, due to homothetic preferences and a linear-homogenous budget, the consumption-saving decision will be independent from the portfolio choice problem which makes the model highly tractable. In the following, we will derive this separation property. To this end, it is convenient to express the household's decision problem as a portfolio choice problem. Thereto, define the following variables:

$$w = h + k + p_{m,-1}m + \tilde{p}_{x,-1}x$$
$$\theta_k = \frac{k}{w}\ ,\ \theta_h = \frac{h}{w}\ ,\ \theta_m = \frac{p_{m,-1}m}{w}\ ,\ \theta_x = \frac{\tilde{p}_{x,-1}x}{w}$$
$$\theta = (\theta_k, \theta_h, \theta_x, \theta_m)$$
$$r_k = \tilde{r}_k - \delta_k$$
$$r_h(s,j) = \tilde{r}_h(j) - \delta_h + \eta(s)$$
$$r_m(\theta,s,j) = \begin{cases} \frac{1}{p_{m,-1}(\theta)} - 1 & if\ d(x,m,s,j) = 0 \\ -1 & if\ d(x,m,s,j) = 1 \end{cases}$$
$$r_x(s,j) = \begin{cases} \frac{(1+\epsilon(s))\tilde{p}_x + \tilde{p}_l(j)}{\tilde{p}_{x,-1}} - 1 - \tau(s) & if\ d(x,m,s,j) = 0 \\ -1 & if\ d(x,m,s,j) = 1 \end{cases}$$
$$r(\theta,s,j) = \theta_k r_k + \theta_h r_h(s,j) + \theta_m r_m(\theta,s,j) + \theta_x r_x(s,j)$$
$$p_x = \frac{\tilde{p}_x}{W}$$
$$p_l = \frac{\tilde{p}_l}{W}$$

where p_{-1} is the price one period before the current period and $W = E[w]$ is aggregate total wealth. Let the law of motion for aggregate wealth be

$$W' = (1+g)W \tag{4.9}$$

where the growth rate g has to be determined later on. Using this notation, the budget constraints become

$$\begin{aligned} w' &= (1 + r(\theta,s,j,d))(1+tr)w - (1+\nu)c_1 \\ 1 &= \theta'_k + \theta'_h + \theta'_m + \theta'_x \\ & \theta'_h \geq 0\ , \theta'_k \geq 0\ ,\ \theta'_x \geq 0\ ,\ \theta'_m \leq 0 \end{aligned} \tag{4.10}$$

and, for households in default,

$$\begin{aligned} w'_d &= (1+r_d(\theta,s,j))(1+tr)w_d - (1+\nu)c_{d1} \\ 1 &= \theta'_k + \theta'_h \qquad (4.11) \\ & \theta'_h \geq 0\,,\theta'_k \geq 0 \end{aligned}$$

where the portfolio return for households in default is $r_d(\theta, s, j) = r(\theta_k, \theta_h, 0, 0, s, j)$.

The recursive formulations of the household maximization problems read:

$$\begin{aligned} V(w,\theta,s,j,W) &= \max\left\{ \max_{w',\theta',c_1} \left\{ \nu \ln(\nu/\tilde{p}_l) + (1+\nu)\ln c_1 + \beta \sum_{j'}\sum_{s'} V(w',\theta',s',j',W')\pi(s')\pi(j'|j) \right\} ; \right. \\ & \left. \max_{w',\theta'_d,c_1} \left\{ \nu \ln(\nu/\tilde{p}_l) + (1+\nu)\ln c_1 + \beta \sum_{j'}\sum_{s'} V_d(w',\theta'_d,s',j',W')\pi(s')\pi(j'|j) \right\} \right\} \quad (4.12) \end{aligned}$$

subject to the budget constraint (4.10), the mortgage pricing schedule (4.3),[7] and the aggregate law of motion (4.9);

$$\begin{aligned} V_d(w_d,\theta_d,s,j,W) &= \max_{w',\theta'_d,c_{d1}} \left\{ \nu \ln(\nu/\tilde{p}_l) + (1+\nu)\ln c_1 - u_d + \beta p \sum_{j'}\sum_{s'} V_d(w'_d,\theta'_d,s',W')\pi(s')\pi(j'|j) \right. \\ & \left. + \beta(1-p)\sum_{j'}\sum_{s'} V(w'_d,\theta'_d,s',W')\pi(s')\pi(j'|j) \right\} \quad (4.13) \end{aligned}$$

subject to the constraints (4.11) and (4.9) where $\theta_d = (\theta_k, \theta_h, 0, 0)$ and there is no disutility u_d in the period of default.

Appendix 4.A.2 derives the solution to these Bellman equations. The value functions are logarithmic and separable:

$$\begin{aligned} V(w,\theta,s,j,W) &= \tilde{V}_0(j) + \frac{1+\nu}{1-\beta}\left[\ln(1+r(\theta,s,j,d)) + \ln w\right] + \frac{\nu}{1-\beta}\ln W \quad (4.14) \\ V_d(w_d,\theta_d,s,j,W) &= \tilde{V}_{0d}(j) + \frac{1+\nu}{1-\beta}\left[\ln(1+r_d(\theta_d,s,j)) + \ln w_d\right] + \frac{\nu}{1-\beta}\ln W \end{aligned}$$

where $\tilde{V}_0(j), \tilde{V}_{0d}(j)$ are type-specific constants (see Appendix 4.A.2). Consumption

[7]While households take the pricing function (4.3) into account, they ignore the effect of their individual default policy on the mortgage price $p_m(\ell)$. That is, they take the default probability $E[d_{max} = 1]$ and the expected house price shock under default $E[\epsilon'|d_{max} = 1]$ as given.

policies are linear in wealth:

$$\begin{aligned} c_1 &= \frac{1-\beta}{1+\nu(1-\beta)}\left(1+r(\theta,s,j,d)\right)(1+tr)\cdot w \\ c_{d1} &= \frac{1-\beta}{1+\nu(1-\beta)}\left(1+r_d(\theta_d,s,j)\right)(1+tr)\cdot w_d \end{aligned} \tag{4.15}$$

$$\begin{aligned} c_2 &= \frac{\nu(1-\beta)}{\tilde{p}_l\cdot(1+\nu(1-\beta))}\left(1+r(\theta,s,j,d)\right)(1+tr)\cdot w \\ c_{d2} &= \frac{\nu(1-\beta)}{\tilde{p}_l\cdot(1+\nu(1-\beta))}\left(1+r_d(\theta_d,s,j)\right)(1+tr)\cdot w_d \end{aligned} \tag{4.16}$$

The laws of motion for wealth are linear, too:

$$\begin{aligned} w' &= \frac{\beta}{1+\nu(1-\beta)}\cdot(1+tr)\cdot(1+r(\theta,s,j,d))\cdot w \\ w'_d &= \frac{\beta}{1+\nu(1-\beta)}\cdot(1+tr)\cdot(1+r_d(\theta_d,s,j))\cdot w_d \end{aligned} \tag{4.17}$$

The optimal portfolio choices, $\theta'_{max}, \theta'_{d,max}$, are independent of wealth. For given default policy d', the portfolio choices are the solution to

$$\begin{aligned} \theta'_{max}(j) &= \arg\max_{\theta'}\sum_{j'}\sum_{s'}\ln\left(1+r(\theta'(j),s',j',d')\right)\pi(s')\pi(j'|j) \\ &\quad \text{subject to (4.3)} \\ \theta'_{d,max}(j) &= \arg\max_{\theta'_d}\sum_{j'}\sum_{s'}\ln\left(1+r_d(\theta'_d(j),s',j')\right)\pi(s')\pi(j'|j) \end{aligned} \tag{4.18}$$

Recall that, being excluded from mortgage markets, households in default have less investment opportunities than households not in default. Hence, their portfolio return will be lower: $r_d(\theta_{d,max}(j),s,j) \leq r(\theta_{max}(j),s,j,d)$. And the optimal default policy

$d_{max}(\theta_x, \theta_m, s, j)$ is described by the following inequality

$$\begin{aligned} & \beta\frac{1-\beta}{1+\nu}\sum_{j'}[\tilde{V}_0(j') - \tilde{V}_{0d}(j')]\pi(j'|j) \\ + & \beta\sum_{j'}\sum_{s'}\ln(1+r(\theta_{max}(j), s', j', d_{max}(\theta'_x, \theta'_m, s', j')))\pi(s')\pi(j'|j) \\ - & \beta\sum_{j'}\sum_{s'}\ln(1+r_d(\theta_{d,max}(j), s', j'))\pi(s')\pi(j'|j)] \\ \geq & \ln(1+r(\theta, s, j, 1)) - \ln(1+r(\theta, s, j, 0)) \end{aligned} \tag{4.19}$$

which has to hold for all states $(\theta_x, \theta_m, s, j)$ with no default, $d(\theta_x, \theta_m, s, j) = 0$, given the current portfolio state θ and next-period optimal portfolio choice θ'_{max}. And for all states $(\theta_x, \theta_m, s, j)$ with default, $d(\theta_x, \theta_m, s, j) = 1$, the reversed inequality is satisfied. The condition (4.19) states that the household chooses to repay his debt whenever the expected discounted utility loss in the future, which arises due to exclusion form mortgage markets ensuing default, outweighs the current utility gain due to the forgiveness of mortgage debt when defaulting. If the opposite is true, the household decides to default.

The following proposition summarizes our findings about optimal household decisions:

Proposition 1. *Consumption expenditures on the standard good and housing services are proportional to each other, linear in current wealth, and increase in the individual portfolio return. Next-period wealth is linear in current wealth and increases in the individual portfolio return. Portfolio choices are independent of current portfolios and current wealth, but depend on next period's default decision rule. Default decisions are independent of wealth, but depend on portfolios.*

The proposition highlights the tractability of the model. Due to the separation of the consumption-savings decision from the portfolio choice and default decision, we just need to solve the latter problem numerically. In a nutshell, for given current portfolio θ and given mortgage price schedule (4.3), next period's optimal portfolio choice, θ'_{max}, and optimal default policy, d_{max}, are the solution to (4.18) and (4.19). Furthermore, the optimal portfolio choice of households in default $\theta'_{d,max}$ is independent of θ and p_m. For the consumption-savings problem, however, we use the analytical solution, that is, consumption policies (4.15) and (4.16) as well as savings policy (4.17).

