Essays on Economic Growth and Fluctuations

by

Victor Tin Yau Hung

London School of Economics

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ABSTRACT

This thesis comprises five chapters and a short introduction. Chapter 1 reexamines the "stylised facts" about cyclical fluctuations in external balances proposed by real business cycle economists and investigates whether technology shocks are the main source of fluctuations in external balances. It is found that real business cycle evidence is not invariant to the method of detrending and a substantial proportion of movement of current accounts is due to demand shocks. Furthermore, it is found that the single commodity real business cycle model cannot explain countercyclical movement of current accounts.

Chapter 2 studies the effect of anticipated inflation on economic growth in an endogenous growth model. Money is introduced into an endogenous growth model which exchange requires cash-in-advance. It is shown that the decentralized competitive outcome is an inefficient balanced growth equilibrium. It is also shown that efficiency is restorable by means of a well-known optimum money supply rule.

Chapter 3 extends the basic product variety endogenous growth model by introducing a fixed cost in research and development. It is shown that the fixed cost determines the rate of growth. By integrating with the human capital accumulation, it is shown that the growth rate of output is twice the rate of human capital accumulation without any increasing returns to scale or externality assumptions. In addition, this chapter also studies the effects of trade liberalization of physical goods on economic growth and further discuss the effect of economic integration on economic growth.

Chapter 4 addresses the question of whether environmental conservation adversely affects growth. It is shown that environmental control is not necessarily a depressant on growth from a *laissez-faire* economy. Even if the economy starts off pursuing optimal growth without considering environmental damage, the growth rate of output may be increased if the environment is a factor of production.

Chapter 5 deals with financial development in an endogenous growth model. The

model integrates theories of growth and financial intermediation. Problems of moral hazard dictate that an optimal loan contract must involve either *ex ante* or *ex post* monitoring which is costly. However, lenders can delegate the monitoring to a financial intermediary. It is found that there is a positive, two-way causal relationship between growth and financial development. Different economies may evolve towards different financial systems depending on cross-country differences in the relative costs of these systems. In addition, it is also shown that the market may choose a financial system which does not generate the fastest possible economic growth.

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INTRODUCTION

Economies grow and change over time. Economic growth, however, is not smooth. At the core of any macroeconomic theory is an explanation of how an economy grows and responds to economic forces. In the past, macroeconomists used a Solow-type long-run growth model to study the general upward path of the economy over time. The growth model focuses on the amount of labour and capital that go into the production of goods. Given exogenous growth rates of technology and population of work force, the economy grows along a deterministic trend. The trend can be used to measure the potential output that would have been produced if the economy had utilised all its capacity. Therefore deviations from the trend are the cyclical fluctuations of the economy.

Before the 80's, most macroeconomists saw potential output as evolving smoothly over time. They viewed the business cycle as a temporary departure from growth's potential level. An important group of macroeconomists, the real business cycle school, disputes this idea. They believe that potential output fluctuates significantly mainly due to productivity shocks. Estimating the relative importance of the sources of economic fluctuations is crucial to the debate between the real business cycle school and the traditional keynesian school.

Macroeconomists estimating the relative importance of the sources of fluctuations face the problem of separating output growth trends from business cycles. Since the Solow model does not put any restrictions on the exogenous nature of technical progress, it can be either deterministic or stochastic. Different assumptions about technical progress - "the trend" - will give different answers to the estimates. Chapter 1 of this thesis tries to illustrate the potential problems of estimation and formulates a structural approach to the problem. It is found that a substantial proportion of fluctuations in output of the G7 countries is due to permanent shocks. Since the study is based on reduced form equations, we may miss out some important points which lead to misspecification of the disturbances. One source of specification error may be due to the information structure problem mentioned in Hansen & Sargent (1990). If agents have more information than the econometrican about the nature of the disturbances, there will be difficulties in identifying the sources of the disturbances unless the econometrican has the same information set as the agents. A second specification error is the independence of transitory and permanent shocks. If technical progess is no longer exogenous, it is determined by economic forces. Any demand policy disturbance may affect the long term potential capacity of the economy in addition to its conventional temporary effect on output. The remain chapters are devoted to studying the nature of the permanent component.

The productivity of most economies have advanced in the twentieth century. Some of the previously less industrialized countries - such as Japan and Italy - have caught up to the productivity levels of the world's industrial leaders, while others, such as Argentina, have lost substantial ground relative to the industrial core. Economies have not "converged" in productivity levels and standards of living over the past century.[1] Nations have not shared equally in the increase of material wealth. It casts some doubts on Solow's growth model.

Recent work on economic growth, largely sparked by Romer (1986), tries to determine technological progress endogenously. The Romer model is similar to the paper of Arrow (1962) on learning by doing. In the Romer model, the productivity of a firm is an increasing function of aggregate investment of the economy. He argues that when investments take place, new knowledge will be discovered which is a public good, generating an externality to other firms. Accumulation of knowledge by forward-looking, profit maximizing agents is the driving force behind the long-run growth in his model. A second influential paper by Lucas (1988), emphasizes the role of human capital accumulation in determining long-term economic growth. The model also provides an explanation for migration flows of skilled and unskilled labour to high income countries.

Subsequent studies extend the Romer and Lucas models in different directions. The Rebelo model (1991) modifies Romer's model (1986) to be compatible with the stylised facts of a steady capital-output ratio and a constant share of capital and labour in total income. The Barro model (1990) tries to take into account the effect of fiscal policy.

[1] Some recent empirical studies on cross-country data by Barro (1991) and Mankiw, Romer & Weil (1991) support the "convergence hypothesis" - that countries with a lower capital stock will grow faster than those with higher capital stocks - an implication of the Solow growth model. However, Quah (1993a, 1993b) illustrates the econometric problems of these studies.

Chapter 2 straddles the literatures on endogenous growth and the real effect of anticipated monetary policy. It is assumed that money is a medium of exchange by requiring agent to use it to finance transactions. Extending the analysis, we also study the financing effect of money. It is shown that money affects growth through two independent channels: externalities in production and private transaction costs in exchange. With the results from Barro (1990), it illustrates that demand side stablization policies - fiscal and monetary policies - may have permanent growth effects on output in addition to their conventional temporary effects. This implies that the dichotomy between short run and long run analyse of macroeconomics may not be the right approach.

The new growth theory also emphasizes the role of research and development investment. Innovation is believed to be a key factor in economic growth. Recent major contributions to the theory are by Grossman and Helpman (1989) and Romer (1990). They focus on purposive activities that lead to technological change in the form of an expansion in the variety of products. A different approach is taken by Aghion and Hewitt (1990) and Grossman and Helpman (1991) who model the research and development sector of an economy in a way that captures the Schumpeterian idea of creative destruction. The emphasis is on the replacement of old consumer goods by new consumer goods, and old methods of production by new methods of production. Both types of technical progress depend upon the level of research which, in turn, depends upon the monopoly rents available to the successful innovator.

Research and development needs human capital. Models like Grossman and Helpman (1989) and Rivera-Batiz and Romer (1991) with a constant stock of human capital can sustain continuous growth in the economy through innovations. Chapter 3 questions this result. It builds on a product variety model and extends the analysis to integrate with human capital. It is found that both human capital accumulation and decentralised research activities are essential to economic growth and that they are complementary to each other. It is also shown that aneconomy can grow faster with coordination policy between decentralised research and development activities and human capital accumulation. In addition, it also addresses the growth effects of trade liberalization.

The relationship between growth and trade has been the subject of numerous investigations.[2] The literature distinguishes between three types of potential trade effects on growth. The first effect is the allocation effect which refers to changes in sectoral output induced by changes in the allocation of basic inputs between sectors. Trade liberalization encourages each country to re-allocate towards that sector in which it enjoys a comparative advantage. The net effect on growth can be positive or negative depending on whether resources are diverted out of, or into the research and development sector. The second effect is the redundancy effect and is confined to the research and development sector. Research is redundant when the same idea is discovered by more than one country. If closer links between economies strengthen the incentives to avoid the redundant research effort, then introducing trade restrictions will have an adverse effect on growth.

The third effect is the integration effect and focuses on the links between the same sector in different countries. Integration between the research and development sectors of economies is a means of increasing the flow of ideas and the extent of knowledge-spillovers both of which induce more research activities. However, integration between the intermediate goods sectors of economies may just have a level effect on productivity unless either the effect of economic integration on market size or specialization of some sectors generates more profit and promotes research activities. Chapter 3 explores the market size effect of economic integration. It is shown that trade in physical goods can induce growth even without information externalities, an absence of research redundancy or no change in specialization.

The environment has assumed a status as *the* economic problem of the 1990's. In relating to my research on growth, to what extent does environmental conservation adversely affect the sustainability of growth in an economy? Chapter 4 investigates some aspects of environmental policy and growth. Is economic development sustainable with environmental control?[3] These are the foremost questions that must be addressed

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[2] They include Backus, Kehoe and Kehoe (1990); Feenstra (1990); Grossman and Helpman (1989); Krugman (1987); Quah and Rauch (1990); Stokey (1991); Rivera-Batiz and Romer (1991) and Young (1990).

[3] The World Bank recently studied on exploring the possible links between economic development and the environment. Its results are summarized in its *World Development Report 1992.*

as governments debate the merits and flaws of different environmental policies. In Chapter 4, economic growth is determined endogenously. Two very specific channels through which the environment can affect growth, technology and resource constraints, are considered. In particular, it addresses the issue of the environment as a scarce factor of production in the form of a resource constraint and how such a constraint has major implications for the analysis of growth. In addition, it invites one to think of growth and environmental conservation as complements rather than substitutes.

The growth process is similar to the one in Chapter 3. There are several channels through which environmental policy (pollution control) might affect economic growth. One possibility is that it leads to a change in the input mix used in production. Another possibility is that it alters the fixed cost in an industry as capital is expended for pollution abatement equipment. A longer-term possibility is that it leads to changes in production processes and stimulates the creation of new and cleaner products. Given our definition of growth - expanding product variety - we focus on the change in input mix and the creation of new products. As indicated above, new products are the result of research and development. Research occurs in both the environmentally friendly and environmentally unfriendly sectors. Since research activity is profit-motivated, any expected intervention in the use of dirty products will have an impact on the flow of new products and therefore an impact on growth. In general, taking care of the environment is costly to growth but is welfare improving. The effects on growth depend on whether the economy starts at the second best equilibrium or the market equilibrium. Pollution control is not necessarily a depressant on growth from a market outcome. Also, if the conservation of the environment is crucial for maintaining an economy's production frontier, moving away from the steady state with dirty products may be both welfare improvement and growth improving.

However, given the cost advantage of dirty production and research activities and the knowledge spillover in the research sector, the analysis here shows that economic development with clean technology may not be sustainable. It is difficult to think of any automatic mechanism for moving from dirty production to clean production. In principle, however a government that commits itself to clean up the environment and abandon all dirty inputs, might change the expectations of designers, such that research activity eventually becomes devoted solely to clean innovations. In the absence of this, market type policies may not be sufficient to establish a clean environment with higher growth.

It is the institutional structure of an economy which provides the motivations and constraints on environmental control. Institutional structure also provides incentives to engage in education and training, and research and development. Economies with similar endowments, similar technologies and similar knowledge may exhibit dissimilar rates of growth because of differences in institutional arrangements which affect growth incentives. Chapter 5 of this thesis is devoted to the study of the development of one type of institution - financial intermediation.

The motivation of this last chapter is the view that cross-country convergence (or divergence) in growth rates has as much as to do with similarities (or differences) in national institutions as it has with the distribution of human capital and technology across countries. Any single economy may experience changes in its growth rate over time according to developments in its own institutions, in particular the financial system.

Modern accounts of the relationship between growth and financial development emphasize the role of financial intermediation in improving the allocation of resources. In Bencivenga and Smith (1991), financial intermediation allows agents to pool idiosyncratic liquidity risk. This has the effect of stimulating capital accumulation and growth through an improvement in the allocation of saving between risky (illiquid and high expected return) investment projects and safe (liquid and low expected return) deposits. In Greenwood and Jovanovic (1990), allocations are distorted because of imperfect information arising from an unobservable shock. Growth performance is improved by the establishment of a financial intermediary which conducts research on the shock and sells its information to agents. Saint-Paul (1992) considers the case in which improvements in growth require the use of more specialized and riskier technologies. Financial development allows this to occur by expanding the opportunities for diversification. A basic insight of this literature is that the relationship between growth and financial development is two-way causal: growth is both encouraged by, and encourages, financial market participation and innovation.

Chapter 5 presents a study of the role of delegated monitoring of financial intermediation, as developed by Diamond (1984), Gale and Hellwig (1985) and Williamson

(1986). The efficient financial arrangement through financial intermediation minimizes the cost due to the incentive problems between potential creditors and potential debtors which lowers the cost of capital for research and development investments. Diversification within the financial intermediary is the key to understanding why delegated monitoring can have a net cost advantage over direct monitoring. The chapter contains a description of alternative optimal financial arrangements - direct or delegated monitoring, *ex ante* or *ex post* monitoring. Each one corresponds to a balanced growth equilibrium. It is proved that different economies may evolve towards different financial systems depending on cross-country differences in the relative cost of these system and the resource endowment. It is also shown that the decentralised market may choose a financial system which does not generates the fastest growth.

This thesis is organised as follows. The next chapter reexamines the stylised facts of business cycles and estimates the relative importance of the sources of external balance fluctuations. Chapter 2 studies the effect of money in an endogenous growth model. Chapter 3 discusses how research and development coordinated with human capital accumulation affect economic growth. Chapter 4 analyses the impacts of environmental policy on growth. The final chapter develops a theory about growth and financial development.

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CHAPTER 1 SOURCES OF EXTERNAL BALANCE FLUCTUATIONS

Abstract:

This study focus on three questions: (i) Are the "stylised facts" about cyclical fluctuations on external balances proposed by Real Business Cycle (RBC) economists robust? (ii) Are technology shocks the main source of fluctuations of external balances. (iii) Are current account fluctuations explained by a simple intertemporal effect? First, we find that RBC evidence are not invariant to the method of detrending. Second, we find that a substantial proportion of movement of current accounts is due to demand shocks. Third we find that the single commodity RBC model cannot explain countercyclical movement of current accounts.

I. Introduction:

What are the sources of balance payments fluctuations? Similar to the question of the sources of business cycle fluctuations, different theories give different answers to the question. Different answers have different policy implications. The essence of Keynesian theories is that in the short run, the output level is determined by demand factors, such as, investment animal spirits, government cyclical fiscal policy and monetary policy. Increased output will induce more consumption, increasing imports which generates the variations in the current account. The main sources of external balance fluctuations are these temporary demand disturbances. On the other hand, classical and new classical theories assume market clearing, changes in output are caused by some permanent disturbances e.g. permanent distortionary tax changes, technology shocks and preference shocks. These permanent disturbances will increase import consumption and investment which in turn, generate the fluctuations in external balances. Identifying the sources of fluctuations are crucial for any policy recommendation. This paper tries to introduce a way to estimate the relative importance of the sources of external balance fluctuations.

There are several ways to uncover the properties of aggregate time series, in particular the relationship between different macroeconomic variables. Regression analysis[1] is the most popular approach. However, in the absence of any knowledge about the structural relationship between aggregate variables, it is problematic to draw inferences from the reduced form regression results. There are two other approaches in analyzing the properties of aggregate time series. The first one is mainly used by Real Business Cycle (we denoted RBC hereafter) economists. Their main objective is to study the regularities of business cycles. The second approach focuses on underlying data generation processes without imposing too many structural restrictions, with its main concern being the sources of business cycle fluctuations. Our paper follows this approach.

This study is an outgrowth of recent work on the sources of business cycles by Stockman (1988), Shapiro and Watson (1988) and Blanchard and Quah (1989). Stockman decomposes the quarterly and annual growth rate of industrial production of the manufacturing sector in seven European countries and the US, into country specific shocks, industry specific shocks and idiosyncratic shocks. He found that most macroeconomic fluctuations can be ascribed substantially both to industry specific shocks and country specific shocks. He interprets the country-specific disturbances as policy shocks that affect most industries in the economy; however, we have some doubt on this interpretation. Subject to his univarate time series decomposition, he assumes away the intertemporal and intratemporal substitution demand by consumers outlined by Long and Plosser (1983). Shapiro and Watson (1988) and Blanchard and Quah (1989) take a multi-variate approach and apply on US data. By ignoring the industry specific effects, they decompose the variations of output into demand and supply disturbances. They find that demand disturbances make a substantial contribution to output fluctuations at short-and medium-term horizons[2]. This paper tries to extend their work to a sample of more countries, to see whether the US experience can be applied to other industrial market economies. We focus on three

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[1] The more sophisticated regression analysis of time series is co-integration analysis proposed by Engle and Granger (1987) and Johansen (1988).

[2] Their results are not very robust with alternative specifications e.g. break and trend of unemployment, deterministic or stochastic trend of labour supply.

questions: (i) Are the "stylised facts" about cyclical fluctuations of the external balances proposed by RBC economists robust? (ii) Are technology shocks (permanent shocks) the main source of fluctuations of the external balances? (iii) Are current account fluctuations explained by a 'simple intertemporal substitution' effect?

Our approach is quite different from that of RBC economists, they focus on the regularity of business cycles, e.g. Prescott (1990) and Backus and Kehoe's paper (1990b). We will review some stylized facts proposed by RBC economists and illustrate some potential bias in their interpretation in the following section. In section III, we discuss our methodology and relate it to recent time series analysis on macroeconomic data. In Section IV, we sketch a small open economy model and explain Blanchard and Quah's representation and estimation method. We present our findings about the sources of current account variations, compare our findings with RBC "stylised" facts in section V, and offer concluding remarks in Section VI.

II. Cycle Properties of External Balance Fluctuations:

Almost all aggregate time-series are non-stationary. To avoid spurious correlation, it is necessary to decompose the macroeconomic time-series into a non-stationary one and stationary one before studying their cross relation. Before the 80's, macroeconomists assume that the non-stationary part is a linear trend. Like other economists, Lucas (1977, p.9) defined the business cycle phenomena as the recurrent fluctuations of output about the linear trend and co-movements among other aggregate time series. Therefore business cycle fluctuations are by definition deviations from a linear trend. However, his definition of business cycles does not restrict to a linear trend. It holds no matter how the "trend" has been defined.

It is well known that the underlying rate of technological change was not constant during the post war period. Nelson and Plosser (1982) questioned the conventional linear trend representation of the non-stationary part. Since then there have been many studies on variable trends both by economists and econometricans[3]. In his 1986 paper, Prescott adopted the variable trend idea by using a filter to eliminate the non-stationary part of the time series. We call it the Hodrick-Prescott filter[4], a computational procedure used to fit the smoothed curve through a single series. He denoted the smoothed curve as the "trend". The smoothing procedure deals with logarithms of a variable because we are only interested in the patterns of percentage deviations of the aggregate time series. The "trend" component, denoted as τ_t, for t=1,2,...,T, is the one that minimizes $\mathcal{L}$

$$\mathcal{L} = \sum_{t=1}^{T} (y_t-\tau_t)^2 + \lambda \sum_{t=2}^{T-1} [(\tau_{t+1}-\tau_t)-(\tau_t-\tau_{t-1})]^2, \qquad (II.1)$$

where λ is arbitrarily chosen. Kydland and Prescott pick $\lambda = 1600$, so the procedure can be interpreted as a high pass filter, eliminating all frequencies of 32 periods or greater. As $\lambda \rightarrow \infty$, the Hodrick and Prescott filter gives a constant linear trend.

There are several studies on business cycles that apply the Hodrick-Prescott filter to aggregate time-series: Backus and Kehoe (1990a, 1990b) study the historical properties of business cycles and the general properties of business cycles of different countries. Another two similar studies, one by Blackburn and Ravn (1991b) on the UK business cycles, and the other by Kydland and Prescott (1990) on US business cycles, both use the same filtering method. Beside their interesting findings of a counter-cyclical movement of the price level, they also look into the properties of external balance fluctuations. All studies found a strong counter-cyclical movement of net exports. In Backus and Kehoe's paper (1990a, p.1), they state:

> *We show first that the share of output devoted to net exports is negatively correlated with output in every country we examine, and in many countries this inverse correlation is quite strong.*

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[3] Those interested in the topic can find detailed references from Stock and Watson (1988).

[4] This method was introduced in an unpublished paper by Hodrick and Prescott (1980).

The findings are quiet difficult to fit into a simple RBC model, which predicts pro-cyclical movement of current accounts by the consumption smoothing argument. Although they also find some inter-country correlation between output, each country still has a substantial idiosyncratic component to its own business cycles. With the well-known puzzle of high correlation between the savings and investment rate amongst OECD countries[5], RBC theorists find it difficult to explain these three stylised facts in a coherent model. In the following, we shall re-examine the two stylised facts, found by RBC studies: (i) counter-cyclical movement of the external balances; (ii) the inter-country correlation of outputs, by using a different detrend method. Since our main concerns are the fluctuations in the current accounts, we apply the detrending procedure on the current account surplus ratios, instead of net exports. We pick the seven OECD countries: Canada, France, Italy, Japan, Germany, UK and US as our sample of countries, because they are the largest industrial economies in the world. Besides, they also dominate world trade, and the capital of these countries can easily access international financial markets. Our sample period is from 1970 first quarter to 1990 first quarter. You can find a more detailed data description in the appendix.

In Table 1, we report the correlation between current account ratios and the change of industrial production, with different assumptions about the trend. In the "stochastic trend" case, we assume that industrial output y_t can decompose into a random walk and a stationary part:

$$\begin{aligned} y_t &= y_{1,t} + y_{2,t} \\ y_{1,t} &= \beta + y_{1,t-1} + u_t \\ y_{2,t} &= C(L)u_t \end{aligned} \qquad (II.2)$$

where u_t is i.i.d., $C(L) = \Sigma^{\infty}_{i=0} c_i L^i$, $c_0 = 1$ and $\Sigma^{\infty}_{i=0} c^2_i < \infty$. The stochastic trend is just $y_{1,t}$ and the correlation is between detrend part ($y_{2,t}$) and the ratio of the current account surplus to $y_{1,t}$. For the "variable trend" case, we filter the real GNP level and industrial production index by a HP filter with the same λ. The current account ratio, is the ratio of

[5] The puzzle of a high correlation between saving rate and investment rate was first documented by Feldstein and Horioka (1980).

the real current account to "trend" value of real GNP, calculated from the filtering method. The correlation is calculated from the ratios of the current account to trend GNP and the detrended value of industrial output. In the column of the "linear trend", we assume the real GNP and industrial output as trend-stationary

$$y_t = \alpha + \beta(T-t) + A(L)\epsilon_t \tag{II.3}$$

where ϵ_t is i.i.d. and $\Sigma^{\infty}_{i=0} a^2_i < \infty$. Results show: in the case of a "stochastic trend", we find that the correlations between current account ratios and industrial production are rather low and there are four positive correlation estimates out of our seven countries. In the case of a "variable trend" and a "linear trend", the estimates support the claims by RBC economists of countercyclical external balances in all seven countries.

Table 2a-2c contain the inter-country correlation statistics of the fluctuations of output - the deviations from trends. It shows high positive correlations amongst output fluctuations in the case of a "variable trend" and a "linear trend". However, in table 2b you will notice that some correlations are very low, and even negative; particularly in the case of the US and UK.

We find that the "stylised facts" are not robust, in particular the countercyclical movement of the trade balance. In Table 4 of Backus and Kehoe's paper (1990b), the correlation statistics of net export ratios and output are different from what we find. In the case of a "stochastic trend", some correlations are positive. However, the results on the cross correlation of output are quite similar and their cross correlations of detrended output match our results of "variable trend" case quite well. This means that their results are quite sensitive to the assumption of the trend.

We have some scepticism about the filtering procedure, as there are two fundamental problems to Hodrick and Prescott's method. Firstly whether it eliminates some important information about the fluctuations. Although Kydland and Prescott (1990) point out that the decomposition into a smooth curve and fluctuations is just a representation of the data, they have not put up convenient arguments in support of their representation and their chosen value for λ. Also similar studies following their procedure do not come out with any explanations.

Cogley (1990) studies the relative stability of long term growth for nine OECD countries[6]. He found that on average, the variations of output due to cycles with frequencies more than 10 years is 25%. France has the largest variation of 40%, Denmark has the lowest with 16% and the US has 22%. It is clear that the spectral density functions of output for different countries are quite different. It will therefore be inappropriate to use the same λ for all countries, and it isimportant to have an idea about the relative importance of the long wave cycle in each variable before filtering the data.

Another problem is related to the RBC theory. Most of the RBC models are based on neo-classical growth models. They all derive the business cycle phenomena as the adjustment to a steady state given the structure of the model[7]; so all variables are in terms of deviations from the steady state. Most studies calibrate the moment from their theoretical models, and compare the theoretical moment with the sample moment from the detrended data. RBC theorists claim that their models can mimic business cycles, and is more or less summarized in Prescott's statement (1986):

> *We have computed the competitive equilibrium stochastic process for variants of the constant elasticity, stochastic growth model.... The finding that when uncertainty in the rate of technological change is incorporated into the growth model it displays the business cycle phenomena was both dramatic and unanticipated.*

Their models assume balanced growth along the steady state. In comparing their calibration results with the data, they neglect the growth properties of their models. The "trend" does not satisfy any balanced growth model prediction. Eventhough we accept the filtering procedure, claiming that RBC theories can explain the properties of business cycles is very misleading. We do not see any justification to explain only the stationary part of time-

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6 The sample countries are Australia, Canada, Denmark, France, Italy, Norway, Sweden, U.K. and U.S..

7 The propagation mechanism of RBC models is related to the production processes and consumers' intertemporal allocation of consumption and leisure.

series data but not the non-stationary part. We understand that it may be too demanding in the beginning of a research programme, but RBC theories must tackle this problem in the future[8].

Can we find out more about the external fluctuations besides the "stylised" facts from RBC studies? Unless we impose some structure to the data generation processes, we cannot get more from the data. In what follows, we restrict the model with some assumptions which are "generally" accepted, in order to allow us to identify the nature of the shocks. Afterwards, we can use the results to discover whether external fluctuations are driven by growth effects (permanent shocks) or short run effects (transitory shocks). It enables us to find out whether the countercyclical movement of external balances is due to demand side effects or supply side effects. By examining the inter-country correlation of the permanent and transitory shocks, we shall be able to understand the spillover effects between business cycles across countries. As a result, we may decover whether inter country correlations of outputs are generated by correlated disturbances or magnified by the propagation mechanism.

III. Methodology:

Our methodology is originated from Sims' vector autoregressive (denoted VAR hereafter) reduced form approach. Sims (1980) used this method to analyze the relative importance of monetary policy on interwar and postwar business cycles. Following Sims, there have been many studies using similar methods try to test the alternative explanations of the money-income relationship e.g. King (1986) and Benanke (1986). There have been a lot of discussions about Sims' VAR methodology, Pagan (1990) provides a comprehensive review on Sims' methodology and compares it with Hendry and Leamer's methodology.

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[8] There are two ways to tackle the problem: (i) to study cycle and trend together e.g. King and Rebelo (1988) and King and Robson (1989) incorporate stochastic growth into RBC models; (ii) by putting balanced growth restrictions on the Hodrick and Prescott filter, and comparing the filtered series moment with the simulated data moment from RBC models; my colleague and I are working in this direction.

Those interested in the econometrics methodology should read Pagan's paper directly. Here, we just summarize some of Pagan's arguments about VAR methodology.

Sims' methodology has four steps: (i) Transform the data to such a form that a VAR can fitted to it; (ii) Choose as large as possible an order and determine the number of variables of the VAR system; (iii) Try to simplify the VAR by reducing the order of the system; and (iv) use the orthogonalised innovations representations to address the question. Beside the problem of non-stationarity of macro time series and the selection problem of the order and dimensionality of the system, it is rather ad hoc to treat the residuals of VAR as orthogonalised innovations and interpret as structural innovations.

Subsequent VAR studies, like Blanchard and Watson (1984) and Benanke (1986), try to modify the system to get around the criticism. They assume the dynamic behaviour of X_t, a n x 1 vector of macroeconomic variables, observed at time t is governed by the following model:

$$X_t = \sum_{i=1}^{l} B_i X_{t-i} + A u_t \qquad (III.1)$$

where u_t is so called "structural disturbances." u_t is serially uncorrelated and $E(u_t u_t') = \Sigma$, a diagonal matrix and $A \neq I$, but with normalized diagonal elements of one. The model improves upon the conventional method of orthogonalization (based on the Choleski decomposition) by restricting A with relevant economic theory. Therefore the interpretations to the innovations are related to the underlying theory. Moreover, the use of orthogonalised innovations for variance decomposition and impulse response functions will be subject to what prior restrictions are imposed upon the causal structure on A.

Following the method of imposing restrictions on the VAR system, our approach uses the long run multiplier effects of the innovations to characterize the system. Our work differs from the studies of persistence of macroeconomic time series, e.g. Campbell and Mankiw (1987) and Cochrane (1988) which focus on the long run response of macroeconomic variable such as GNP to a shock. Quah (1988) has shown that "persistence " turns out to be logically distinct from whether permanent disturbance are important. Similar views have been made by Campbell and Mankiw (1987), Cochrane (1988) and West (1988b). A recent paper by Christiano and Eichenbaum (1989) question the idea of trying to discriminate between a unit root process and a trend-stationary process in order to measure the persistence. Their results suggests that the implications of a wide range of dynamic macroeconomic models are indifferent to whether the forcing variables in an agent's information set are modelled as trend or difference stationary. They think macroeconomists should be concerned more about the relative importance of permanent and temporary shocks rather than the degree of persistence.

IV. Model and Estimation:

Although macroeconomists may disagree on the neutrality of monetary or fiscal policy in the short run, most of them will agree that monetary and fiscal policy are neutral to output in the long run[9]. By using the long run neutrality property of most linear macro models, we assume that

In the long run, given the constant supply of labour input, the level of output is only determined by technological shocks (or by definition, a permanent effect).

We adopted the same restriction, made by Blanchard and Quah (1989), in order to identify the demand disturbances and supply disturbances (we interchange the words "demand disturbances" with "transitory disturbances" and "supply disturbances" with "permanent disturbances" throughout the paper). There are several other studies following the same approach, e.g. Shapiro and Watson (1988) and Ghosh (1990). The assumption does not exclude any demand side effects or temporary shocks nor impose any specific frequency restrictions on the movement in macroeconomic variables in RBC studies. It only eliminates the possibility of any permanent effect on the level of output from demand or transitory

9 Beside the famous Tobin effect, monetary and fiscal policies may affect the long run level of output in endogenous growth models e.g. Bean (1989) and Blackburn and Hung (1991) and multi-equilibria rational expectations models e.g. Diamond & Fudenberg (1989).

disturbances. Blanchard and Quah (1989) use an IS-LM model to relate transitory shocks as demand disturbances and permanent shocks as supply disturbances. As they mention, interpreting the shocks in small dimensional systems as "structural" disturbances due to supply and demand shocks, is always perilous. However for illustrative purposes, as well as to focus further estimation and discussion below, we provide a simple model which gives similar implications. We will come back to discuss the interpretation in section VI.

The model is a simple linear model of an open economy with:

$$y_t = (1-\theta)q_t + \theta w_t. \tag{III.2}$$

$$q_t = \beta(p_t - E_{t-1}p_t) + s_t. \tag{III.3}$$

$$m_t - p_t = y_t. \tag{III.4}$$

$$w_{t+1} - w_t = -\gamma(1-\rho)\sum_{i=1}^{\infty} \rho^i \, (E_t q_{t+i} - q_t). \tag{III.5}$$

The variables y_t, q_t, w_t, p_t, s_t and m_t denote the log of income, domestic output, foreign assets, price level, productivity and money supply respectively. Equation (III.2) states that total income is the sum of the income from domestic production and the income from foreign assets, where θ is the steady state proportion of income from foreign assets holding. Equation (III.3) is the Lucas supply curve with an additional term for productivity: increased productivity will raise domestic output. Although s_t can also be interpreted as external demand or cost disturbances, we restrict the interpretation to supply disturbances here. Equation (III.4) is just the aggregate demand for real balances. Finally, the last equation (III.5) is the foreign asset accumulation equation derived from the Permanent Income Hypothesis[10]: dissaving anticipates rising income and saving anticipates falling income, where ρ is the discount factor and γ is the marginal propensity to consume out of permanent income. It is assumed that the steady state proportion of wealth in foreign

10 One can find a similar expression of equation (III.5) in Campbell (1987).

assets is constant and labour income is proportional to domestic production.

We need to specify how exogenous variables m_t and s_t evolve. Let us assume that they follow:

$$m_t = m_{t-1} + e_t^t$$
$$s_t = s_{t-1} + e_t^p \qquad (III.6)$$

where e^t_t and e^p_t are serially uncorrelated and pairwise orthogonal demand and supply disturbances. By solving the model, we can express the change of domestic output and foreign asset holding in terms of demand and supply disturbances:

$$X_t = A(0)e_t + A(1)e_{t-1} + \dots = \sum_{j=0}^{\infty} A(j)e_{t-j}, \quad Var(e) = I, \qquad (III.7)$$

where X_t is the vector of $[\Delta w_{t+1}, \Delta q_t]'$ and e_t is the vector of $[e^t_t, e^p_t]'$.We normalise the variance to 1, so I is an identity matrix. The coefficients of $a_{11}(j)$, $a_{12}(j)$, $a_{21}(j)$ and $a_{22}(j)$ are the elements of 2x2 matrices A(j), which are the functions of the structural parameters θ, β and γ[11]. You can see that the sum of the matrices, A(j)'s lower left hand entry, $\Sigma^{\infty}_{j=0} a_{21}(j)$, equals zero. Due to misperceived demand disturbances: the unanticipated changes in money supply have short run effects on output, but their effects disappear over time. In the long run, only the technology shocks matter here. If we drop rational

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11 The function of $a_{11}(j)$, $a_{12}(j)$, $a_{21}(j)$ and $a_{22}(j)$ are

$$a_{11}(0) = \frac{\beta\gamma}{1+(1-\theta)\beta}, \quad a_{12}(0) = -\frac{(1-\theta)\beta\gamma}{1+(1-\theta)\beta}$$
$$a_{11}(j) = a_{12}(j) = 0 \quad for\ j = 1,2,\dots$$

$$a_{21}(j) = \begin{cases} \dfrac{\beta}{1+(1-\theta)\beta} & j=0 \\ -\dfrac{\beta}{1+(1-\theta)\beta} & j=1 \\ 0 & j=2,3\dots \end{cases} \qquad a_{22}(j) = \begin{cases} \dfrac{1}{1+(1-\theta)\beta} & j=0 \\ \dfrac{(1-\theta)\beta}{1+(1-\theta)\beta} & j=1 \\ 0 & j=2,3\dots \end{cases}$$

expectations but include some learning mechanism in a more general setting, $X_t = \Sigma^{\infty}{}_{j=0}$ $A(j)\ e_t$ will still hold. Since X_t is stationary, it has a Wold-moving average representation[12]:

$$X_t = v_t + C(1)v_{t-1} + \dots = \sum_{j=0}^{\infty} C(j)v_{t-j}, \quad Var(v) = \Omega. \tag{III.8}$$

The Wold moving-average representation is unique. It can be obtained by first estimating the VAR coefficients, and then invert to get the moving average representation of X_t.

From the set up , we know $v_t = A(0)\ e_t$ and $A(j) = C(j)A(0)$. Thus knowledge of A(0) allows us to recover e_t from v_t, we can identify A(0) by the conditions: (i) $A(0)\ A(0)' = \Omega$ and (ii) Given $\Sigma^{\infty}{}_{j=0}\ C(j)$, the 2x1th element of matrix $\Sigma^{\infty}{}_{j=0}\ A(j)$ is zero, where $\Sigma^{\infty}{}_{j=0}\ A(j) = \Sigma^{\infty}{}_{j=0}\ C(j)\ A(0)$, which is the condition of absence of the long run effect of demand disturbances on output.