Equilibrium

From now on, we focus on balanced growth path equilibria of the model economy. On a balanced growth path (BGP) all variables grow at constant rates. Suppose the economy grows at rate g which is endogenously determined in our model. Since the aggregate stock of housing is in fixed supply, on BGP the housing price $\tilde{p}_x$ grows at the growth rate of the economy.

To solve the model for a BGP equilibrium, it is useful to express the market clearing condition (4.5) in terms of stationary variables. For convenience, define $\tilde{w} = (1+tr)\cdot(1+r(\theta,d))\cdot w$ as cash at hand, that is, wealth after all assets have paid off and after transfer payments. Let $\tilde{W} = E[\tilde{w}] = \sum_i E[\tilde{w}|j=i]\pi(i)$ denote total cash at hand,[8] then the share of cash at hand owned by type z is

$$\Omega^z = \frac{E[\tilde{w}|j=z]\pi(z)}{\tilde{W}} = \frac{E[\tilde{w}|j=z]\pi(z)}{\sum_i E[\tilde{w}|j=i]\pi(i)} \tag{4.20}$$

where $E[\tilde{w}|j=z]$ is the average cash-at-hand level of type z. For later reference, let $\Omega = \{\Omega^i\}_i$ denote the wealth distribution of households and note that Ω is a finite-dimensional object. The market clearing condition (4.5) can be written as

$$\begin{aligned} \tilde{K} &= \frac{\sum_i \theta_k^i \cdot \Omega^i}{\sum_i \theta_h^i \cdot \Omega^i} \\ p_x &= (1+g)\cdot \sum_i \theta_x^i \cdot \Omega^i \\ p_l &= \nu \frac{1-\beta}{\beta}\cdot(1+g) \end{aligned} \tag{4.21}$$

where the last line uses the consumption policy for housing services (4.16). Now, define a stationary recursive competitive equilibrium in the usual manner:

Stationary recursive competitive equilibrium. *For given government policy $\bar{\tau}$, a stationary recursive competitive equilibrium is a vector of prices $(p_x, p_l, p_m(\ell), \tilde{r}_k, \tilde{r}_h)$, household value functions V, V_d, household policy functions $c_1, c_2, w', \theta, d, c_{d1}, c_{d2}, w'_d, \theta_d$,*

[8]Note that total cash at hand $\tilde{W}$ and aggregate wealth W are related by $W' = \frac{\beta}{1+\nu(1-\beta)}\cdot\tilde{W}$. Hence, on BGP total cash at hand and aggregate wealth grow at the same rate, g.

and a stationary distribution of households Ω*, such that*

1. *Utility maximization: the policy functions satisfy the household's problem (4.12) and (4.13), respectively;*

2. *Profit maximization: the aggregate capital-to-labor ratio* $\tilde{K}$ *satisfies the necessary and sufficient conditions for profit maximization (4.4);*

3. *Financial Intermediation: mortgage contracts are priced according to (4.3)*

4. *Market-clearing: condition (4.21) holds;*

5. *Policy: the government budget constraint (4.8) holds;*

6. *Consistency: the law of motion for aggregate wealth and the wealth distribution of households* Ω *are consistent with individual decisions.*

The stationary equilibrium is characterized in Appendix 4.A.3 where the stationary wealth distribution Ω and the equilibrium growth rate are derived. It turns out that the growth rate is proportional to a weighted average of individual portfolio returns

$$1 + g = \frac{\beta(1 + tr)}{1 + \nu(1 - \beta)} \sum_i E[1 + r(\theta^i, s, j)] \cdot \Omega^i \tag{4.22}$$

Last but not least, for calibration purposes it is useful to compute the equilibrium rent-price ratio

$$\frac{p_l}{p_x} = \nu \frac{1 - \beta}{\beta} \frac{1}{\sum_i \theta_x^i \cdot \Omega^i} \tag{4.23}$$

which only depends on the housing portfolio shares θ_x, the wealth distribution, and model parameters.

Finding a stationary equilibrium means finding the three numbers $\tilde{K}, p_x$ and g solving (4.22) and (4.21), where the corresponding portfolio choice θ is the solution to the household decision problem and mortgage rates are determined by the zero profit condition for the banking sector.

Default policy. In stationary equilibrium, the optimal default policy can be characterized in more detail. Recall that the current default decision $d(\theta_x, \theta_m, s, j)$ has to satisfy condition (4.19) for given next-period optimal portfolio choice θ'_{max} as well as next-period optimal default policy d'_{max}. In a stationary equilibrium, both the portfolio choice and the default decision are time invariant, or $\theta'_{max} = \theta_{max}$ and $d'_{max} = d_{max}$. In other words, we are looking for a fix point of condition (4.19).

Suppose now that house price shocks ϵ have continuous support on $[\epsilon_{min}, \epsilon_{max}]$, but human capital shocks η are discrete. Then, the optimal default policy d_{max} is a cut-off rule. For every given portfolio state θ and human capital shock η_k with $k = 1, ..., K$, there exists a cut-off value ϵ_c for the house price shock such that if the realization of the shock is ϵ_c the household is indifferent between defaulting and repaying his debt. For better realizations of the house price shock, the household decides to repay; for worse, he defaults. Since the optimal portfolio choices depend only on the household type j, there are K default cut-off values for every type. In sum, the optimal default policy d_{max} is given by

$$d(\epsilon, \eta_k, j) = \begin{cases} 0 & if \ \epsilon \geq \epsilon_{ckj} \\ 1 & otherwise \end{cases} \tag{4.24}$$

where the cut-off values ϵ_{ckj} are determined by the requirement that condition (4.19) has to hold with equality. That is, continuous house price shocks yield the following indifference condition

$$\begin{aligned}
& \beta\frac{1-\beta}{1+\nu}\sum_{j'}[\tilde{V}_0(j') - \tilde{V}_{0d}(j')]\pi(j'|j) \\
+ \quad & \beta\sum_{j'}\sum_{k'}\int_{\epsilon_{ckj}}^{\epsilon_{max}} \ln(1 + r(\theta'_{max}(j), \epsilon', \eta'_k, j', 0))\, d\pi(\epsilon)\pi_k\pi(j'|j) \\
+ \quad & \beta\sum_{j'}\sum_{k'}\int_{\epsilon_{min}}^{\epsilon_{ckj}} \ln(1 + r(\theta'_{max}(j), \epsilon', \eta'_k, j', 1))\, d\pi(\epsilon)\pi_k\pi(j'|j) \\
- \quad & \beta\sum_{j'}\sum_{k'}\ln(1 + r_d(\theta'_{d,max}(j), \eta'_k, j'))\pi_k\pi(j'|j)] \\
= \quad & \ln(1 + r(\theta, \epsilon_{ckj}, \eta_k, j, 1)) - \ln(1 + r(\theta, \epsilon_{ckj}, \eta_k, j, 0)) \qquad (4.25) \\
\approx \quad & r(\theta, \epsilon_{ckj}, \eta_k, j, 1) - r(\theta, \epsilon_{ckj}, \eta_k, j, 0) \\
= \quad & -[\theta_m\frac{1}{p_{m,-1}} + \theta_x\frac{(1+\epsilon_{cj})p_x + p_l}{p_{x,-1}}] \\
= \quad & -[m + ((1+\epsilon_{cj})\tilde{p}_x + \tilde{p}_l)x]/w
\end{aligned}$$

where the last three lines follow from a first-order Taylor approximation. Applying a first-order Taylor approximation, the gain from default is exactly the change in the portfolio return due to defaulting which is independent of the human capital shock η. Hence, the optimal default policy ϵ_{cj} does no longer depend on the labor shock.

For comparison, it is convenient to call the future utility loss due to exclusion – i.e. the left hand side of the indifference condition – $\Upsilon(\theta^j, \epsilon_{cj})$ and rearrange terms

$$\epsilon_{cj} = \frac{-m}{\tilde{p}_x x} - \left(1 + \frac{\tilde{p}_l}{\tilde{p}_x}\right) - \frac{w}{\tilde{p}_x x} \cdot \Upsilon(\theta^j, \epsilon_{cj}) \tag{4.26}$$

The first term of the default cut-off is the amount of forgiven mortgage debt per dollar of the housing asset. The second term represents the loss of the house and its rent due to foreclosure. The third term captures the future utility loss due to default: As default triggers exclusion from mortgage markets for some time, the defaulter's portfolio choice is restricted to human and physical capital. Hence, the defaulter's portfolio will earn a lower return which decreases his future consumption. While $\Upsilon(\theta^j, \epsilon_{cj})$ is the future utility loss per unit of wealth, the third term in ϵ_{cj} is the future utility loss per dollar of the housing asset. Note that our default policy nests the cut-off rule of Jeske, Krueger, and Mitman (2013) if $p = 0$. That is, if there is no exclusion from mortgage markets, households will walk away from their mortgage debt as soon as the house is under water. However, if default is punished by an exclusion from mortgage markets in the future, the cut-off level will be lower. This means that households are willing to suffer some losses today in order to maintain the opportunity to borrow in the future.

The following proposition characterizes the stationary recursive competitive equilibrium of the model economy:

Proposition 2. *The value functions (4.14), consumption policies (4.15) and (4.16), savings policy (4.17), portfolio choices (4.18), default policy (4.24) with default cut-off values* ϵ_{ckj} *determined by indifference condition (4.25) for* $\theta'_{max} = \theta_{max}$ *and* $d'_{max} = d_{max}$*, an aggregate growth rate (4.22), a stationary wealth distribution* Ω *determined as fix point of (4.47), as well as prices given by (4.3), (4.4), and (4.21) comprise the stationary recursive competitive equilibrium of the model economy.*

4.3 Quantitative Analysis

In this section, we study the quantitative effects of the Taxpayer Relief Act of 1997 on the U.S. economy. In addition, we consider a hypothetical tax reform that repeals the preferential tax treatment of housing capital gains. To this end, we solve the model economy numerically for a partial equilibrium in the housing market and simulate these two reforms. First, we lay out our calibration strategy. Then, we describe the tax reform experiments in more detail and discuss our findings.

4.3.1 Calibration

The model economy's balanced growth path is calibrated to match various stylized facts of the U.S. economy before the Taxpayer Relief Act of 1997 came into effect, that is, the pre-TRA97 period. In the following, we lay out our calibration strategy. We begin with parameters that are directly related to our targets and can be set immediately. Then, the remaining parameters are calibrated jointly by matching a set of targets. All parameters are listed in Table 4.1.

Demographics. Let's begin with the demographic structure of the model population. We calibrate the ageing process to the following age groups: young (18-40 years), middle-aged (40-60 years), and old (60-85 years). Besides, the share of middle-aged households with high human capital return (type $m1$) $\pi(m1|m)$ is set to match an average loan-to-value ratio of 50% for the middle-aged group, as in U.S. data.[9] Next, the probabilities of being a first-time buyer b_y, b_m are set to match the home-ownership rates of young (37.9% for households younger than age 35) and middle-aged households (75.4% for age 45-54) in the 1995 Survey of Consumer Finances (Kennickell, Starr-McCluer, and Sunden, 1997). Finally, the probability of leaving default $1 - p$ is calibrated to match an average duration of exclusion from mortgage markets of 10 years. This completes the calibration of exogenous type transition probabilities.

Taxation. Next, consider the tax system. The tax rate on capital gains from the sale of a home $\bar{\tau}$ is set to 25%. This matches the average marginal capital gains tax

[9]The 1995 Survey of Consumer Finances (Kennickell, Starr-McCluer, and Sunden, 1997) reports median values of asset holdings for families by age of head. We compute a loan-to-value ratios based on residential property of 50% for age groups both 45-54 and 55-64.

before TRA97 (Barro and Redlick, 2011). Furthermore, the probability of home sale ς is calibrated to match an mobility rate of 5%, as reported in the literature (Cunningham and Engelhardt, 2008; Shan, 2011). This implies an holding period of 20 years. Given that a capital gain from housing is only taxable if the house is downsized, the probability of a taxable home sale is 2.5% under this calibration.

Banks. Now we turn to the banking sector. There are two banking parameters to be calibrated: the cost of financial intermediation and the recovery rate at foreclosure. We follow Jeske, Krueger, and Mitman (2013) to calibrate the recovery rate at foreclosure γ to match an average loss in foreclosure $1-\gamma$ of 22%. Estimates for the cost of financial intermediation Δ vary considerably, ranging from 0.11% to 2.18% (Mehra, Piguillem, and Prescott, 2011; Mitman, 2012; Philippon, 2012). We choose an intermediate value of 1%.

Risk. Finally, the labor shock and the house price shock are to be calibrated. We choose the labor shock η to be normally distributed with zero mean and a standard deviation of 15% (see Krebs, 2003, and references therein). In our quantitative analysis, however, we consider a four-state approximation of the labor shock that is based on Gauss-Hermite quadrature. The individual house price shock ϵ is uniformly distributed with zero mean and a standard deviation of 20%.[10]

Having selected the parameters that are directly related to our targets, we now turn to the parameters which are calibrated jointly by solving the model and matching a set of model statistics with their data equivalents.

Preferences. First, consider the preference parameters. As usual, we calibrate the discount factor β to match the growth rate of the U.S. economy which is about 2% p.a. (Krebs, 2003). Next, we choose the utility weight of housing services consumption ν so that the model generates a rent-to-price ratio of 4.9% as calculated by Davis, Lehnert, and Martin (2008) for the aggregate stock of U.S. owner-occupied housing in 1997.

Finally, the disutility of being in default u_d can be used to calibrate the equilibrium foreclosure rate π_d as the indifference condition determining the default cutoff-level

[10] There are several estimates of the cross-sectional house price volatility in the literature (e.g. Campbell and Cocco, 2014; Corbae and Quintin, 2013; Glaeser, Gyourko, and Saiz, 2008; Zhou and Haurin, 2010), ranging from 15% to 22%.

Table 4.1: Calibration

Parameter	**Symbol**	**Value**	**Target**	**Value**	**Source**
Preferences					
utility weight of housing service	ν	0.1369	rent-to-price ratio	4.9%	Davis, Lehnert, and Martin (2008)
discount factor	β	0.9629	consumption growth rate	2%	Krebs (2003)
utility cost of being in default	u_d	0.0272	aggregate foreclosure rate	0.72%	Corbae and Quintin (2013)
gain fraction	Γ	0.25			
Technology					
depreciation rate	$\delta_h = \delta_h = \delta$	0.0713	mortgage-debt-to-GDP ratio	44%	NIPA, FOF
cost of financial intermediation	Δ	0.01		1%	literature: 0.11% - 2.18%
recovery rate at foreclosure	γ	0.78	average loss in foreclosure	22%	Jeske, Krueger, and Mitman (2013)
Institutions					
housing tax rate	$\bar{\tau}$	0.25	average marginal capital gains tax	25%	Barro and Redlick (2011)
Transition probabilities					
prob of leaving default	$1-p$	0.1	average duration of exclusion	10	
prob of home sale	ς	0.05	mobility rate	5%	Cunningham and Engelhardt (2008) Shan (2011)
prob of first-time buyer	b_y	0.0350	home-ownership rate of young	37.9%	SCF 1995, for age less 35
prob of first-time buyer	b_m	0.0792	home-ownership rate of middle-aged	75.4%	SCF 1995, for age 45-54
age transition probabilities	$\pi(j'\|j)$		average duration in group		age groups: 18-40; 40-60; 60-85
share of type m1	$\pi(m1\|m)$	0.5769	LTV of middle-aged	50%	SCF 1995, for age 45-54 & 55-64
Shocks					
std. dev. of labor shock	std(η)	15%		15%	Krebs (2003)
std. dev. of house price shock	std(ϵ)	20%		20%	literature: 15% - 22%

(4.25) suggests.[11] We follow Corbae and Quintin (2013) and target an aggregate annual foreclosure rate of 0.72%, computed as the population-weighted average of the default rates of all types holding mortgages. Our calibration implies a default rate of 1.75% for young households which is close to the U.S. foreclosure rate on subprime residential mortgages reported by the Federal Reserve Bank of Richmond (2011) for 1998.

Investment returns. Now, we turn to the calibration of the rental rates on physical and human capital. We aim at matching the portfolio choices by age-group, in particular the implied loan-to-value ratios. Our calibration strategy is as follows: first, consider households with high housing return, i.e. potential home-owners. For young households we target a loan-to-value ratio of 80% as computed from the 1995 Survey of Consumer Finances (Kennickell, Starr-McCluer, and Sunden, 1997) for households younger than age 35. In addition, we target a housing portfolio share of 22.5% which implies housing wealth of \$450'000 given total wealth of \$2'000'000. In sum, the portfolio target for young households is $\theta^y = (\theta^y_h, \theta^y_m, \theta^y_x, \theta^y_k) = (0.955, -0.18, 0.225, 0)$. To this end, we select the rental rates of human capital for young r^y_h and physical capital r_k which determines the mortgage rate appropriately.

The rental rate of human capital for middle-aged households with high human capital return r^{m1}_h is assumed to be the same as for young agents, while the corresponding rental rate for middle-aged with low human capital return r^{m2}_h is set to match a human capital portfolio share of 75% ($\theta^{m2}_h = 0.75$).

As we interpret old households as retired, their rental rate of human capital is set such that they do not invest in human capital, and, hence do not earn wage income. Besides, we assume old households are renters rather than home-owners. Consequently, they invest only in physical capital.[12]

Technology. Finally, we calibrate the depreciation rates as follows: we assume that the depreciation rates on physical and human capital are equal $\delta_k = \delta_h = \delta$. Then, we set δ such that the model economy matches the aggregate mortgage-debt-to-GDP ratio

[11] In the quantitative analysis, we assume that the household suffers also in the period he actually defaults and, hence, enjoys just a fraction of the current utility gain due to default. We capture this idea by introducing the factor Γ to the right hand side of (4.25). We set $\Gamma = 0.25$.

[12] This assumption is necessary to get a plausible physical-capital-to-GDP ratio. Otherwise there would not be enough physical capital in the economy. The reason is that in our calibrated model economy home-owners do not hold physical capital and renters mainly invest into human capital.

of 44% in 1997.[13]

4.3.2 Findings

The main quantitative experiment is to study the consequences of Taxpayer Relief Act of 1997 for the U.S. housing market. In addition, we simulate the effects of an hypothetical reform that would repeal the tax-breaks for owner-occupied housing and treat all capital gains in the same way.

The U.S. Tax Reform of 1997

In this section, we analyze the reform of housing-capital-gains taxation issued by the Taxpayer Relief Act of 1997. Before the 1997 reform capital gains from the sale of a primary residence were taxed as long as the taxpayer did not replace his residence by a more expensive one, rolling the capital gain over. Given a 20-years holding period of the home, the average taxable gain under our calibration amounts to ca. 50% which is taxed at the average marginal tax rate on capital gains of 25%. This implies an expected annual tax payment of 0.3% of individual housing wealth. Nowadays, capital gains from the sale of owner-occupied housing are de facto tax-exempt due to the TRA97.

The experiment. We mimic this reform by setting the tax rate for capital gains from housing $\bar{\tau}$ to zero. According to our calibration, the Taxpayer Relief Act of 1997 means, on average, a tax relief of 0.3% of individual housing wealth per year. We simulate this reform by computing the balanced growth path equilibrium of the post-reform model economy ($\bar{\tau} = 0$). This way, the computational experiment allows us to isolate the effects of the TRA97 from other factors that simultaneously impacted the U.S. economy during the post-TRA97 period. Comparing this simulated post-reform economy to the actual performance of the U.S. economy sheds light on the role the Taxpayer Relief Act of 1997 has played for the recent housing boom. In particular, this comparison allows us to quantify the fraction of the observed increase in U.S. house prices that can – according to the model – be attributed to the TRA97.