We estimated the bivariate autoregressive regression of current accounts to gnp ratio Y_t and change of production Z_t, using the same data set mentioned above.

$$\begin{aligned} Y_t &= \alpha_{0,1} + \sum_{i=1}^{k} \alpha_{i,1} Y_{t-i} + \sum_{i=1}^{k} \beta_{i,1} Z_{t-i} + u_{1,t} \\ Z_t &= \alpha_{0,2} + \sum_{i=1}^{k} \alpha_{i,2} Y_{t-i} + \sum_{i=1}^{k} \beta_{i,2} Z_{t-i} + u_{2,t} \end{aligned} \tag{III.9}$$

We use the Akaike Information Criterion (denoted as AIC) to identify the orders of the

12 Recently, Lippi and Reichlin (1990) argued that there are other representation besides the Wold representation used in Blanchard and Quah (1989)'s paper. In general economic theory does not provide sufficient information to identify the position of the roots (inside or outside the unit circle). They show that by choosing alternative representations the importance of demand shocks is considerably reduced.

VAR system[13]. Table 3 presents the AIC statistics, by minimizing the AIC statistics, we pick the order of VAR models of Canada, France, Italy, Japan, Germany, UK and US to be 9, 10, 8, 5, 2, 2 and 1 respectively.

V. Sources of External Fluctuations:

Table 4a and 4b give our VAR estimation results. In the last row of Table 4b, we report the augmented Dickey-Fuller unit root test for output. Only the US output is rejected at 5%. If we drop either the first year's observations or last year's observations from the US sample, we can not reject the presence of unit root. We do not apply the ADF tests on the current account ratios, but one can notice that the sum of lag coefficients of current account regressions are close to 0.9 except for France and Italy. Some may suggest the possibility of presence of unit roots, but we doubt whether it makes sense to perform the test for current account ratios, given that they are bounded. One may argue that the current account ratios can behave like an integrated process inside the bounds. Eventhough this is true, the available unit root tests are not based on this complicated processes, so it would be inappropriate to apply them here.

We also report the normality tests (although it is not quite necessary) and LM tests for serial disturbances. In the current account ratio equations, both tests do not reject this possibility at the 5% significance level. Whereas in the output equations, UK and US results reject both tests at the 5% level. By imposing two impulse dummies in the UK output equation at the first quarter of 1972 and 1974, the statistics of normality tests and the LM test are .02 and .56 respectively, and do not reject both tests. Similarly for the US, with a time dummy at 1975, the tests become insignificant. Given the R^2 statistics, it should

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13 AIC statistics are defined as

$$AIC(k) = N \log D(k) + 2n^2k,$$

where k is the order of the VAR system, N is the sample size, n is the dimensionality of the system and D(k) is the determinant of the covariance matrix of the residuals of the VAR model.

be noted that the explanatory power of the regressors for the German and UK output equation are very low.

By expressing VAR models in terms of infinite sum of moving averages, we can calculate the sum of moving average coefficients $\Sigma^{\infty}_{j=0}$ C(j) for the seven countries. By applying the above identification restrictions on estimated Ω and $\Sigma^{\infty}_{j=0}$ C(j), we can estimate the A(0) matrices. We report the estimates and estimated standard errors in Table 5. From the estimated matrix A(0), we can calculate the impulse response function of output and current account ratios with respect to demand and supply shocks.

The dynamic effects of demand (or transitory) and supply (or permanent) shocks on the current account ratios of the sample countries are plotted in Figures 1a-1f. We find that both permanent and transitory shocks have persistence effects on current accounts. However, the dynamic structures are quite different in different countries. Firstly, the responses of Japan and UK current accounts decline much faster than others. Secondly, the magnitude of the initial responses of the shocks on current accounts are different in different countries, ranging in magnitude from .2% to 2%. Thirdly, the timing of the maximum impact of the shocks are also different. Most of them have their maximum impacts in the initial period except the responses to transitory shocks of Canada, France and Japan and the response to permanent shocks of the US.

The most interesting thing we found is that initial responses of current accounts to a positive demand shocks, or transitory shocks, of all our sample countries except US, are opposite to those of outputs. It means that current accounts will be worsened when there are positive temporary shocks affecting their outputs, similar to the variable trend correlation in Table 1 (consistence with the RBC stylised facts). However, this is contradicted by the consumption smoothing argument of the model given above, where $a_{11}(0) > 0$ (However it is quite similar to RBC correlation in Table 1). By the Permanent Income Hypothesis, consumption is equal to permanent income. When there is a temporary increase in current income, one will anticipate a lower average future income, inducing agents to save up most of the increase in income; thus current accounts will improve when there are temporary shocks. One possible explanation for $a_{11}(0) < 0$ is the intertemporal price effect. Suppose there is a temporary decrease in exportable good prices in this period, the price will be likely go up in the next period. The real interest rate in terms of consumption will decrease, and one will substitute future consumption with current consumption. However, the price decrease will increase the real wealth, and future consumption will rise. As a whole, current consumption may rise if intertemporal elasticity is large enough. Besides, a price decrease will stimulate demand, raise investment and output. As long as the wealth effect is small, the current account will decrease.

We also find a positive effect of permanent shocks on the current account: $a_{12}(0) > 0$ for all sample countries except US. According to the Permanent Income Hypothesis, a permanent increase in income can stimulate less saving or more saving depending whether the increase is positively serially correlated. For example: the supply shock $s_t = s_{t-1} + e^P{}_t - \phi e^P{}_{t-1}$, then $a_{12}(0) = \gamma\{\phi - \beta(1-\theta)/[1+(1-\theta)\beta]\}$. Without analyzing the process of permanent disturbances, it seems nothing wrong with positive and negative estimates of $a_{12}(0)$ from our sample.

In Figures 2a-2f, we show the dynamic responses of output. Similar to current accounts, both shocks have persistent effects on output. But some of the responses are oscillated, whereas some of them are exponentially declining. The maximum impacts of demand or transitory shocks on output of all countries was reached within the first 6 periods ($1\frac{1}{2}$ years). However, the relative instantaneous responses to supply and demand shocks are quite different: France, Germany, UK and US outputs respond more to supply shocks, but Canada, Italy and Japan have similar responses to both shocks. Besides, all countries adjusted faster to the steady state than the US.

Having shown the dynamic effects of each type of shocks, we assess their relative contributions to fluctuations of current accounts and outputs. We do this by examining variances decompositions of current account ratios and outputs in transitory and permanent disturbances at various horizons. But first we examine the "demand" or the transitory components and the "supply" or the permanent components of the current account ratios and outputs. With our estimation result of the joint processes for the current account ratios and outputs, and the estimated A(0) matrices, we can form transitory components by setting the permanent disturbance to zero and vice versa. Besides, we assume that the mean of the transitory component is zero. The time-series for these components are constructed and shown in Figures 3a-3f and 4a-4f.

By examining into Figures 3a-3f, one can see that the UK has small variations in her permanent component of current accounts, whereas Canada and France have the biggest swings. Of the transitory components, Canada and the US have smaller swings than the others. Increasing Canadian, UK and US external deficits in the 80's is mainly due to deteriorating position in transitory components. It seems to me that different countries have experienced different types of sources of shocks in their current accounts during the 70's and 80's. Canada, France, Italy and the US have equally been affected by transitory and permanent disturbances, whereas Japan, Germany and the UK were more affected by "demand" shocks. Lastly we also find that the decreases in transitory components of the Canadian, French, UK and US current accounts in the 80's are corresponding to the increases in current account surpluses in Japanese and German transitory components. This supports the intuitive understanding of the close link between the seven industrial economies.

We abstract the permanent component of outputs from the "trend" components of outputs by the Hodrick and Prescott filter, and plot them with Hodrick and Prescott's detrended components, named "RBC detrended components", and our transitory components. As a result, the sum of permanent and transitory will equal the RBC detrended component. With the diagrams, one can see that in all countries neither the transitory nor the permanent components dominated the output fluctuations over the whole sample period. Any simple correlations amongst macro variables may induce biased interpretations. For example: consumption $c_t = u^p_t - a\, u^t_t$ and income $y_t = u^p_t + bu^t_t$, $1 > a,b > 0$ where u^p_t and u^t_t are technology and demand disturbances respectively. The correlation of c_t and y_t is less than one if the variances of u^p_t and u^t_t are equal. One may try to build a model to explain this "stylised" facts. Only French and US permanent components match quite well with the "cycles" obtained from the RBC detrended series. We found that Canadian, Italian, Japanese, German and the UK "cycles" are mainly due to transitory components during the 70's and 80's. One can also check with the variance decompositions, which estimates the percentage of variance of output fluctuations due to transitory disturbances. We reported them in Table 6a and 6b.

Tables 5a and 5b have the following interpretation. Define the j quarter-ahead forecast error in the current account ratio/output as the difference between the actual value of the current account/output and its forecast from equation (III.9) in the j quarter earlier. This forecast error is due to both unanticipated transitory and permanent shocks in the last j quarters. The number in the tables gives the percentage of variance of the j-ahead forecast error due to transitory shocks. The numbers in *Italic* are the estimated confidence intervals. Table 6a shows that "demand" disturbances have relative large contributions to current account fluctuations for all economies in the short run and long run, except Canada, which has a relatively small short run fluctuations due to "demand" disturbances. However, the relative contribution varies with the time horizon.

In Table 6b, our estimate of US output fluctuations due to "demand" shocks is only 5%, which contradicts the findings of Blanchard and Quah (1989) and Shapiro and Watson (1988)[14]. The differences may be due to the choices of output. We use an industrial production index whereas their studies use GNP series. With a counter-cyclical mark up, value added will be lower when economy is hit by a positive demand side shock. Rotemberg and Woodford (1989) give a similar story. Since industrial output index is measured with value-added approach, using GNP as output is more easy to capture the "demand" side effect than the industrial output index. Besides, other countries' relative contribution of "demand" disturbances on output fluctuations are much greater, at a four quarters horizon, than the US. Canada has 70%, France has 6%, Italy has 63%, Japan has 61%, Germany has 19% and the UK has 27%.

In Table 7, we calculate the correlation of different components of current account ratios and outputs. In the first row, we have the correlation between the permanent components and the change of those in outputs. The UK has the largest estimates and France has the smallest estimates. In the second row, we report the correlation between

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[14] Blanchard and Quah (1989) found that 40% of output fluctuations are due to "demand" disturbances in a one-year horizon in the case of no trend in unemployment, and no break in constant growth rate (p.667 Table 2C). Shapiro and Watson (1988) found that 28% of output fluctuations are due to "demand" disturbances in a one-year horizon in a case of a stochastic trend in hours of work supplied (p.128 Table 2).

the transitory components of the current account ratios and the level of those of outputs because the transitory components are stationary. We find large correlations in most of the sample countries except France, with only US giving a negative correlation coefficient. Comparing this with the "stylised facts" of cyclical regularity in RBC studies in section II, the counter-cyclical current account is only apparent in the US, not in other countries if we interpret the transitory components as the cycle component. Furthermore, we examine again the another "stylised" fact of RBC: the counter-cyclical price movement; we find that the US and France give no support to the stylised fact. Besides, it also do not support our monetary interpretation of the transitory disturbances. In followings, we look into the cross-country effects of the sources of business cycles.

Given the results from section III, we can calculate the cross-country correlation of the permanent and transitory disturbances. We can also examine the spillover effects of the shocks between countries. First from the A(0) matrices we estimated, we can decompose the residuals from the VAR regression into permanent and temporary disturbances by $v_t = A(0)\, e_t$, where v_t is the residual vector of VAR regressions and $e_t = [e^t_t, e^p_t]'$, where e^t_t and e^p_t are transitory and permanent disturbances respectively.

Tables 8a and 8b report the cross country contemporary correlation between transitory and permanent disturbances for the whole sample. One will notice that there is not much cross effects of transitory and permanent disturbances across countries. The highest correlations are the ones between Japan and Italy's permanent shocks and Japan and Germany's transitory shocks. Those high correlation coefficients may be due to some common factors, it would be wrong to interpret any causal relations from the results. Our findings do not support much co-movements between transitory or permanent components of outputs across countries. If one interprets transitory shocks as stabilization policy shocks, this will not show supporting evidence for international policy coordinations. If one interprets permanent shocks as technology shocks, not much support will be found on technology spillover in our studies.

VI. Conclusions:

We have reexamined two "stylised" facts proposed by RBC studies: (i) the counter-cyclical movement of external balances (ii) the cross country correlation of output changes in this section. Firstly, we find that the result of counter-cyclical movement of current accounts is very sensitive to the filtering method. Secondly, we find that a substantial proportion of movement of current accounts is due to demand disturbances (transitory disturbances). Thirdly, US counter-cyclical movements of the current accounts are mainly due to "supply" or permanent shocks, but we cannot find this in other countries. Lastly we find that the high correlation of output changes are not due to common "supply" or technology shocks. There is no evidence to support the conventional spillover effect of monetary and fiscal policies across countries.

Our study is only based on reduced form equations, we may miss out some important structure which may lead us to misidentify the disturbances as Hansen and Sargent (1990) mention. If agents have more information than the econometrician about the structure of the disturbances, there will be no way for us to identify the sources of fluctuations unless we have the same information set as the agents. It is the common problem of reduced form analysis. Unless we are quite satisfied with structural assumptions to identify the model, it seems that we have to live with these defects.

In our study, we find that the correlation between the transitory components of current accounts and output changes is negative in all sample countries except the US. The model above can not give appropriate explanations to the findings. One of the reasons may be due to the wrong interpretation of the transitory shocks as money shocks. In the same way, a single commodity RBC model cannot explain this puzzle either. If one views the demand side as a temporary preference shift from one good to others, it will generate some intertemporal price effects, which may enable us to explain the findings. The future research may have to focus more on the identifications of transitory disturbances. We suspects that RBC economists may have to incorporate more trade effects in their models in order to explain the properties of the external fluctuations.

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DATA DESCRIPTION APPENDIX

All series are from DATASTREAM and are quarterly data except stated.
SA: Seasonally Adjusted.
NSA: Non-seasonally Adjusted.
AN: Annual Rate.
Q: Quarter

Canada: Sample: 1969 Q1 - 1990 Q4.
Current Account Balance: SA, in mil. Canada $.
GDP: SA, in mil Canada $, AN.
GDP Deflator: SA, (1985=100).
Industrial Production: SA, (1985=100).

Current Account Ratio (%): 4*100*Current Account Balance/GDP.
Output Change (%): 100*[log(Industrial Production)-log(Industrial Production{-1})].
Real GNP: GDP/GDP Deflator/4.
Real Current Account: Current Account Balance/GDP Deflator.

France: Sample: 1973 Q1 - 1990 Q3.
Current Account Balance: NSA, in mil. FrF.
GDP: SA, in bil FrF, AN.
GDP Deflator: SA, (1980=100).
Industrial Production: SA, (1985=100).

Current Account Ratio (%): 4*100*Seasonally Adjusted Current Account Balance/GDP/1000.
Output Change (%): 100*[log(Industrial Production)-log(Industrial Production{-1})].
Real GDP: GDP/GDP Deflator/4.
Real Current Account: Seasonally Adjusted Current Account Balance/GDP Deflator/1000.
Notes: we use seasonal dummies for adjusting the current account series.

Italy: Sample: 1969 Q1 - 1990 Q2.
Current Account Balance: NSA, in bin. Lit.
GDP: SA, in bil Lit, AN.
GDP Deflator: SA, (1985=100).
Industrial Production: SA, (1985=100).

Current Account Ratio (%): 4*100*Seasonally Adjusted Current Account Balance/GDP.
Output Change (%): 100*[log(Industrial Production)-log(Industrial Production{-1})].
Real GDP: GDP/GDP Deflator/4.
Real Current Account: Seasonally Adjusted Current Account Balance/GDP Deflator.
Notes: we use seasonal dummies for adjusting the current account series.

Japan: Sample: 1970 Q1 - 1990 Q4.

Average Exchange Rate: Yen/US$.
Current Account Balance: SA, in mil. US$.
GNP: SA, in bil Yen, AN.
GNP Deflator: SA, (1985=100).
Industrial Production: SA, (1985=100).

Current Account Ratio (%): 4*100*Current Account Balance*
Average Exchange Rate/GNP/1000.
Output Change (%): 100*[log(Industrial Production)-
log(Industrial Production{-1})].
Real GNP: GNP/GNP Deflator/4.
Real Current Account: Current Account Balance*Average Exchange Rate/GNP
Deflator/1000.

West Germany: Sample: 1970 Q1 - 1990 Q4.
Current Account Balance: SA, in bil. DM.
GNP: SA, in bil DM, AN.
GNP Deflator: SA, (1985=100).
Industrial Production: SA, (1985=100).

Current Account Ratio (%): 4*100*Current Account Balance/GNP.
Output Change (%): 100*[log(Industrial Production)-
log(Industrial Production{-1})].
Real GNP: GNP/GNP Deflator/4.
Real Current Account: Current Account Balance/GNP Deflator.

United Kingdom: Sample: 1970 Q1 - 1990 Q4
Current Account Balance: SA, in mil. £.
GDP: SA, in mil. £, AN.
GDP Deflator: SA, (1985=100).
Industrial Production: SA, (1985=100).

Current Account Ratio (%): 4*100*Current Account Balance/GDP.
Output Change (%): 4*100*[log(Industrial Production)-
log(Industrial Production{-1})].
Real GDP: GDP/GDP Deflator/4.
Real Current Account: Current Account Balance/GDP Deflator.

United States: Sample: 1970 Q1 - 1990 Q3.
Current Account Balance: SA, in mil. US$.
GNP: SA, in bil US$, AN.
GNP Deflator: SA, (1985=100).
Industrial Production: SA, (1985=100).

Current Account Ratio (%): 4*100*Current Account/GNP/1000.
Output Change (%): 4*100*[log(Industrial Production)-
log(Industrial Production{-1})].
Real GNP: GNP/GNP Deflator/4.
Real Current Account: 4*Current Account Balance/GNP Deflator.

Table 1: Correlations between Current Account Ratios and Fluctuations of Industrial Production

Country	Stochastic Trend	Variable Trend	Linear Trend
Canada	.174	-.340	-.595
France	-.010	-.204	-.113
Italy	-.003	-.286	-.280
Japan	.162	-.275	-.300
Germany	.098	-.061	-.036
UK	.034	-.293	-.514
US	-.185	-.138	-.086

Notes: CN:Canada, FR:France, IT:Italy, JP:Japan, BD:Germany, UK:United Kingdom, US:United States.

Table 2a: Cross-country Correlations in Fluctuations of Industrial Production (Variable Trend)

	CN	FR	IT	JP	BD	UK	US
CN	1						
FR	.47	1					
IT	.57	.76	1				
JP	.60	.74	.70	1			
BD	.64	.77	.67	.83	1		
UK	.23	.60	.33	.53	.60	1	
US	.18	.13	.26	.26	.27	.23	1

Notes: CN:Canada, FR:France, IT:Italy, JP:Japan, BD:Germany, UK:United Kingdom, US:United States

Table 2b: Cross-country Correlations in
Fluctuations of Industrial Production
(Stochastic Trend)

	CN	FR	IT	JP	BD	UK	US
CN	1						
FR	.29	1					
IT	.33	.45	1				
JP	.41	.49	.47	1			
BD	.24	.53	.34	.46	1		
UK	-.09	.30	.22	.14	.37	1	
US	-.07	-.06	.09	.08	-.04	-.03	1

Notes: CN:Canada, FR:France, IT:Italy, JP:Japan, BD:Germany, UK:United Kingdom, US:United States.

Table 2c: Cross-country Correlations in
Fluctuations of Industrial Production
(Linear Trend)

	CN	FR	IT	JP	BD	UK	US
CN	1						
FR	.48	1					
IT	.60	.81	1				
JP	.36	.68	.61	1			
BD	.66	.83	.76	.75	1		
UK	.49	.56	.37	.44	.65	1	
US	.31	.34	.45	.35	.46	.30	1

Notes: CN:Canada, FR:France, IT:Italy, JP:Japan, BD:Germany, UK:United Kingdom, US:United States

Table 3: Identifications of the Order of Vector Autoregressive Processes of G7 Current Account GNP Ratios and Output Changes

Order	CN	FR	IT	JP	BD	UK	US
k	Akaike Information Criterion AIC(k)						
1	-110.2	223	-1342	-30.5	-1468	-1370	**-91.2**
2	-102.6	224	-1352	-25.5	**-1469**	**-1374**	-85.0
3	-96.1	229	-1382	-20.7	-1465	-1367	-80.6
4	-98.3	228	-1387	-30.9	-1459	-1367	-75.1
5	-93.0	224	-1390	**-36.7**	-1455	-1364	-68.6
6	-84.1	219	-1389	-32.1	-1453	-1355	-71.6
7	-92.4	205	-1394	-28.7	-1449	-1350	-76.0
8	-95.0	197	**-1397**	-29.9	-1444	-1360	-79.2
9	**-110.7**	194	-1389	-28.8	-1437	-1364	-72.2
10	-104.8	**190**	-1387	-21.5	-1431	-1362	-64.6

Notes: CN:Canada, FR:France, IT:Italy, JP:Japan, BD:Germany, UK:United Kingdom, US:United States

Table 4a: VAR Regressions of G7 Current Account GNP Ratios

	CN	FR	IT	JP	BD	UK	US
constant	.37	-1.12	-.10	.17	.14	-.02	-.03
	1.77	*-2.13*	*-.65*	*1.93*	*1.10*	*-.17*	*-.69*
Sum of CAR(j)	.92	.33	.62	.94	.92	.87	.96
	.00	*.00*	*.00*	*.00*	*.05*	*.00*	*.00*
Sum of DLQ(j)	-.58	3.24	.13	-.10	.01	-.14	-.04
	.07	*.23*	*.33*	*.02*	*.77*	*.17*	*.05*
DW	1.9	2.1	2.0	2.0	1.9	2.0	1.9
$RBAR^2$	.75	.53	.66	.90	.81	.72	.94
k	9	10	8	5	2	2	1
Normality Test	.99	.89	.90	.09	.22	1.76	.08
LM-Test	.10	.17	.43	.26	.80	.53	.22

NOTES: Numbers in *italics* are the t-statistics for the constant and signif. level of F-test for the test of the sum of coefficients; LM(9,n) tests for order 9 of serial correlations of residuals except FR with order 7, where the n=41 for CN, n=25 for FR, n=42 for IT, n=49 for JP, n=58 for BD and UK, and n=60 for US; k is the order of VAR.

Table 4b: VAR Regressions of the Changes of G7 Outputs

	CN	FR	IT	JP	BD	UK	US
constant	.73	.56	1.38	.48	.27	.34	.31
	2.87	*2.38*	*3.42*	*1.93*	*1.08*	*1.28*	*1.34*
Sum of	.18	.06	.88	.17	.06	.14	-.05
CAR(j)	*.21*	*.49*	*.03*	*.13*	*.05*	*.02*	*.73*
Sum of	.30	-.28	-1.18	.32	.18	-.04	.47
DLQ(j)	*.00*	*.37*	*.14*	*.00*	*.42*	*.96*	*.00*
DW	2.0	1.9	2.0	1.87	2.1	2.1	1.8
$RBAR^2$	.36	.15	.25	.49	.04	.05	.21
k	9	10	8	5	2	2	1
Normality Test	.57	.30	.98	.75	1.92	17.0	29.7
LM-Test	.35	.31	.88	.61	.92	1.62	1.90
ADF(k) Test	-2.8	-2.1	-2.3	-2.5	-1.9	-2.7	-3.5

NOTES: Numbers in *italics* are the t-statistics for the constant and signif. level of F-test for the test of the sum of coefficients; LM(9,n) tests for order 9 of serial correlations of residuals except FR with order 7, where the n=41 for CN, n=25 for FR, n=42 for IT, n=49 for JP, n=58 for BD and UK, and n=60 for US; ADF is an augmented Dickey-Fuller test where k is the number of lags and the order of VAR.

Table 5: Estimated A(0) Matrices

	CN	FR	IT	JP	BD	UK	US
$a_{11}(0)$	-.23	-2.1	-.76	-.36	-.71	-.95	.30
	.03	*.20*	*.06*	*.03*	*.07*	*.08*	*.03*
$a_{12}(0)$	.49	.50	.45	.30	.38	.44	-.13
	.05	*.30*	*.10*	*.05*	*.16*	*.12*	*.05*
$a_{21}(0)$	.54	.18	1.7	.94	.56	1.0	.38
	.05	*.03*	*.16*	*.09*	*.11*	*.12*	*.19*
$a_{22}(0)$	.37	1.0	1.4	.95	1.5	2.0	1.6
	.07	*.10*	*.25*	*.15*	*.15*	*.20*	*.14*

NOTE: Numbers in *italics* are estimated standard error.

Table 6a: Variance Decomposition of G7
Current Account GNP Ratios

Percentage of Variance Due to Transitory Disturbances							
Country	CN	FR	IT	JP	BD	UK	US
Horizon Quarter							
0	18.8	94.8	74.0	58.6	77.7	82.5	84.2
	9,35	*70,99*	*46,92*	*34,82*	*40,99*	*58,96*	*55,99*
1	25.0	93.6	74.9	76.3	75.0	86.8	75.7
	13,35	*68,99*	*48,92*	*52,92*	*38,99*	*64,97*	*47,96*
2	35.7	84.3	73.3	81.3	75.6	90.1	70.2
	20,43	*57,96*	*46,91*	*58,95*	*38,99*	*70,98*	*41,93*
3	44.7	75.8	75.5	83.0	75.6	91.6	66.5
	27,65	*48,91*	*49,92*	*60,96*	*38,99*	*72,98*	*38,91*
4	50.2	71.6	76.7	84.3	75.7	92.4	64.1
	31,70	*44,89*	*50,93*	*61,96*	*38,99*	*74,98*	*36,89*
10	58.7	59.4	69.3	87.6	75.9	93.8	58.9
	39,75	*35,80*	*44,88*	*66,98*	*38,99*	*77,99*	*31,86*
20	67.2	55.9	67.3	87.9	76.0	94.1	56.5
	49,79	*35,73*	*47,80*	*66,98*	*38,99*	*77,99*	*30,85*
40	67.3	55.7	67.2	87.9	76.0	94.1	55.6
	51,78	*35,73*	*46,80*	*67,98*	*38,99*	*77,99*	*29,84*
80	67.3	55.7	67.2	87.9	76.0	94.1	55.4
	51,78	*35,73*	*46,80*	*67,98*	*38,99*	*77,99*	*29,84*

NOTE: Numbers in *italics* are estimated confidence intervals.

Table 6b: Variance Decomposition of
the Changes in G7 Outputs

Percentage of Variance Due to Transitory Disturbances							
Country	CN	FR	IT	JP	BD	UK	US
Horizon Quarter							
0	67.1	3.1	60.1	49.4	11.7	21.7	5.1
	59,78	*2,4*	*53,71*	*44,57*	*6,15*	*20,22*	*0,13*
1	66.4	4.5	59.1	48.9	18.0	25.5	4.9
	64,83	*4,5*	*52,70*	*43,57*	*18,18*	*24,29*	*0,13*
2	71.9	4.9	59.9	47.8	18.2	26.6	4.8
	65,84	*4,6*	*53,71*	*42,56*	*18,19*	*24,31*	*0,13*
3	72.6	5.2	62.7	48.4	18.2	26.7	4.8
	63,81	*4,7*	*55,75*	*43,57*	*18,19*	*24,31*	*0,13*
4	70.1	5.9	62.8	48.9	18.3	27.0	4.8
	63,81	*5,8*	*55,75*	*42,59*	*18,19*	*24,32*	*0,13*
10	69.5	15.5	68.0	60.5	18.5	27.8	4.8
	62,80	*10,26*	*58,81*	*52,72*	*18,20*	*25,33*	*0,13*
20	67.5	15.4	66.6	61.4	18.8	28.0	4.9
	60,78	*9,26*	*56,81*	*53,73*	*18,20*	*25,34*	*0,13*
40	67.8	15.8	66.6	61.5	18.8	28.0	4.9
	61,78	*10,27*	*56,81*	*53,73*	*18,21*	*25,34*	*0,13*
80	67.8	15.8	66.6	61.5	18.8	28.0	5.0
	61,78	*10,27*	*56,81*	*53,73*	*18,21*	*25,34*	*0,13*

NOTE: Numbers in *italics* are estimated confidence intervals.

Table 7: Correlation of the Different Components of G7 Current Account GNP Ratios and Outputs

	CN	FR	IT	JP	BD	UK	US
$\rho(CA^p, \Delta Q^p)$	.58	.18	.36	.72	.46	.80	-.25
$\rho(CA^t, Q^t)$	-.90	-.17	-.85	-.81	-.95	-.98	.98
$\rho(P^t, Q^t)$	-.38	.00	-.16	-.28	-.19	-.40	.19

Table 8a: Cross-country Correlations of the Permanent Disturbances

	CN	FR	IT	JP	BD	UK	US
CN	1						
FR	-.01	1					
IT	-.15	.04	1				
JP	.11	-.04	-.29*	1			
BD	-.09	.12	.11	.00	1		
UK	-.08	.26	.11	.03	.27	1	
US	.18	-.17	-.02	.03	-.11	-.11	1

Table 8b: Cross-country Correlations of the Transitory Disturbances

	CN	FR	IT	JP	BD	UK	US
CN	1						
FR	-.12	1					
IT	.03	.08	1				
JP	-.08	.07	.08	1			
BD	.03	-.12	.21	.26*	1		
UK	-.18	.00	-.03	-.08	.06	1	
US	-.22	.16	.15	.07	.20	.17	1

Figure 1.a: Dynamic Responses of Current Account Ratio to Shocks

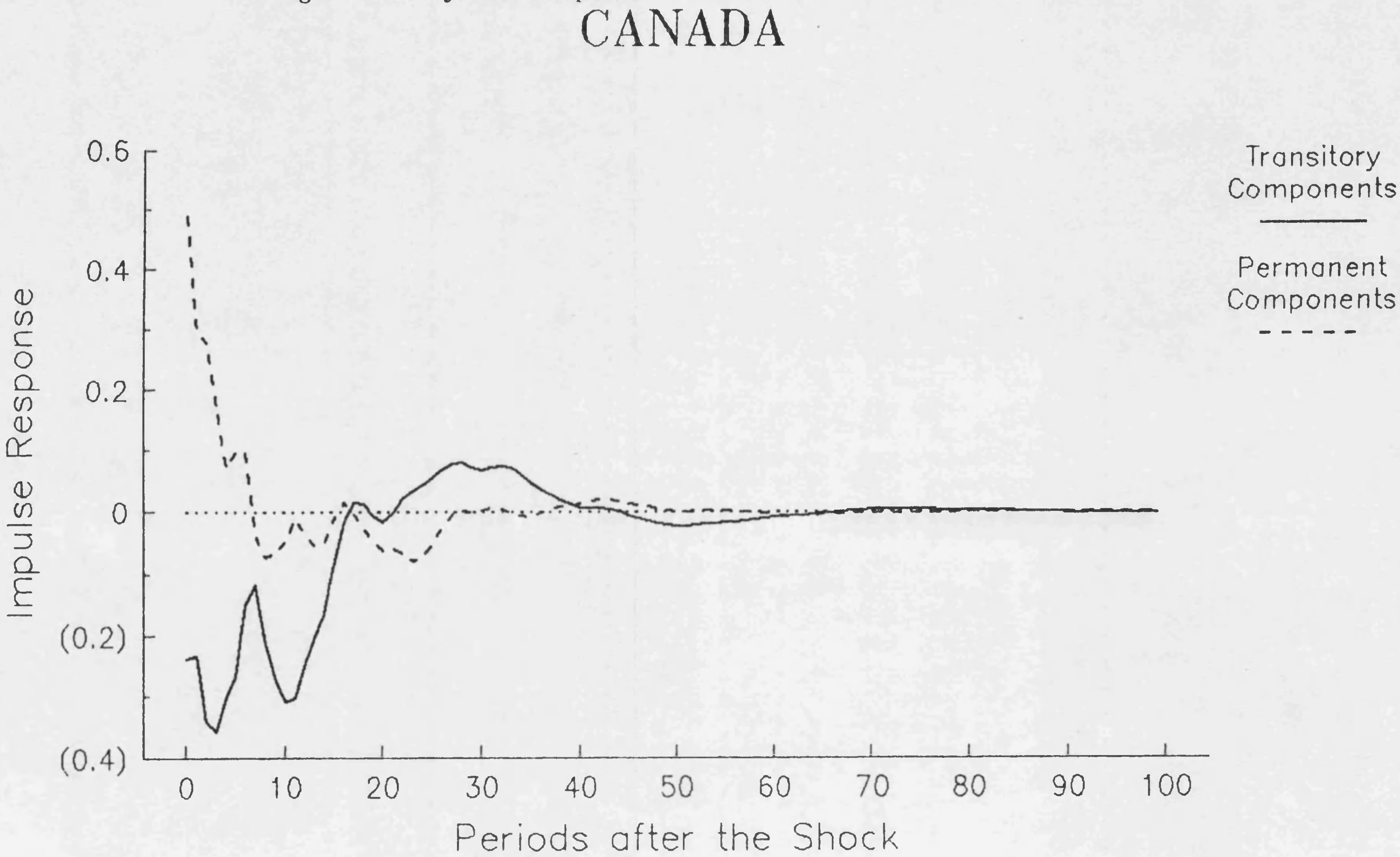


Figure 1.b: Dynamic Responses of Current Account Ratio to Shocks

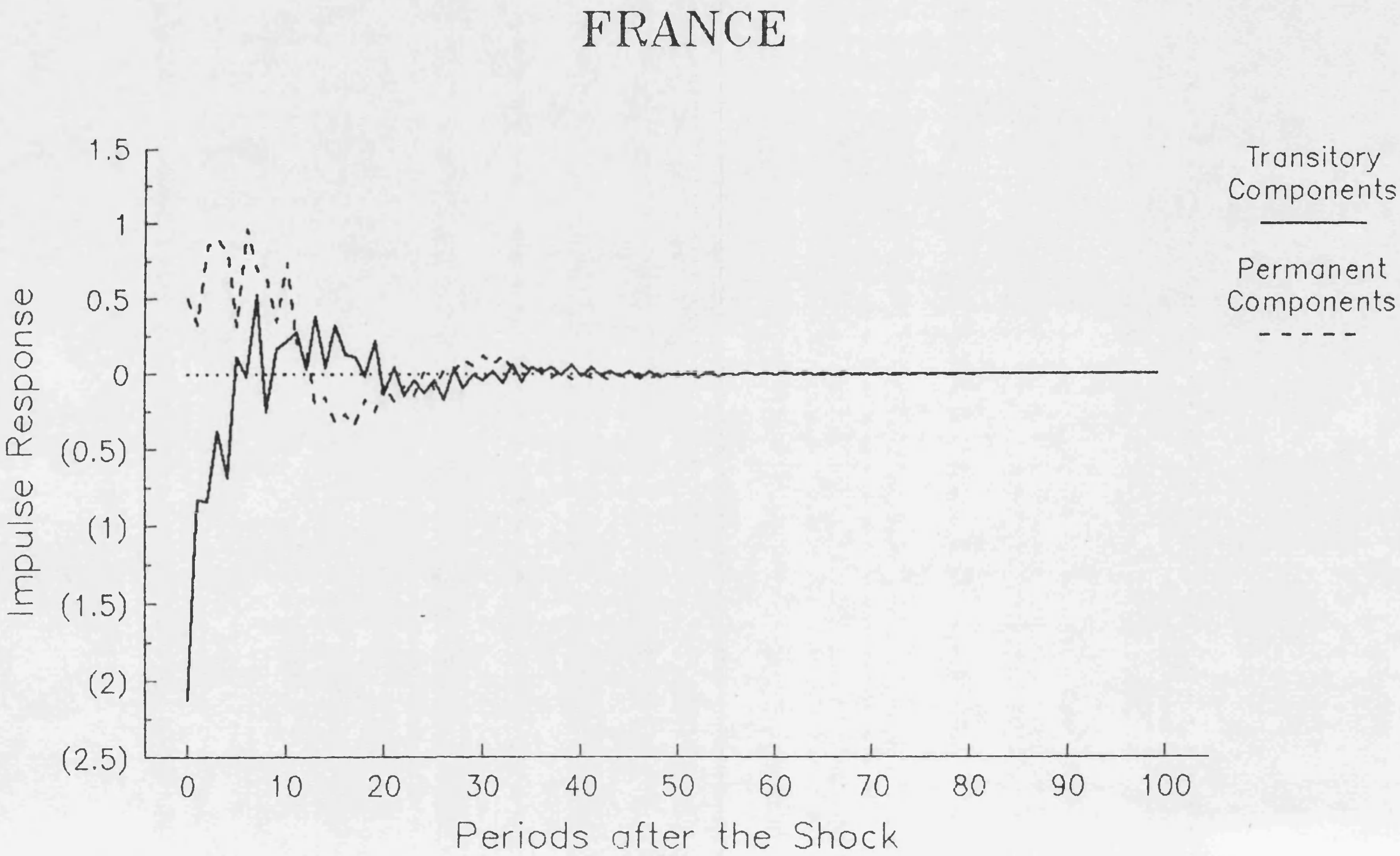


Figure 1c: Dynamic Responses of Current Account Ratio to Shocks

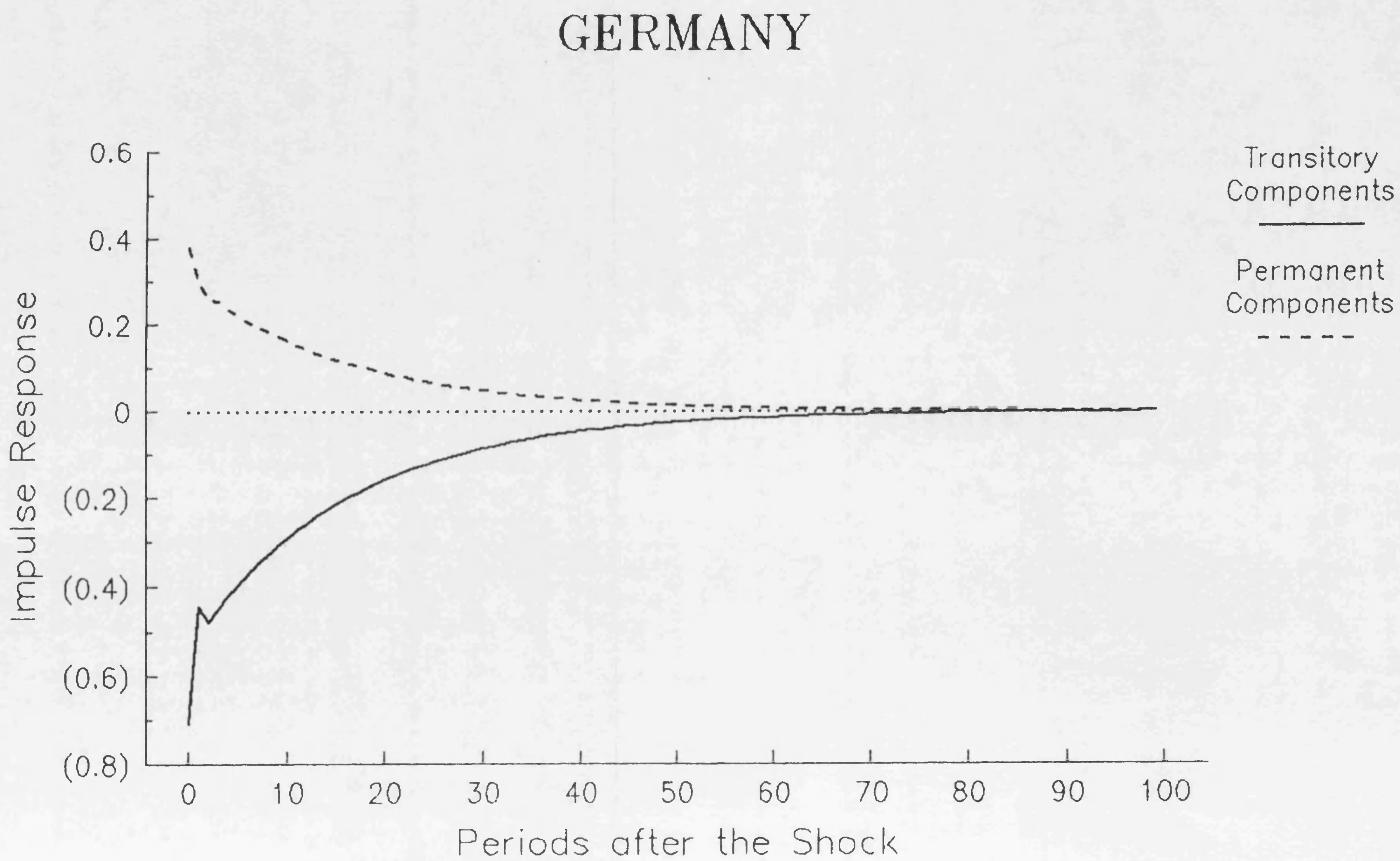


Figure 1.d: Dynamic Responses of Current Account Ratio to Shocks

ITALY

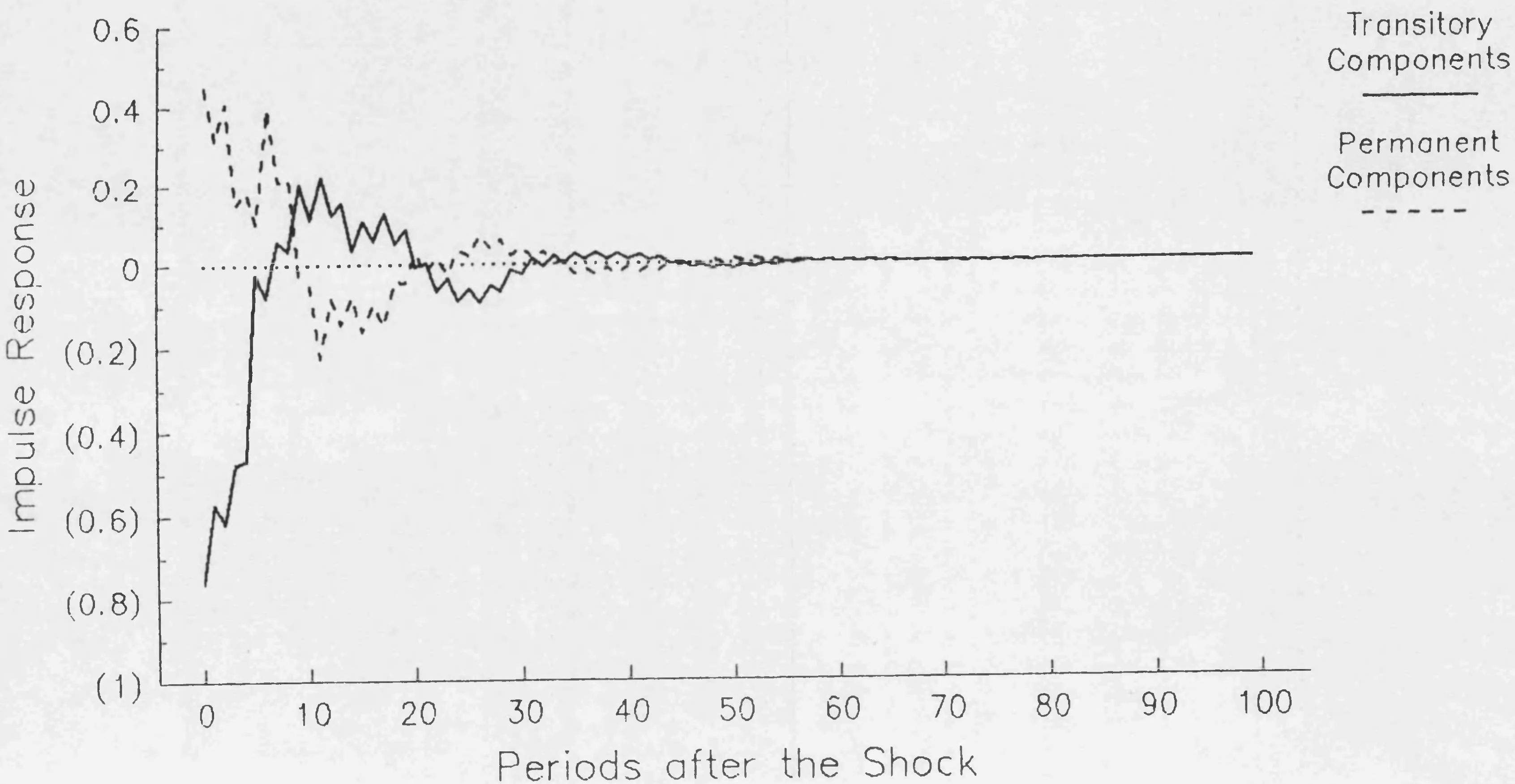


Figure 1.e: Dynamic Responses of Current Account Ratio to Shocks

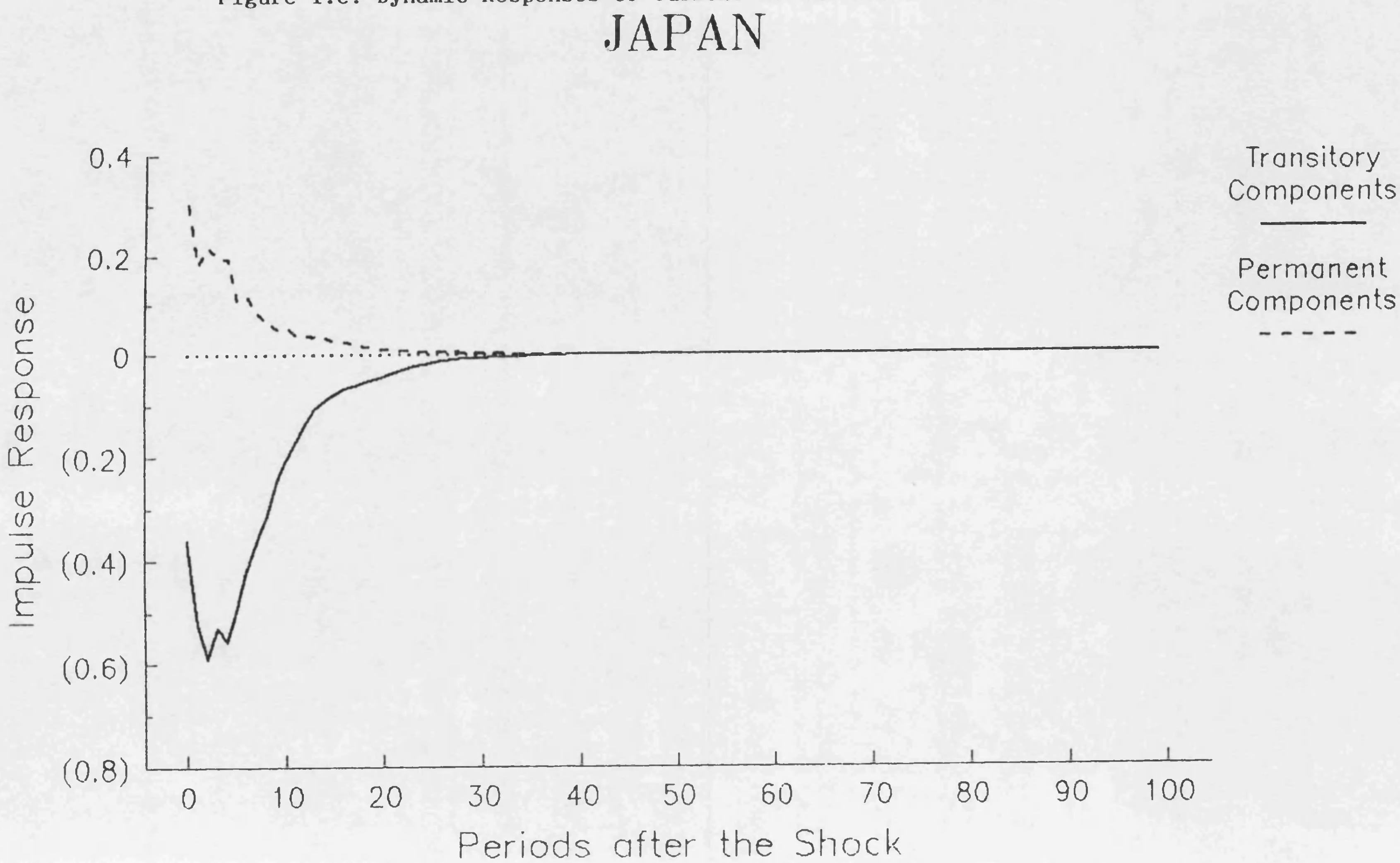


Figure 1f: Dynamic Responses of Current Account Ratio to Shocks

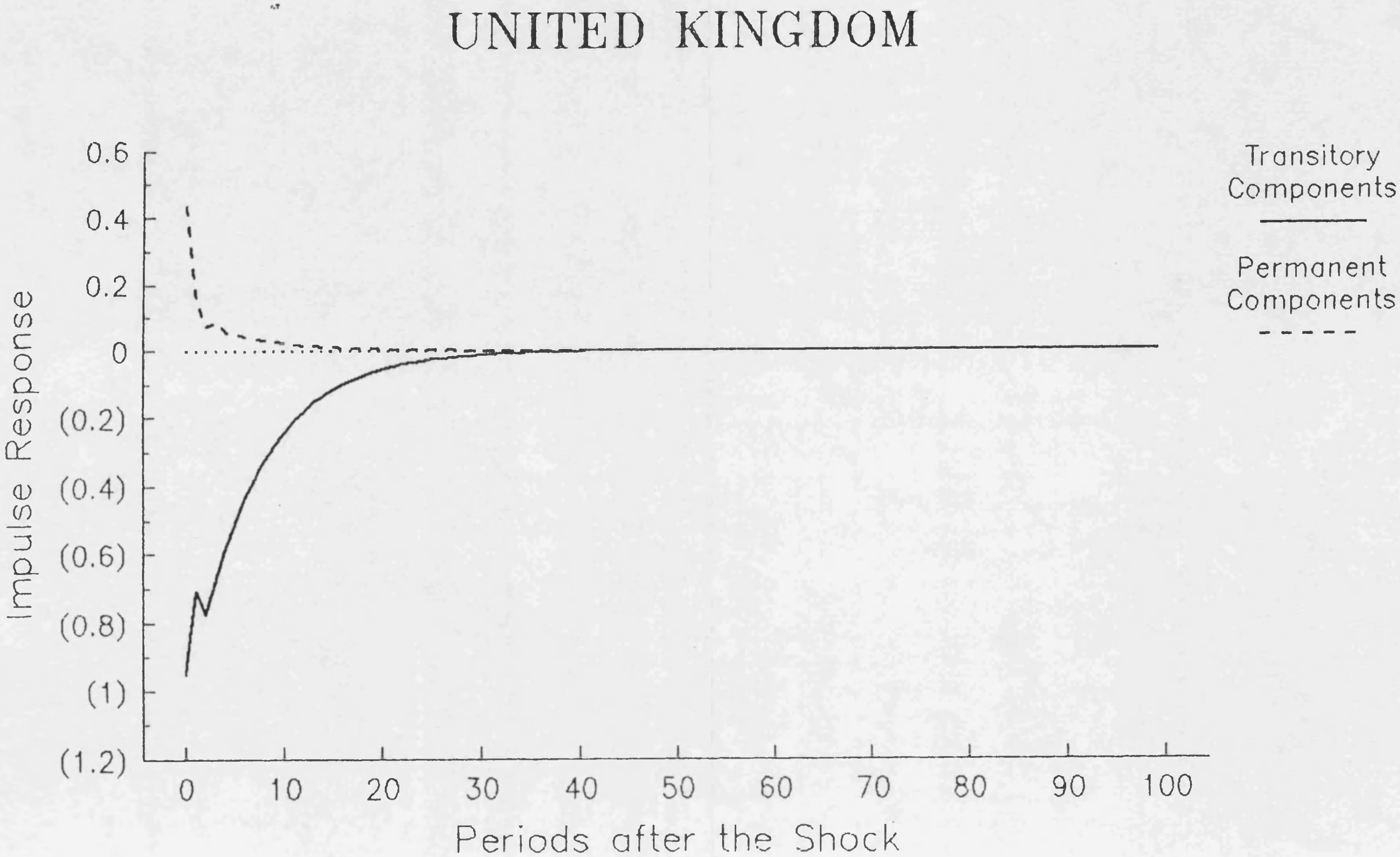


Figure 1.g: Dynamic Responses of Current Account Ratio to Shocks

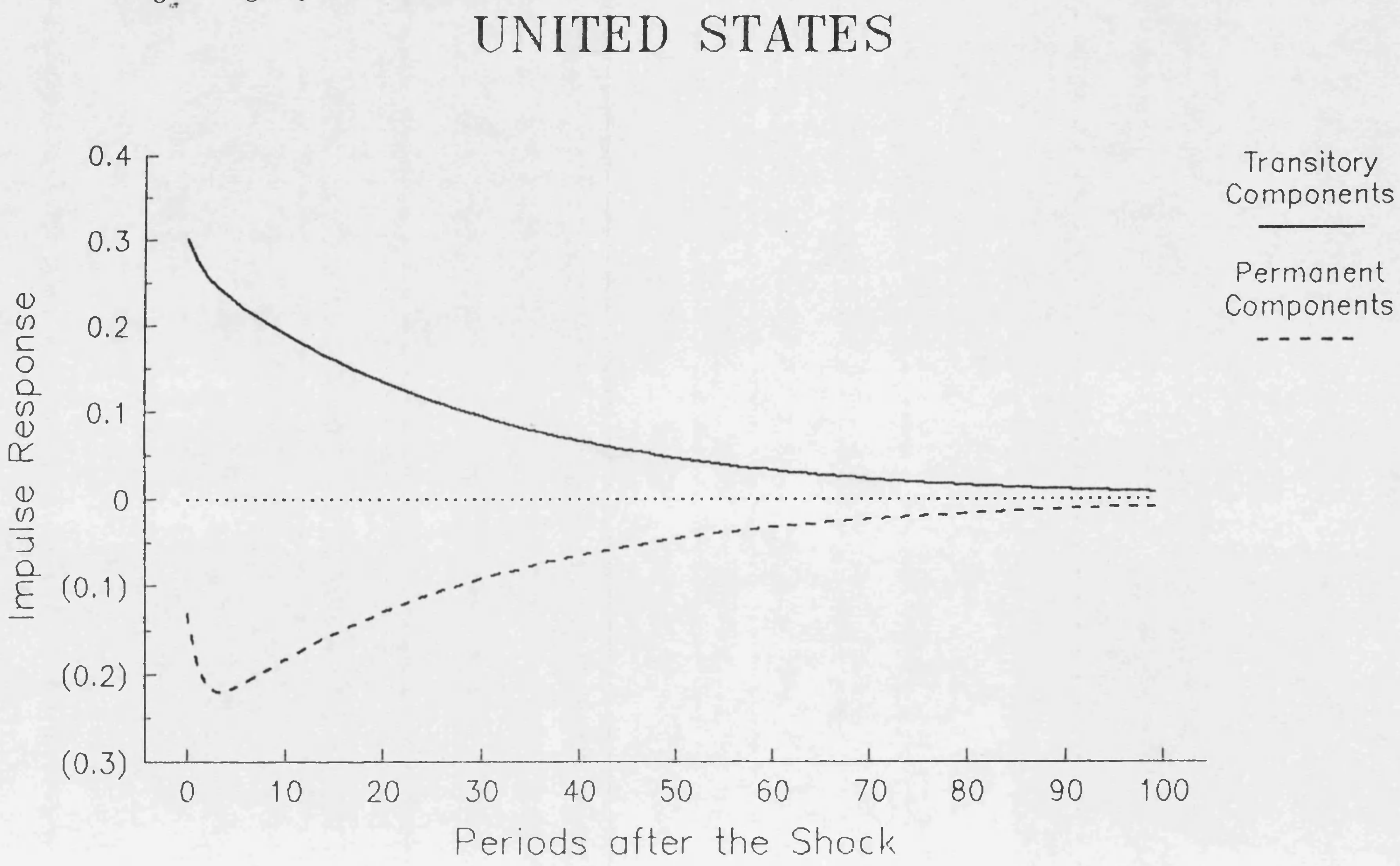


Figure 2.a: Dynamic Responses of Output to Shocks

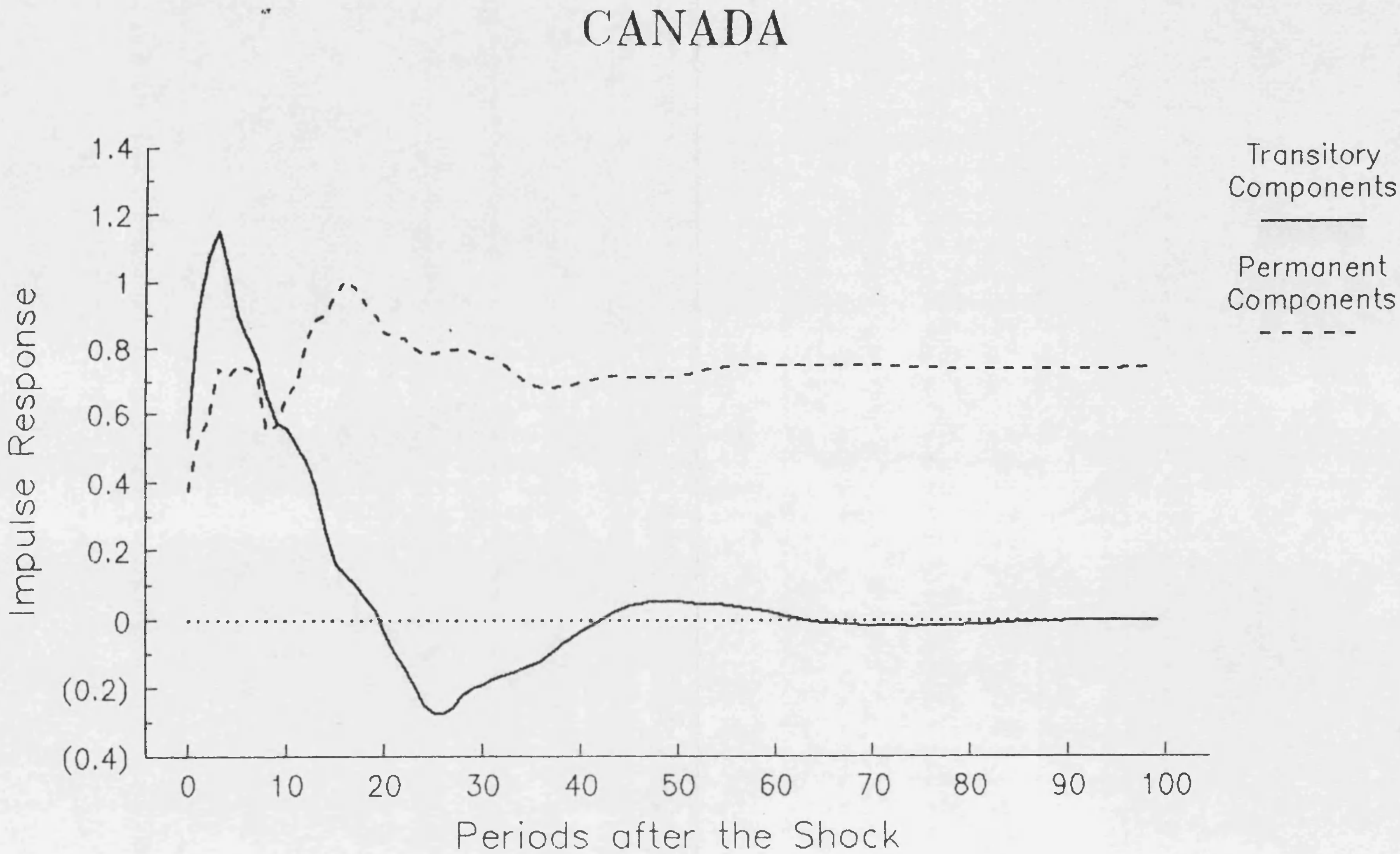


Figure 2.b: Dynamic Responses of output to Shocks

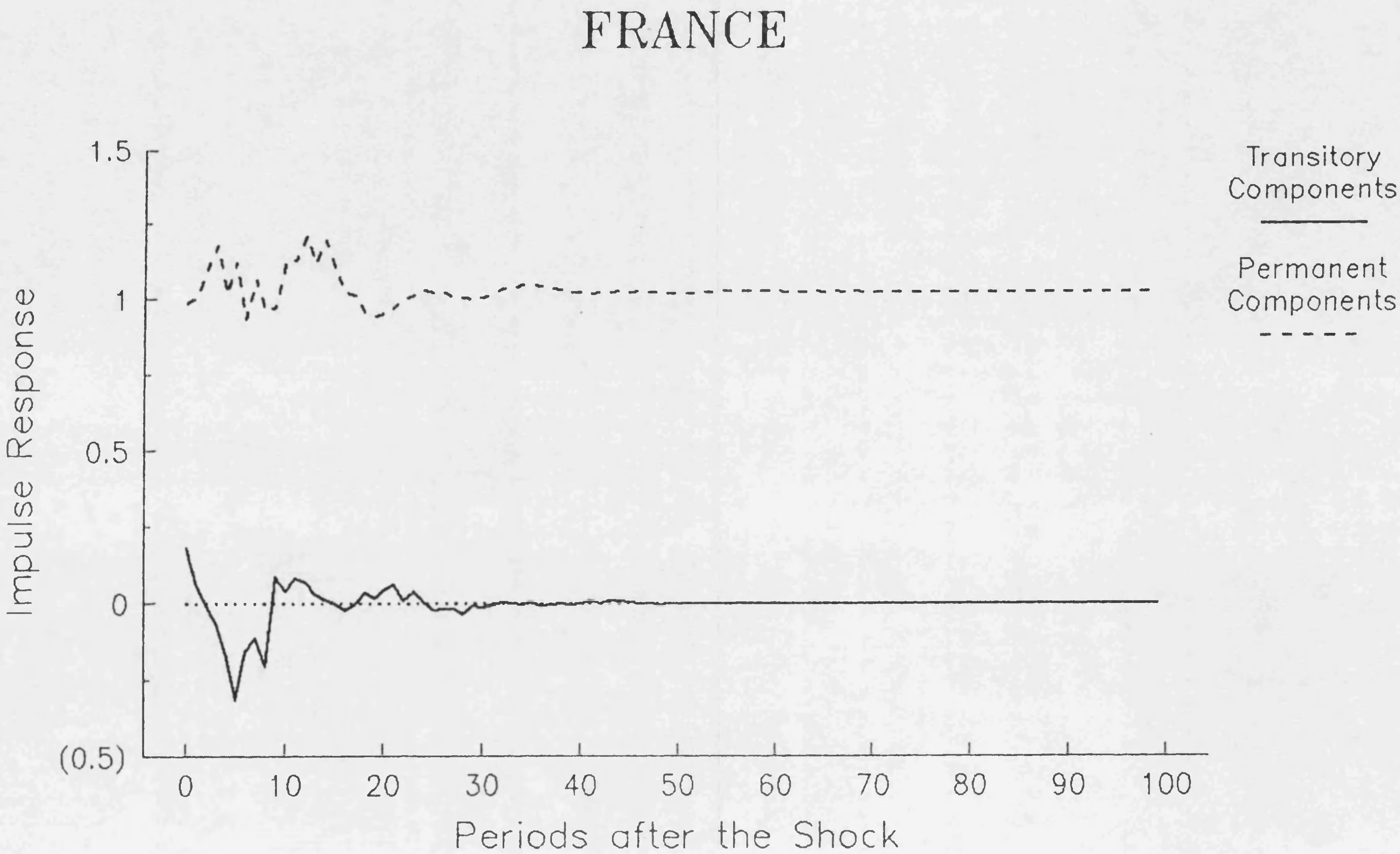


Figure 2.c: Dynamic Responses of Output to Shocks

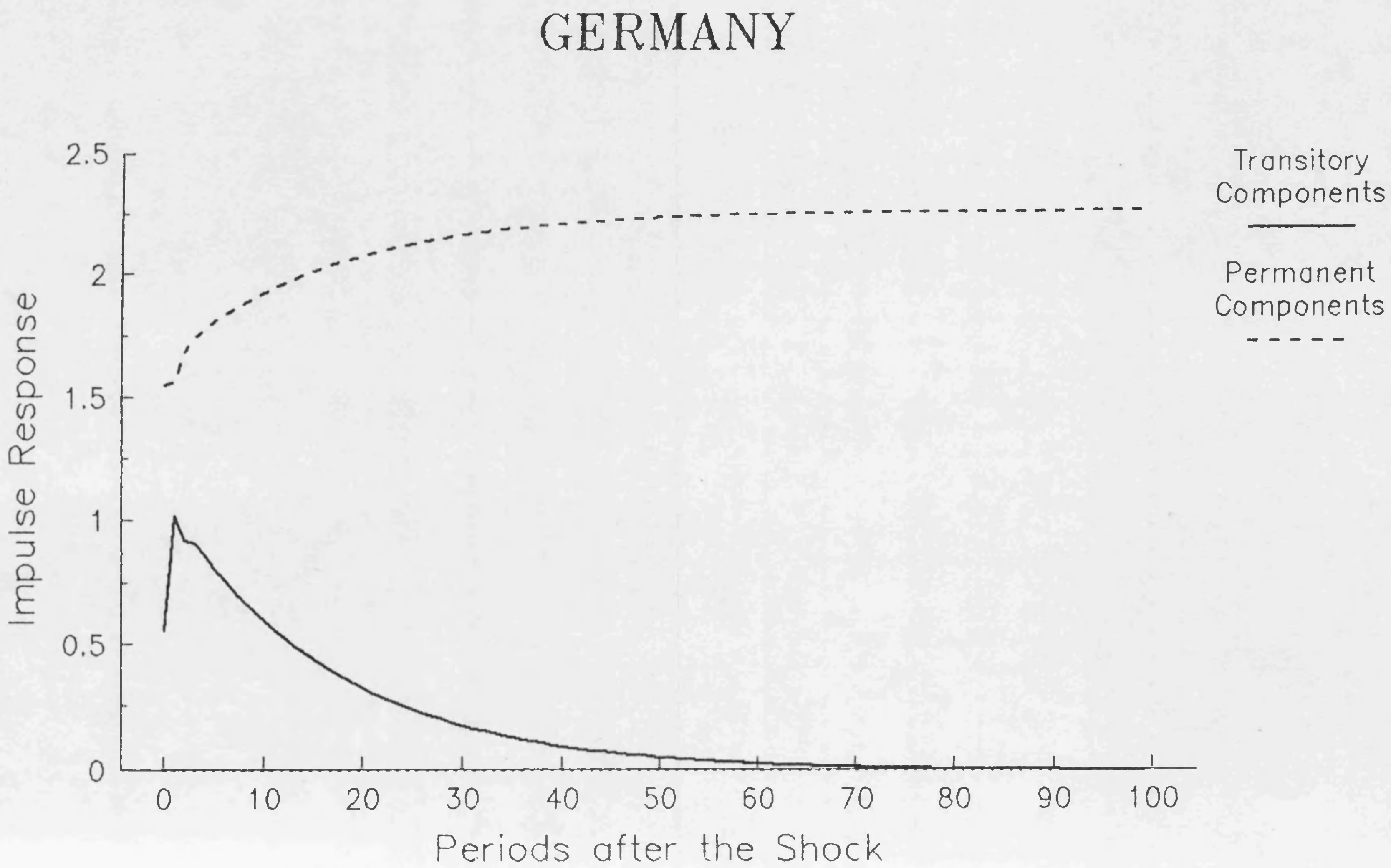


Figure 2.d: Dynamic Responses of Output to Shocks

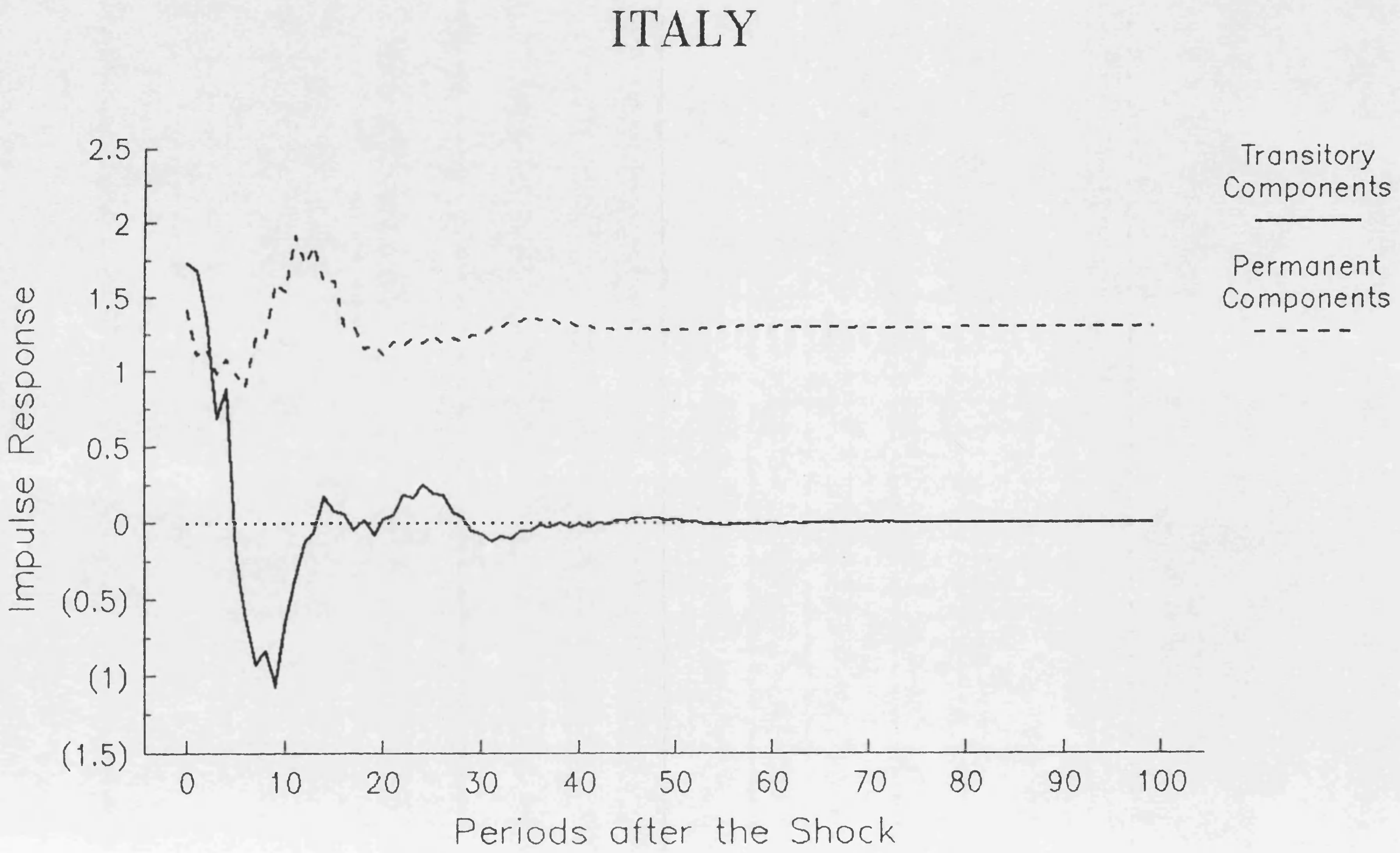


Figure 2.e: Dynamic Responses of Output to Shocks

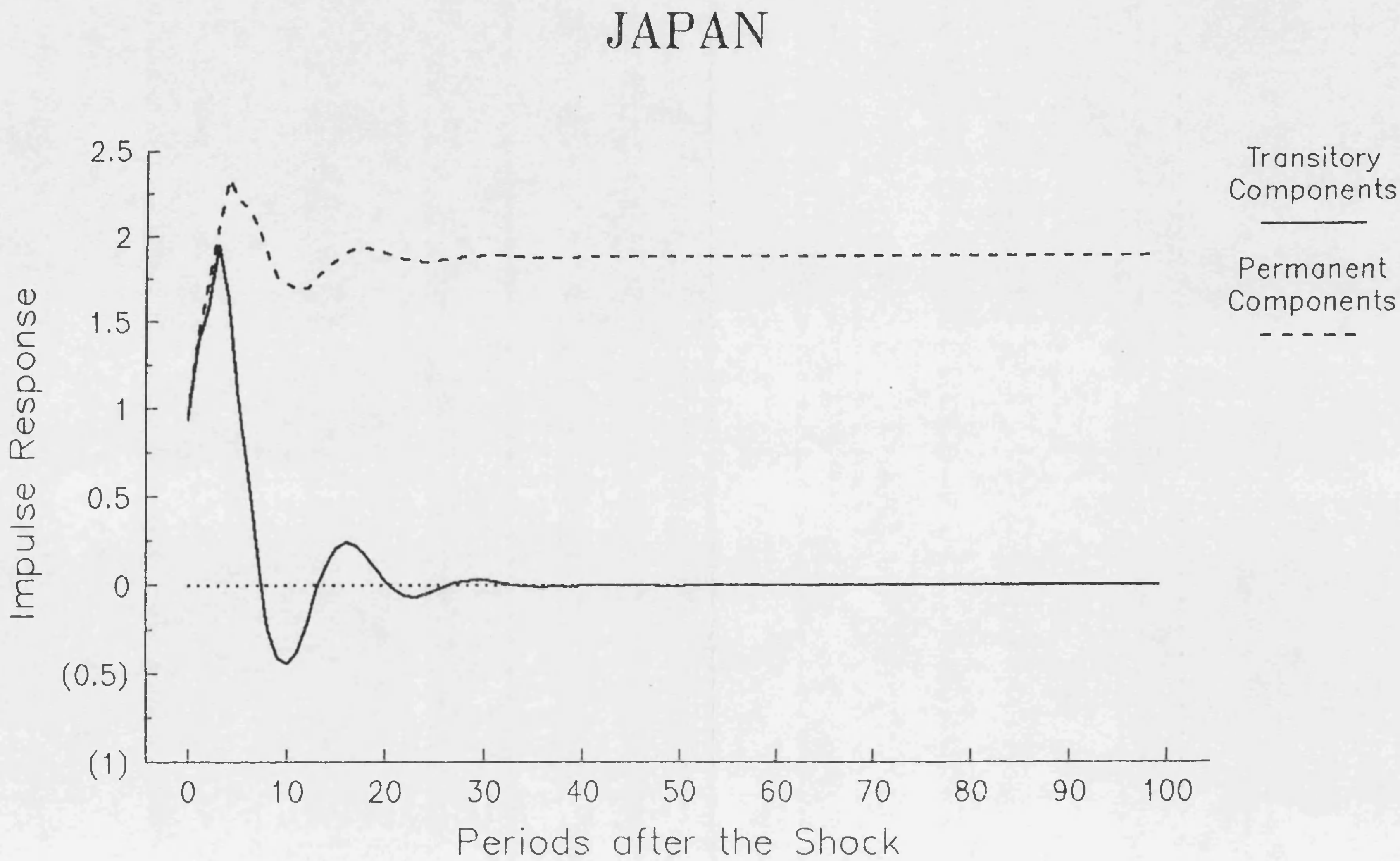


Figure 2.f: Dynamic Responses of Output to Shocks

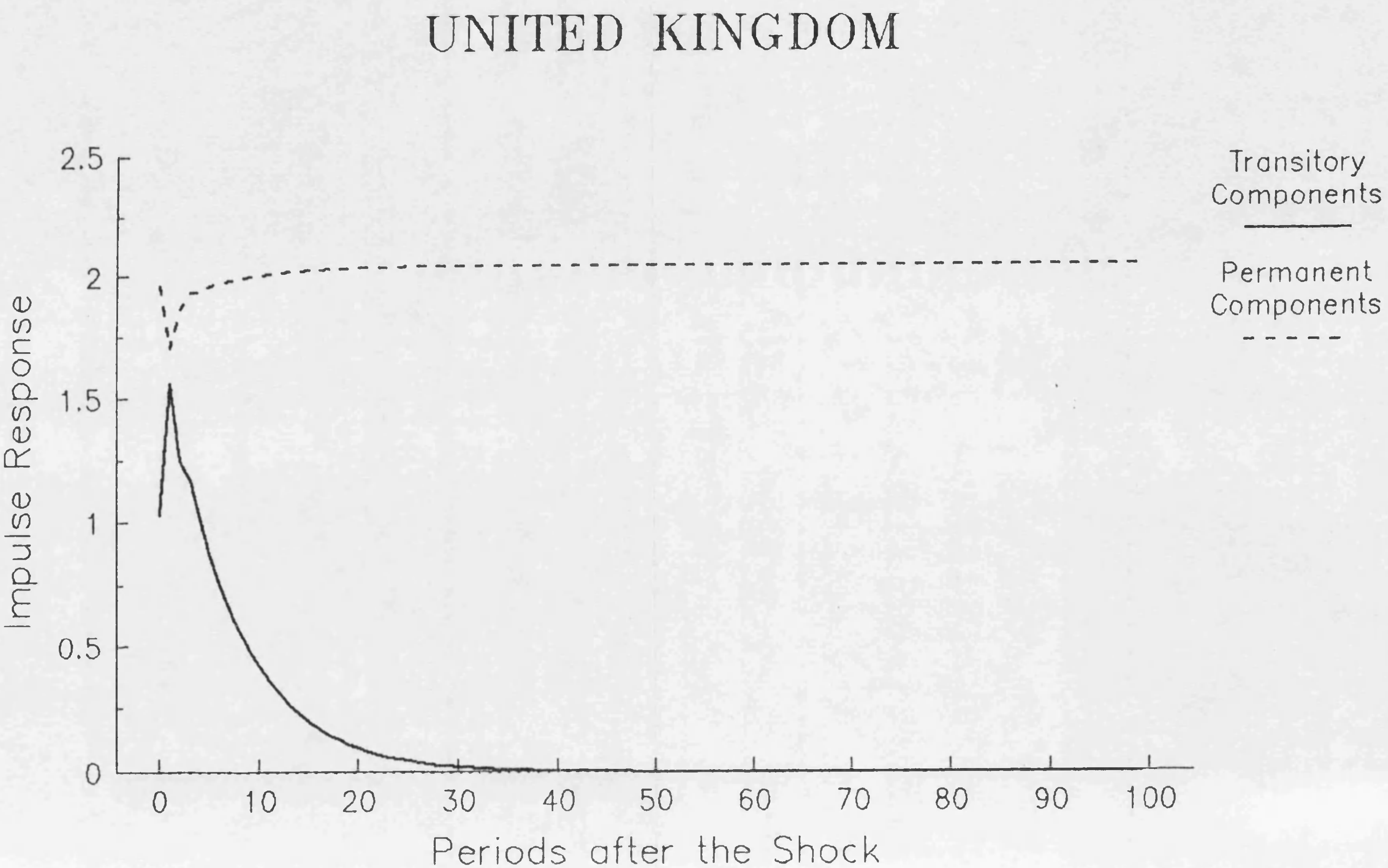


Figure 2.g: Dynamic Responses of Output to Shocks

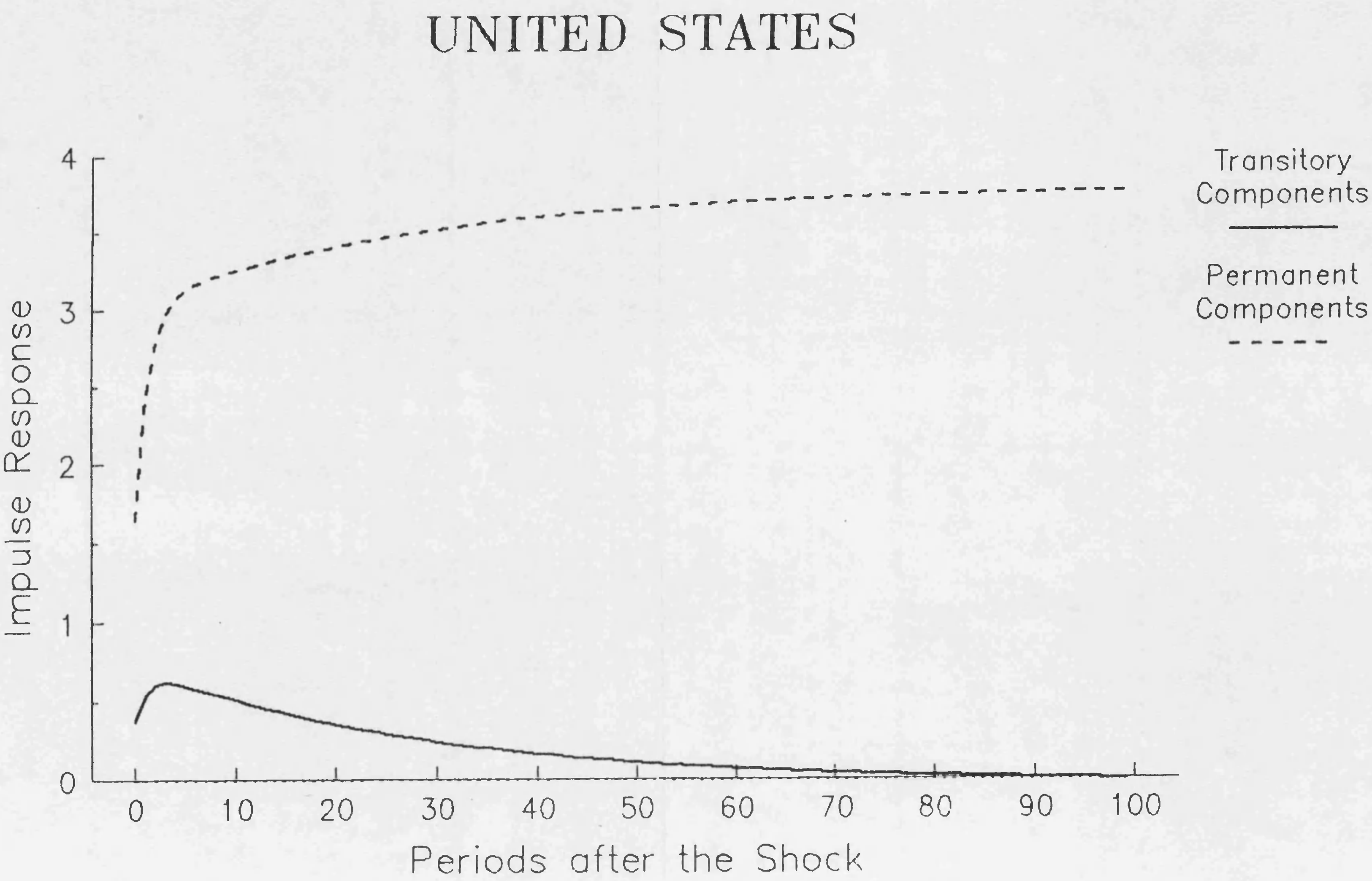


Figure 3.a: Permanent and Transitory Components of Current Account

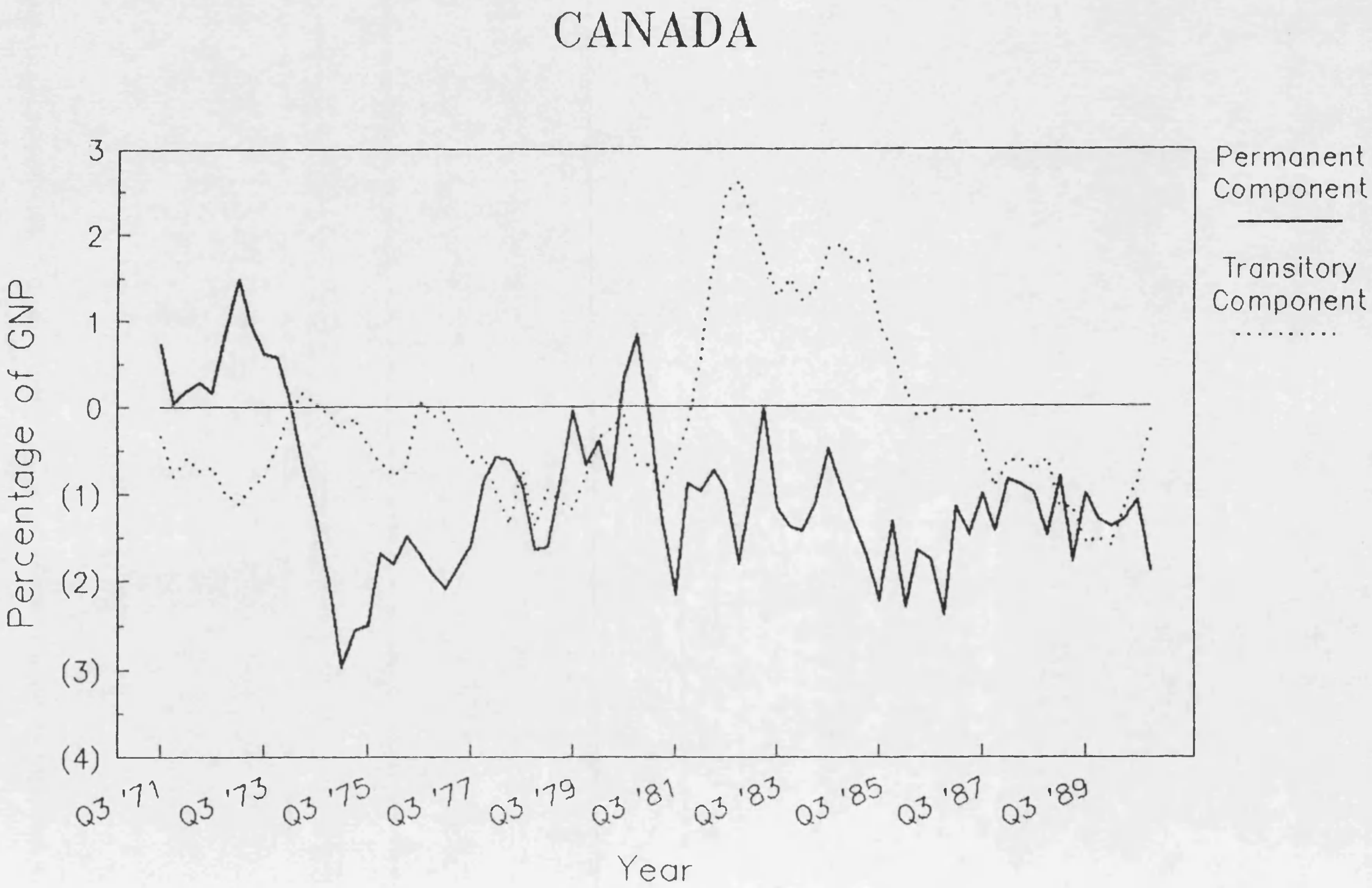


Figure 3.b: Permanent and Tranitory Components of Current Account

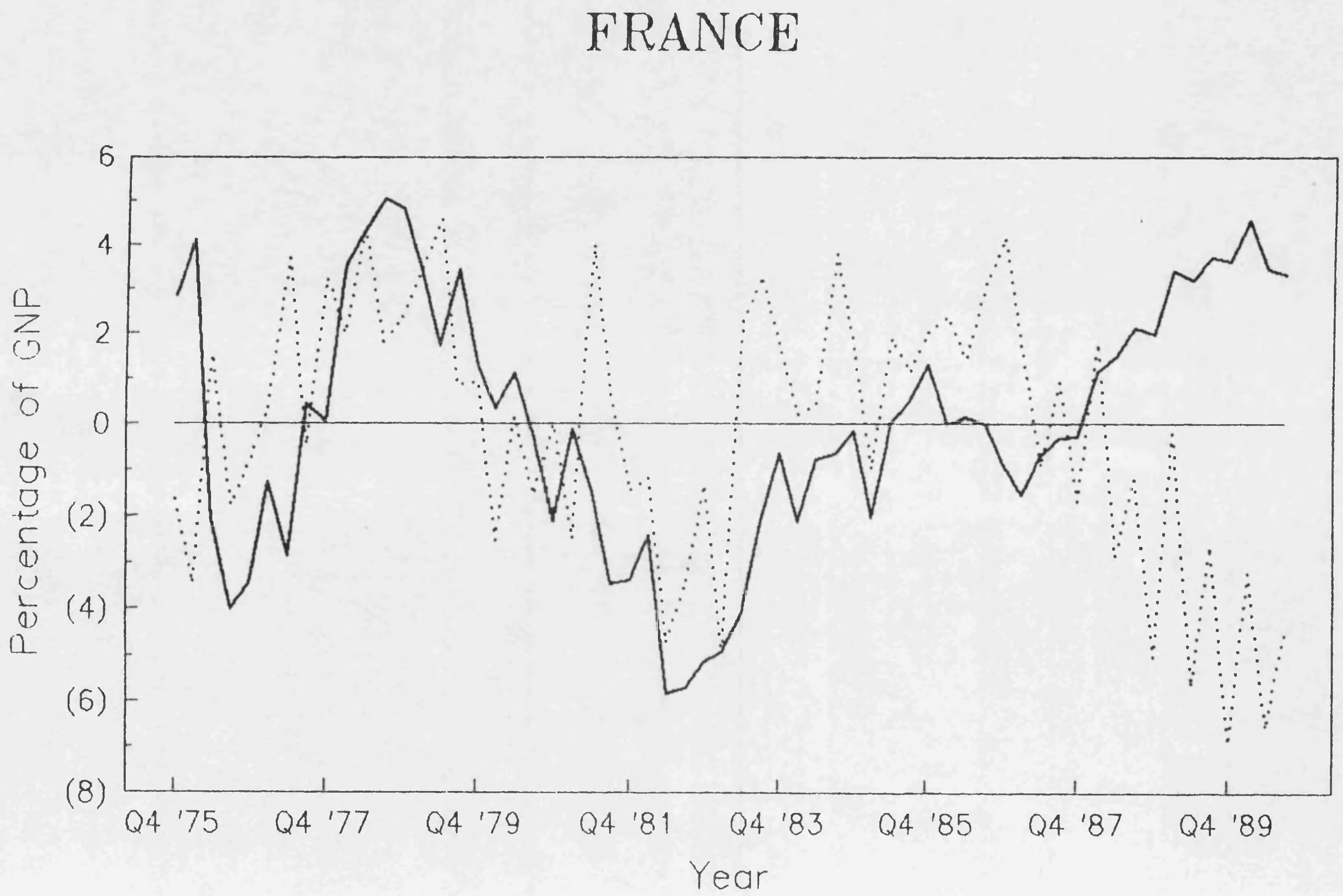


Figure 3.c: Permanent and Transitory Components of Current Account

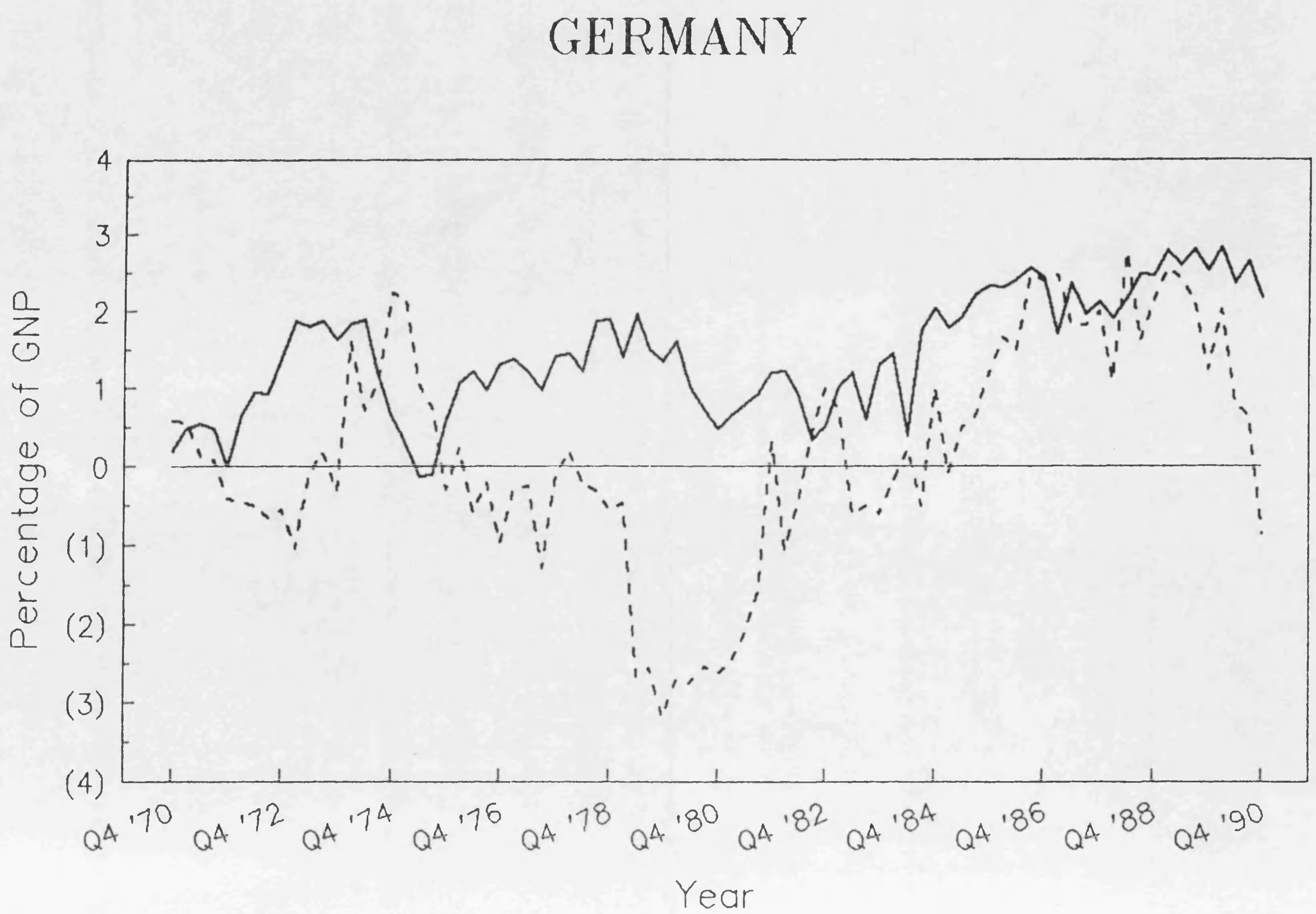


Figure 3.d: Permanent and Transitory Components of Current Account

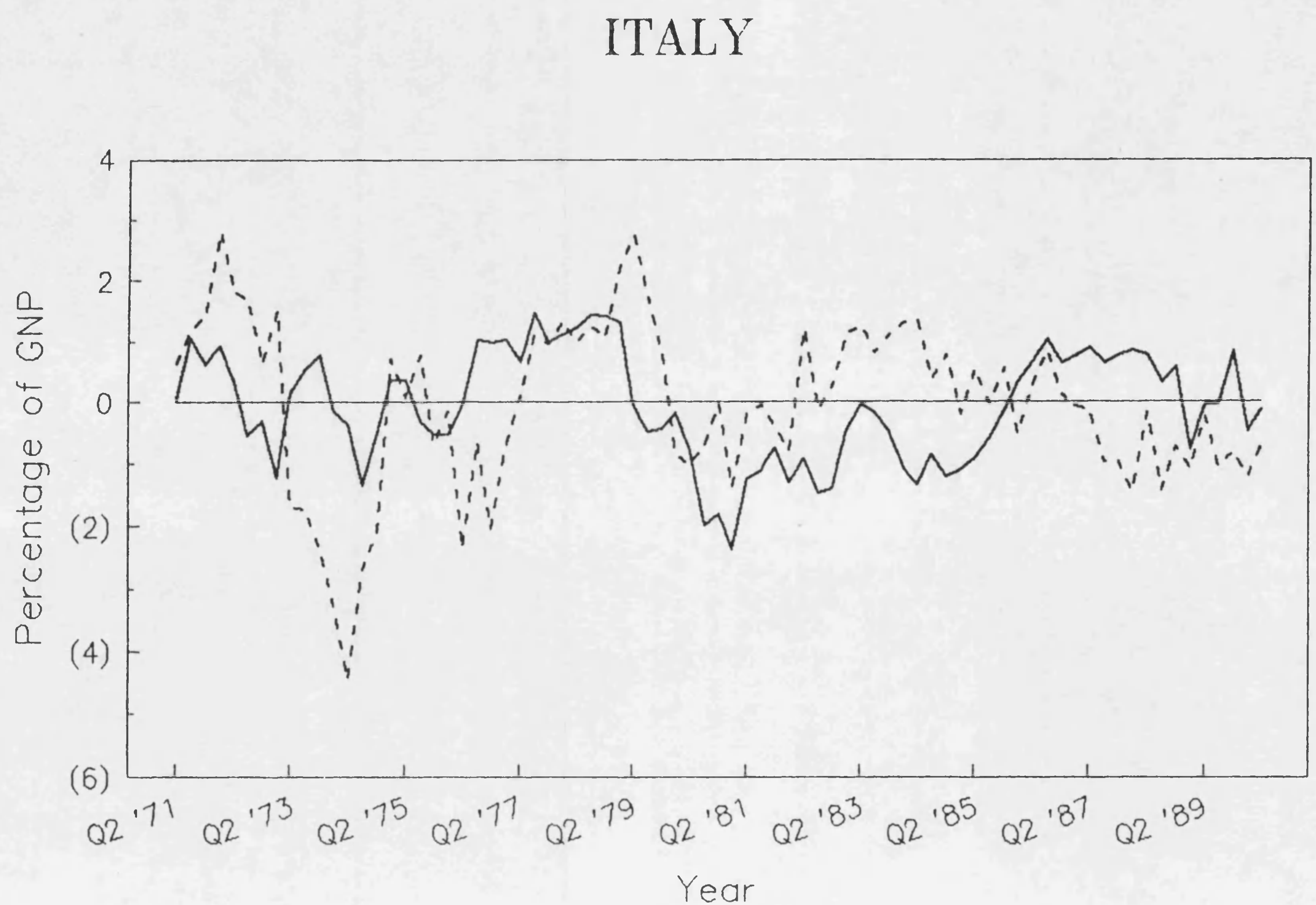


Figure 3.e: Permanent and Transitory Components of Current Account

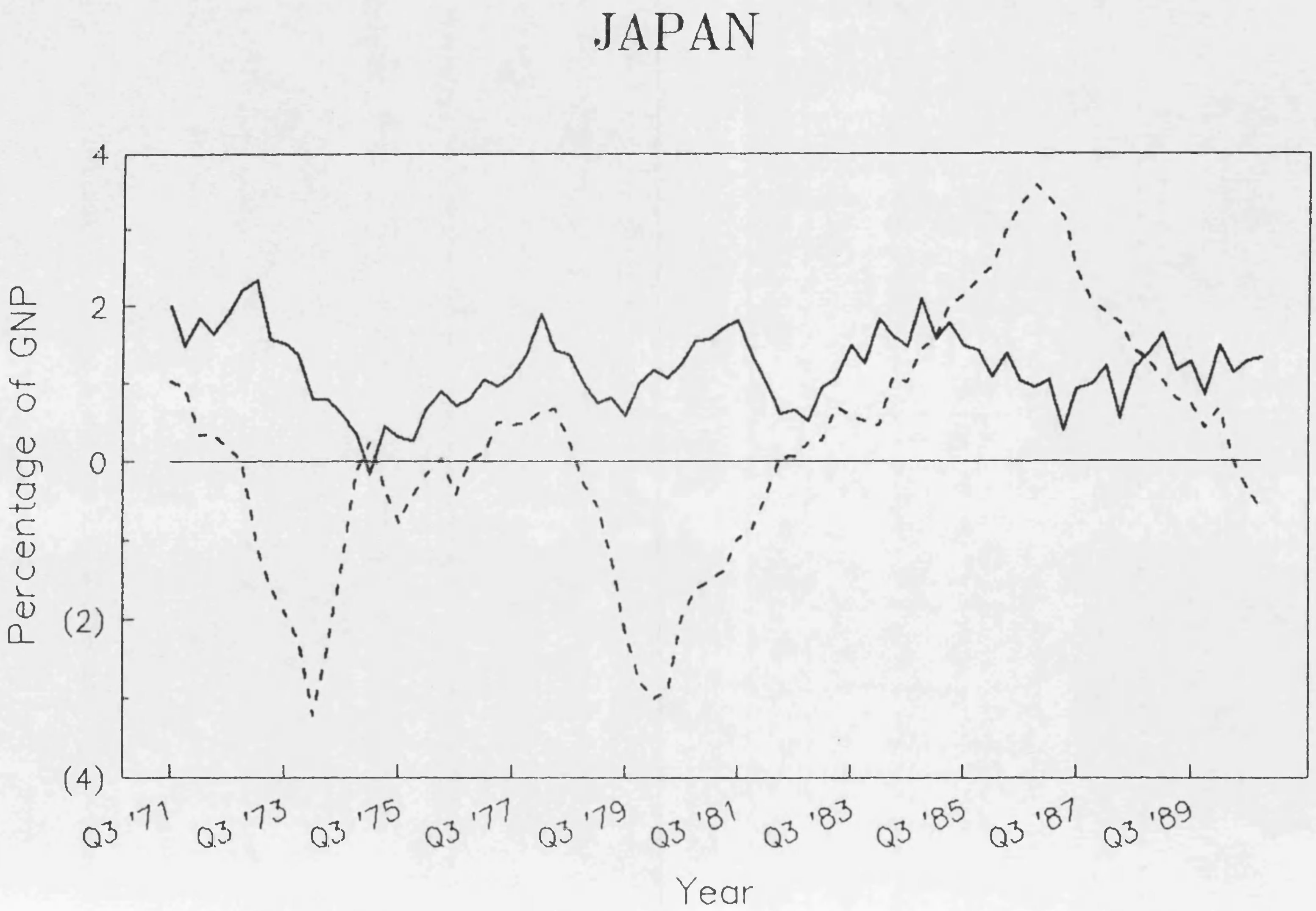


Figure 3.f: Permanent and Transitory Components of Current Account

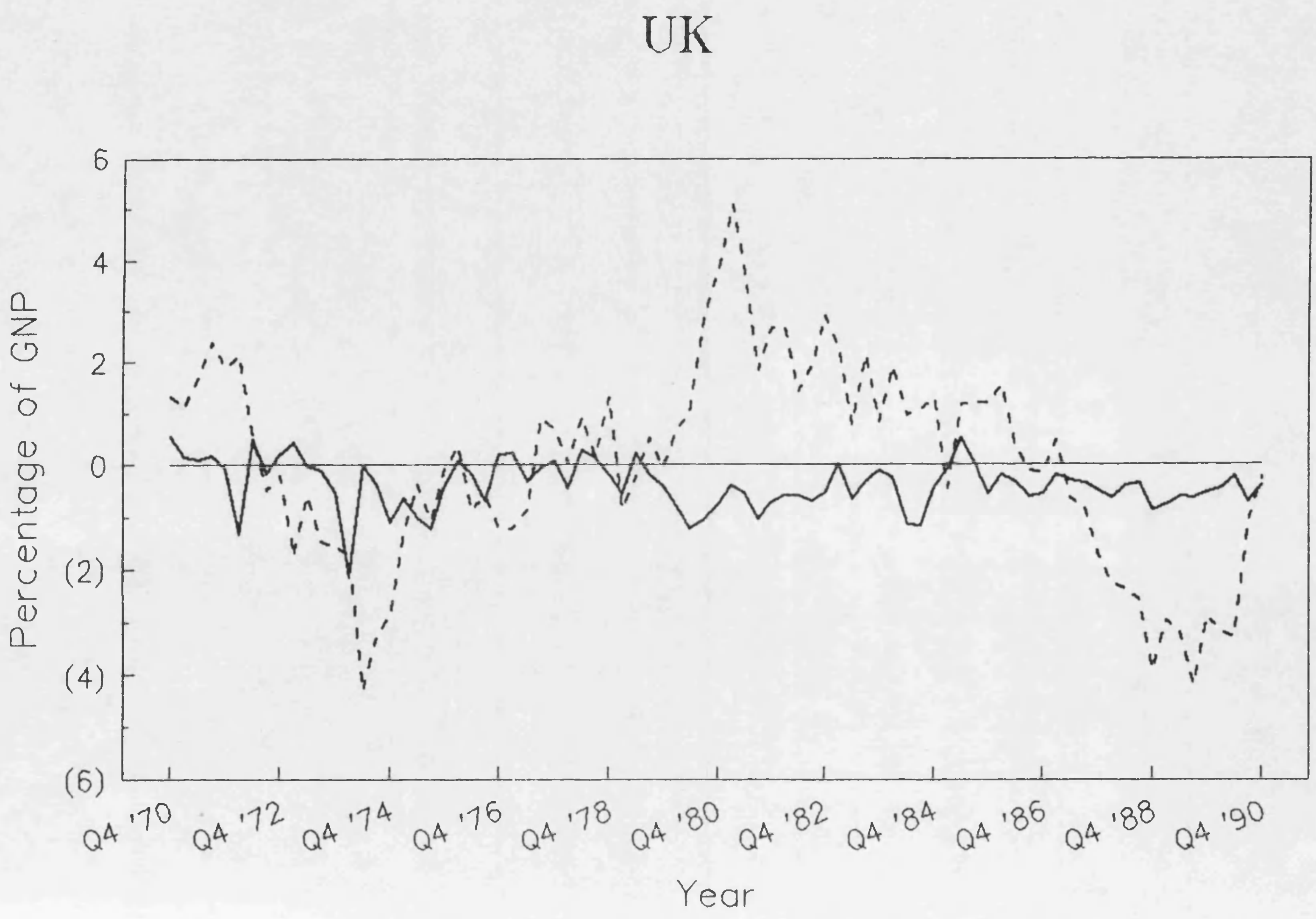


Figure 3.g: Permanent and Tranistory Components of Current Account

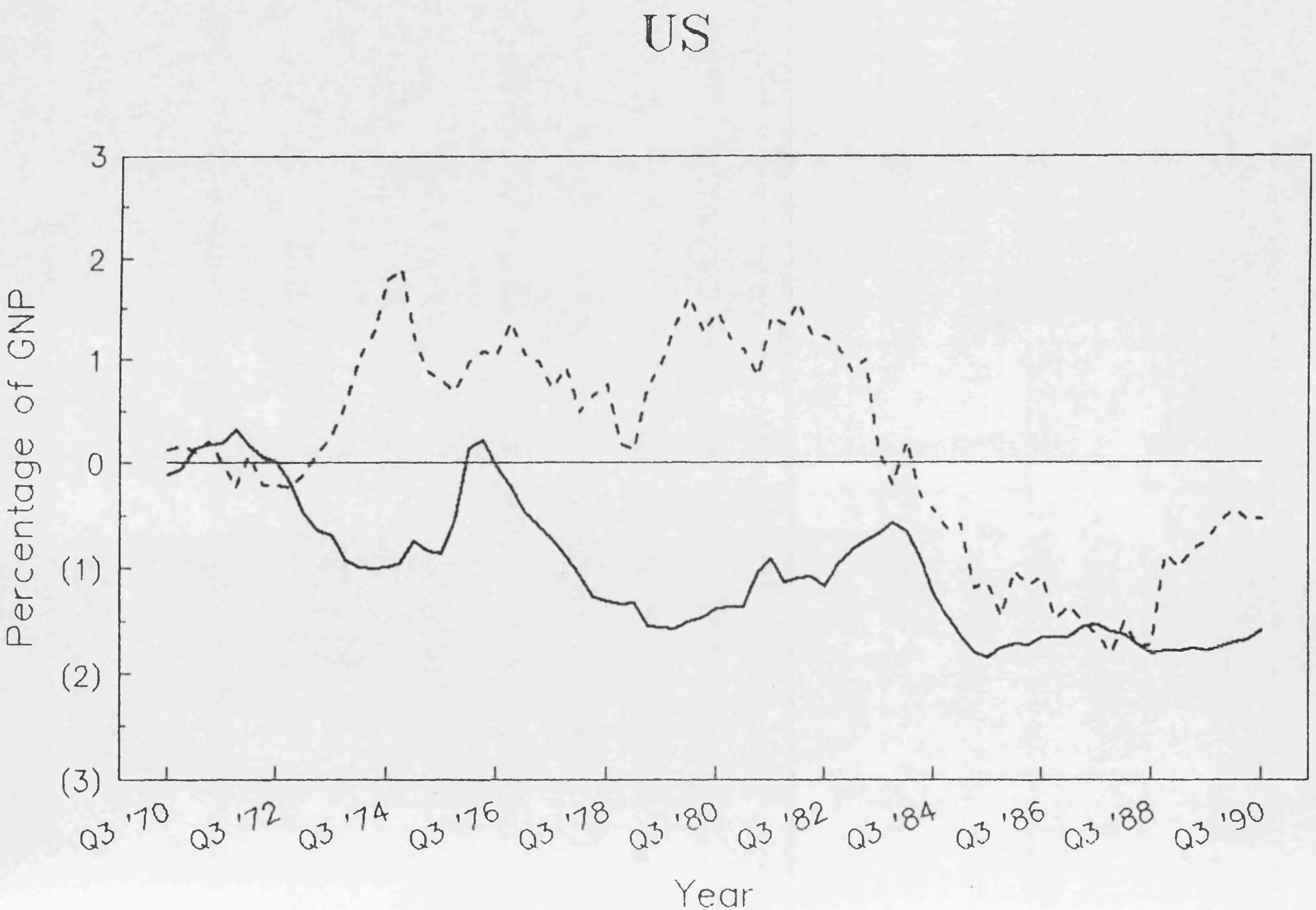


Figure 4.a: Permanent and Transitory Components of Output

CANADA

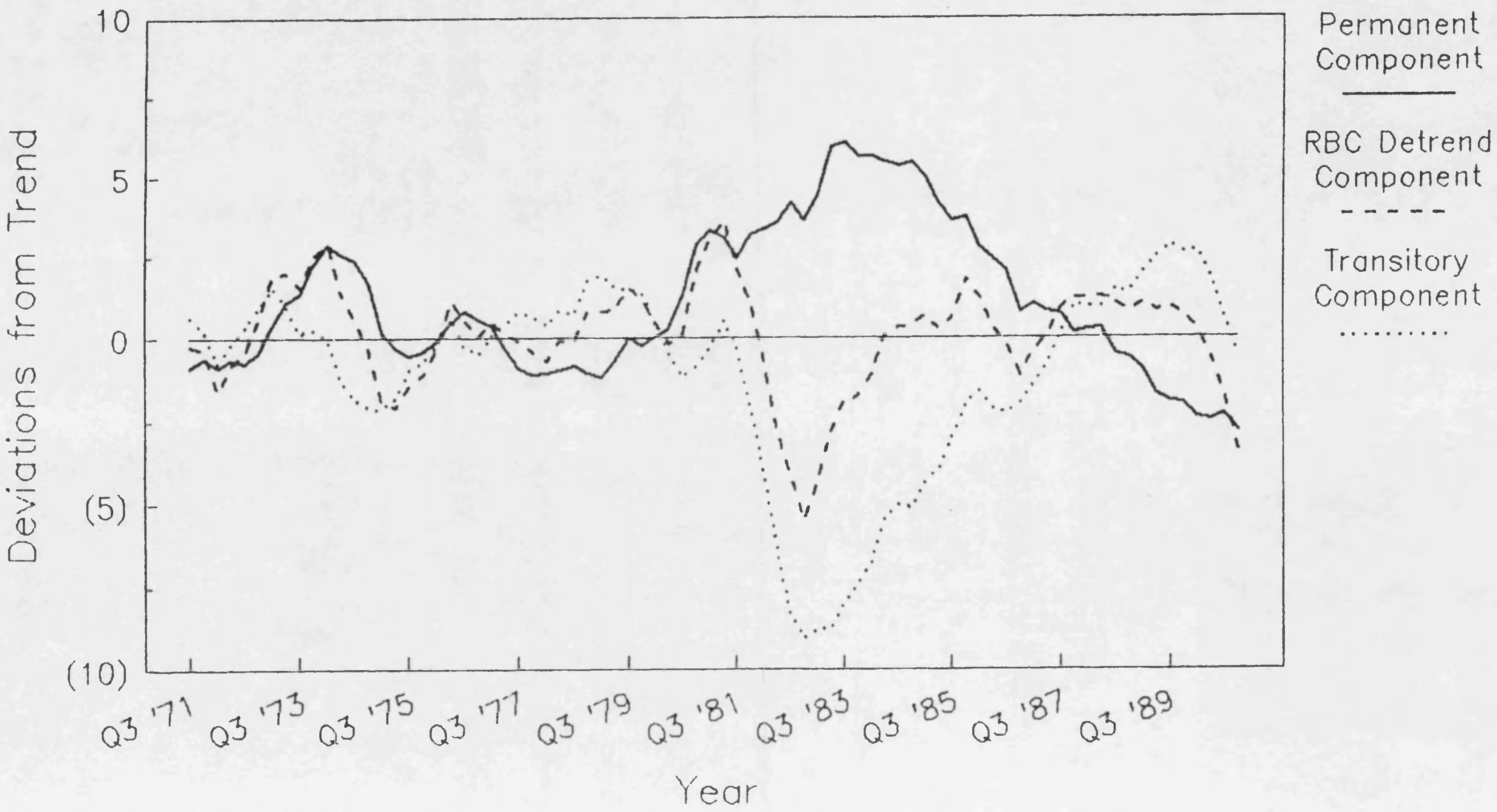


Figure 4.b: Permanent and Transitory Components of Output

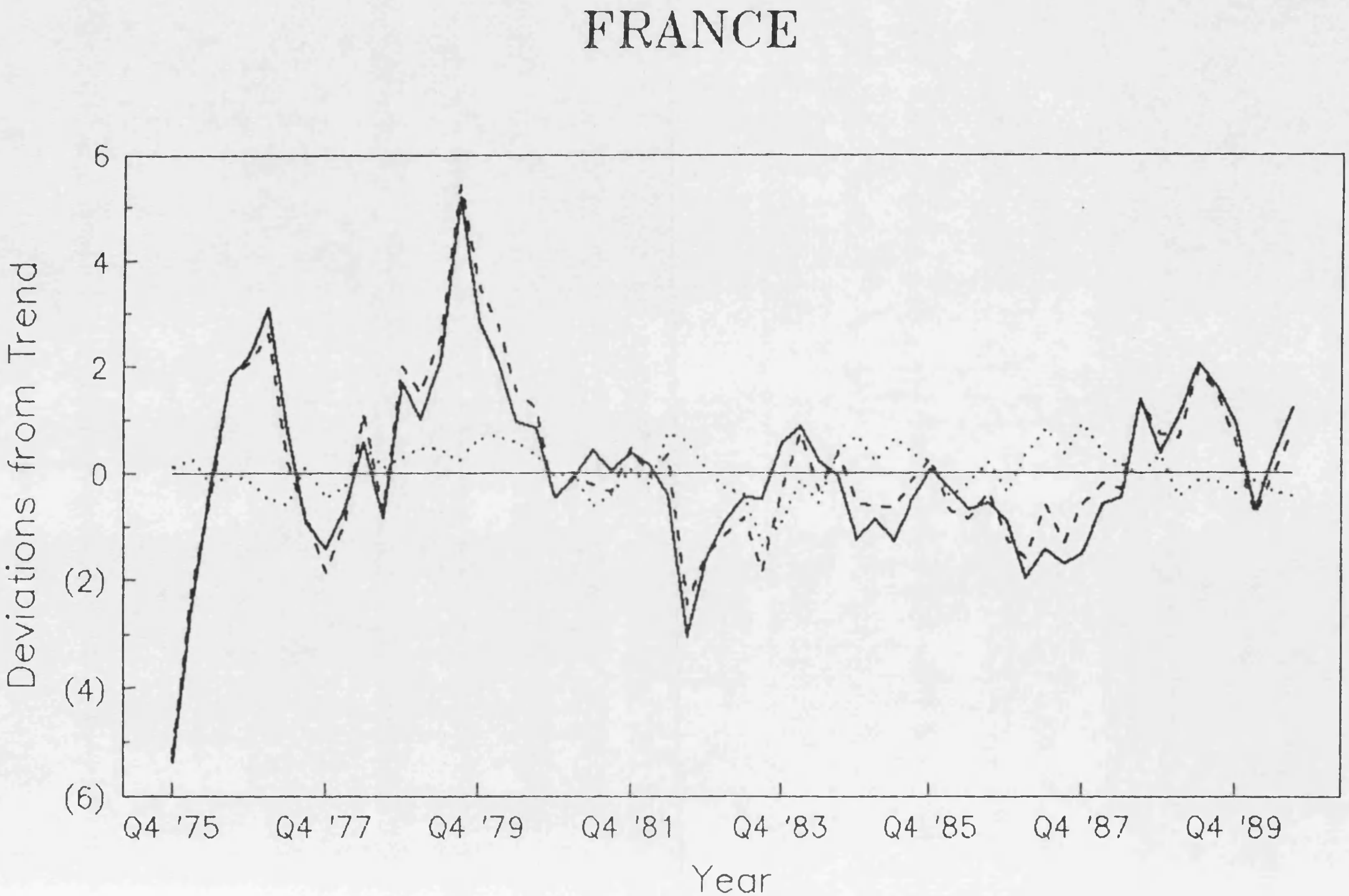


Figure 4.c: Permanent and Transitory Components of Output

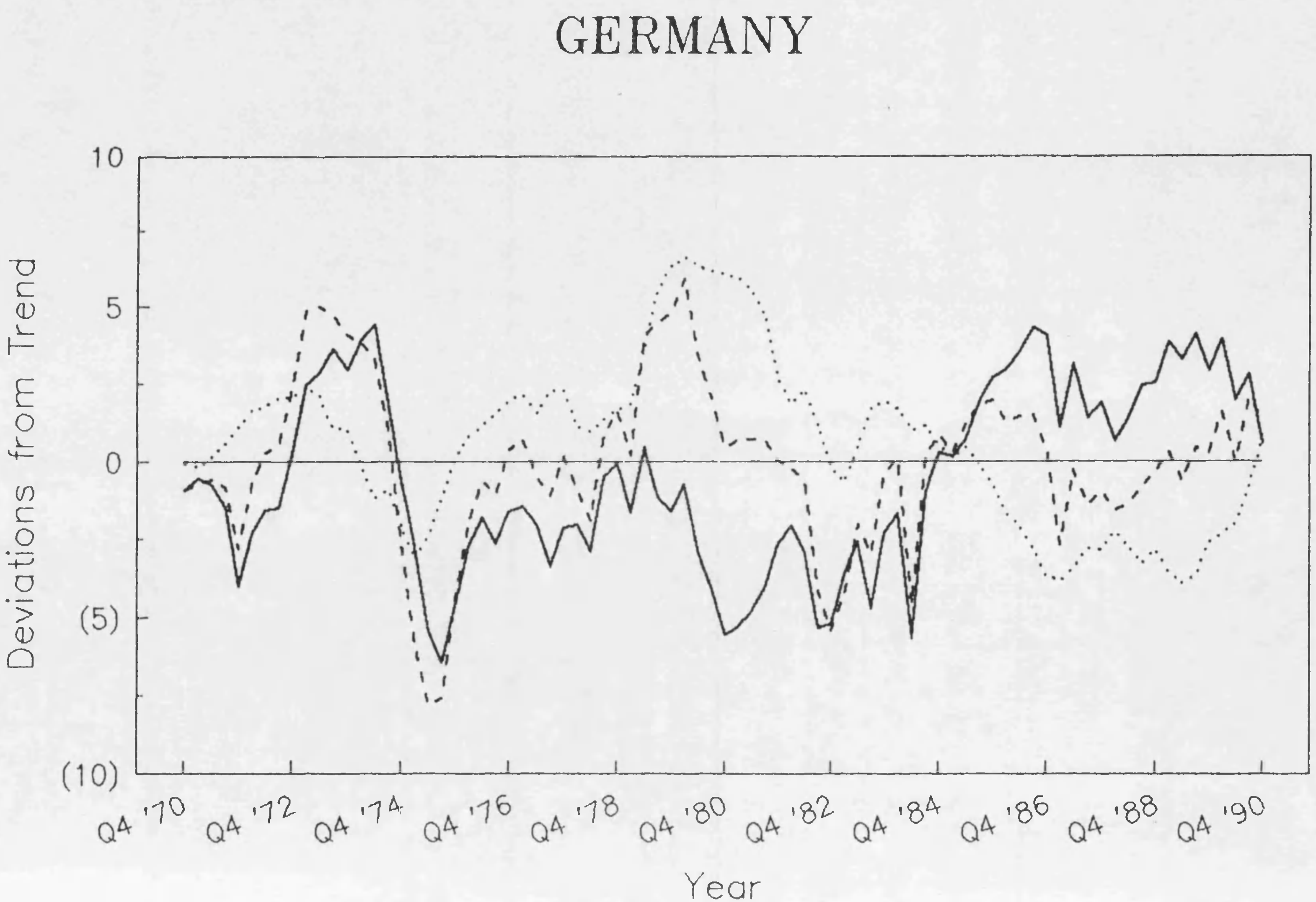


Figure 4.d: Permanent and Transitory Components of Output

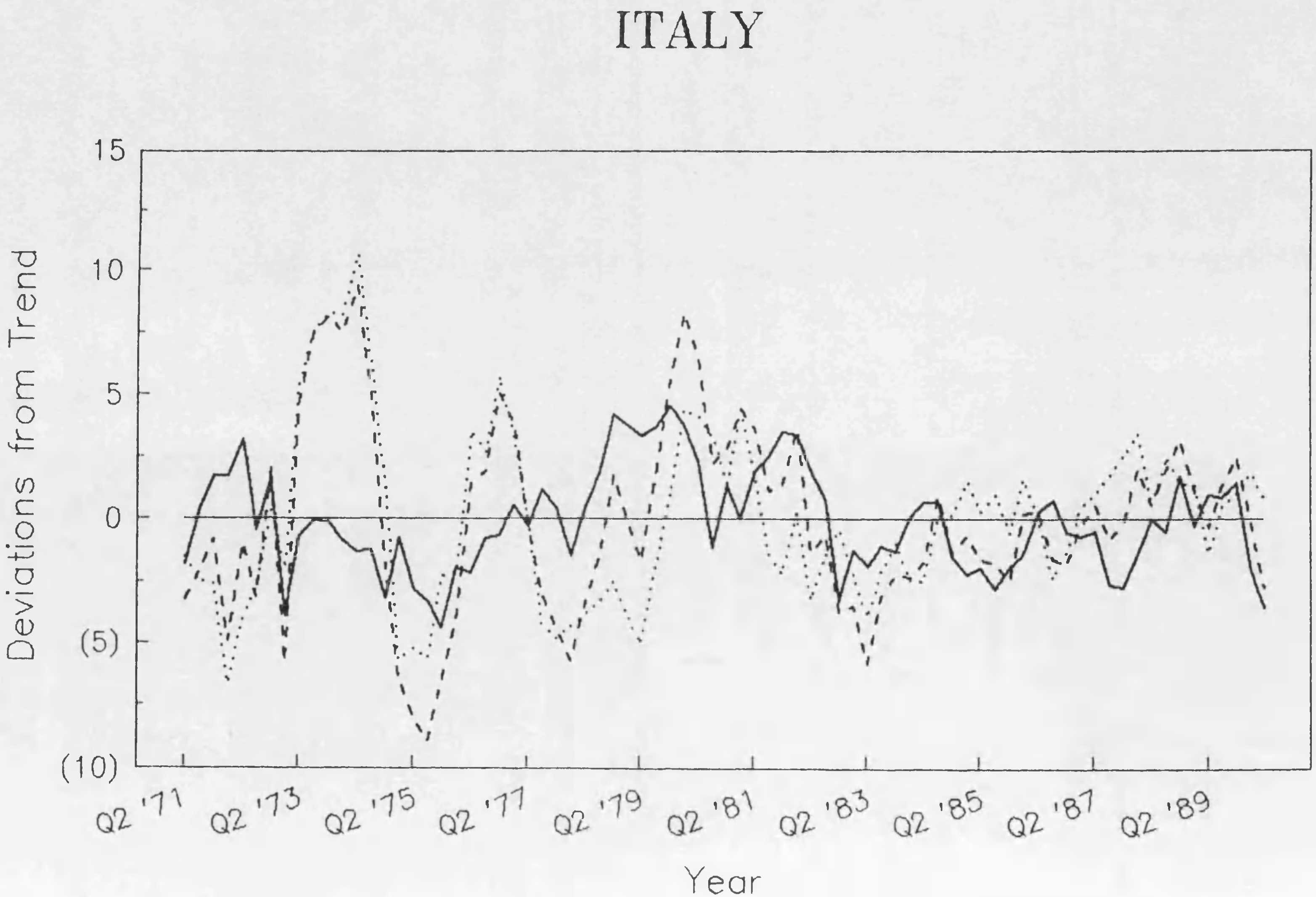


Figure 4.e: Permanent and Transitory Components of Output

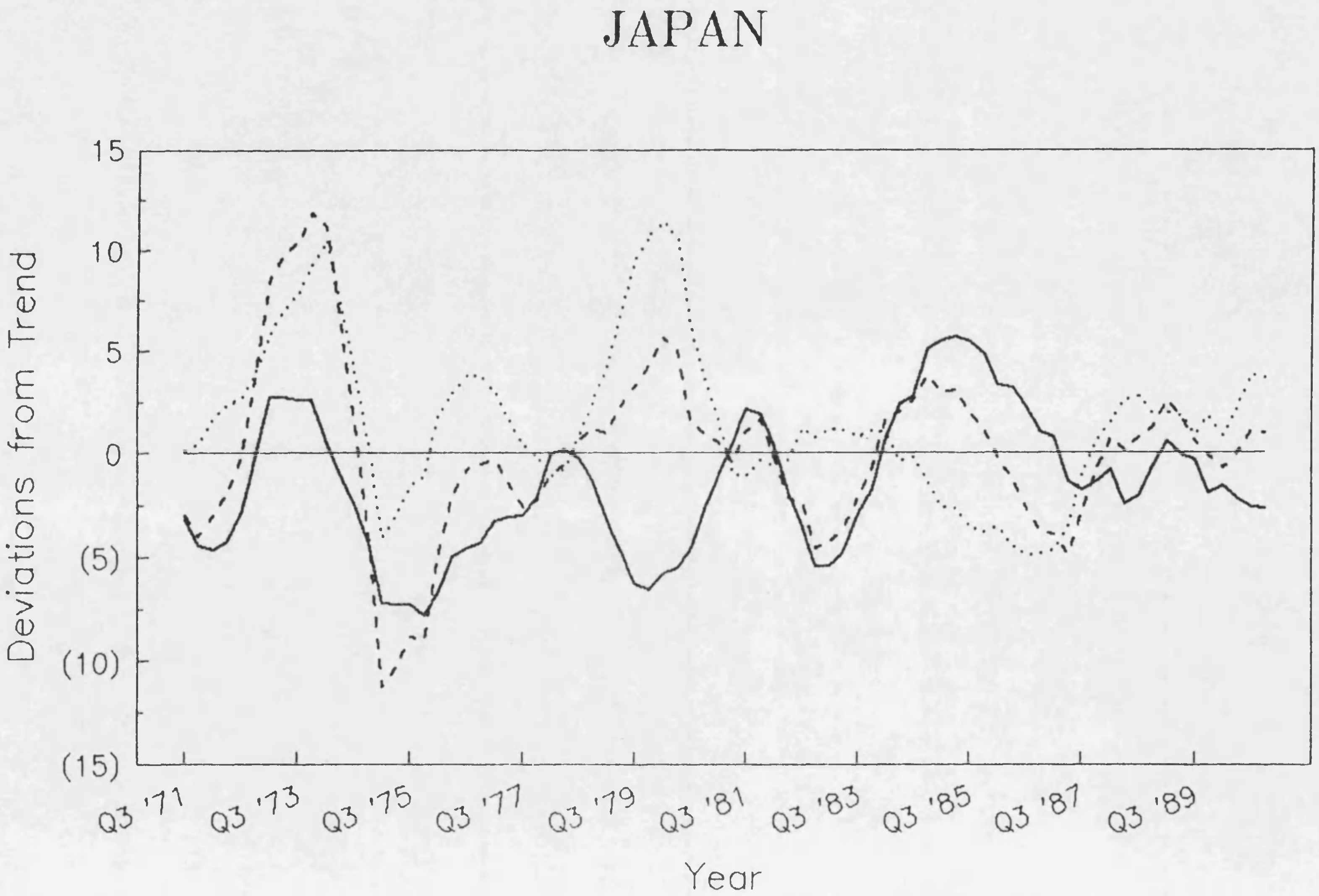


Figure 4.f: Permanent and Transitory Components of Output

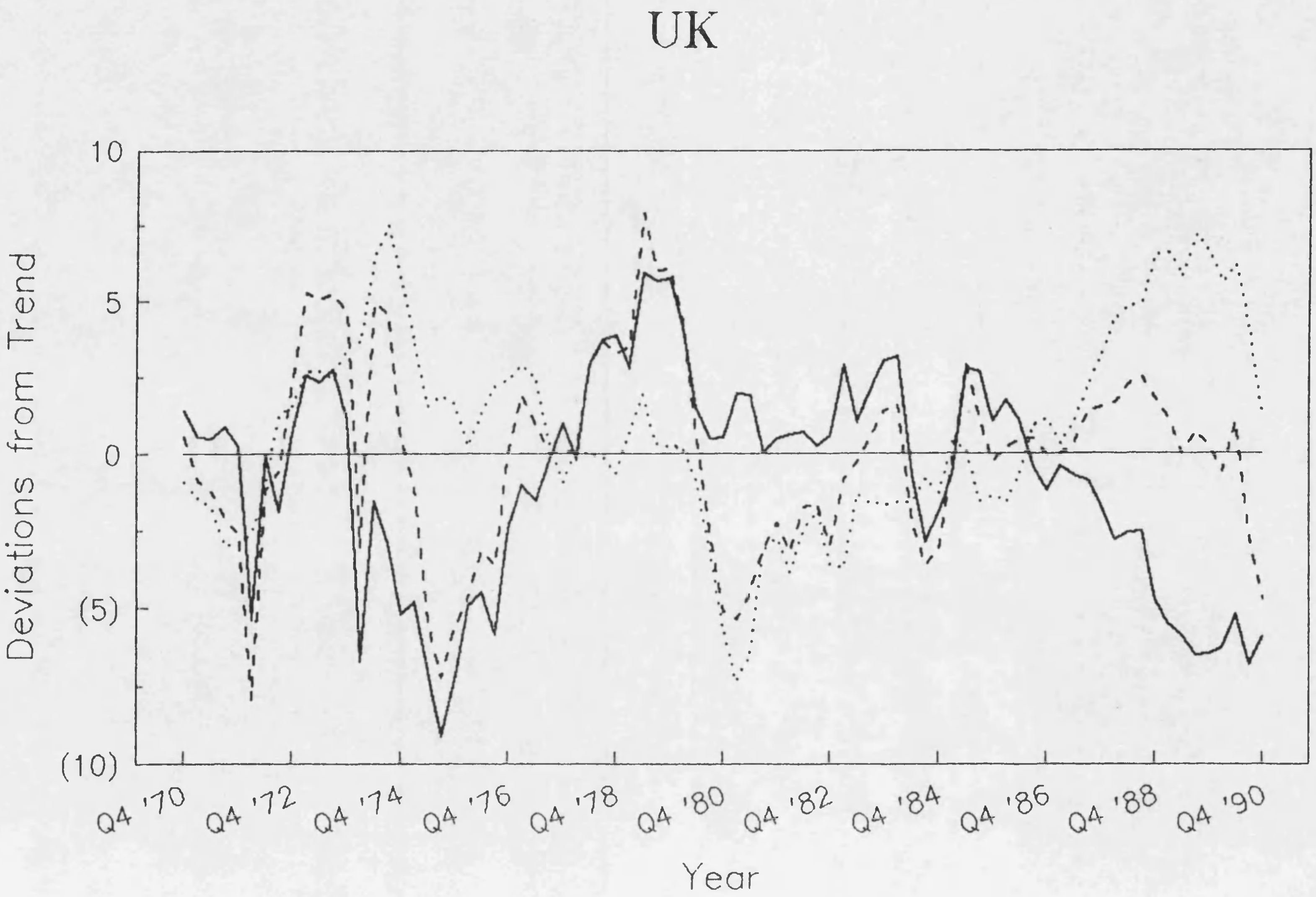
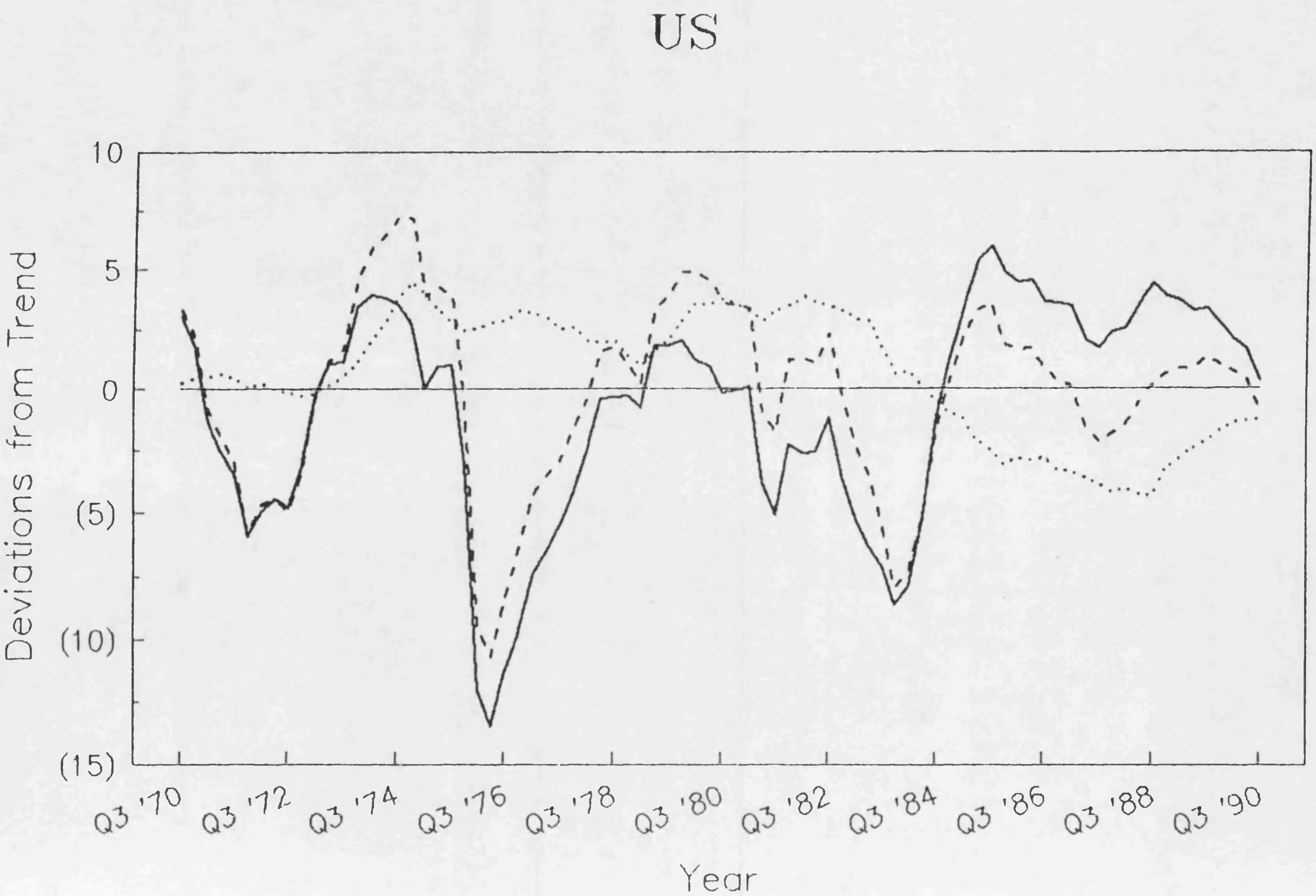


Figure 4.g: Permanent and Transitory Components of Output



CHAPTER 2 MONEY, INFLATION AND GROWTH

Abstract

Money is introduced into an endogenous growth model which exchange requires cash-in-advance. We show that the decentralized competitive outcome is an inefficient balanced growth equilibrium in which money affects growth through two independent channels: externality in production and private transactions cost in exchange. We compute the growth (and welfare) maximizing monetary policy which trades off these two effects. We also show that, in the absence of the externality, efficiency is restorable by means of a well-known optimum money supply rule.