[13] We compute the aggregate mortgage-debt-to-GDP ratio from NIPA and FOF data by dividing home mortgage debt of the household sector by GDP.

Table 4.2: TRA97 reform: portfolios by household type

	pre-TRA97				**post-TRA97, endo. default**			
	young	middle1	middle2	old	young	middle1	middle2	old
Human Capital	95.5	92.4	75.0	0.0	95.2	92.3	75.5	0.0
Mortgage	-18.0	-21.4	-5.4	0.0	-20.3	22.7	-6.6	0.0
Housing	22.5	29.0	30.4	0.0	25.1	30.4	31.1	0.0
Phys. Capital	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
LTV Ratio	80.0	73.9	17.9	0.0	81.0	74.7	21.1	0.0
Default Rate	1.75	0.28	0.00	0.00	1.41	0.13	0.00	0.00

in per cent.
This table reports the portfolios of high-housing-return types, not in default. The corresponding portfolios for households in default consist of 100% human capital.

Effects on household behavior. Before discussing aggregate effects of the Taxpayer Relief Act, we inspect how individual households react to the tax-cut. We focus on household portfolios and their default decisions. Table 4.2 displays the results. As already mentioned, the TRA97 tax-cut implies an increase in the after-tax housing return by 31 basis points, holding all else equal. Consequently, investors adjust their portfolios. They take on additional mortgage debt in order to increase their housing portfolio share. Besides, young and middle-aged households with high human capital return (type $m1$) slightly shift resources from human capital into housing. As a result, their loan-to-value ratio increases. Middle-aged investors with low human capital return (type $m2$), in contrast, increase both their housing and their human capital share.

This suggests that the TRA97 reform has two counteracting effects: firstly, by increasing the after-tax return the tax-cut leads to a portfolio shift towards housing. Secondly, by abolishing the dependency of the housing tax on the human capital state the TRA97 reform induces more risk-taking. The reason is that before 1997 the roll-over rule implied that capital gains from housing were only taxed when the house was downsized. Downsizing, in turn, happens when negative human capital shocks hit the household. In this view, the pre-reform tax code had the opposite effects of an insurance. When abolishing this tax schedule, the middle-aged investor of type 2 reduces, consequently, his position in risk-free assets by increasing mortgage debt and shifts funds into human capital and housing which are risky. Young and middle-aged investors of type 1, however, do not have the opportunity to sell risk-free assets as neither they hold physical capital nor mortgage debt is save for them, given their positive default rate.

Table 4.3: TRA97 reform: key statistics for the U.S. and model economies

	U.S. Economy		**Model: TRA97 reform**				
				exo. default		**endo. default**	
Statistic	1997	Δ_{1997}^{2007}	pre	post	Δ	post	Δ
Housing Tax Rate	25.0%[a]	-100%	25.0%[T]	0.0%	-100.0%	0.0%	-100.0%
House Price	100	+55%	0.1052	0.1113	+5.8%	0.1119	+6.4%
Rent-to-Price Ratio	4.9%[b]	-27%	4.9%[T]	4.63%	-5.5%	4.60%	-6.1%
Mortgage Debt/GDP	44.0%	+67%	44.0%[T]	49.4%	+12.3%	-49.0%	+11.3%
Housing Wealth/GDP	78.8%	+32%	79.1%	83.5%	+5.6%	84.1%	+6.3%
Loan-to-Value Ratio	55.8%	+26%	55.7%	59.2%	+6.4%	58.2%	+4.6%
Physical Capital/GDP			2.12	2.11	-0.3%	2.11	-0.3%
Growth Rate			2.00%[T]	1.98%	-1.0%	1.98%	-1.1%
Default Rate	0.72%[c]		0.72%[T]	0.72%	0.0%	0.55%	-23.8%

[a] Barro and Redlick (2011)
[b] Davis, Lehnert, and Martin (2008)
[c] Corbae and Quintin (2013)
[T] Target

In fact, young and middle-aged investors of type 1 would have adjusted their portfolio in the same direction, if default rates had remained unchanged. However, default rates decreased by 34 and 15 basis points for young and middle-aged investors of type 1, respectively. Lower default rates, in turn, reduce the risk premium competitive banks charge to cover their losses in foreclosure and, hence, mortgage rates. This means that households are willing to accept higher losses on their houses for a reduction in their mortgage rate. In contrast, if default rates had remained unchanged, mortgage rates would have increased due to the collateral channel. That is, higher loan-to-value ratios imply less collateral per unit of mortgage and, hence, higher losses in foreclosure. A decline in default rates, however, reduces mortgage rates and makes leverage less desirable. This way, endogenous mortgage default dampens the effects of the TRA97 reform on individual portfolios. Besides, for higher levered portfolios, the exclusion from mortgage markets ensuing default is more costly.

Aggregate effects. Now we turn to our evaluation of Taxpayer Relief Act of 1997. We analyze the effects of the tax reform on the U.S. macroeconomy and, in particular, the U.S. housing market. Table 4.3 reports the main results: we find that house prices increase by 6.4% due the TRA97 in our model, while the rent-to-price ratio declines by 30 basis points, or 6.1%. As a consequence, in equilibrium the expected after-tax housing return hardly changes. Furthermore, the mortgage-debt-to-GDP ratio increases by 11.3% and the aggregate loan-to-value ratio by 4.6%. Compared to the actual U.S.

data for the period 1997 to 2007, our computational experiment accounts for more than one ninth of the observed increase in U.S. house prices of 55%. At the same time, almost a quarter of the observed decline in the aggregate rent-to-price ratio as well as a bit more than one sixth of the rise in both the aggregate loan-to-value ratio and mortgage-debt-to-GDP ratio can be attributed to the TRA97 reform. In a nutshell, our quantitative analysis suggests that Taxpayer Relief Act of 1997 made some important contributions to developments in the U.S. housing market during subsequent decade that culminated in a boom-bust-cycle.

Discussion. Microeconometric evaluations of the Taxpayer Relief Act of 1997 find that residential mobility rates increased by 19% to 31% among affected homeowners (Cunningham and Engelhardt, 2008; Shan, 2011). They argue that homeowners who wanted to buy a less expensive house felt ”locked-in” before 1997 and the TRA97 enabled them to sell their homes without paying capital-gains taxes. Biehl and Hoyt (2014) provide evidence supporting this view: after 1997, home sellers were 6.6% less likely to move for a larger home and 6.2% more likely to move for a house that is cheaper to maintain. Finally, a recent study by Heuson and Painter (2014) does not only confirm the previous findings for affected homeowners. Rather, they find that housing turnover increased for all age groups and independently of whether homeowners traded up or down. Their time-series of aggregate housing turnover shows an increasing trend since the passage of the TRA97. By 2005, the peak, the turnover rate increased by almost two thirds, compared to 1997.

Clearly, our stylized way of modeling home sales abstracts from such considerations. Rather, by calibrating the sales probability to pre-TRA97 residential mobility rates we neglect locked-in households. Therefore, the current experiment may understate the share of households benefitting from the Taxpayer Relief Act.

Repeal of Housing Tax-breaks

In addition to the TRA97 reform, we study the effects of an hypothetical reform that would repeal the tax-breaks for capital gains from owner-occupied housing. Rather, these capital gains would be treated in exactly the same way as other capital gains. This counterfactual experiment serves as a natural benchmark case.

Table 4.4: Repeal of housing tax-breaks: key statistics for the U.S. and model economies

	U.S. Economy		**Model: repeal of housing tax-breaks**				
				exo. default		**endo. default**	
Statistic	1997	Δ_{1997}^{2007}	pre	post	Δ	post	Δ
Housing Tax Rate	25.0%[a]	-100%	25.0%[T]	25.0%	0.0%	25.0%	0.0%
House Price	100	+55%	0.1052	0.1006	-4.3%	0.1008	-4.1%
Rent-to-Price Ratio	4.9%[b]	-27%	4.9%[T]	5.12%	+4.5%	5.11%	4.3%
Mortgage Debt/GDP	44.0%	+67%	44.0%[T]	41.7%	-5.1%	-41.5%	-5.8%
Housing Wealth/GDP	78.8%	+32%	79.1%	75.6%	-4.4%	75.8%	-4.1%
Loan-to-Value Ratio	55.8%	+26%	55.7%	55.2%	-0.8%	54.7%	-1.7%
Physical Capital/GDP			2.12	2.12	0.0%	2.12	0.0%
Growth Rate			2.00%[T]	1.99%	-0.7%	1.99%	-0.7%
Default Rate	0.72%[c]		0.72%[T]	0.72%	0.0%	0.66%	-8.9%

[a] Barro and Redlick (2011)
[b] Davis, Lehnert, and Martin (2008)
[c] Corbae and Quintin (2013)
[T] Target

We implement this hypothetical reform by assuming that the tax function (4.6) is applied independently of the human capital shock, i.e. for every realization of η. While the tax rate $\bar{\tau}$ remains at 25% as in the pre-TRA97 economy, now every home sale would be taxable, even when the home is replaced by a more expensive one. Hence, the probability of a taxable home sale is now 5%, compared to 2.5% during the pre-reform period. This implies that the expected annual tax payment doubles to approximately 0.6% of individual housing wealth. Nevertheless, this hypothetical reform abolishes the anti-insurance character of the pre-1997 tax code, as the TRA97 did. However, by increasing the capital gains tax on housing, this reform would not nourish a housing boom. Rather, it could have mitigated the recent developments in the housing market.

Aggregate effects. On the aggregate level, such a repeal of the housing tax-breaks makes housing investments less attractive. Indeed, the proposed reform would reduce the expected after-tax return on housing by approximately 30 basis points, all else equal. As a result households reduce their housing portfolio shares, pay back some mortgage debt, and de-lever. Since housing demand goes down, the equilibrium house price falls by 4.1% so that the rent-to-price ratio increases by 21 basis points. Hence, in equilibrium the expected after-tax housing return declines by only ca. 0.1%. Furthermore, aggregate housing wealth, relative to GDP, declines by 4.1%. The mortgage-debt-to-GDP ratio shrinks even stronger – to be precise: by 5.8% – so that the aggregate loan-to-value ratio declines by 1.7%. Default rates decline, too.