I. Introduction

The "Neutrality of Money" is always a popular topic in macroeconomics. Of the many literature surveys on this topic, those of Gale (1982), Hoover (1988) and Blanchard (1990) are amongst the best. Over the years, different economists have addressed the question "Does money matter?" in different ways. In this chapter we are interested in whether money matters for growth.

We consider two ways of introducing money into an economy: The first is through lump sum transfers to households. The second is through the financing of a government service used in production. Even within the context of rational expectations models. Eventhough with this restricted context, there are many different mechanisms through which monetary policy can affect output. These occur in Lucas's (1972) signal extraction model, Taylor (1980) and Fischer's (1977) staggered contract model, Mankiw (1985) and Blanchard and Kiyotaki's (1987) menu cost model and Caplin and Leahy's (1991) buffer-stock model. All of these models focus on the temporary real effect of money. In contrast, we focus on the permanent real effect of anticipated inflation (the money growth rate). The most relevant of the established potential real effects of anticipated inflation is the effect on the steady state capital stock. This effect can be positive (Fischer (1979) and Tobin (1965)), zero (Sidrauski's model (1967)) or negative (Stockman

(1981)) depending on how money is introduced into the economy[1] and whether there is price rigidity in the model. However the literature has not mentioned how money relates to growth.

This paper straddles the literatures on endogenous growth, the real effects of anticipated inflation and the optimal quantity of money. The simplest device for generating endogenous growth is a linear production technology with physical capital as the only input Rebelo model (1991). This is a special case of Romer model (1986) model where the mechanism for growth is through a private sector externality. Other mechanisms considered in the recent endogenous growth literature include human capital accumulation (King and Rebelo 1990, Lucas 1988), fertility choices (Barro and Becker 1988 and 1989) and research and development (Grossman and Helpman 1989; Romer 1990; Aghion and Hewitt 1992). Nowhere in the literature does money appear and relatively little attention is given to policy issues.

We develop a simple model in which money matters for growth. We model money as a medium of exchange by requiring agent to use it to finance transactions. This is the simplest of transaction technologies and is represented by a cash-in-advance constraint. The implication is that money (inflation) and growth are inversely related.[2] This accords with the well-established fact that inflation and growth are negatively correlated.[3] Extending the analysis, we modify the model along the line with Barro (1990) by introducing a publicly-provided input to production. Since the government finances this input through the issue of money and study the financing effect of money, the modification this time is that money and growth may be positively related.