In sum, the computational experiment shows that a repeal of the housing tax-breaks has stabilizing effects on the economy by bringing down mortgage debt and leverage. In particular, the repeal of tax-breaks would have counteracted the house price boom during the 2000s. Altogether, implementing instead of the TRA97 a tax reform that treats capital gains on home sales as ordinary capital gains would have dampened the observed rise in house prices by about 20 percent.

4.A Model Appendix

4.A.1 Demographic Structure

The population consists of three age groups $\{y, m, o\}$ and two housing-return groups $\{L, H\}$. Furthermore, for middle-aged households there are two human-capital-return groups $\{1, 2\}$. Combining the these groups with the solvency state, i.e. in default (d) / not in default (n), gives 12 types:[14]

- young, not in default, high housing return: ynH
- young, in default, high housing return: ydH
- young, not in default low housing return: ynL
- middle-aged 1, not in default, high housing return: m1dH
- middle-aged 1, in default, high housing return: m1dH
- middle-aged 1, not in default low housing return: m1nL
- middle-aged 2, not in default, high housing return: m2nH
- middle-aged 2, in default, high housing return: m2dH
- middle-aged 2, not in default low housing return: m2nL
- old, not in default, high housing return: onH
- old, in default, high housing return: odH
- old, not in default, low housing return: onL

Let Π^J denote the age transition matrix with typical transition probability $\pi_{a,b} = \pi(j' = b|j = a),\ a, b \in \{y, m1, m2, o\}$. Note that the transition from old to young is understood

[14]Note that according to this type classification the groups ynH and m1nH consist of both agents that decide to pay off their mortgage debt and those that decide to default.

as death of old agents and birth of young agents. Given these age transitions, the exogenous probability of being a first-time home buyer b_j, the endogenous default probabilities π_j^d , and the exogenous probability of re-entering mortgage markets after default $(1-p)$, type transitions are determined. The resulting type transition matrix is

$$\Pi^T = \begin{bmatrix} \Pi^T_{yy} & \Pi^T_{m1y} & \Pi^T_{m2y} & 0 \\ 0 & \Pi^T_{m1m1} & 0 & \Pi^T_{om1} \\ 0 & 0 & \Pi^T_{m2m2} & \Pi^T_{om2} \\ \Pi^T_{nb} & 0 & 0 & \Pi^T_{oo} \end{bmatrix} \tag{4.27}$$

with

$$\Pi^T_{yy} = \begin{bmatrix} (1-\pi^d_y)\pi(y|y) & \pi^d_y\pi(y|y) & 0 \\ (1-p)\pi(y|y) & p\pi(y|y) & 0 \\ b_y\pi(y|y) & 0 & (1-b_y)\pi(y|y) \end{bmatrix} \tag{4.28}$$

$$\Pi^T_{m1y} = \begin{bmatrix} (1-\pi^d_y)\pi(m1|y) & \pi^d_y\pi(m1|y) & 0 \\ (1-p)\pi(m1|y) & p\pi(m1|y) & 0 \\ b_y\pi(m1|y) & 0 & (1-b_y)\pi(m1|y) \end{bmatrix} \tag{4.29}$$

$$\Pi^T_{m2y} = \begin{bmatrix} (1-\pi^d_y)\pi(m2|y) & \pi^d_y\pi(m2|y) & 0 \\ (1-p)\pi(m2|y) & p\pi(m2|y) & 0 \\ b_y\pi(m2|y) & 0 & (1-b_y)\pi(m2|y) \end{bmatrix} \tag{4.30}$$

$$\Pi^T_{m1m1} = \begin{bmatrix} (1-\pi^d_{m1})\pi(m1|m1) & \pi^d_{m1}\pi(m1|m1) & 0 \\ (1-p)\pi(m1|m1) & p\pi(m1|m1) & 0 \\ b_m\pi(m1|m1) & 0 & (1-b_m)\pi(m1|m1) \end{bmatrix} \tag{4.31}$$

$$\Pi^T_{om1} = \begin{bmatrix} (1-\pi^d_{m1})\pi(o|m1) & \pi^d_{m1}\pi(m1|m1) & 0 \\ (1-p)\pi(o|m1) & p\pi(o|m1) & 0 \\ b_m\pi(o|m1) & 0 & (1-b_m)\pi(o|m1) \end{bmatrix} \tag{4.32}$$

$$\Pi^T_{m2m2} = \begin{bmatrix} \pi(m2|m2) & 0 & 0 \\ (1-p)\pi(m2|m2) & p\pi(m2|m2) & 0 \\ b_m\pi(m2|m2) & 0 & (1-b_m)\pi(m2|m2) \end{bmatrix} \tag{4.33}$$

$$\Pi^T_{om2} = \begin{bmatrix} \pi(o|m2) & 0 & 0 \\ (1-p)\pi(o|m2) & p\pi(o|m2) & 0 \\ b_m\pi(o|m2) & 0 & (1-b_m)\pi(o|m2) \end{bmatrix} \tag{4.34}$$

$$\Pi^T_{oo} = \begin{bmatrix} \pi(o|o) & 0 & 0 \\ (1-p)\pi(o|o) & p\pi(o|o) & 0 \\ b_o\pi(o|o) & 0 & (1-b_o)\pi(o|o) \end{bmatrix} \tag{4.35}$$

$$\Pi^T_{nb} = \begin{bmatrix} b_{nb}\pi(y|o) & 0 & (1-b_{nb})\pi(y|o) \\ b_{nb}\pi(y|o) & 0 & (1-b_{nb})\pi(y|o) \\ b_{nb}\pi(y|o) & 0 & (1-b_{nb})\pi(y|o) \end{bmatrix} \tag{4.36}$$

where b_{nb} is the probability that a newborn is of the high-housing-return type. However, in the following we assume that newborns do not inherit houses, i.e. $b_{nb} = 0$. In addition, old agents cannot be first-time buyers, i.e. $b_o = 0$.

Obviously, the demographic structure of the population evolves according to the law of motion

$$\pi^T_{t+1} = \Pi^T \cdot \pi^T_t \tag{4.37}$$

where π^T denotes the vector of population shares $\pi(j)$. The stationary type distribution is the fix point to this law of motion (4.37).

4.A.2 Solution to the Bellman equation

We solve the Bellman equations of the households decision problem (4.12) by the guess-and-verify method. Our guess is

$$\begin{aligned} V(w,\theta,s,j,W) &= \tilde{V}_0(j)+\tilde{V}_1\ln\left(1+r(\theta,s,j,d(s,j))\right)+\tilde{V}_2\ln w+\tilde{V}_3\ln W \\ V_d(w,\theta_d,s,j,W) &= \tilde{V}_{0d}(j)+\tilde{V}_{1d}\ln\left(1+r_d(\theta_d,s,j)\right)+\tilde{V}_{2d}\ln w+\tilde{V}_{3d}\ln W \\ c_1 &= \tilde{c}\left(1+r(\theta,s,j,d(s,j))\right)(1+tr)w \\ c_{d1} &= \tilde{c}_d\left(1+r_d(\theta_d,s,j)\right)(1+tr)w \end{aligned} \tag{4.38}$$

Substituting this guess into the Bellman equation yields

$$\begin{aligned} &\tilde{V}_0(j)+\tilde{V}_1\ln\left(1+r(\theta,s,j,d(s,j))\right)+\tilde{V}_2\ln w+\tilde{V}_3\ln W \;= \\ \max\quad &\Big\{\nu\ln\left(\nu/p_l\right)+\nu\ln W+\max_{\tilde{c}}\Big[(1+\nu)\ln\tilde{c}+\beta\tilde{V}_2\ln(1-(1+\nu)\tilde{c})\Big] \\ &+\beta\sum_{j'}\tilde{V}_0(j')\pi(j'|j)+\beta\tilde{V}_1\max_{\theta'}\sum_{j'}\sum_{s'}\ln\left(1+r(\theta',s',j',d(s',j'))\right)\pi(s')\pi(j'|j) \\ &+(1+\nu+\beta\tilde{V}_2)\ln\left(1+r(\theta,s,j,0)\right)\;+\;(1+\nu+\beta\tilde{V}_2)\ln w\;+\;(1+\nu+\beta\tilde{V}_2)\ln(1+tr) \\ &+\beta\tilde{V}_3\ln\left((1+g)W\right)\Big\}\;; \\ &\Big\{\nu\ln\left(\nu/p_l\right)+\nu\ln W+\max_{\tilde{c}}\Big[(1+\nu)\ln\tilde{c}+\beta\tilde{V}_{2d}\ln(1-(1+\nu)\tilde{c})\Big] \\ &+\beta\sum_{j'}\tilde{V}_{0d}(j')\pi(j'|j)+\beta\tilde{V}_{1d}\max_{\theta'_d}\sum_{j'}\sum_{s'}\ln\left(1+r_d(\theta'_d,s',j')\right)\pi(s')\pi(j'|j) \\ &+(1+\nu+\beta\tilde{V}_{2d})\ln\left(1+r(\theta,s,j,1)\right)\;+\;(1+\nu+\beta\tilde{V}_{2d})\ln w\;+\;(1+\nu+\beta\tilde{V}_{2d})\ln(1+tr) \\ &+\tilde{V}_{3d}\ln\left((1+g)W\right)\Big\}\Big\} \end{aligned}$$

and

$$\begin{aligned} &\tilde{V}_{0d}(j)+\tilde{V}_{1d}\ln\left(1+r_d(\theta,s,j)\right)+\tilde{V}_{2d}\ln w+\tilde{V}_{3d}\ln W \;= \\ &\nu\ln\left(\nu/p_l\right)+\nu\ln W\;-\;u_d\;+\;\max_{\tilde{c}_d}\Big[(1+\nu)\ln\tilde{c}_d+\beta\left(p\tilde{V}_{2d}+(1-p)\tilde{V}_2\right)\ln(1-(1+\nu)\tilde{c}_d)\Big] \\ +\quad &\beta p\sum_{j'}\tilde{V}_{0d}(j')\pi(j'|j)+\beta(1-p)\sum_{j'}\tilde{V}_0(j')\pi(j'|j) \\ +\quad &\beta\left(p\tilde{V}_{1d}+(1-p)\tilde{V}_1\right)\max_{\theta'_d}\sum_{j'}\sum_{s'}\ln\left(1+r_d(\theta'_d,s',j')\right)\pi(s')\pi(j'|j) \\ +\quad &\Big[1+\nu+\beta\left(p\tilde{V}_{2d}+(1-p)\tilde{V}_2\right)\Big]\ln\left(1+r_d(\theta,s,j)\right) \\ +\quad &\Big[1+\nu+\beta\left(p\tilde{V}_{2d}+(1-p)\tilde{V}_2\right)\Big]\ln w\;+\;\Big[1+\nu+\beta\left(p\tilde{V}_{2d}+(1-p)\tilde{V}_2\right)\Big]\ln(1+tr) \\ +\quad &\beta\left(p\tilde{V}_{3d}+(1-p)\tilde{V}_3\right)\ln\left((1+g)W\right) \end{aligned}$$

The guess works for

$$\tilde{V}_1 = \tilde{V}_2 = \tilde{V}_{1d} = \tilde{V}_{2d} = \frac{1+\nu}{1-\beta}$$

$$\tilde{V}_3 = \tilde{V}_{3d} = \frac{\nu}{1-\beta}$$

$$\tilde{c} = \tilde{c}_d = \frac{1-\beta}{1+\nu(1-\beta)}$$

and $\tilde{V}_{0d}$ and $\tilde{V}_0$ given by

$$\tilde{V}_0(j) = A + \beta \cdot \max\left\{ \sum_{j'} \tilde{V}_0(j')\pi(j'|j) + B(j) \; ; \; \sum_{j'} \tilde{V}_{0d}(j')\pi(j'|j) + B_d(j) \right\} \tag{4.39}$$

$$\tilde{V}_{0d}(j) = A - u_d + \beta \left(p \sum_{j'} \tilde{V}_{0d}(j')\pi(j'|j) + (1-p) \sum_{j'} \tilde{V}_0(j')\pi(j'|j) + \frac{B_d(j)}{(1-\beta p)} \right) \tag{4.40}$$

where

$$\begin{aligned}
A &= \nu \ln(\nu/p_l) + \beta \ln(1+g) + (1+\nu)\ln(1-\beta) \\
&+ \frac{1+\nu}{1-\beta}\left[\beta \ln \beta - \ln(1+\nu(1-\beta)) + \ln(1+tr)\right] \\
B(j) &= \frac{1+\nu}{1-\beta} \sum_{j'} \sum_{s'} \ln\left(1 + r(\theta'_{max}(j), s', j', d(s',j'))\right) \pi(s')\pi(j'|j) \qquad (4.41) \\
B_d(j) &= \frac{1+\nu}{1-\beta} \sum_{j'} \sum_{s'} \ln\left(1 + r_d(\theta'_{max,d}(j), s', j')\right) \pi(s')\pi(j'|j)
\end{aligned}$$

and θ'_{max} and $\theta'_{d,max}$ denote the optimal portfolio choices for next period and d the optimal default decision rule.

Note that $B(j) \geq B_d(j)$ as $r(\theta'_{max}(j), s', j', d(s',j') \geq r_d(\theta'_{max,d}(j), s', j')$ and suppose $\tilde{V}_0(j) \geq \tilde{V}_{0d}(j)$ for all j. Then $\tilde{V}_0(j) = A + \beta \cdot B(j)$. Denote $\tilde{\mathbf{V}}_0 = [\tilde{V}_0(y)\ \tilde{V}_0(m)\ \tilde{V}_0(o)]'$, $\tilde{\mathbf{V}}_{0d} = [\tilde{V}_{0d}(y)\ \tilde{V}_{0d}(m)\ \tilde{V}_{0d}(o)]'$, $\mathbf{B} = [B(y)\ B(m)\ B(o)]'$, $\mathbf{B_d} = [B_d(y)\ B_d(m)\ B_d(o)]'$, and Π the age-type transition matrix. Then equations (4.39) and (4.40) can be written in matrix notation as:

$$\tilde{\mathbf{V}}_0 = (I - \beta\Pi)^{-1}[A + \mathbf{B}] \tag{4.42}$$

$$\tilde{\mathbf{V}}_{0d} = (I - \beta p\Pi)^{-1}[A - u_d + \mathbf{B}_d + \beta(1-p)\tilde{\mathbf{V}}_0] \tag{4.43}$$

In other words, one has to solve a linear equation system to compute the constant terms of the value function $\tilde{V}_0(j), \tilde{V}_{0d}(j)$.

Default decision. Having substituted our solutions for the value function and the policy function into the Bellman equation that describes the decision problem of a household that is not in default (4.12), we can now solve the maximum operator for the default decision. Recall that the default policy function $d = d(\theta_x, \theta_m, s, j)$ maps the current state into a default decision $\{0, 1\}$ where 1 denotes default. Simplifying terms we get

$$\begin{aligned}
& \frac{1+\nu}{1-\beta}\ln(1+r(\theta,s,j,0)) + \beta\sum_{j'}\tilde{V}_0(j')\pi(j'|j) \\
& +\frac{\beta(1+\nu)}{1-\beta}\sum_{j'}\sum_{s'}\ln(1+r(\theta_{max}(j),s',j',d_{max}(s',j')))\pi(s')\pi(j'|j) \\
\geq \quad & \frac{1+\nu}{1-\beta}\ln(1+r(\theta,s,j,1)) + \beta\sum_{j'}\tilde{V}_{0d}(j')\pi(j'|j) \\
& +\frac{\beta(1+\nu)}{1-\beta}\sum_{j'}\sum_{s'}\ln(1+r_d(\theta_{d,max}(j),s',j'))\pi(s')\pi(j'|j)
\end{aligned} \tag{4.44}$$

which has to hold for all states $(\theta_x, \theta_m, s, j)$ with $d(\theta_x, \theta_m, s, j) = 0$. And the reverse is true for all states $(\theta_x, \theta_m, s, j)$ with $d(\theta_x, \theta_m, s, j) = 1$. Rearranging terms, we get an easy-to-interpret condition that is stated in the main text, equation (4.19).

4.A.3 Characterization of the Stationary Equilibrium

The growth rate of the economy is determined as a weighted average of individual portfolio returns by the aggregation of individual wealth. First, recall that on BGP aggregate cash at hand $\tilde{W}$ and aggregate wealth W grow at the same rate g because of $W' = \frac{\beta}{1+\nu(1-\beta)} \cdot \tilde{W}$. Next, note that the law of motion for individual wealth (4.17), expressed in terms of cash at hand, reads as

$$\tilde{w}' = \frac{\beta}{1+\nu(1-\beta)} \cdot (1+tr') \cdot (1+r(\theta', d')) \cdot \tilde{w} \tag{4.45}$$

Finally, aggregation yields the growth rate

$$1+g = \frac{\beta(1+tr)}{1+\nu(1-\beta)} \sum_i E[1+r(\theta^i, s, j)] \cdot \Omega^i \tag{4.46}$$

Next, turn to the law of motion for the wealth distribution. The individual wealth share of type z, Ω^z, evolves according to

$$\begin{aligned}\Omega^{z\prime} &= \frac{E[\tilde{w}'|j'=z]\pi(z)}{\sum_i E[\tilde{w}'|j'=i]\pi(i)} \\ &= \frac{\sum_i E[(1+tr')\cdot(1+r(\theta^{i\prime},d'))\cdot\tilde{w}|j=i]\cdot\pi(z|i)\cdot\pi(i)}{\sum_m\sum_i E[(1+tr')\cdot(1+r(\theta^{i\prime},d'))\cdot\tilde{w}|j=i]\cdot\pi(m|i)\cdot\pi(i)} \\ &= \frac{\sum_i E[1+r(\theta^{i\prime},d')|j'=z]\cdot E[\tilde{w}|j=i]\cdot\pi(z|i)\cdot\pi(i)}{\sum_m\sum_i E[1+r(\theta^{i\prime},d')|j'=m]\cdot E[\tilde{w}|j=i]\cdot\pi(m|i)\cdot\pi(i)} \\ &= \frac{\sum_i E[1+r(\theta^{i\prime},d')|j'=z]\cdot\Omega^i\cdot\pi(z|i)}{\sum_m\sum_i E[1+r(\theta^{i\prime},d')|j'=m]\cdot\Omega^i\cdot\pi(m|i)\cdot}\end{aligned} \tag{4.47}$$

where the second line applies the equilibrium law of motion for individual cash at hand and the law of iterated expectations, the third line follows from the fact that portfolio choices are independent of wealth, and the last one simply uses the definition of Ω^z. The stationary wealth distribution Ω is determined as fix point of the law of motion (4.47).

4.B A brief History of the U.S. Law of Taxation

4.B.1 Personal Income Taxation

The U.S. federal government introduced personal income taxation in 1913. At that time the basic structure of the current federal income tax system was developed. Firstly, taxable income – the tax base – is defined, and secondly tax liabilities are computed by applying a tax schedule to taxable income (Slemrod and Bakija, 1999). The Internal Revenue Code of 1954, for example, defines taxable income as *"all income from whatever source derived"* minus allowable deductions minus personal exemptions and imposes a progressive tax schedule consisting of 24 brackets (for details see Sunley and Stotsky, 2005). In the following the major reforms since the 1970s are sketched:

- the Revenue Act of 1978 was a first step to simplify the income tax system: It reduced the number of tax brackets from 26 to 16, thereby lowering personal income taxes, and increased both the personal exemption and the standard deduction.

- the Economic Recovery Tax Act of 1981 gradually cut ordinary tax rates over 3 years and introduced inflation indexation of tax brackets in 1984.

- the Tax Reform Act of 1986 changed federal income taxation substantially: it broadened the tax base by cutting back preferences and exemptions, reduced the number of brackets to 5, and lowered ordinary tax rates.