According to the original statement of the optimum quantity of money (Friedman 1969),[4] the rate of inflation should be set equal to the negative of the real rate of

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[1] The effect is positive in portfolio balance models, zero in (separable) money-in-the utility models and negative in transactions cost models.

[2] It is possible to conjecture other ways in which inflation could affect growth (e.g. by reducing the efficiency of the exchange mechanism and by creating uncertainty).

[3] See, for example, Fischer (1991).

[4] This makes the private cost of holding money (the nominal rate of interest) equal to zero which is the social opportunity cost of supplying money.

interest so that the opportunity cost of holding money (the nominal rate of interest) is equal to the social opportunity cost of supplying it(which is zero). This was later challenged on the basis of public finance (optimal taxation) considerations (Phelps 1973) and has since been the subject of further re-evaluation (Drazen 1979; Weiss 1980; Benhabib and Bull 1983; Kimbrough 1986).[5] The externality in our model precludes a money supply rule which is capable of delivering the social optimum. The rule which maximizes growth (and also welfare) is the one which trades off the negative and positive effects of money or growth alluded to above. In the absence of the externality, however, efficiency is restorable by means of the traditional optimum quantity of money rule.

The paper is organised as follows. Section II sets out the Rebelo model with a cash-in-advance constraint. In section III, we show that the market outcome is inefficient and growth is inversely related to money growth. In section IV, we introduce the public input to production and obtain the solutions for the decentralised and centralised equilibria of the model. Section V contains a discussion of the properties of these equilibria. The conclusion is in section VI.

II. Rebelo's Model with Money

We consider an artificial economy which is populated by a large number of infinitely-lived identical agents. Each agent produces and consumes a single storable commodity. The decision problem for the representative producer-consumer is

$$\max \sum_{t=0}^{\infty} (1+\rho)^{-t} u(c_t) \ s.t. \tag{II.1}$$

$$c_t + i_t + \frac{M_t + B_t}{P_t} = y_t + \frac{M_{t-1} + \tau_t}{P_t} + \frac{(1+R_{t-1}B_{t-1})}{P_t} \ ; \ y_t = Ak_t \tag{II.2}$$

[5] The public finance argument is that inflation should be chosen optimally like any other distortionary tax by equating the marginal distortion of the last unit of tax revenue across different tax bases.

$$i_t = k_{t+1} - (1-\delta)k_t \tag{II.3}$$

$$\frac{M_{t-1} + \tau_t}{P_t} \geq c_t + i_t \tag{II.4}$$

where c_t is consumption, y_t is the total output, i_t is investment, k_t is the (beginning of period t) capital stock, M_t denotes (end of period t) nominal money balances, B_t denotes (end of period t) nominal private loans, τ_t is a (beginning of period t) lump sum monetary transfer, P_t is the price level and R_t is the nominal rate of interest.

Equation (II.1) is the intertemporal utility function which depends on life time consumption. The parameter $\rho \geq 0$ is the subjective rate of time preference. We assume that the momentary utility function, $u(c_t)$, possesses the usual curvature properties and satisfies the Inada conditions.

Equation (II.2) is the budget constraint which defines the feasible allocations of total real resources between consumption and savings. The term Ak_t is the constant-returns-to-capital (and constant-returns-to-scale) production function, where $A > 0$ is a technological shift parameter. Equation (II.3) defines investment, or capital accumulation, where $\delta \in (0,1)$ is the rate of depreciation.

Equation (II.4) specifies the transactions technology which is the key ingredient of the model. For the analysis in the text, we assume a cash-in-advance constraint which requires that purchases of consumption and investment goods be financed by post-transfer money holdings at the beginning of the period. The assumption that money must be used in both consumption and capital transaction is essential for our results. In the appendix we generalise the analysis to the case of a more flexible transactions technology.

The economy as a whole is subject to three equilibrium conditions. Equilibrium in the (private) loan market implies $B_t = 0$ for all t. Equilibrium in the money market is given by $M_t = H_t$ for all t, where H_t denotes nominal money supply. Assuming that monetary transfer are issued at the rate μ, it follows that

$$M_t = (1+\mu)M_{t-1} \tag{II.5}$$

Equilibrium in the goods markets is given by

$$c_t + i_t = Ak_t \tag{II.6}$$

for all t, which is merely the aggregate resource constraint.

III. The Balanced Growth Equilibrium

The first-order conditions for the representative agent's optimization problem are

$$u'(c_t) = \lambda_t + \phi_t \tag{III.1}$$

$$(1+\rho)^{-1}(A+1-\delta)\lambda_{t+1} + (1+\rho)^{-1}(1-\delta)\phi_{t+1} = \lambda_t + \phi_t \tag{III.2}$$

$$(1+\rho)^{-1}\left[\frac{\lambda_{t+1} + \phi_{t+1}}{P_{t+1}}\right] = \frac{\lambda_t}{P_t} \tag{III.3}$$

$$\frac{(1+\rho)^{-1}(1+R_t)\lambda_{t+1}}{P_{t+1}} = \frac{\lambda_t}{P_t} \tag{III.4}$$

$$\phi_t\left[\frac{M_{t-1} + \tau_t}{P_t} - c_t - i_t\right] \geq 0,\ \phi_t \geq 0,\ \frac{M_{t-1} + \tau_t}{P_t} - c_t - i_t \geq 0. \tag{III.5}$$

where λ_t is the multiplier on the budget constraint and ϕ_t is the multiplier on the liquidity constraint. Equation (III.1) states that the marginal utility of consumption is equal to the marginal cost of consumption (which is the marginal value of an additional unit of money). Equation (III.2) states that the marginal value of an additional unit of capital (which is the value of output it produces next period plus the value of having 1-δ units leftover after next period) is equal to the marginal cost of that additional unit. Equation (III.3) (equation (III.4)) states that the marginal value of an additional unit of money (loans) at the beginning of the next period is equal to the marginal cost of that additional unit. Equation (III.5) gives the complementary slackness conditions for the liquidity constraint.

To solve for the balanced growth equilibrium of the economy, we proceed as follows. From equations (III.3) and (III.4), we obtain $\phi_{t+1} = R_t\lambda_{t+1}$ which shows that the cash-in-advance constraint is binding if $R_t > 0$. Assuming this to be the case, equations (III.1)-(III.3) may be written more compactly as

$$u'(c_t) = \nu_t \tag{III.1'}$$

$$(1+\rho)^{-1}(1-\delta)\nu_{t+1} + (1+\rho)^{-1}A\lambda_{t+1} = \nu_t \tag{III.2'}$$

$$\frac{(1+\rho)^{-1}\nu_{t+1}}{P_{t+1}} = \frac{\lambda_t}{P_t} \tag{III.3'}$$

where $\nu_t = \lambda_t + \phi_t$. from equation (III.1'), we have $u'(c_t)/u'(c_{t+1}) = \nu_t/\nu_{t+1}$. For simplicity, let $u(c_t) = \log(c_t)$ and define $(1+\gamma) = c_{t+1}/c_t$ as the (gross) growth rate of consumption. Then $(1+\gamma) = \nu_t/\nu_{t+1}$. Similarly, define $(1+\pi) = P_{t+1}/P_t$ as the gross rate of inflation. Together with $(1+\gamma) = \nu_t/\nu_{t+1}$ and (III.3'), we obtain λ_t/ν_t as the constant

$$\frac{\lambda_t}{\nu_t} = [(1+\rho)(1+\gamma)(1+\pi)]^{-1}$$

which may be substituted with $(1+\gamma) = \nu_t/\nu_{t+1}$ into equation (III.2') to arrive at

$$(1+\gamma) = (1+\rho)^{-1}\{A[(1+\rho)(1+\gamma)(1+\pi)]^{-1} + 1 - \delta\} \tag{III.6}$$

To determine the rate of inflation, observe that equilibrium money balances satisfy the quantity theory: $M_t/P_t = Ak_t$. This follows from equation (II.2) with $B_t = 0$ and $(M_{t-1} + \tau_t)/P_t = c_t + i_t$ in equilibrium. Equation (II.6) and the production function, Ak_t, may be used to verify that capital, output and consumption all grow at the same steady state rate of $1+\gamma$. The economy is always on this balanced growth path and all variables are determined once the initial value of capital is known. It follows from equation (II.5) and the quantity theory equation that $(1+\pi) = (1+\mu)(1+\gamma)^{-1}$. Our basic result - the competitive equilibrium endogenous growth rate of the economy - is obtained by combining $(1+\pi) = (1+\mu)(1+\gamma)^{-1}$ with equation (III.6):

$$(1+\gamma) = (1+\rho)^{-1}\{A[(1+\rho)(1+\mu)]^{-1} + 1 - \delta\} \tag{III.7}$$

There are two important properties of this equilibrium. The first is that real growth γ is inversely related to money growth μ, $d\gamma/d\mu < 0$. The second is that the equilibrium is inefficient, the efficient outcome being given by $(1+\gamma^*) = (1+\rho)^{-1}$ $[A + 1 - \delta] > 1+\gamma$.[6]

The inverse relationship between real growth and nominal growth is explained as follows. A higher rate of monetary expansion leads to a higher rate of inflation which induce agents to economize on money balances. Since money is used to purchase both consumption and investment goods, there is a fall in investment and a fall in the steady state growth rate. In short, inflation acts like a tax on both money and capital. The implied negative correlation between inflation and growth is recognized as one of the most stylized facts in the business cycle and growth literature.[7]

The difference between the competitive and socially-optimal equilibria depends solely on the term $[(1+\rho)(1+\mu)]^{-1}$. The difference is eliminated by setting $(1+\mu) = 1/(1+\rho)$ which implies $(1+\pi) = [A+1-\delta]^{-1}$ and $R_t = 0$. This is our re-statement of the traditional optimum quantity of money rule: set the rate of monetary growth equal to the negative of the rate of time preference so that the real rate of interest is equal to zero.

As indicated earlier, the essential, but trivial, requirement for our results is that money must be used to finance capital (as well as consumption) expenditure. We have modelled this in the simplest possible way by imposing a cash-in-advance constraint. We have no reason to believe that more general transactions technologies would not deliver similar results and we provide support for this presumption in the Appendix. In the following section, we introduce a public input to production and study how "money finance" affects the growth.

IV. Money Finance in an Endogenous Growth Model

Following Barro (1990) and Barro and Sala-i-Martin (1990), we introduce government expenditure as input to production. Output is $y_t = AF(k_t,g_t) = Af(k_t/g_t)g_t$, where $A > 0$ is a technological shift parameter. Production depends on privately-owned capital and a complementary public service.[8] These inputs exhibit constant returns jointly and

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6 This is obtained as the solution to the problem of maximizing (II.1) subject to (II.3) and (II.6).

7 See, for examples, Prescott (1990) and Fischer (1991).

8 For a discussion of this, see Barro (1990).

decreasing returns separately. A Cobb-Douglas representation is $F(.) = k_t^{\alpha} g_t^{1-\alpha}$ or $f(.) = (k_t/g_t)^{\alpha}$. For the special case of a linear technology without the public service, $\alpha = 1$ and $F(.) = k_t$ or $f(.) = k_t/g_t$. The government in this economy finances its expenditure by issuing money. Its budget constraint is $g_t = (H_t - H_{t-1})/P_t$, where H_t denotes nominal money supply.

The equilibrium is similar to the one in section III: the loan market, the money market and the goods market are in equilibrium when imply $B_t = 0$, $M_t = H_t$ and $c_t + i_t + g_t = y_t$. Together with the private sector's and government's budget constraints, these define the aggregate consistency conditions. As usual, they are linearly dependent so that one of them may be ignored.

It is legitimate to study the economy along the balanced growth path. Since there are no transitional dynamics, the economy is always on this path. Thus, all variables start at some initial value depending on the initial capital stock and grow thereafter at a common constant rate. We compute the steady state growth equilibrium of the decentralized economy through the optimization of the representative household. The first-order conditions for the stand-in-agent's optimization problems are (III.1), (III.3), (III.4) and

$$(1+\rho)^{-1}[Af'(\frac{k_{t+1}}{g_{t+1}})+1-\delta]\lambda_{t+1}+(1+\rho)^{-1}(1-\delta)\phi_{t+1} = \lambda_t+\phi_t \qquad \text{(IV.1)}$$

$$\phi_t[\frac{M_{t-1}}{P_t}-c_t-i_t] = 0, \quad \phi_t > 0, \quad \frac{M_{t-1}}{P_t}-c_t-i_t \geq 0. \qquad \text{(IV.2)}$$

where λ_t and ϕ_t are the multipliers. Equations (III.1), (III.3), (III.4), (IV.1) and (IV.2) can be interpreted similarly to equations (III.1)-(III.5) respectively. Following the argument in section III, if the liquidity constraint is binding, then $R_t > 0$. We can rewrite equations (III.1), (III.3), (III.4), (IV.1) and (IV.2) as (III.1'), (III.3') and

$$(1+\rho)^{-1}(1-\delta)v_{t+1} + (1+\rho)^{-1}Af'(\frac{k_{t+1}}{g_{t+1}})\lambda_{t+1} = v_t \qquad \text{(IV.1')}$$

where $v_t = \lambda_t + \phi_t$. From equation (IV.1'), we have $u'(c_t)/u'(c_{t+1}) = v_t/v_{t+1}$. For simplicity, let $u(c_t) = \log(c_t)$ and so $(1+\gamma) = c_{t+1}/c_t$(where γ is the growth rate defined in section III). Then $(1+\gamma) = v_t/v_{t+1}$. At steady state, $c_{t+1}/c_t = y_{t+1}/y_t = k_{t+1}/k_t = i_{t+1}/i_t$

$= g_{t+1}/g_t = 1+\gamma$. After some substitution, we obtain a similar equation to (III.6):

$$(1+\gamma) = (1+\rho)^{-1}\{Af'(\frac{k_{t+1}}{g_{t+1}})[(1+\rho)(1+\gamma)(1+\pi)]^{-1} + 1 - \delta\} \qquad \textbf{(IV.3)}$$

To determine the rate of inflation, we use the credit market equilibrium: $B_t = 0$, the quantity equation $M_t/P_t = y_t$ and the assumption that money is issued at the rate of μ. We obtain $(1+\pi) = (1+\mu)(1+\gamma)^{-1}$.

To determine the steady state ratio $k_{t+1}/g_{t+1} = k/g$, use equation $y_t = Af(k/g)g_t$ and $y_t = M_t/P_t$ in conjunction with $g_t = \mu M_{t-1}/P_t$ (from government budget constraint $g_t = (H_t - H_{t-1})/P_t$ and money market equilibrium $H_t = M_t$):

$$\frac{k}{g} = f^{-1}[\frac{1+\mu}{A\mu}] \qquad \textbf{(IV.4)}$$

Substituting equation (IV.4) and $(1+\pi) = (1+\mu)(1+\gamma)^{-1}$ into equation (IV.3) gives us our basic result

$$(1+\gamma) = (1+\rho)^{-1}\{(1+\rho)^{-1}Af'[f^{-1}(\frac{1+\mu}{A\mu})] + 1 - \delta\} \qquad \textbf{(IV.5)}$$

which is the competitive equilibrium balanced growth rate. A useful alternative representation is

$$(1+\gamma) = (1+\rho)^{-1}[(1+\rho)^{-1}\frac{(Af(\frac{k}{g}) - 1)f'(\frac{k}{g})}{f(\frac{k}{g})} + 1 - \delta] \qquad \textbf{(IV.6)}$$

In either of the above expressions, the term in the bracket measures the private marginal return to capital.

The social optimum of the model is the equilibrium that would be chosen by a central planner. The planner maximizes equation (II.1) subject to $y_t = Af(k_t/g_t)g_t$,(II.3) and the resource constraint, $c_t + i_t + g_t = y_t$. It is straightforward to show that the solution is

$$(1+\gamma^*) = (1+\rho)^{-1}[Af'(\frac{k}{g})+1-\delta] \tag{IV.7}$$

$$A[f(\frac{k}{g}) - \frac{k}{g}f'(\frac{k}{g})] = 1 \tag{IV.8}$$

Equation (IV.7) defines the socially optimal steady state growth rate. The term in [.] is the social return to capital. Equation (IV.8) is the condition for productive efficiency.

V. Effects of Inflation with the Public Externality

A straightforward comparison of equation (IV.6) and (IV.7) reveals that $\gamma^* > \gamma$: the competitive equilibrium is inefficient. The reason is that the private return to capital is less than the social return to capital. The public externality provides part, but not the whole, of the explanation for this. As we shall see shortly, the inefficiency remains in the absence of the externality. Under such circumstances, decentralized choices continue to deliver a non-Pareto optimal equilibrium as the solution to a second-best problem.

The effect of money on growth in the competitive equilibrium is ambiguous. Money has both negative and positive effects on growth. from equation (IV.5), we find

$$\frac{d\gamma}{d\mu} \overset{>}{\underset{<}{=}} 0 \Leftrightarrow f'[f'^{-1}(\frac{1+\mu}{A\mu})] + \frac{f''[f'^{-1}(\frac{1+\mu}{A\mu})]f'^{-1}(\frac{1+\mu}{A\mu})}{A\mu^2} \overset{<}{\underset{>}{=}} 0.$$

which has the following interpretation. The first term on the right-hand-side is positive and reflects the negative effect of money on growth. This operates through the transactions cost mechanism and allude to in the previous section. A higher rate of monetary expansion leads to higher inflation which induces agents to economize on money holdings, lower capital stock and growth. In this way, inflation acts like a tax on both money and capital. The second term on the right-hand-side is negative and reflects the positive effect of money on growth. This operates through the production technology. The engine of growth in the economy is the money-financed public service which affects production. Higher monetary growth implies more of this service and higher real growth. It will be useful to express the above condition in an alternative form:

$$\frac{d\gamma}{d\mu} \overset{>}{\underset{<}{=}} 0 \rightarrow A[f(\frac{k}{g}) - \frac{k}{g}f'(\frac{k}{g})] \overset{<}{\underset{>}{=}} 1.$$

For the Cobb-Douglas technology, this implies that $d\gamma/d\mu > 0$, if and only if $\mu < (1-\alpha)/\alpha$. In case of $\mu = (1-\alpha)/\alpha$, $d\gamma/d\mu = 0$. The condition is equivalent to $g/y < 1-\alpha$. As in Barro (1990), therefore, the effect of government action on growth depends on the size of the government. A positive effect is more likely if the government is small than if the government is large.

Given the above, it is possible to say something about optimal monetary policy. A growth maximizing government will trade off the negative and positive effects of money and growth such that the right-hand side of either of the above condition holds with equality. This implies $d\gamma/d\mu = 0$. For the Cobb-Douglas technology, the optimal monetary policy is to set $\mu = (1-\alpha)/\alpha$. Equivalently, $g/y = 1-\alpha$ which states that the government should set its share of output equal to the share that it would obtain if the public service was supplied competitively. Of course, there is no reason for a benevolent government to maximize growth. What it should maximize is the welfare of the representative household. In this model, however, the two problems are equivalent. To see this, write equation (IV.6) as $1+\gamma = (1+\rho)^{-1}[(1+\rho)^{-1}\mu^{-1}(g_t/k_t) + 1 - \delta]$ and the resource constraint as $\mu^{-1}(g_t/k_t) = c_t/k_t + (1-\gamma) - (1-\delta)$.[9] Combine these expressions and set t=0 to obtain an initial value for consumption,

$$c_0 = \frac{[1-\alpha(1+\rho)^{-2}](1+\gamma) - (1+\rho)^{-1}[1-\alpha(1+\rho)^{-1}](1-\delta)}{\alpha(1+\rho)^{-2}} k_0.$$

Substitute this into the intertemporal utility function, $U = \Sigma^{\infty}_{t=0}(1+\rho)^{-1}u[(1+\gamma)^t c^0]$, and observe that U is increasing in γ. Hence, anything which maximizes growth also maximizes welfare.

It is of interest to compare the results above with those obtained when money affects growth solely through the transactions technology and not also through the

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9 Use $f'(k_t/g_t)/f(k_t/g_t) = \alpha(g_t/k_t)$ and $g_t = \mu M_{t-1}/P_t = \mu(y_t - g_t) = \mu[Af(k_t/g_t)] - 1]g_t$.

production technology. In this case, as in section II, there is no public input to production which depends linearly on capital alone.[10] As before, we have shown that $1+\gamma < 1+\gamma^*$ due the presence of liquidity constraint. Thus, the competitive equilibrium remains inefficient even in the absence of the public externality. In section III, $d\gamma/d\mu < 0$ unambiguously which is different from here. This follows immediately from the fact that money affects growth solely through the exchange mechanism. This result illustrates the fact that whether monetary policy can promote growth depends on how the government uses its seigniorage. If the government uses it to finance a service which is not complementary to production, it may adversely affect the output level and may even alter its trend.

VI. Conclusions

There is a strong presumption that macroeconomic policies matter for economic growth. This presumption is supported by an overwhelming body of empirical evidence but has received relatively attention at the theoretical level.[11] A particularly notable feature of the new growth theory, to date, has been the absence of money and, with it, the absence of monetary policy considerations. The purpose of the present paper has been to fill this gap by constructing a simple model economy in which money and monetary policy do, indeed, matter for growth.

Of the assumptions that kept the analysis tightly-focused, we may single out three for further consideration. The first is the assumption that the only means of government finance is money. A potentially rewarding avenue for future research would be to explore the implications of other means of finance. Of particular interest would be the introduction of government borrowing and the relationship between debt, deficits and development. What matters for our own results is that at least some government revenue is raised through seigniorage. The second important assumption is that we treat the money supply as exogenous. Relaxing this assumption would almost certainly change

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10 As in section II, this is the simplest way of generating endogenous growth. Since government expenditure are now wasteful, we assume that $g_t = 0$. Agents are assumed to receive money in the form of lump-sum transfer.

11 For a review of the evidence, see Barro (1991) and Fischer (1991).

our results and complicate the analysis.[12] The third assumption is that agents must have cash-in-advance of transacting in both consumption and investment goods, We have no reason to believe that our results would be significantly altered by adopting a more general transactions technology, like the one in the appendix. Provided only that capital cannot be traded without cost, there is potential for money to affect capital accumulation and growth. This transactions cost effect is independent of the public externality effect in production. Even in the absence of this externality, there is still a mechanism through which money can affect growth.

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[12] Buiter (1982) has shown that increases in government expenditure through money financing will have a temporary effect on output even in a zero effect model like Sidrauski's model.

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Appendix

We present a generalization of the analysis in the text to the case of a more flexible transactions technology according to which money is a means of freeing a scarce resource (time) which must be used in transacting. This version of the model has the additional implication of an inverse relationship between money growth and velocity.

The decision problem of the representative agent is

$$\max \sum_{t=0}^{\infty} (1+\rho)^{-t} u(c_t, l_t) \ s.t. \tag{A.1}$$

$$c_t + i_t + \frac{M_t + B_t}{P_t} = y_t + \frac{M_{t-1} + \tau_t}{P_t} + \frac{(1+R_{t-1}B_{t-1})}{P_t} \ ; \ y_t = Ak_t \tag{A.2}$$

$$i_t = k_{t+1} - (1-\delta) k_t \tag{A.3}$$

$$s_t + l_t = 1 \tag{A.4}$$

$$s_t = s(m_t) \ ; \ m_t = \frac{M_{t-1}}{P_t (c_t + i_t)} \tag{A.5}$$

Equation (A.1) defines intertemporal utility which now depends on lifetime consumption and leisure l_t. We assume that $u(c_t,l_t)$ possesses the usual curvature properties and satisfies the Inada conditions. We also demand that $u(c_t,l_t)$ be such as to generate no long-run trend in l_t. This require either $u(c_t,l_t) = [c_t^{1-\sigma}/(1-\sigma)] \ v(l_t)$ or $u(c_t,l_t) = \log(c_t) + v(l_t)$. For simplicity, we choose the latter. Equations (A.2) and (A.3) are the same as equation (II.2) and (II.3). Equation (A.4) defines the time constraint which states that total time (normalised to unity) is allocated between leisure and time spent transacting (s_t). The transaction technology is given in equation (A.5) and states that the transactions time required for each unit of consumption and investment depends on the ratio of money holdings to nominal expenditure. We make the standard assumptions, $s'(m_t) \leq 0$ for $m_t < m^*$ and $s'(m_t) \geq 0$ for $m_t > m^*$ where $m^* < \infty$, $s''(m_t) \geq 0$, $s'(0) = -\infty$ and $s'(m^*) = 0$. In this version of the model, it is essential for our result that time must be spent on transacting in both consumption and capital goods. The equilibrium conditions for the economy as a whole are given by $B_t = 0$ and equations (II.5) and (II.6).

The first-order conditions for the above problem are

$$u'(c_t) + \frac{v'(l_t)\, s'(m_t)\, m_t}{c_t + i_t} = \psi_t \tag{A.6}$$

$$(1+\rho)^{-1}\left[(A+1-\delta)\,\psi_{t+1} - \frac{(1-\delta)\, v'(l_{t+1})\, s'(m_{t+1})\, m_{t+1}}{c_t + i_t}\right] = \psi_t - \frac{v'(l_t)\, s'(m_t)\, m_t}{c_t + i_t} \tag{A.7}$$

$$(1+\rho)^{-1}\left[\frac{\psi_{t+1} - v'(l_{t+1})\, s'(m_{t+1})}{P_{t+1}}\right] = \frac{\psi_t}{P_t} \tag{A.8}$$

$$\frac{(1+\rho)^{-1}(1+R_t)\,\psi_{t+1}}{P_{t+1}} = \frac{\psi_t}{P_t} \tag{A.9}$$

where ψ_t is the multiplier on the budget constraint. Equation (A.6) defines the marginal utility of consumption which is the sum of two components - the direct (positive) effect on utility of an additional unit of consumption and the indirect (negative) effect on utility of extra expenditure which increases transactions time. Equation (A.7) states that the marginal benefit of an additional unit of capital (which is the marginal value of output it produces next period plus the marginal direct and indirect values of having 1-δ units leftover after next period) is equal to the marginal cost of that additional unit (which is the marginal utility cost of foregone current consumption plus the marginal cost of currently transacting in capital). Equation (A.8) states that the marginal benefit of an additional unit of money (which includes the marginal value of a reduction in current transactions time) is equal to the marginal cost of that additional unit. Equation (A.9) gives the equalisation of the marginal benefit and marginal cost of an additional unit of loans.

Using $u(c_t) = \log(c_t)$, $c_t + i_t = Ak_t$ and $c_t/Ak_t = (A - \gamma - \delta)/A$ (where γ is the net growth rate), equations (A.6)-(A.8) can be rewritten as

$$A + v'(l_t)\, s'(m_t)\, m_t\,(A-\gamma-\delta) = A z_t \tag{A.10}$$

$$(1+\rho)^{-1}\left[A z_{t+1} - v'(l_{t+1})\, s'(m_{t+1})\,(A-\gamma-\delta)\right] = (1+\gamma)(1+\pi)\, A z_t \tag{A.12}$$

$$(1+\rho)^{-1}[A(A+\gamma-\delta)z_{t+1} - (1-\delta)v'(l_{t+1})s'(m_{t+1})m_{t+1}(A-\gamma-\delta)] = (1+\gamma)[Az_t - v'(l_t)s'(m_t)m_t(A-\gamma-\delta)] \tag{A.11}$$

where $z_t = \psi_t c_t$ and $1 + \pi = P_{t+1}/P_t$. Along the balanced growth path, $l_t = l_{t+1} = l$ and $s_t = s_{t+1} = s$. From equation (A.5), therefore, $s(m_{t+1})/s(m_t) = 1$ with $m_t = M_{t-1}/(P_t A k_t)$. Hence, at the steady state where $m_{t+1} = m_t$, we have $(1+\pi) = (1+\mu)(1+\gamma)^{-1}$ and $z_t = z_{t+1}$. Substituting these results into equations (A.10)-(A.12) delivers

$$A + v(l)s'(m)m(A-\gamma-\delta) = Az \tag{A.13}$$

$$v'(l)s(m)m(A-\gamma-\delta)[(1+\delta) - (1+\rho)^{-1}(1-\delta)] = [(1+\gamma) - (1+\rho)^{-1}(A+1-\delta)]Az \tag{A.14}$$

$$(1+\rho)^{-1}v'(l)s'(m)(A-\gamma-\delta) = [(1+\rho)^{-1} - (1+\mu)]Az \tag{A.15}$$

Equations (A.13) and (A.15) may each be combined with equation (A.14) to produce two loci in (m,γ) space:

$$v'[1-s(m)]s'(m)m = \frac{(1+\rho)(1+\gamma) - (A+1-\delta)}{A-\gamma-\delta} \tag{A.16}$$

$$m = \frac{(1+\gamma)(1+\rho) - (A+1-\delta)}{[1-(1+\rho)(1+\mu)][(1+\gamma)(1+\rho) - (1-\delta)]} \tag{A.17}$$

Together, these relationships determine the equilibrium growth rate (γ) and the velocity (m) as shown in Figure A1. The Figure is drawn on the assumption that $s'(m) + m\,s''(m) > 0$ which is a sufficient condition for the schedule defined by equation (A.16) to be upward sloping. The schedule defined by equation (A.17) is unambiguously downward sloping. This schedule shifts to the left as μ is increased. Hence, an increase in the rate of monetary expansion reduce both the growth rate and velocity.

The socially optimal growth rate is again given by $(1+\gamma^*) = (1+\rho)^{-1}(A+1-\delta)$. This is obtained as the solution to the problem of maximizing equation (A.1) subject to (A.3)-(A.5) and (II.6). A property of the solution is that $s'(m) = 0$: intuitively, a social planner will generate that level of transactions balances at which the marginal reduction in transactions cost is equal to zero. Inspection of equation (A.16) and (A.17) reveals that the inefficiency of the decentralized equilibrium is removed as before by setting $(1 + \mu) = (1 + \rho)^{-1}$, implying $s'(m) = 0$, $(1 + \pi) = (A + 1 - \delta)^{-1}$ and $R_t = 0$.

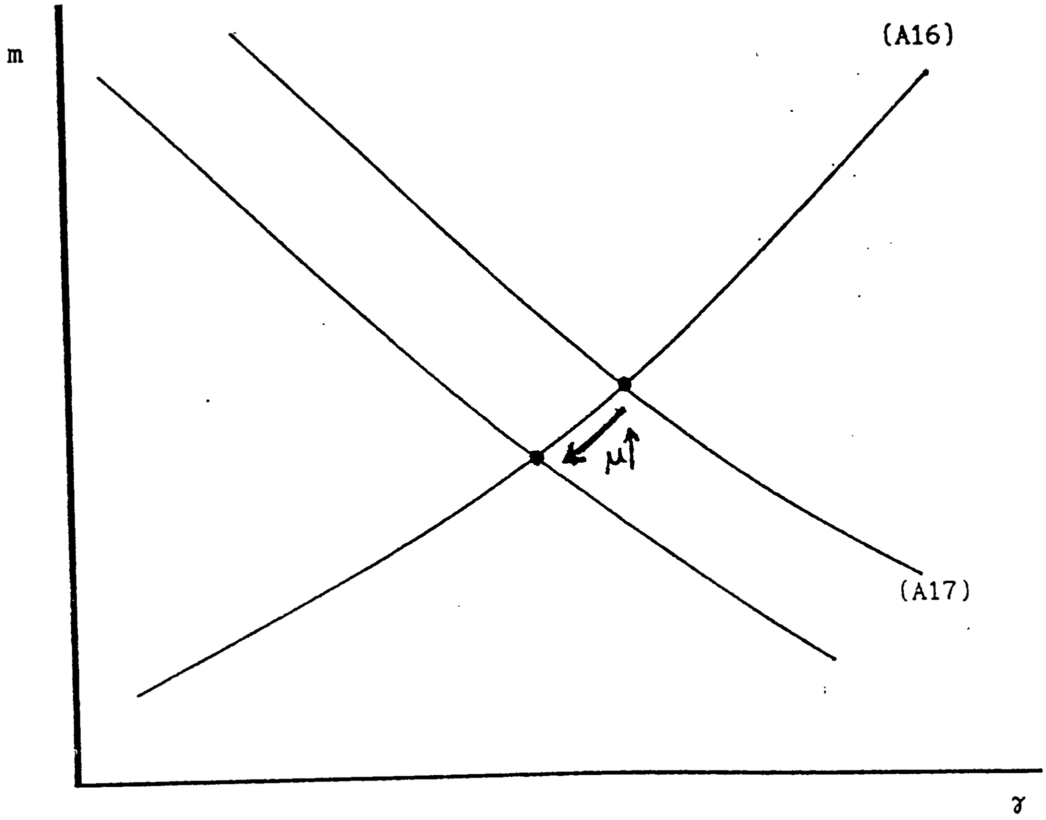

Figure A.1: Growth and Real Balances

CHAPTER 3 GROWTH, HUMAN CAPITAL, R&D AND TRADE

Abstract

This chapter develops an endogenous growth model in which growth is driven by expanding product variety and decentralised R&D activities. The main result is that the stock of human capital and the fixed cost of R&D determine the rate of growth in the medium run. We also show that even without technology spillovers and no research redundancy, trade liberalization can affect the long term growth rate in the medium run. In the long run, growth is determined by human capital accumulation and only trade liberalization matters for growth.

I. Introduction

Many economists believe that increased trade across countries has tended to increase the long-run rate of economic growth. Some would suggest that prospects for growth would be enhanced if trade barriers were eliminated. They would also predict that the free flow of goods would move developing countries out of stagnation. The success of many Asian countries has often been attributed directly to their increased trade and communication with the rest of the world. Not only have they expanded their overseas markets (through vigorous export policies), but they have also taken advantage of knowledge spillovers from developed countries.

Historical analysis shows that the creation and transmission of ideas have been extremely important in the development processes of most of industrialized economies. Romer (1986) and Lucas (1988) used the ideas of information externalities and human capital formation to stimulate the new theories of endogenous growth. Their arguments are very similar to the endogenous growth literature that existed in the 60's. The essential feature of Romer and Lucas' models is the inefficiency of the decentralised competitive equilibrium. By showing that the market economy may induce sub-optimal outcomes, they drew attention to the potentially positive role of government intervention.

This paper builds on some recent major contributions to the new theories of endogenous growth - in particular, the contributions by Grossman and Helpman (1989, 1991b) and Romer (1990). These authors focus on purposive activities that lead to technological change in the form of an expansion in the variety of products. They extend their analysis to consider the role of international linkages in determining the rate of technological progress (hence, the long term rate of growth). A different approach is taken by Aghion and Hewitt (1990) and Grossman and Helpman (1991a, 1991b) who model the research and development sector of an economy in a way that captures the Schumpeterian idea of creative destruction. The emphasis is on the replacement of old consumer goods by new consumer goods, and old methods of production by new methods of production. This process of creative destruction depends upon the level of research which, in turn, depends upon the monopoly rents available to the successful innovator.

These analyses stress the roles of knowledge spillovers, the adoption of new technologies and the replacement of old methods of production in generating growth. However, Adam Smith's analysis of the pin factory illustrates the potential importance of fixed costs and the extent of the market in determining growth of an economy. It is these two factors that we wish to focus on in this paper and which distinguishes our analysis from the exiting literature. We showed that market size and fixed costs are important in determining whether an economy can sustain its growth forever. Extending our analysis, we study the effects of trade liberalization on growth.

The potential for trade to affect growth has often been talked about in the past but it is only recently that economists have developed growth theory into a discipline that is capable of providing the invaluable check against ill-defined concepts and poorly-formulated arguments.[1] Several authors have now constructed models in which trade effects on growth are both present and explicit (Backus, Kehoe and Kehoe (1990); Freenstra (1990); Grossman and Helpman (1989,1991a&b); Rivera-Batiz and Romer (1991a,1991b); Young (1991)). These effects are (i) the contemporary or intertemporal knowledge spillover

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1 For a review of the new growth theory, see Romer (1989) and Sala-i-Martin (1990).

effect and (ii) the resource allocation effect between the R&D sector and manufacturing sector. Very little mentions have been mentioned on the market size effect due to trade.

R&D needs human capital. Models like Grossman and Helpman (1989a) and Rivera-Batiz and Romer (1991a,1991b) feature a constant stock of human capital but can sustain continuous growth in the economy through innovations. Our paper questions this result. With decentralised R&D and a minimum human capital requirement for R&D activities, we show that unless there is human capital accumulation, growth will vanish. In the long run, economic growth is generated through human capital accumulation and innovations together.

The paper is organised as follows. In section II, we present the model as a closed economy. In section III we analyze the effects of trade liberalization on growth. In section IV, we study the limit of growth with a constant stock of human capital and solve for the steady state with human capital accumulation in section IV. Concluding remarks are contained in section V.

II. The Closed Economy Model

In this section, we specify the model as a closed economy. We believe that it is useful to explain some basic ingredients of the model before any discussion about the effect on growth from trade liberalization. Although the model is very similar to Judd's model (1985), Romer's model (1990) and Grossman and Helpman's model (1989), we modify their models by introducing a fixed cost in the R&D sector. This enables us to generate different results about the effects of trade liberalization and to study the relationship between growth and the size of the market.

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1. Production Side

There are three sectors of production in this model: a final goods sector, a producer goods sector and a research and development sector. Basic inputs to the production of final goods are human capital, intermediate producer goods and an index of the level of technology. Both final goods Y and producer goods $x(i)$ are non-durable goods, where i is an index. In order to simplify the notation, we leave out the time subscript. The set of possible producer goods is $\{i | i \in [0, M]$, where $M \in \Re_+\}$ where $\Re_+$ is the non-negative real line. One can interpret M as the range of producer goods available for current production. We adopt Romer's set up (1990) where product variety generates an efficiency gain in production. We formulate the efficiency gain in terms of the range and level of the inputs. In order to simplify the computation of the equilibrium, we assume away labour services as inputs. The simplest functional form of final goods production is the Cobb-Douglas technology:

$$Y = \int_0^M x(i)^\alpha \, H_Y^{1-\alpha} \, di \tag{II.1}$$

where $x(j)$ is the quantity of the j^{th} intermediate input in final goods production. Firms will employ all available inputs that could enter into production to achieve the highest efficiency. H_Y is the amount of human capital services employed in the final goods sector. Since the production of final goods exhibits constant return to scale, we can assume that there is a representative firm in the final goods sector. Let all prices be expressed in terms of the price of the final good. The representative aggregate firm maximizes its profit by taking the prices of producer goods $p(i)$, the wage rate w and the number of existing producer goods M as given:

$$\max_{x(i),\ i \in [0,M];\, H_Y} \Pi = \int_0^M x(i)^\alpha \, H_Y^{1-\alpha} \, di - wH_Y - \int_0^M p(i)x(i)\,di \tag{II.2}$$

Given the firm's maximization problem, we can solve for the derived demands for human capital services H_Y and each of the inputs $x(i)$ as

$$H_Y = \frac{(1-\alpha)Y}{w}$$

$$x(i) = \frac{\alpha Y p(i)^{-\frac{1}{1-\alpha}}}{P}, \quad where\ P = \int_0^M p(i)^{-\frac{\alpha}{1-\alpha}} di \qquad (II.3)$$

Each firm j in the intermediate goods sector requires η units of the final good to produce one unit of the producer good. In addition, the production requires the acquisition of a permit from the owner of the design of the product. Once the right has been granted, the firm can produce whatever amount they desire during the period. Let $q(j)$ denote the price of the permit. We express the profit of the firm $\pi_I(j)$ as

$$\pi_I(j) = p(j)x(j) - \eta x(j) - q(j) \qquad (II.4)$$

where $x(j)$ is the derived demand given above. We assume that the intermediate goods firms set prices to maximize their profits, taking $q(j)$ as given. If M is large enough or the share of each firm in total demand is measure zero, we can neglect any feedback effects from P. It follows that the Bertrand equilibrium is characterized by the constant mark up pricing rule: $p(j) = \eta/\alpha$.