- During the 1990s top marginal personal income tax rates were increased several times. However, the Taxpayer Relief Act of 1997 reduced capital gains tax rates and introduced a more favorable exemption for capital gains on home sales (see below).

- the Economic Growth and Tax Relief Reconciliation Act of 2001 created a new bottom rate of 10% and phased-in a lowering of the whole income tax schedule.

Figure 4.4 shows the development of the income tax burden, as measured by the source-of-income weighted average marginal tax rate (see Barro and Redlick, 2011), over time. The federal income tax time series reflects the Reagan tax cuts, the subsequent increase under Bush senior and Clinton, as well as Bush junior's tax relief. Detailed changes in the U.S. federal ordinary income tax schedule, in particular tax brackets and marginal rates, can be studied from Center for Federal Tax Policy (2011).

4.B.2 Capital Gains Taxation

U.S. federal income tax code distinguishes two types of realized capital gains depending on the holding period of the corresponding capital asset: short-term capital gains and long-term capital gains. While the former are subject to ordinary income taxation, long-term capital gains have generally been taxed at lower rates during the post-war period (Break, 1999).[15] The holding period required to classify as long-term was 6 month before 1977 and has been increased to 1 year for most of the following years.[16]

According to the Internal Revenue Code of 1954, only 50% of long-term capital gains where recognized for computing adjusted gross income (Esenwein, 2006; Office of

[15]The only exception in the post-war period were the years 1987 to 1990 (Break, 1999).
[16]Esenwein (2006) reports a time-series with holdings period for long-term capital gains treatment.

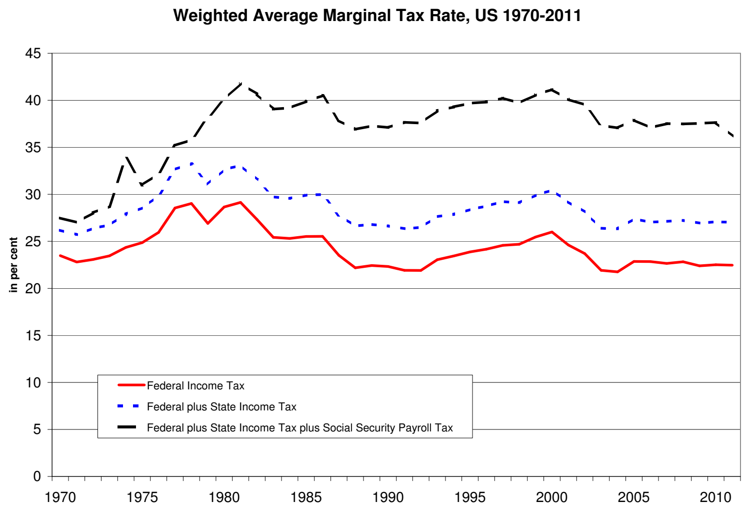

Figure 4.4: Average Marginal Income Tax Rate
SOURCE: Barro and Redlick (2011), updated data:
http://users.nber.org/~taxsim/marginal-tax-rates/index.html

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the Secretary of the Treasury and Office of Tax Analysis, 1985). Hence, because of this exclusion, the effective tax rates applied to long-term capital gains were 50% of the ordinary rates. The 1978 Revenue Act lowered the capital gains tax by increasing the exclusion rate to 60%. However, the Tax Reform Act of 1986 repealed the exclusion of long-term capital gains and thereby increased capital gains rates (Auten, 2005; Esenwein, 2006). Till 1990 long-term capital gains were treated like ordinary income. Then the Revenue Reconciliation Act of 1990 established a maximum tax rate on long-term capital gains of 28% which was reduced to 20% by the Taxpayer Relief Act of 1997. Further reductions in the tax schedule were implemented by the Jobs and Growth Tax Relief Reconciliation Act of 2003 lowering the top marginal rate to 15%. Recent changes in the capital gains tax schedule are reported in Center for Federal Tax Policy (2010).

Figure 4.5 shows the statutory top marginal capital gains tax together with two series of weighted average marginal capital gains tax rates. Evidently, the link between statutory top marginal tax rates and average marginal taxes changed due to the Tax Reform Act of 1986: while during the 1970s statutory top rates were considerable higher than the marginal rate of an average taxpayer, the Reagan reforms led to a

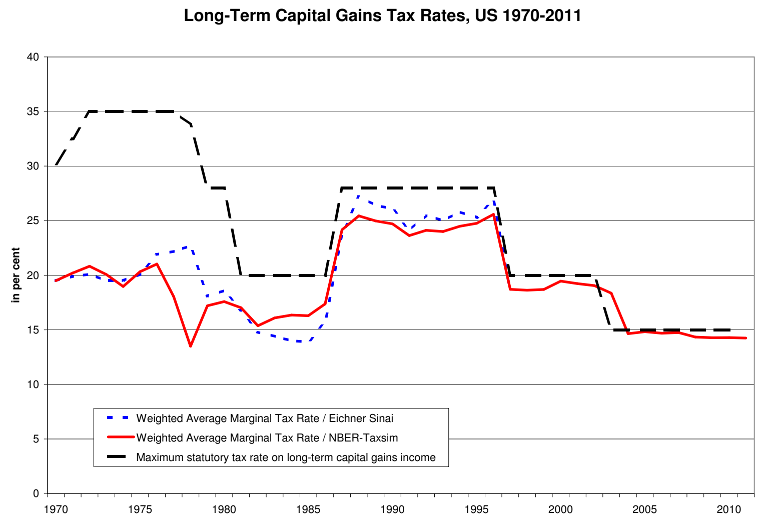

Figure 4.5: Federal Capital Gains Tax Rate
SOURCE: NBER Taxsim; Eichner and Sinai (2000); Esenwein (2006)

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stronger comovement of top and average marginal rates. In particular, by reducing the number of tax brackets, the 1986 tax increase significantly affected the average taxpayer: the weighted average marginal capital gains tax was hiked up by almost 10 percentage points. However, recent tax reliefs more than reversed this hike by cutting top marginal rates.

4.B.3 Home Mortgage Interest Deduction

U.S. federal income tax has allowed for interest deductions since its creation. While in the beginning all interest paid within a year were deduced from income, the Tax Reform Act of 1986 limited interest deductions to "qualified residence interest" (Ventry, 2010). Interest qualifies for deduction if the corresponding loan is collateralized by a principal or secondary residence and used to buy, construct, or improve the residence (acquisition indebtedness). However, the total amount of deducible residence interest is limited to interests on the first $1 million (married filing) of acquisition indebtedness. In addition, regardless of the purpose of the mortgage, interests on home equity debt qualify for deduction as long as home equity indebtedness does not exceed the market value of the residence minus acquisition indebtedness or $100'000 (married filing).

4.B.4 Capital Gains on Principal Residences

Under U.S. income tax code there is a special treatment of capital gains on the sale of a taxpayer's principal residence. The following special regulations deal with non-recognition of capital gains and tax exclusions. Capital gains on principal residences beyond these exclusions are subject to capital gain taxes.

Tax-free rollover of gains on home sales. Section 1034 of the Internal Revenue Code allowed taxpayers to defer recognition of a gain if the principal residence was replaced by another one of at least equal value. In this case capital gains were rolled over into the purchased residence. For eligibility, the replacement residence had to be bought and occupied within a year after the sale. The Tax Reduction Act of 1975 prolonged the replacement period to 18 month, and the Economic Recovery Act of 1981 increased the period to 2 years. This provision was valid from 1951 to 1997. (Office of the Secretary of the Treasury and Office of Tax Analysis, 1985; Ventry, 2010)

One-time exclusion of gains from home sales for elderly taxpayers. The Revenue Act of 1964 introduced a one-time exclusion of capital gains on the sale of principal residences up to $20'000. Taxpayers over the age of 65 were eligible for this exclusion if they had owned the house for at least 8 years and had lived in the house for at least 5 years before the sale. In 1976, the ceiling on the exclusion was increased to $35'000. The Revenue Act of 1978 shortened the occupation period to 3 out of the last 5 years. Besides, it reduced the age limit to 55 years and raised the exclusion to $100'000 (married filing). Finally, the Economic Recovery Tax Act of 1981 increased this allowance to $125'000 (married filing) (Auten, 2005; Newman and Reschovsky, 1987; Office of the Secretary of the Treasury and Office of Tax Analysis, 1985).

Taxpayer Relief Act of 1997. The Taxpayer Relief Act of 1997 replaced both the tax-free rollover and the one-time exclusion by a new exclusion of up to $500'000 (married filing) which can be claimed once every two years. Taxpayers qualify for this exclusion if they have owned and lived in the residence during 2 of the last 5 years prior to the sale. This exclusion of gain from sale of principal residence is codified in Section 121 of the Internal Revenue Code. (Auten, 2005; Office of the Secretary of the Treasury and Office of Tax Analysis, 1985; Ventry, 2010).

Figure 4.6 displays these exclusions of capital gains together with two time-series of

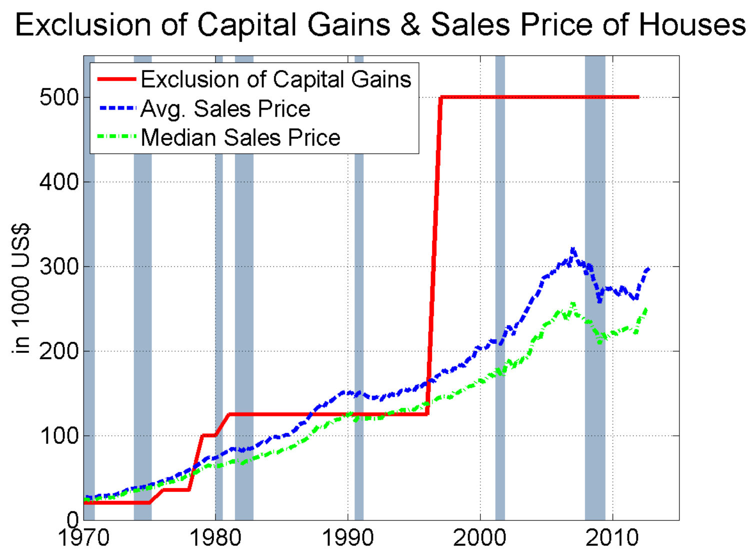

Figure 4.6: Exclusion of Capital Gains on the Sale of Principal Residences
NOTES: The shaded regions correspond to NBER-recessions.