Given the symmetry in the model, the price of each input is the same: $p(j) = p$. With the same price p, the demand for each input from the final goods sector will also be the same: $x(j) = x$. As a result, total final goods output Y can be written as $M\, y$, where $y = x^{\alpha} H_Y^{1-\alpha}$. Moreover, constant mark up pricing implies that the profit of each firm is equal to

$$\pi(j) = (1-\alpha)px - q(j) = \frac{\alpha(1-\alpha)Y}{M} - q(j) \qquad (II.5)$$

Given the free entry assumption in the intermediate goods sector, firms will compete for the right to produce. In our model, we exclude any collusion amongst firms in the intermediate goods sector and assume competition patent holders of the designs. As a result, the price of the permit $q(j)$ will be bid up until all the profits of the intermediate goods sector firm have been extracted. Since all the firms have the same revenue excluding variable cost, therefore all $q(j)$ are equal and given by $q = (1-\alpha)\alpha Y/M$.

The mechanism of growth is the accumulation of new designs M. In each period there are N firms engaged in research activities. There is no contemporaneous knowledge spillover in the research sector. A research firm will experience innovations with a probability of $\lambda(.)$ at the end of the current period. The probability is a function of its current efficiency unit of input v in its research activities. Both private knowledge and public knowledge can improve the effectiveness of research activities. Following Romer's (1990) arguments, anyone engaged in research can freely access the entire stock of knowledge because it is a public and nonrival good. Hence, all researchers can take advantage of the entire stock of knowledge at the same time. We assume that the stock of knowledge is related to the stock of designs M_R. Since human capital is a rival and excludable input, it can not be shared with another R&D firm. Given the externality associated with the knowledge spillover, we assume that the k^{th} R&D firm, which employs $h_R(k)$ units of human capital, will have $M_R h_R(k)$ units of efficiency input. Observe that having a product is not the same as having knowledge about the product because the product can be designed, manufactured in foreign countries and imported for production. Despite this, M_R will equal M in a closed economy.

There is also free entry into the R&D sector. We assume that every firm will use up γ amount of final goods during their research activity in every period, no matter how much human capital they employ. This can be interpreted as some fixed cost for engaging in R&D activities. Once the firm has the new design, they can start to auction the right to produce the product in the next period. Thus, the R&D firm will expect to collect the revenue from next period onwards. As shown above, the price of the production license of each design is the same in equilibrium (i.e. $q(k) = q$). It follows that the present value of future revenue will be $1/(1+r)\ \Sigma^{\infty}_{i=0}\ q/(1+r)^t$. Each R&D firm k takes its future revenue as given, and maximizes the discounted sum of its expected profit

$$V(k) = \frac{\lambda(v)q}{r} - wh_R(k) - \gamma;\ v \equiv Mh_R. \qquad (II.6)$$

where $V(k)$, v and $h_R(k)$ are respectively, the value of the firm, the efficiency unit of inputs and the amount of human employed by the k^{th} R&D firm. At the margin, each R&D firm will equalise its expected marginal profit and marginal total cost. Given free entry into the R&D sector, together with the assumption of symmetry, the discounted sum of expected profit will be zero at equilibrium.

$$\frac{M\lambda'(\nu)q}{r} = w$$
$$\frac{\lambda(\nu)q}{r} = wh_R + \gamma \qquad (II.7)$$

In contrast to Romer (1990) and Grossman and Helpman (1989), we do not assume a constant marginal product of h_R for a given M in the R&D sector. A linear production of new designs (or a proportional effect of human capital employed on the arrival rate of innovations) can not determine the number of R&D firms in equilibrium. In the models of Aghion and Hewitt (1992) and Grossman and Helpman (1991a), R&D activities are treated as a Possion process. By applying the law of large number, they can eliminate the idiosyncratic risk of the individual firm. We believe that it is essential to determine whether the number of R&D firms will grow at the same rate as the steady state growth rate. If the number of R&D firms grows with the economy, a growing mature economy will have much lower aggregate risk than a stagnant economy. In addition, since the probability of having a new design is bounded, the constant returns to scale technology does not seem appropriate. The diminishing returns to scale technology emphasizes the problem of the centralisation of R&D activities. As human capital or knowledge accumulates, if R&D activities remain concentrated amongst a fixed number of firms, the growth rate of the economy will eventually go to zero. Moreover, by adding the fixed cost, we can separate the human capital sectoral allocation condition of human capital resources amongst different sectors from the zero profit condition of R&D firms. The later condition relates to the balanced growth condition and will be returned to shortly. To complete the description of the model, it remains to specify preferences and endowments.

2. Household Side

Assume that there is a representative individual with a fixed level of human capital endowment H^1. Assume that the individual has the intertemporal utility function:

$$U = \sum_{t=0}^{\infty} (1+\rho)^{-t} \frac{C_t^{1-\sigma} - 1}{1-\sigma} \quad for\ \sigma \in [0,\infty). \tag{II.8}$$

where C_t denotes consumption of the final good. The parameter ρ is the subjective rate of time preference and the quantity $1/\sigma$ is the elasticity of intertemporal substitution. The individual's budget constraint is

$$w_t H^1 + (1+r_t)A_t = C_t + A_{t+1}. \tag{II.9}$$

where w_t, r_t and A_t are the wage rate, interest rate and wealth respectively. Households make saving and consumption decisions taking the interest rate and wage rate as given. Along the optimal consumption path, the marginal rate of intertemporal substitution is equal to the interest rate minus the subjective discount rate, i.e.

$$\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} = \frac{1+\rho}{1+r_{t+1}} \Rightarrow \sigma g_{c,t} \approx r_{t+1} - \rho \tag{II.10}$$

where g_C is the growth rate of consumption.

3. Balanced Growth Equilibrium

The equilibrium for this model will be paths for prices and quantities such that (i) the supply of human capital is equal to the total demands from the final goods sector and the R&D sector; (ii) the supply of each good is equal to the demand for each good; (iii) total savings is equal to total investment; and (iv) there is a common growth rate g for all these variables

$$g = g_c = \frac{\Delta Y}{Y} = \frac{\Delta M}{M} = \frac{\Delta N}{N} \tag{II.11}$$

Since every firm in the R&D sector is the same, we can denote the efficiency unit of R&D inputs as $v \equiv M h_R = M/N\, H_R$. From the marginal condition of R&D activities, we can find out the demand for human capital from the R&D sector. Given equilibrium in the human capital market ($H^1 = H_Y + H_R$), and the demand for human capital from the final goods sector ($H_Y = (1-\alpha)Y/w$), we can determine the amount of human capital services in the R&D sector. The marginal willingness to pay an additional unit of human capital in an R&D firm equals $M \lambda' q/r$ and the price of production permit equals to $\alpha(1-\alpha)Y/M$. Since the marginal willingness to pay will equal the market wage rate in equilibrium, therefore $w = \alpha(1-\alpha)\lambda' Y/r$. Given equilibrium in the capital market, where the interest rate can be expressed as $\sigma g + \rho$, the allocation of human capital must satisfy the following condition:

$$H^1 - H_R = \frac{\sigma g + \rho}{\alpha \lambda'(\nu)} \qquad (II.12)$$

One can observe a trade-off between M/N and H_R. In this product variety model, the first firm to innovate can obtain the patent, so that the optimal strategy of each R&D firm is to operate at different kinds of research. One can interpret N/M as the ratio of the potential flow of new designs to the stock of existing designs. The greater the number of firms engaged in R&D activities, the greater the competition for human capital services. This bids up the wage rate and induces more human capital to the research sector. However, with decreasing returns to scale, each individual R&D firm will employ less human capital.

Given that each firm's probability of success is independent of all others, the expected flow of new designs ΔM is equal to λN. At the steady state, output per unit design y is determined so that output grows with M. With $\Delta Y/Y = \Delta M/M$, the steady state growth rate g is equal to $\lambda N/M$. By substitution into (II.12), we obtain

$$H^1 - H_R = \frac{\frac{\sigma N \lambda(\nu)}{M} + \rho}{\alpha \lambda'(\nu)} \qquad (II.13)$$

Combining the zero expected profit condition and marginal conditions in the R&D sector,

$$\left[\frac{\lambda(\nu) - \lambda'(\nu)\nu}{\lambda'(\nu)}\right]\frac{w}{M} = \gamma \qquad (II.14)$$

With constant marginal cost in the intermediate goods sector and constant mark up pricing, the ratio of inputs $x(i)$ to human capital is fixed, so that the growth adjusted wage rate is independent of the distribution of human capital across sectors (This remains true when one modifies the producer goods technology to the same form as the final goods production technology. The proof is contained in the appendix). As a result, the fixed cost γ determines the efficiency level of inputs v in equation (II.14). Once v has been determined, the ratio of N/M can be calculated from (II.13) and $H_R = vN/M$. The economy wide expected growth rate is then given by $g = \lambda N/M$.

Proposition 1: With $\lambda' > 0$, $\lambda'' < 0$, $\lambda > \lambda' v$, $C > 0$ and $v^* < v_1$, where $\gamma = w^*(\alpha,\eta)[\lambda(v^*)-\lambda'(v^*)v^*]/\lambda(v^*)$ and $\alpha H\lambda'(v_1) = \rho$, $\exists$ a steady state growth rate $g^* > 0$.

(shown in Appendix)

The underlying source of growth in our model is through the increasing number of firms engaged in R&D activities. As the economy grows, the concentration of research activities amongst a constant number of firms will induce more and more inefficiency in R&D production. In order to reduce the inefficiency, it is essential that research activities are diversified. As the economy grows and more resources become available to finance new research activities, the economy can maintain a constant growth rate of designs by splitting the human capital between the N R&D firms. In Romer's model, there is no constraint on growth. In our model, a constraint can be added by imposing a minimum requirement of human capital in any single research project. As the economy reaches this binding constraint, sustained growth will be dictated by the growth of human capital rather than the innovation in R&D. We will discuss this further in section IV.

Abstracting from the minimum requirement on human capital in this section, there are two types of resource constraints in the economy: the first relates to the allocation of human capital between the final goods and R&D sectors; the other concerns the generation of sufficient savings to achieve balanced growth equilibrium. Both Romer's model (1990) and Grossman and Helpman's model (1989), automatically satisfy the balanced growth condition where savings equals investments. But since human capital demand is determined by the marginal condition of the firm, and the balance of saving and investment is related to amount of resources generated, it is difficult to see why the human capital allocation condition and the balanced growth condition should, in fact, be automatically satisfied.

In the following, we identify what particular features of other models that could make the human capital allocation and balanced growth conditions the same. To do this we note that output may be written in the following two ways, depending on whether one adapts an expenditure approach or a valued-added approach:

$$\begin{aligned} Y &= C + I_Y + I_R \\ Y &= Mq + wH_Y + \eta Mx \end{aligned} \qquad (II.15)$$

where I_Y and I_R are investment expenditure on final production and R&D activities respectively. Since the investment on final production is equal to the current production of producer goods, $I_Y = \eta\, M x$. In addition, since R&D investment is equal to the total fixed cost plus the hiring cost, $I_R = N\gamma + w_R$. By combining these results with the household budget constraint (II.10), we obtain

$$S = N\gamma + wH_R + (rA - Mq). \qquad (II.16)$$

With no other asset in the economy, the total wealth of the economy equals the present value of claims on the patent right, $A = Mq/r$. By definition, saving equals the change in asset holdings. In the steady state, the rate of change of the asset A will equal g because q and r are constant, i.e. $g = S/A$. As a result, balanced growth requires

$$g = \frac{N\gamma + wH_R}{A}; \quad where\ A = \frac{Mq}{r}. \qquad (II.17)$$

Using $g = \lambda N/M$, and dividing both side by N, we obtain the zero profit condition. Hence, the balanced growth condition is related only to the zero profit condition and not the marginal condition of R&D production. Only in the case of a linear R&D technology does condition for the market allocation of human capital coincide with the zero profit condition. With this special assumption, the size of the market does not affect growth. We return to discuss the effect of the size of the market in next section. Despite these differences, our model can generate some results that are similar to those in Romer's paper (1990) and Grossman and Helpman's paper (1989):

Corollary 1: (i) Higher H, lower ρ and lower σ implies higher g^* and higher H_R; (ii) Higher γ implies lower g^* and, with $\lambda'' < 0$, implies lower H_R.
(shown in Appendix)

It is common in the endogenous growth literature, to compare the market equilibrium with the socially optimal equilibrium. Since we do not propose to do any welfare analysis, we just outline the conditions of the balanced growth social optimum in the appendix.

The model gives some interesting policy implications which do not appear in Romer's and Grossman and Helpman's model. Suppose that the government was to subside equally all sectors employing human capital. Although this has no initial impact on the human capital market, it makes existing R&D firms begin to operate at a positive expected profit level. This encourages more firms to enter the R&D sector. Competition between the final goods sector and R&D sector, and also between R&D firms, results in a greater number of R&D firms with each R&D firm operating on a smaller scale. In equilibrium, the economy experiences a higher growth rate. Trade liberalization policy is similar to this subsidy policy. In the following section, we will use the model to study the effects on growth when an economy opens itself to trade.

III. Trade Liberalization Between Identical Economies

There are different kinds of gains from trade liberalization: (i) Trade can produce a static gain from production comparative advantage (the conventional type of gain); (ii) Trade can increase market size and so encourage entrepreneurs to pursue new ideas and designs; and (iii) Trade can induce communication between countries which facilitates the transmission of technical information which increases efficiency both in the production sector and R&D sector; There are two distinct mechanisms by which trade liberalization can affect the long run growth performance in our model. The first is through the integration of producer goods markets. The second is through technology spillovers. The effects of knowledge spillover have already received considerable attention. Those interested can find the main results in Rivera-Batiz and Romer's paper (1991a, 1991b) and Helpman and Grossman (1991b)'s book. This section focuses on the trade liberalization policy result of Rivera-Batiz and Romer (1991a) and Helpman and Grossman (1991b). That result is as follows:

> *In the specific model outline here (Knowledge-Driven Model, Romer 1990), free trade in goods can affect the level of output and can therefore affect welfare, but it does not affect long run growth rates.*
>
> *Rivera-Batiz and Romer (1991a, QJE pp.544)*

> *If there happens to be no research redundancy in the equilibrium without trade, the integration of product markets will have no effect on the long-run growth rate in either countries.*
>
> *Helpman and Grossman (1991b, pp.245)*

Our objective in this section is to show that even without technology spillover and no research redundancy, trade liberalization can affect long term growth.

Both of the above papers present the argument for no growth effect of trade liberalization based on the competition for the underlying resources. In Rivera-Batiz and Romer's model, as an economy opens up its market, the profits that the holder of each patent can extract increases because the market size for the goods increases. This profit opportunity return tends to encourage more R&D activities. However this effect is exactly offset by the increase in the wage rate, due to the upsurge in the marginal productivity of human capital in final goods sector resulting from the expanding varieties of intermediate goods from imports. As a result, there is no change in the allocation of human capital between different sectors and so no effect on growth.

In Helpman and Grossman's model, as new products are being developed in each of the trading economies, the extra demand that each producer enjoys in a larger world market exactly matches the loss of sales that each suffers due to the expansion in the number of competing varieties. The underlying mechanism is the same as Rivera-Batiz and Romer's model (1991a), since increasing product varieties reduces the marginal willingness to pay of the representative household for each unit of product or it decrease the demand for the product. However the loss of sales is matched with the increase in demand from the outside world. As a result, there is no extra demand for human capital from the R&D sector and so no change in steady state growth rate.

As we mentioned in last section, the assumption of a linear R&D technology makes the marginal condition and the zero profit condition the same. In what follows, we seek to illustrate how trade liberalization can promote growth by separating the two conditions. Let us suppose that there are L identical economies which have the same human capital endowment H^1 and the same number of intermediate goods M, and the same production technologies. Thus each country has the same Cobb-Douglas function and the same $\lambda(.)$ function with the same parameters α, η and γ. In addition, they also have same type of utility function and same preference parameters ρ and σ.

As noted in section II, all intermediate product firms will have the same revenue excluding variable cost. With complete trade liberalization, no knowledge spillover ($\nu = Mh_R$) and no redundant products, the revenue excluding variable cost is equal to $(1-\alpha)\alpha \{\Sigma_{l=1}^{L} Y_l\}/\{\Sigma_{l=1}^{L} M_l\}$. When economies are allowed to trade, every country's the final goods sector imports intermediate goods, so that the varieties of inputs increases. This improves productivity. In equilibrium, output of country l (Y_l) equals $\Sigma_{k=0}^{L} M_k y_l$. Since we assume identical economies, the equilibrium price of the permit q_L equals $(1-\alpha)\alpha Ly$. Without any transfer of knowledge between countries, the conditions for the optimal scale of R&D activities and free entry can be expressed as

$$\frac{M\lambda'(\nu)q_L}{r} = w$$
$$\frac{\lambda(\nu)q_L}{r} = \frac{w}{M}\nu + \gamma \qquad (III.1)$$

Since the total number of intermediate inputs is ML, with Cobb-Douglas production function, the demand for human capital services from the final goods sector is $H_Y = (1-\alpha)MLy/w$. Thus, the market equilibrium condition for human capital, the balanced growth condition and the capital market equilibrium condition can be written as

$$g = \frac{\lambda(\nu)N}{M}$$
$$\sigma g + \rho = r$$
$$H^1 - H_R = \frac{r}{\alpha\lambda'(\nu)} \qquad (III.2)$$
$$\frac{\lambda(\nu) - \lambda'(\nu)\nu}{\lambda'(\nu)}\left(\frac{w}{ML}\right) = \left(\frac{\gamma}{L}\right)\ !$$

The equilibrium condition for human capital market is exactly the same as the one in the closed economy. This is exactly what Rivera-Batiz and Romer (1991a) and Helpman and Grossman (1991b): both marginal willingness to pay by the R&D sector and the marginal willingness to pay by the final sector increases by the same amount. As a result, there is no change in the market clearing condition for human capital. Now, we have argued before , that the growth adjusted wage rate is independent of the allocation of human capital across sectors. Therefore we have

Proposition 2: Suppose there are L identical economies, no redundant intermediate products, all grow at the rate g_0^*. After open trade between economies, the growth rate increases, i.e. $\Delta g^*/\Delta L > 0$. !

Proof:

From the second equation of (III.2), $\nu = \psi[\gamma/(w^*L)]$ is derived, and $w^* = w/ML$ & $\psi_L < 0$.

Since the function $m = m(v,\sigma,\rho,H^1)$ remains the same, and $\partial g^*/\partial v < 0$. So g^* for $L > 1$ is greater than g_0^* for $L=1$ and $\Delta g^*/\Delta L > 0$. Q.E.D.

The explanation is that when economies open themselves to trade, the market becomes larger so that R&D firms begins to operate at positive profit. This induces more firms to engage in R&D activities. As the total number of firms in the R&D sector increases, the total demand for human capital increases. More human capital shifts towards to the R&D sector and increases the number of firms. But as competition between R&D firms intensifies, the scale of R&D activities of each firm decreases. However, in this model decentralised research is always better than concentrated research activities. It results in a higher rate of success in innovations on average so that a higher steady state growth rate is obtained.

Corollary 2: Suppose there are L identical economies, no redundant intermediate products. If initially all of them in a state of stagnation: $g^* = 0$, as number of free trade partners increases, economies can get out of stagnation.

Proof:

For a economy to have zero growth in our model ($g^* = 0$): $v^* = \psi[(\gamma/(w^*L)] > v_1$, where $\alpha \lambda'(v_1) H^1 = \rho$. As L increases, since $\psi_L < 0$. It implies that $\exists\, L_1, \forall\, L > L_1$, i.e. $\psi[\gamma/(w^*L_1)] \leq v_1$, which $g^*(L) > 0$. Q.E.D.

The explanation is similar to proposition 2. The reason why economies are trapped in stagnation is simple. It is because the fixed cost is too high. The economy can not generate enough savings to sustain the increasing number of R&D firms in the steady state. Even without any increase in the human capital endowment, economies can pull themselves out of stagnation by just opening up markets to each other. As the number of free trade partners increases, the size of the potential market is greater so that firm's expected profit increases. As a result, increasing research activities becomes more sustainable.

It is not difficult to see that the results in section II and III are dependent on the absence of a minimum requirement of human capital in R&D. As the economy grows, without any human capital accumulation, the economy will eventually stop growing as long as the minimum requirement is not zero. This is because R&D firms can no longer reduce their scale to balance the diminishing returns to R&D activities ($\lambda''(.) \leq 0$). In the next section, we introduce human capital accumulation. We show how the expanding R&D activities is constrained by the rate of growth of human capital. Furthermore, we illustrate how the growth rate of human capital and rate of innovation are determined simultaneously in the steady state growth rate equilibrium.

IV. The Limit to Growth

In the last section, the growth is due solely to an increase in the number of available intermediate inputs. However, in previous section v (the efficiency unit of input in the R&D sector) is constant along steady state growth path. This implies that the expected rate of success of each activity is constant at $\lambda(v)$. With $v = MH_R/N$, as M grows, the amount of human capital employed by each R&D firm H_R/N decreases. The critical assumption is that the model allows H_R/N to go to zero.

1. Bottle-Neck Constraint in the R&D Sector

Suppose that there is a minimum requirement of human capital $\hat{h}$ for each R&D project. Once h_R decreases to $\hat{h}$, there is no longer any variable factor consequently, R&D firms can not reduce their demand for human capital to increase efficiency and balance the rising cost. When the economy grows, the cost of doing R&D is increasing, but the expected profit increases only gradually (due to the productivity increase of intermediate goods caused by the increase of human capital employed by the final goods sector, the intermediate goods sector, and the probability λ). As a result, less R&D firms enter[2] and

[2] As one may notice that $\lambda(v)$ increase at a decreasing rate. Given that $\lambda(v)$ is bounded and $\lambda' > 0$, $\lambda \rightarrow$ constant.

the rate of innovation eventually decreases to zero. We can formulate the following proposition:

Proposition 3: Given the constraint $h_R \geq \hat{h}$, if human capital grows at the rate g_H, growth rate of design in the steady state is $g_M = g_H$.

Proof:

(i) Suppose there is a steady state with constant m^*, $\lambda(v^*)$, H_R/H^1, H_Y/H^1 and g_M^* but $g_H^* > g_M^*$. Since $g_H^* > g_M^*$, it must be true that $g_H > g_N$ *(because* m^* *is constant),* so $h_R \geq \hat{h}$ is not binding after some time. $\therefore$ v is given by $\gamma = w^*(\alpha,\eta)\ [\lambda(v^*) - \lambda'(v^*)v^*]/\lambda'(v^*)$. But g_M^* is increasing with $\partial m/\partial H^1 < 0$. This is not a steady state equilibrium.

(ii) Suppose there is a steady state with constant m^*, $\lambda(v^*)$, H_R/H^1, H_Y/H^1, and g_M^* but $g_H^* < g_M^*$. This means that $h_R \geq \hat{h}$ is binding after some time. With binding constraint we have[3]

$$\begin{aligned} \lambda(v)\Big[\frac{\frac{\alpha y}{1+\alpha}}{r+g_H}\Big] &= w\hat{h} + \gamma \\ H^1 - N\hat{h} = H_Y + H_I &= \frac{My}{(1+\alpha)w} \\ r &= \sigma(g_M^* + g_H^*) + \rho \end{aligned} \qquad (IV.1)$$

Since M increases and $\lambda(.)$ is bounded, with $\lambda' > 0$ & $\lambda'' < 0$, it must be true that $\lambda \rightarrow$ constant $\bar{\lambda}$ in the long run. By combining the three equations, $\Delta M/M$ can be expressed as

[3] The first equation is the zero-profit condition, the second is the human capital market equilibrium and the last one is the capital market equilibrium.

$$\frac{\Delta M}{M} = \frac{\bar{\lambda} N}{M} = \frac{\bar{\lambda}\frac{H^1}{M} + [\frac{\sigma g_H + \rho}{\alpha}(\hat{h} - \frac{\gamma}{w^* M})]}{\hat{h}(1+\frac{\sigma}{\alpha})}. \qquad (IV.2)$$

When $M \to \infty$, unless $g_H^* = g_M^*$, $\Delta M/M$ is not a constant. Q.E.D.

2. Human Capital Accumulation

Obviously, if consumers can choose the rate of human capital accumulation, then g_H also depends on g_M. First let us model the human capital accumulation. We follow the Lucas model (1988) and assume that households take the g_M path as given. The representative household decision problem is the following:

$$\begin{aligned} \max_{C_t\, H_t^1\, A_t\, H_t} \quad & U = \sum_{t=0}^{\infty} (1+\rho)^{-t} \frac{C_t^{1-\sigma} - 1}{1-\sigma} \quad for \ \sigma \in [0,\infty) \\ s.t.\ \dot{A}_t &= w_t H_t^1 + r_t A_t - C_t = w^* M_t H_t^1 + r_t A_t - C_t \\ \dot{H}_t &= \phi H_t^2 - \delta H_t \\ H_t &= H_t^1 + H_t^2 \\ \frac{\dot{M}}{M} &= g_M \end{aligned} \qquad (IV.3)$$

where H^1 and H^2 are human capital devoted to working and schooling. With the assumption $\phi > \delta + \rho$ (which makes it both viable and worthwhile for the economy to have a positive rate of human capital accumulation even when $g_M = 0$), we got $\sigma g_C + \rho = r$, $g_H = [(\phi-\delta-\rho) + g_M(1-\sigma)]/\sigma$ and $g_C = g_H + g_M$ in steady state.[4] Hence, $dg_H/dg_M = (1-\sigma)/\sigma > 0$ (for $\sigma < 1$). This means that if the intertemporal elasticity is greater than one ($\sigma < 1$), one percentage increase in the growth rate of innovations g_M induces less than one percentage change in the interest rate. Thus, the gain from an increase in human capital level in the

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4 Reminding w^* is constant.

next period is positive (even taking into account the increase in the discount rate) at the margin. So when g_M increases, g_H increases.

3. Steady State Equilibrium

Given proposition 2, $g_M = g_H$ and $g_H = [(\phi-\delta-\rho) + g_M(1-\sigma)]/\sigma$. we may compute the steady state growth equilibrium as follows

$$
\begin{aligned}
g_H &= \frac{\phi-\delta-\rho}{2\sigma-1} \text{ for } \sigma > 1/2 \\
g_M &= g_N = g_{H_Y} = g_{H_R} = g_H \\
g_C &= g_Y = g_A = 2g_H
\end{aligned}
\qquad (IV.4)
$$

The necessary and sufficient conditions to have a stable positive rate of growth are $\phi - \delta - \rho > 0$ and $(1-\sigma)/\sigma < 1 \leftrightarrow \sigma > .5$. If these conditions are not satisfied, the only possible solution is zero growth.[5]

The steady state equilibrium above is a competitive equilibrium. Both households and firms take g_M and g_H as given respectively. They do not internalize the effects of the accumulation of human capital and innovations on each other. The model looks as if it has increasing returns to human capital but the driving force is actually the coordination problem between households and R&D firms. In a coordinated equilibrium, households would incorporate the effect on innovation (releasing the constraint on the R&D sector through their human capital accumulation). In this case, the household maximization problem would be similar except that it would take $g_M = g_H$ instead of taking g_M as given. The solution would be $g_H = [2(\phi-\delta)-\rho]/\sigma$ which is greater than that of the competitive equilibrium when $\sigma \in [2/3,1]$. However the growth rate is lower in the case of $\sigma < 2/3$ or $\sigma > 1$. Consumer welfare would always be higher in the coordinated equilibrium. Given these results, it is possible to obtain different implications about the effects of economic integration and trade on growth.

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[5] The rate of growth cannot explode to infinity because H^2 is bounded to be less H. The proof is in a subsequent paper by Hung, Pozzolo & Blackburn (1992).

V. Economic Integration, Trade and Growth

Our model has different implications concerning trade, research and growth from the models of Grossman and Helpman (1991b) and Rivera-Batiz and Romer (1991a&b). In the absence of the constraint on human capital in R&D sector, the model demonstrates other mechanisms for growth. In addition to the knowledge spillover effect, redundancy effect, allocation effect and economic integration effect (all mentioned in Grossman and Helpman (1991b) and Rivera-Batiz and Romer (1991a&b)), we emphasize the market size effect. The crucial factor is the fixed cost. Although the literature does refer to fixed costs, what is actually modelled are variable costs in the R&D sector. In the model presented here, we found that, when introducing the real fixed cost, the market size can influence the growth of the economy.

If we allow a bottle-neck in R&D activities, the growth rate is determined by the growth of human capital. Through this constraint, we are able to link up human capital accumulation and technological progress. Any knowledge spillovers, redundancy in R&D activities and reallocation of human capital across sectors can have only a temporary effect on growth.[6] For identical economies, economic integration and trade liberalization through increasing the size of H and M have no permanent effect on growth.

In the case of non-identical economies with different rate of human capital accumulation, the effect of economic integration and free trade on growth is not zero. Assume that there are two countries A and B where A has a higher rate of growth of human capital. In order to avoid corner solutions, suppose that there is no capital flows across countries. Country A, with the higher rate of growth of human capital will also have the higher growth rate of intermediate products. Once trade is open, country B, with the lower rate of human capital accumulation, will find that its final goods sector will be dominated by the imported inputs from country A. Therefore, M^B will grow at the rate

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[6] Given at the steady state, $\lambda \rightarrow \bar{\lambda}$, any exogenous increase in M will not matter. Similarly the growth of R&D sector ultimately depends on the growth rate of human not the relative size of allocation across sector.

g^A_H, and output will grow at the rate $g^B_H + g^A_H$ which is higher than $2\ g^B_H$ without trade liberalization. Economic integration means merging the human capital resources together, so that human capital grows at the weighted average of g^A_H and g^B_H (the weight depends on the population size). As a result, the faster growing economy will suffer while the slower growing economy will gain. A detailed study can be found in Hung, Pozzolo and Blackburn (1992).

The results of the paper are very model-specific. By introducing some fixed cost and the constraint on human capital accumulation, some of the results of Grossman and Helpman (1991b) and Rivera-Batiz and Romer (1991a&b) have been challenged, In addition, the model implies that policy on education and industrial policy on R&D should be considered together. Future research should be directed towards specifying on more general type of human capital accumulation. This will no doubt yielded more insights into the effects of government policies directed towards growth, trade and education.

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Appendix

A. Constant Growth Adjusted Wage Rate:

In the text paper, we use constant marginal cost in the intermediate goods sector in order to simplify the model. Suppose now we let the intermediate goods have the same production technology as the final goods sector:

$$z(j) = \int_0^M x(i,j)^\alpha \, h_I(j)^{1-\alpha} di, \quad j \in [0,M] \tag{A.1}$$

where $z(j)$, $x(i,j)$ and $h_I(j)$ are the total production of intermediate goods j, the demand for inputs i and human capital input from j^{th} producer goods industry respectively. After some tedious algebra, we can find that the marginal cost $c(j)$ equals

$$\begin{aligned} c(j) &= \kappa w^{1-\alpha} [\int_0^M p(i)^{-\frac{\alpha}{1-\alpha}} di]^{-(1-\alpha)}, \; where \; \kappa = \frac{1}{\alpha^\alpha (1-\alpha)^{1-\alpha}} \\ &= \kappa (\frac{w}{P})^{1-\alpha}, \quad j \in [0,M] \end{aligned} \tag{A.2}$$

where P is the same as in (II.3) With constant return to scale production, the average variable cost will equal the marginal cost. The profit of the producer goods firm $\pi_I(j)$ can be written as

$$\begin{aligned} \pi_I(j) &= p(j)z(j) - \kappa(\frac{w}{P})^{1-\alpha} z(j) - q(j) \\ where \; z(j) &= x(j) + \int_0^M x(j,i) \, di \end{aligned} \tag{A.3}$$

$z(j)$ is just the total demand for inputs j which is equal to the sum of the demand from final goods sector $x(j)$ and demands from all available producer/goods industries $\int x(j,i) \, dj$. The total demand for inputs, from final goods sector and intermediate goods sectors can be written as

$$z(j) = x(j) + \int_0^M x(j,i)\, di$$
$$= x(j) + \frac{p(j)}{P}^{-\frac{1}{1-\alpha}} \alpha\kappa(\frac{w}{P})^{1-\alpha} \int_0^M x(i)\, di \tag{A.4}$$

By substituting *x(j)* with

$$x(j) = \frac{\alpha Y\, p(j)^{-\frac{1}{1-\alpha}}}{P}, \tag{A.5}$$

we can get

$$x(j) = [\ \alpha Y + \alpha\kappa(\frac{w}{P})^{1-\alpha}\ X\ ]\ \frac{p(j)^{-\frac{1}{1-\alpha}}}{P}, \text{ where } X = \int_0^M x(i)\, di \tag{A.6}$$

so that *x(j)* can be expressed as a function of αY, *w, P, X and p(j).* If *M* is large enough or the share of each industry in the total demand *X* is measure zero, we can assume away the feedback effects from *P* and *X*. With price competition amongst firms, and with take *w*, *Y*, *P* and *X* taken as given, we can obtain the constant standard mark up pricing

$$p(j) = \frac{\kappa}{\alpha}(\frac{w}{P})^{1-\alpha} = \frac{c(j)}{\alpha} \tag{A.7}$$

With symmetric arguments, all price and demands from the final goods sector are equal: $p(i) = p$, $x(i) = x\ \forall\, i$. As a result, $w/Mp = (\alpha/\kappa)^{1/(1-\alpha)}$. Since the price ratio is constant, there is a constant inputs ratio between *x(i)* and H_Y at equilibrium. As a result, the growth adjusted wage rate *w/M*, which is related to the inputs ratio, will be independent of the allocation of human capital at steady state.