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house prices. As the sales price of a house constitutes an upper bound of the realized capital gain, we can infer from Figure 4.6 that these gains on the sale of a primary residence are effectively tax-free for the vast majority of households.[17]

4.C Mortgage default

A mortgage is considered to be in default when the borrower does not make his payments on the mortgage. Typically, mortgage documents define that default occurs if more than 30 days after the due date pass by. Then the lender is allowed to initiate foreclosure, i.e. the legal process by which the mortgage holder forces a sale of the property used as collateral. Usually banks begin the foreclosure procedure within the next two or three months. Moreover, they will also notify a credit agency of the mortgage default (Elias, 2011; Garriga and Schlagenhauf, 2009; Li and White, 2009).

[17]Data from FRED, for example, indicate that only 4 to 12 per cent of new houses sold in the U.S. in the years 2002 to 2012 were sold at prices exceeding $500'000. Shan (2011, p. 187) mentions that *"about 5% of homeowners in the 2007 SCF have more than $500 K housing capital gains. Among them, the median homeowner also faces a tax liability of around $30,000."*

4.C.1 Foreclosure

State legislations vary with respect to the details determining foreclosure. By and large, there are two types of procedures: judicial foreclosures and non-judicial foreclosures. In case of judicial foreclosure, the whole process is supervised by a court and the lender has to obtain a court order before auctioning the property. Non-judicial foreclosures or foreclosures by power of sale, in contrast, do not require judicial supervision. Instead mortgage lenders proceed according to the specifics set out by state law. In both cases, the mortgage holder will eventually obtain a legal title to the property and sell it. However, there is a substantial variation in the duration of the foreclosure procedure across states (Elias, 2011; Li and White, 2009).

The sales price after expenses is used to repay the mortgage debt. Often the revenues are insufficient to repay the mortgage completely. Whether the borrower still owes the difference between the principal and the sales revenue depends again on state law.[18] In some states the mortgage is non-recourse debt which means that the lender cannot sue the borrower to cover the losses evoked by foreclosure. Hence, the borrowers other assets are protected. In most states, however, mortgages are recourse debt so that the lender may obtain a deficiency judgment which obligates the borrower to repay the difference from his other assets.[19] In most judicial foreclosure states a deficiency judgment can be part of the foreclosure lawsuit while a few judicial foreclosure and all non-judicial foreclosure states require a separate lawsuit. In the latter states lenders have to incur substantially higher costs in pursuing a deficiency and, hence, won't often do so (Elias, 2011; Garriga and Schlagenhauf, 2009; Ghent and Kudlyak, 2011; Mitman, 2012).

If mortgage debt is (legally or de facto) non-recourse, borrowers have an incentive to default strategically. Strategic default means the borrower can afford to service his debt but decides to default because the home has turned into a lousy investment with its current value falling below the mortgage debt. In this case the limitation of liability to the collateral allows the borrower to walk away from his mortgage debt by sacrificing his home while keeping his other assets (Elias, 2011; Lerner, 2010).

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[18] Many states limit deficiency to the difference between loan amount and fair market value.

[19] According to the classification of Ghent and Kudlyak (2011) in 41 U.S. states mortgages are recourse and in 11 states non-recourse debt.

4.C.2 Future credit standing

Being a predictor of future credit risk, arrears and foreclosures have a negative impact on the borrower's credit score. According to the American Bankers Association the FICO score deteriorates by 100 to 400 points due to a foreclosure. Foreclosures remain on a credit report for at least seven years. However, scores typically recover after a couple of years given the borrower fulfills all his payment obligations (Lerner, 2010). The following rule of thumb characterizes lending customs before the recent crisis (Elias, 2011): it takes about two years after bankruptcy to rebuild credit scores in order to be able to buy a car and four to five for a house. Similarly, Lerner (2010) reports that it takes three to seven years to qualify for a new mortgage. Strategic defaulters, however, are nowadays penalized more severely: FannieMae and FreddieMac will effectively deny them a new mortgage for at least seven years after foreclosure due to new regulations they face (Elias, 2011; Lerner, 2010).

4.C.3 Tax issues

A short sale or foreclosure may incur capital gains tax liability. If the sales price is higher than the adjusted tax basis of the house, this difference qualifies as a capital gain which is taxed at the capital gains tax rate (Elias, 2011). For capital gains on principal residences the usual tax-breaks are available (see Appendix 4.B.4).

At the same time an income tax liability may arise. Suppose the house is sold for less than the actual debt and the borrower's remaining debt is forgiven. Then, this deficiency is, in general, subject to income taxation. Since from the tax system's perspective the borrower receives a gift from the lender which amounts to the difference between principal and sales revenue. Hence, this amount counts as taxable income. However, since 2007 there is an exception to this rule: deficiencies on loans secured by and used to buy or improve the borrower's principal residence are exempt form income taxation. As a response to the current crisis, this Mortgage Forgiveness Debt Relief Act was intended to be a temporary exception but has been prolonged twice till end of 2013 (Elias, 2011; Garriga and Schlagenhauf, 2009).

4.D Data Sources

4.D.1 Federal Reserve Economic Data

The following time-series stem from the Federal Reserve Economic Data by the Federal Reserve Bank of St. Louis.

- Inflation rate: U.S. Department of Labor, Bureau of Labor Statistics, Consumer Price Index for All Urban Consumers: All Items

- Consumer Price Index for All Urban Consumers: All items less shelter (CUUR0000SA0L2): U.S. Department of Labor, Bureau of Labor Statistics

- Gross Domestic Product: U.S. Department of Commerce, Bureau of Economic Analysis

- Home Mortgages (HMLBSHNO): Board of Governors of the Federal Reserve System, Z.1 Flow of Funds Accounts of the United States. Home mortgage debt is debt on owner-occupied homes, including home equity loans.

- Real estate of Households (incl. mobile homes and farm houses) at market value (REABSHNO): Board of Governors of the Federal Reserve System, Z.1 Flow of Funds Accounts of the United States

- Residential Structures of Households at Replacement-Cost Value (RCVSHNWBSHNO): Board of Governors of the Federal Reserve System, Z.1 Flow of Funds Accounts of the United States

- Delinquencies On Single-Family Residential Mortgages (DRSFRMACBN): Board of Governors of the Federal Reserve System, Charge-Off and Delinquency Rates on Loans and Leases at Commercial Banks

- Delinquency Rate On Loans Secured By Real Estate (DRSREACBN): Board of Governors of the Federal Reserve System, Charge-Off and Delinquency Rates on Loans and Leases at Commercial Banks

4.D.2 House Price Indices

- All-Transactions House Price Index for the United States (USSTHPI): Federal Housing Finance Agency, House Price Index (taken from FRED)

  The Federal Housing Finance Agency estimates a quarterly house price indexes for single-family detached properties using data on conventional conforming mortgage transactions obtained from Freddie Mac and Fannie Mae. Based on sales prices and appraisal data, the index measures average price changes in repeat sales or refinancings on the same properties.

- Average Sales Price of Houses Sold for the United States (ASPUS): U.S. Department of Commerce, Census Bureau, Quarterly New One-Family Home Sales by Price and Financing (taken from FRED)

- Median Sales Price of Houses Sold for the United States (MSPUS): U.S. Department of Commerce, Census Bureau, Quarterly New One-Family Home Sales by Price and Financing (taken from FRED)

- S&P Case-Shiller 20-City Home Price Index (SPCS20RSA): Standard and Poor's (taken from FRED)

  The S&P Case-Shiller 20-City Home Price Index tracks Single-Family housing in on 20 metro areas. Data are collected on transactions of all residential properties during the months in question. The composite index is a weighted average of the different regional indices which calculated as a three-month moving average from the collected data.

4.D.3 Rent-Price Ratio

Davis, Lehnert, and Martin (2008) compute a quarterly time-series of the ratio of imputed annual rents of homeowners to the value of owner-occupied housing in the U.S. To estimate the rent-price ratio, they use micro data from the Decennial Census of Housing surveys. In between these decennial surveys they interpolate rents and house prices employing the BLS's index for the rent of primary residence and Freddie Mac's repeat-sales house price index (CMHPI). These quarterly rent-price ratio data are regularly updated by the Lincoln Institute of Land Policy and published at `http://www.lincolninst.edu/subcenters/land-values/rent-price-ratio.asp`. For the period starting in 2000, the Lincoln Institute computes an alternative series of the rent-price ratio when house prices are based on the Case-Shiller-Weiss index.

4.D.4 Taxation

Ordinary income taxation

Barro and Redlick (2011) compile an annual time-series of average marginal income tax rates (AMTR) in the U.S. Their AMTR measure comprises of federal individual income taxes, state income taxes as well as the social security payroll tax. Recent data is mainly derived from the NBER TAXSIM program which depicts the U.S. federal and state income systems (for details see Feenberg and Coutts, 1993). The AMTR measure is intended to capture a concept of income that is close to labor income. Hence, Barro and Redlick (2011) calculate marginal tax rates for wages and related forms of income. Then, they compute the AMTR as the weighted mean of these marginal rates where the weight is the amount of income of various types reported on the filing. Daniel Feenberg of the NBER publishes updated AMTR data at `http://users.nber.org/~taxsim/barro-redlick/`

Long-term capital gains taxation

- Maximum statutory marginal tax rates for the U.S. are compiled in Esenwein (2006). The maximum statutory marginal capital gains tax rate is the marginal tax rate on the highest income bracket.
- Eichner and Sinai (2000) construct a time-series of the weighted average marginal capital gains tax rate for the period 1954 to 1997 following the methodology of the U.S. Congressional Budget Office.
- Average marginal long-term capital gains tax rates are taken from NBER's Average Marginal U.S. Income Tax Rates by Income Type table. They are dollar weighted average marginal tax rates derived from the NBER TAXSIM model (see `http://users.nber.org/~taxsim/marginal-tax-rates/index.html`).

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