B. Proof of Proposition 1 and Corollary 1

Let $m = M/N$, multiply both side of (II.13) by *m* and express *m* in terms of *v*:

$$m = \frac{\nu\lambda'(\nu)\alpha + \sigma\lambda(\nu)}{\alpha\lambda'(\nu)H^1 - \rho} \tag{A.8}$$

as long as *when* $\nu \to 0$, $\alpha\lambda' H^1 > \rho$ with $\lambda'' < 0$, $\exists\, \nu_1$ i.e. $\alpha\lambda'(\nu_1)H^1 = \rho$. With $\lambda'' < 0$, $\forall \nu < \nu_1 \Rightarrow m > 0$ & $m'(\nu) > 0$. Since $\nu \to \infty$, $\lambda' \to 0$, $\gamma = w^*(\alpha,\eta)\,[\lambda(\nu^*)-\lambda'(\nu^*)\nu^*]\,/\lambda'(\nu^*)$, $\nu^* > 0$. With $\nu^* < \nu_1$, so $g^* = \lambda(\nu^*)/m(\nu^*) > 0$.

$$\text{With } m = m(\nu,\sigma,\rho,H^1),\ \nu = \nu(\gamma), \quad m_\nu > 0;\ m_\sigma > 0;\ m_\rho > 0;\ m_H < 0. \tag{A.9}$$

Since $g = \lambda(\nu)/m(\nu)$, $g^*_\sigma < 0$, $g^*_\rho < 0$ and $g^*_H > 0$. And $H_R = \nu/m$, so

$$\frac{\partial H_R^*}{\partial\sigma} < 0;\ \frac{\partial H_R^*}{\partial\rho} < 0;\ \frac{H_R^*}{\partial H^1} > 0. \tag{A.10}$$

With

$$\frac{dg}{d\nu} = \frac{\alpha\lambda'' H^1\sigma - \frac{\lambda'(\lambda - \nu\lambda')}{\lambda^2}\alpha(\alpha\lambda' H^1 - \rho) + \frac{\nu\lambda''\rho\alpha}{\lambda}}{[\alpha(\frac{\nu\lambda'}{\lambda}) + \sigma]^2} <.0. \tag{A.11}$$

and $\nu^*_\gamma > 0$, it implies $g^*_\gamma < 0$. Given $\lambda'' < 0$, such that $m_\nu'' > 0$ and

$$\textit{with } m(0) = 0, \Rightarrow \frac{\partial\left(\frac{\nu}{m}\right)}{\partial\nu} = \frac{\nu}{m^2}\left(\frac{m}{\nu} - \frac{\partial m}{\partial\nu}\right) < 0,\ \textit{so}\ \frac{\partial H_R^*}{\partial\gamma} < 0. \tag{A.12}$$

C. Conditions of the Balanced Growth Social Optimum

To derive the necessary conditions for the social optimization problem, we modify the model such that the current production of intermediate goods are used for next period production. Let $K_{t+1} = \int_0^M \eta x(j)\, dj$, so K_{t+1} can be interpreted as the amount of foregone output for capital instalment in next period. If the social planner only concentrates R&D activities in a fixed number of plants, the steady state growth rate will eventually be zero.

We specify here a decentralised social planning problem for which the number of plants engaging in R&D activities is a choice variable with a stock capital H. It can be written as:

$$\max \sum_{t=0}^{\infty} (1+\rho)^{-t} \frac{C_t^{1-\sigma}-1}{1-\sigma}$$
$$s.t.\ K_{t+1} = M_t H_{Y,t}^{1-\alpha}(\frac{K_t}{M_t \eta})^{\alpha} - C_t - N_t \gamma \tag{A.13}$$
$$M_{t+1} = N_t \lambda(\frac{M_t H_{R,t}}{N_t})$$
$$H \geq H_{Y,t} + H_{R,t}\ .$$

Therefore the Lagrangian of the social optimization can be expressed as:

$$\max \mathcal{L} = \sum_{t=0}^{\infty} (1+\rho)^{-t} \{\frac{C_t^{1-\sigma}-1}{1-\sigma} + \mu_{1,t}[\ M_t(H-H_{R,t})^{1-\alpha}(\frac{K_t}{M_t \eta})^{\alpha} - C_t - N_t\gamma - K_{t+1}\ ] + \mu_{2,t}[\ N_t\lambda(\frac{M_t H_{R,t}}{N_t}) - M_{t+1}\ ]\} \tag{A.14}$$

the choice variables are N_t, K_{t+1}, $H_{R,t}$, C_t *and* M_{t+1}. The first order conditions are:

$$C_t^{-\sigma} = \mu_{1,t} \rightarrow (\frac{C_{t+1}}{C_t})^{\sigma} = (1+g_t)^{\sigma} = \frac{\mu_{1,t}}{\mu_{1,t+1}}$$
$$\alpha\eta^{-\alpha}(H-H_{R,t+1})^{1-\alpha}(\frac{K_{t+1}}{M_{t+1}})^{\alpha-1} = (1+\rho)\frac{\mu_{1,t}}{\mu_{1,t+1}}$$
$$H_{R,t+1}\lambda'(v_{t+1}) = (1+\rho)\frac{\mu_{2,t}}{\mu_{2,t+1}}\ ,\ v_{t+1} \equiv \frac{M_{t+1}H_{R,t+1}}{N_{t+1}} \tag{A.15}$$
$$\frac{\lambda(v_t) - v_t\lambda'(v_t)}{\gamma} = \frac{\mu_{1,t}}{\mu_{2,t}}$$
$$\frac{H_{R,t}\lambda'(v_t)}{(1-\alpha)\eta^{-\alpha}(H-H_{R,t})^{-\alpha}(\frac{K_t}{M_t})^{\alpha}} = \frac{\mu_{1,t}}{\mu_{2,t}}$$

At steady state, $g_t = g^*$, with following conditions,

$$
\begin{aligned}
\frac{\mu_{1,t+1}}{\mu_{1,t}} &= \frac{\mu_{2,t+1}}{\mu_{2,t}} \\
g &= \frac{M_{t+1}}{M_t} = \frac{\lambda(v)}{m} \qquad (A.16) \\
\eta^{-\alpha}(H-H_R)^{1-\alpha}k^{\alpha} &= c + \gamma/m + kg \ .
\end{aligned}
$$

the steady state values of $k \equiv K/M$, $m \equiv M/N$, $v \equiv (M\,H_R)/N$ and $c \equiv C/M$ can be solved.

CHAPTER 4 ENDOGENOUS GROWTH and ENVIRONMENT

Abstract

In this chapter, we examine how environmental conservation affects production costs adversely and analyze this impact on growth. Growth is driven by expanding product variety. We find that economy may be stuck with dirty technology if they do not care about the environment in the beginning. In most cases, pollution control is not necessarily a depressant on growth from a market outcome. Even if the economy starts off pursuing optimal growth without considering environmental damage, it may still possible increase its growth rate by taking into account of the environment.

I. Introduction

To what extent does environmental conservation adversely affect the sustainability of growth in an economy? Is economic development sustainable with environmental control?[1] These are the foremost questions that must be addressed as governments debate the merits and flaws of different environmental policies. Although recent developments in growth theory improved our understanding and forecasting of the growth rates of different economies, we have yet to fully incorporate environmental concerns into our models. Consumers are making decisions about the trade-offs between consumption and environmental conservation. That the degradation of the environment does, indeed, lead to consumer dissatisfaction must be taken into consideration as we discuss growth and welfare. Does environmental protection necessarily foreshadow dire consequences for the sustainability of growth? If it does, are there policies which the government can implement not only to ensure environmental conservation but also to maintain a steady

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[1] World Bank recently has a study on exploring the possible links between economic development and the environment. Their results are summarized in its *World Development Report 1992.*

growth of output per capita?

A recent study by Jorgenson and Wilcoxen (1990) focused on the relationship between pollution abatement costs and economic growth. It was found that, over the period 1974-1985, environmental controls has a definite adverse effect in the U.S.. The estimated costs of environmental regulation were a .19% decline in the annual growth rate of U.S. and a 2.59% decline in the level of gross national product. A drawback of this study is that it was based on a Solow-type growth model in which growth occurs exogenously. In the present chapter, we model growth endogenously and look at two very specific channels, technology and resources constraints, through which the environment can affect growth. In particular, we address the issue of the environment as a scarce factor of production in the form of a resource constraint. The existence of such a constraint has major implications for the analysis of growth. To be sure, it invites one to think, growth and environmental conservation as complements rather than substitutes. Environmental degradation may ultimately limit the growth of an economy as the stock of this factor of production is depleted. We study the potential growth effects of environmental conservation using an endogenous growth model of the type found in Romer (1990), Rivera-Batiz and Romer (1991) and Hung (1993). We isolate one particular aspect of environmental damage, namely that of pollution. We assume that there are two different sets of intermediate inputs used in final production: a set of environmentally friendly (or clean) inputs and environmentally unfriendly (or dirty) inputs. Each input within each set is manufactured using a design (or blueprint) created from using research and development. Environmentally unfriendly inputs lead to higher levels of pollution and a degradation of the environment. If pollution is damaging to consumers, there is a negative externality which may impose a net cost on the economy. The market solution is inefficient because of a failure to price pollution and so a failure to take account of the externality. Environmental policy has the potential to improve the market outcomes by altering the relative production costs of clean and dirty inputs. In doing so, it has the potential to affect growth as well.

We model the growth process as an expansion in the number of differentiated intermediate inputs which raises the productivity of other inputs in final production. There are several channels through which environmental policy (pollution control) might affect this process. One possibility is that it leads to a change in the input mix used in production. For example, a firm may choose to use natural gas as opposed to coal. Another possibility is that it alters the fixed cost in an industry as capital is expended for pollution abatement equipment. The installation of scrubbers in smoke stacks is a good example of this. And a longer-term possibility is that it leads to changes in production processes and stimulates the creation of new and cleaner products. The growth of the recycled paper immediately comes to mind here. Given our definition of growth - expanding product variety - we focus on the change in input mix and the creation of new products. As indicated above, new products are the result of research and development. Research occurs in both the environmentally friendly and environmentally unfriendly sectors. Since research activity is profit-motivated, any expected intervention in the use of dirty products will have an impact on the flow of new products and therefore, an impact on growth.

If pollution is a negative externality in the economy, then achieving a social optimum would require government intervention. Research on environmental economics has yielded a body of literature concerned with the types of economic instruments used for environmental protection. These instruments differ across countries, pollutants, media and industries. The most frequently documented instruments include charges, subsidies, tax credits, penalties, quotas and permits. In our model, the government can affect growth through four channels. First, by taxing the royalties to innovation, it can alter the profitability of innovating. Second, by placing stringent emission standards on firms, it can force producers to install pollution abatement equipment which would increase their fixed or marginal costs and lowers the willingness to pay for the right to produce for the new product. Third, by expanding or limiting the market for new products, it can alter the profitability of research and development and thereby control the number of firms wishing to engage in research and development. Fourth, by encouraging the transfers of ideas, it can increase the total knowledge base which would in turn would increase the probability of successful innovation.

Our analysis here shows that the balanced growth equilibrium is an unstable one. The only stable equilibria are those of unbalanced growth where either the clean or dirty sector, but not both, are growing. We compare the steady state growth rates in five different equilibria: the market equilibrium with clean sector growth; the market equilibrium with dirty sector growth; the social optimum with no concern for the environment; the social optimum with disutility resulting from pollution and with positive growth in the dirty sector and the social optimum with disutility resulting from pollution and with positive growth in the clean sector. The differences in growth rates between these five cases are the result of the degree to which environmental degradation is a negative externality, the imperfect competition in the intermediate clean and dirty sectors, and the differential costs associated with clean and dirty technology.

If consumers and the government do care about environmental conservation, then starting from a dirty growth equilibrium, one would expect that there is a social optimum, which optimally trades off between growth against current consumption. At the same time, it is also possible to imagine the economy moving off of this steady state path and into a better social optimum with positive growth only in the clean sector.

This chapter covers our preliminary findings on how consideration of pollution costs can affect our standard predictions about growth. The remainder of the chapter is organised as follows. Section II contains a description of our artificial economy. In Section III we compute the balanced and unbalanced growth equilibria of this economy. Section IV is concerned with the potential growth effects of environmental policy, in particular when environmental externality affects resource constraint. A few concluding remarks are contained in Section V.

II. The Model

The physical set-up of our representative economy builds on the models of Romer (1990), Rivera-Batiz and Romer (1991) and Hung (1993). There are three sectors of production: a final goods sector in which a single consumption good is manufactured; a producer goods sector in which a range of intermediate inputs is produced; and a research and development sector in which designs for new intermediate goods are created. A producer good can be either of two types -an environmentally friendly (clean) type and an environmentally unfriendly (dirty) type. In this section, we abstract from the environmental impacts on the resource constraint.[2] A constant population of infinitely-lived agents make up a dynastic household sector. All markets are characterized by price-taking except the market for each producer good which is characterized by monopolistic competition. The numeraire of the economy is the final consumption good.

1. Producers

A. The Final Goods Sectors

Final output Y, is produced using human capital, H_F, the set of environmentally friendly intermediate inputs $X_C = \{x_C(i) | i \in [0, M_C], M_C \subset \Re_+\}$ and the set of environmentally unfriendly intermediate inputs $X_D = \{x_D(i) | i \in [0, M_D], M_D \subset \Re_+\}$, according to the function $f: \Re_+ \times \Re^{MC}{}_+ \times \Re^{MD}{}_+$.[3] We choose the continuous index i on the non-negative real line so as to avoid complications associated with integer constraints. The quantity $x_s(i)$ $(s=C,D)$ is understood to be the amount of s-type producer good i employed in final production. Both types of intermediate input are non-durable goods. The number $M_C + M_D$ represents the total range of producer goods available for current production. Following Ethier (1982), we think of greater product variety as generating efficiency gains: an increase in the number of varieties of differentiated intermediate inputs leads to an increase in total factor productivity in final manufacturing. Thus, technological progress is represented by the invention of new types of producer good which shows up as an increase in M_C and M_D. We specialize the production function to the constant return to scale Cobb-Douglas technology,[4]

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[2] An important issue concerns about the environmental impact on renewable resources, subsequently affecting the prospect for further growth.

[3] We abstract from labour effort for simplicity and leave out the time index to minimize on notation.

[4] Further work is needed on more general forms of production function, such as functions which allow different elasticities of substitution between clean and dirty producer goods.

$$Y = H_F^{1-\alpha} \left[\int_0^{M_C} x_C(i)^\alpha \, di + \int_0^{M_D} x_D(i)^\alpha \, di \right] \tag{II.1}$$

where $\alpha \in (0,1)$.

The representative producer of final output hires human capital from household at the wage w and buys clean and dirty intermediate inputs from the producer goods sector at the prices $p_C(i)$ and $p_D(i)$ respectively. Both w and $p_S(i)$ $(s=C,D)$ are taken as given, as are the numbers of existing intermediate goods, M_C and M_D. The producer maximizes

$$\Pi = H_F^{1-\alpha} \left[\int_0^{M_C} x_C(i)^\alpha di + \int_0^{M_D} x_D(j)^\alpha dj \right] - wH_F - \int_0^{M_C} p_C(i) x_C(i) di - \int_0^{M_C} p_D x_D(j)^\alpha dj \tag{II.2}$$

by choosing $x_C(i), x_D(j), i \in [0,M_C]$ and $j \in [0,M_D]$ and H_F. Solving this problem delivers the following derived demands for human capital and intermediate inputs:

$$H_F = \frac{(1-\alpha)Y}{w}$$

$$x_C(i) = \frac{\alpha Y p_C(i)^{-\frac{1}{1-\alpha}}}{P}, \; x_D = \frac{\alpha Y p_D(j)^{-\frac{1}{1-\alpha}}}{P} \tag{II.3}$$

$$\text{where } P = \int_0^{M_C} p_C(i)^{-\frac{\alpha}{1-\alpha}} di + \int_0^{M_D} p_D(j)^{-\frac{\alpha}{1-\alpha}} dj$$

B. The Intermediate Goods Sector

Each Firm in an s type producer goods sector needs γ_S units of the final good to produce one unit of intermediate input. An intermediate input embodies a design created in the research and development sector. To use a design, a firm must acquire a permit from the owner of it. This is the institutional structure of our economy: there is a patent law which prohibits any firm from manufacturing an intermediate input without the consent of the patent holder of a design. We assume that the patent holder of a design for *s* type good *j* licenses the design to a manufacturer for a fee $q_S(j)$.[5]

Intermediate goods firms are monopolistically-competitive producers of differentiated products which are sold to final goods producers and other intermediate goods firms at the profit maximizing monopoly price $p_S(j)$ $(s=C,D)$. Given $q_S(j)$, each of these firms faces the following decision problem

$$\max_{p_s(j)} \pi_s(j) = p_s(j)x_s(j) - \gamma_s x_s(j) - q_s(j), \ (s=C,D) \tag{II.4}$$

where $x_S(j)$ is the derived demand given above. If $M_C + M_D$ is sufficiently large (or if each firm's share of total demand is measure zero), then any feedback effect from P will be small and so may safely ignored. The Bertrand equilibrium is then characterized by the standard constant mark-up rule, $\alpha p_S(j) = \gamma_S$ $(s=C,D)$. In addition, given free entry and no collusion, competition amongst firms and designers will bid up the price of each permit until all the profits of each firm have been extracted.

Now given the symmetry in the model, the prices of inputs of the same type will be equal: $p_S(j) = p_S$ $(s=C,D)$. Consequently, the demands for inputs of the same type will be equal as well: $x_S(j) = x_S$ $(s=C,D)$. As a result, total final output Y can be written as $M_C y_C + M_D y_D$, where $y_C = x_C^{\alpha} H_F^{1-\alpha}$ and $y_D = x_D^{\alpha} H_F^{1-\alpha}$. It follows that the prices of all s-type permits are the same, being given by $q_S = \alpha(1-\alpha)y_S$ $(s=C,D)$.

C. The Research and Development Sector

Growth occurs from the accumulation of new designs represented by increases in M_C and M_D. Each period, there are N_C and N_D firms engaged in environmentally friendly and environmentally unfriendly research activities. The product of each activity is a design, or blueprint, for a new intermediate good. Research is conducted using human capital and previously accumulated, generally available knowledge. We denote by $h_{R,S}(k)$ $(s=C,D)$ the

[5] The patent, or property right, provides the necessary excludability condition for protecting a designer's monopoly profits and preserving the incentives to innovate.

amount of human capital employed in the kth s-type research firm and approximate the existing quantity of disembodied knowledge available to this firm by the existing stock of s-type designs, M_S.[6] Each s-type firm then has $M_S h_{R,S}$ efficiency units of input with which to innovate. We assume that an innovation occurs with some finite probability which is given by the function $\lambda: \Re_+^2 \rightarrow [0,1]$, where $\lambda'(M_S h_{R,S}(k)) > 0$ and $\lambda''(M_S h_{R,S}(k)) < 0$. As in other models, therefore, the creation of new designs depends (positively) on both rival and non-rival, excludable and non-excludable inputs. But in contrast to other models, this research technology is concave rather than linear. The justification for this is discussed in Hung (1993). It captures the idea that a doubling of research effort need not result in a doubling of research output because some of the research effort may be redundant.

Another departure from existing models is the inclusion of a fixed research cost, κ_S $(s=C,D)$. Together with the concave technology, this allows us to separate the marginal condition for allocating human capital across different sectors from the zero profit condition of research firms.

There is free entry into the research and development sector. Once a firm innovated, it can start to auction the right to use its new design in the next period. Hence each designer will expect to collect revenue from next period onwards. Therefore the present discounted value of future revenue is

$$Q_s(k) = \int_t^{\infty} q_s(k,\tau)\, e^{-\int_t^{\tau} r(v)dv}\, d\tau \quad (s=C,D). \qquad (II.5)$$

where $r(t)$ is the instantaneous interest rate and $q_S(k,\tau) = q_S(\tau)$ in equilibrium from above. The decision problem for each designer is to maximize the expected present discounted value of profits from a successful innovation. We write this problem as

6 In general, the quantity of disembodied knowledge available to each firm would include both M_C and M_D. For example: the quantity of such knowledge available to a C-type (D-type) firm could be approximated by $M_C + \delta M_D$ ($M_D + \delta M_C$). Allowing for this does not alter the main results of the paper.

$$\max_{h_{R,s}(k)} V_s(k) = \lambda[M_s h_{R,s}(k)]Q_s(k) - wh_{R,s}(k) - \kappa_s (\ s=C,D). \tag{II.6}$$

At the margin, a designer will equate expected marginal revenue with marginal cost. In addition, given free entry, expected equilibrium profit will be zero.[7] Hence,

$$\begin{aligned} M_C \lambda'[M_C h_{R,C}(k)]Q_C(k) &= M_D \lambda'[M_D h_{R,D}(k)]Q_D(k) = w \\ \lambda[M_C h_{R,C}(k)]Q_C(k) &= wh_{R,C}(k) + \kappa_C \\ \lambda[M_D h_{R,D}(k)]Q_D(k) &= wh_{R,D}(k) + \kappa_D \end{aligned} \tag{II.7}$$

In general, clean and dirty producer goods are distinguished by their production and development costs.

2. Consumers

The representative consumer of final output choose plans for consumption *C*, and asset holdings, *A*, which solve the following problem:

$$\begin{aligned} \max_{C(t),A(t)} \quad U(t) &= \int_t^\infty e^{-\rho(\tau-t)} u(\tau)d\tau \\ u(\tau) &= \log C(\tau) - \beta \log\left[\int_0^{M_D(\tau)} z[x_D(i,\tau)]di \right] \\ s.t. \quad \dot{A}(t) &= w(t)H + r(t)A(t) - C(t) \end{aligned} \tag{II.8}$$

where ρ denotes the subjective rate of time preference. We assume a momentary utility function $u: \Re_+ \times \Re^{MD}_+ \rightarrow \Re_+$, which displays an externality from dirty producer goods. Specifically, we assume that x units of production of these goods causes $z(x)$ units of environmental damage where $z' \geq 0$ and β measures the marginal disutility from

[7] In this product variety model, the optimal strategy of each R&D firm is to conduct different kinds of research.

environmental damage.[8] The faster these goods grow and the more they are used to produce final output, the more disutility to the household. Each consumer is endowed with a fixed stock of human capital, H, which earns the rate of return w. The single asset, A, represents ownership claims on the patent right and earns the rate of return r. Changes in asset holdings denote savings.

Along the optimal consumption path,

$$\frac{\dot{C}}{C} = g_c = r - \rho \tag{II.9}$$

where g_C is the growth rate of consumption. Equation (II.9) shows the usual positive relationship between the rate of growth and the rate of interest: a higher rate of growth makes current consumption more valuable relative to future consumption so that consumers are more willing to borrow at a higher rate of interest.

III. Steady State Equilibrium

The market equilibrium for this model will be paths for prices and quantities such that (i) all participants are optimizing, (ii) all markets are clearing and (iii) all non-stationary variables are growing at the common growth rate, g. The underlying source of growth is the increasing number of firms engaged in research activities. As the economy grows, the concentration of research activities amongst a constant number of firms would induce more and more inefficiency in the research sector. In order to reduce this inefficiency, it is essential that research activities are diversified. This is made possible by the increasing availability of resources which can be used to finance new research activities. In this way the economy can maintain a constant growth rate of designs by dividing the human capital

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[8] We consider only the flow of pollution and not the cumulative effect of pollution.

amongst the $N_C + N_D$ research firms.[9]

In equilibrium, we have

$$\frac{x_s}{H_F} = \left(\frac{\gamma_s}{\alpha^2}\right)^{\frac{1}{\alpha-1}}, \; s = C,D.$$
$$\frac{w}{M} = (1-\alpha)\left[\frac{M_D}{M}\left(\frac{\gamma_C}{\alpha^2}\right)^{\frac{1}{\alpha-1}} + \frac{M_C}{M}\left(\frac{\gamma_D}{\alpha^2}\right)^{\frac{1}{\alpha-1}}\right] \qquad (III.1)$$
$$\frac{x_C}{x_D} = \left(\frac{\gamma_C}{\gamma_D}\right)^{\frac{1}{\alpha-1}} \Rightarrow \frac{y_C}{y_D} = \left(\frac{\gamma_C}{\gamma_D}\right)^{\frac{\alpha}{\alpha-1}}$$

Let $m = M_C/M$, and $w^* = w/M = W(m)$, where $W' < 0$ for $\gamma_C > \gamma_D$. Let $n_C \equiv N_C/M_C$ and $n_D \equiv N_D/M_D$, being measures of the potential flow of new designs relative to the stock of existing designs. Finally, let $v_C \equiv M_C h_{R,C}$ and $v_D \equiv M_D h_{R,D}$, being the efficiency units of inputs to research and development. Then $H_{R,C} = n_C v_C$ and $H_{R,D} = n_D v_D$.

In a balanced growth equilibrium, where $m \in (0,1)$, $Q_S = \alpha(1-\alpha)y_S/r$ or $\alpha(1-\alpha)M_S y_S \lambda'(v_S)/r = w$ $(s=C,D)$. Hence,

$$\frac{\lambda'(v_C)}{\lambda'(v_D)} = \left(\frac{M_D}{M_C}\right)\left(\frac{y_D}{y_C}\right) = \left(\frac{1-m}{m}\right)\left(\frac{\gamma_D}{\gamma_C}\right)^{\frac{\alpha}{\alpha-1}} \qquad (III.2)$$

From (II.7), we obtain

$$\left[\frac{\lambda(v_C) - \lambda'(v_C)v_C}{\lambda'(v_C)}\right]\frac{w^*}{m} = \kappa_C$$
$$\left[\frac{\lambda(v_D) - \lambda'(v_D)v_D}{\lambda'(v_D)}\right]\frac{w^*}{1-m} = \kappa_D \qquad (III.3)$$

Since equilibrium in the human capital market requires $H = H_F + H_{R,C} + H_{R,D}$, the

9 If research activities required some minimum level of human capital, then there would be a limit to growth. For growth to be sustained, one would have to allow for human capital accumulation. A model which does this is presented in Hung, Pozzolo and Blackburn (1992).

allocation of human capital to the research and development sector must satisfy

$$H - v_C n_C - v_D n_D = \frac{r}{\alpha}\left[\frac{1}{\lambda'(v_C)} + \frac{1}{\lambda'(v_D)}\right] \tag{III.4}$$

Along the balanced growth path, consumption, output and the number of designs all grow at the rate *g*:

$$g = g_c = \frac{\dot{Y}}{Y} = \frac{\dot{M}_C}{M_C} = \frac{\dot{M}_D}{M_D}. \tag{III.5}$$

Given that the probability of a successful innovation is independent across firms, the law of large numbers allows us to write the expected flow of new designs as $\dot{M}_S = \lambda(v_S)N_S$ $(s=C,D)$. Thus, since steady state growth occurs at the rate $(\dot{M}_C + \dot{M}_D)/(M_C + M_D)$, we have

$$g = \frac{\lambda(v_C)N_C + \lambda(v_D)N_D}{M_C + M_D} = \lambda(v_C)n_C m + \lambda(v_D)n_D(1-m). \tag{III.6}$$

But since $\dot{M}_C/M_C = \dot{M}_D/M_D$ in the balanced growth equilibrium,

$$g = \frac{\dot{M}_C}{M_C} = \frac{\dot{M}_D}{M_D} \Rightarrow \lambda(v_C)n_C = \lambda(v_D)n_D. \tag{III.7}$$

Together with equations (II.9), (III.2), (III.3), (III.4) and (III.6), we can compute the balanced growth rate g and the stationary variables m, v_C, v_D, n_C and n_D (H_F, x_C and x_D can be determined from these variables).

Proposition 1: *Given (i) $\lambda'(v) > 0$ and $\lambda''(v) < 0$, (ii) $\lambda(v) > v\,\lambda'(v)$, (iii) $\lim_{m \to 0} \lambda'(v)$ = constant $< \infty$ and (i) v^1 is large, where $\alpha H \lambda(v^1) = \rho$, $\exists$ a unique steady state equilibrium $\{g^*, m^*, v^*_C, v^*_D, n^*_C\ n^*_D\}$ which satisfies equations (II.9), (III.2), (III.3), (III.4), (III.6) and (III.7).*

Proof:

Substitute $W(m)$ into equation (III.3) and express $v_C = f_C(m)$ and $v_D = f_D(m)$ where $f'_C >$

0 and $f'_D < 0$. In equation (III.2), the *LHS* is a monotonic decreasing function of m and the *RHS* is monotonic decreasing function of m. Let $A = (\gamma_D/\gamma_C)^{\alpha/(\alpha-1)}$. Given $lim_{m\to 0}\, f_D(m) = v^*_D < \infty$ and $lim_{m\to 0}\, \lambda'(f_C(m)) = constant < \infty$, we have $lim_{m\to 0}\, A(1-m)/m > lim_{m\to 0}\, \lambda'(v_C)/\lambda'(v_D)$. In addition, given $lim_{m\to 1}\, f_C(m) = v^*_C < \infty$ and $lim_{m\to 1}\, \lambda'(f_D(m)) = constant < \infty$, we have $lim_{m\to 1}\, A(1-m)/m < lim_{m\to 1}\, \lambda'(v_C)/\lambda'(v_D)$. m is defined in $[0,1)$ and $\exists$ a unique m^* which satisfies $A(1-m^*)/m^* = \lambda'(f_C(m^*))/\lambda'(f_D(m^*))$. Computing v^*_C and v^*_D and combining with equations (II.9), (III.4) and (III.5), n^*_C, n^*_D and g^* can be found. Q.E.D.

If there is no difference in the production and development costs of clean and dirty intermediate inputs (i.e. if $\gamma_C = \gamma_D = \gamma$, $\kappa_C = \kappa_D = \kappa$), the ratio M_C/M_D equals one in the balanced growth equilibrium. Given that there is no additional cost for the economy in using all clean products, the only factor which matters in developing the product is the existing knowledge M_C and M_D. If the disembodied knowledge is the same across the research sectors, both types of research are equally efficient and both will produce designs at the same rate maintaining the balanced growth path. In the case where $\kappa_C = \kappa_D = \kappa$ but $\gamma_C > \gamma_D$, the balanced growth equilibrium will require a higher efficiency in clean research and development, (i.e. a higher M_C/M_D ratio) so as to compensate the lower expected profit. A similar result holds for the case where $\gamma_C = \gamma_D = \gamma$ but $\kappa_C > \kappa_D$.

Any temporary deviation from the balanced growth ratio m^* will shift the comparative advantage of different type of research. The knowledge spillover effect in the research sector will push the economy away from the balanced growth equilibrium to an unbalanced growth equilibrium where only one type of research (clean or dirty) can survive (i.e. where either $n_C = v_C = 0$ or $n_D = v_D = 0$). Whichever steady state survives will depend on the initial value of M_C/M_D.[10]

In the unbalanced growth economy with $n_C = v_C = 0$ ($n_D = v_D = 0$), the steady state growth rate is determined solely by the level of H, γ_D and κ_D (H, γ_C and κ_C). The

[10] Of course. expectations can play a role is bringing the steady state to a cleaner environment. If everybody believes that the government will phase out all the dirty products. Designers may move out of dirty research and development in anticipation of the fall in future profit.

equilibrium can be formulated as follows:

Proposition 2: Given (i) $\lambda'(v_S) > 0$ and $\lambda''(v_S) < 0$, (ii) $\lambda(v_S) > v_S \lambda'(v_S)$ and (iii) a $v^*_S < v^1_S$, where $\alpha H \lambda(v^1) = \rho$ and $w^*_S[\lambda(v^*_S) - v^*_S \lambda'(v^*_S)]/\lambda'(v^*_S) = \kappa_S$, $\exists$ a steady state growth rate $g^*_S = g_S(\gamma_S, \kappa_S, H)$ where

$$\frac{\partial g}{\partial H} > 0 , \frac{\partial g}{\partial \gamma_s} < 0 , \frac{\partial g}{\partial \kappa_s} < 0 \ (s=C,D). \tag{III.8}$$

Proof:

Given $m < m^*$, we have $n_C = v_C = 0$ and $m \to 0$. Hence (III.4) becomes

$$H - v_D n_D = \frac{r}{\alpha \lambda'(v_D)} \tag{III.9}$$

and $w^*[\lambda(v_D) - v_D \lambda'(v_D)]/\lambda'(v_D) = \kappa_D$. Together with (II.9), we obtain

$$n_D = \frac{\lambda'(v_D)\alpha H - \rho}{\lambda(v_D) + v_D \lambda'(v_D)\alpha} = n_D(v_D, H) \tag{III.10}$$

Provided $\lim_{v \to 0} \lambda'(v)\alpha H > \rho$, $\exists$ a $v_1 > 0$ such that $\lambda'(v^1)\alpha H = \rho$. Given $\lambda''(v) < 0$, then $\partial n_D/\partial v_D > 0 \ \forall \ v_D < v^1$. Since $\lim_{v \to \infty} \lambda'(v) = 0$. $\exists$ a $v^* = v(\kappa) > 0$ which satisfies $w^*[\lambda(v^*_D) - v^*_D \lambda'(v^*_D)]/\lambda'(v^*_D) = \kappa_D$. Hence, $\exists$ a $g^* = \lambda(v_D)\, n_D(v_D, H) > 0 \ \forall \ v^* < v^1$. With $\lambda'(v) > 0$ and $\lambda''(v) < 0$, the functions $n_D(v_D, H)$ and $v_D(\gamma_D, \kappa_D)$ satisfy $\partial n_D/\partial v_D < 0$, $\partial n_D/\partial H > 0$, $\partial v_D/\partial \gamma_D > 0$ and $\partial v_D/\partial \kappa_D$. Thus, the growth rate $g(\gamma_D, \kappa_D, H)$ satisfies (III.8)

Q.E.D.

Any increase in the costs γ_S and κ_S, will lower the inflow of new firms to the research sector, lower the rate of innovation and so lower the rate of growth. Any increase in the human capital stock can support more research activity and so support a higher rate of growth. The model shares some implications of other product variety models of growth. In particular, economic integration which allows the sharing knowledge (adding M_S or H) and avoids research redundancy. All these will increase the productivity of research activities and have a positive effect on growth. An implication of the model which is not shared by others is the positive growth effect of trade liberalization in the producer goods sector only. Such liberalization would expand the market for new designs such that firms engaged research would begin to operate at a positive expected profit. This would encourage new firms to enter the research sector. Whilst each firm, individually, would cut backs on its scale of research activity, the world, as a whole, would experience an increase in research activity. Consequently, each economy would experience higher steady state growth. The positive growth effects of economic integration and trade liberalization may have adverse effects on the environment if some of the new designs are for dirty producer goods.

In this model, the government can formulate trade policy to fulfil its environmental objectives. Suppose that the government was to restrict trade in dirty products whilst encouraging trade in clean products and encouraging transfers of clean technology knowledge. Then m^* would be lowered, making it easier to transfer production to clean sector. Nevertheless, achieving environmental objectives and promoting growth are not separate issues. In the following section, we will try to assess the impact of environmental policy on growth and discuss the optimal policy when environmental considerations are taken into account.

IV. Environmental Policy and Growth

The damage caused by the externality from environmentally unfriendly producer goods may be reduced by imposing a tax on the dirty sector or granting a subsidy to the clean sector. However, since the cost of production affects the rate of growth, any such environmental policy will have a side effect on growth. In order to clarify the analysis, two important points should be noted. First, it matters considerably where the economy starts off at. Even without any externality from the dirty technology, the market equilibrium is still sub-optimal. This is due to the imperfect competition in producer goods markets and the knowledge spill-overs in research and development sectors. A policy which corrects for sub-optimal growth and the environmental externality will bring the economy to the first best solution. A government that ignores the pollution problem will be following a policy aimed at achieving the second best equilibrium. This second best solution may not be a welfare improvement on the market outcome. The effects on growth will depend on whether the economy starts at the second best equilibrium or the market equilibrium.

The second point of interest concerns the steady state of the economy. Since clean intermediate inputs do not give rise to any pollution problem, replacing the dirty technology by the clean one will surely be welfare improving unless there is differential costs in the technologies. A government may have to choose whether to adopt a policy to promote the use of clean technology or just regulate the existing dirty technology. Given that their cost structures are different ($\gamma_C \geq \gamma_D$ *and* $\kappa_C \geq \kappa_D$) policies which substitute growth for environmental improvement will be different.

Let us assume that the economy starts out in steady state equilibrium with dirty technology. Our welfare analysis is concerned only with the steady state, not with the dynamics towards the steady state. In order to simplify the analysis, we assume that $z(x) = z$ (a constant). Therefore we do not need to study the relation between the level and growth of pollution. This section focuses on the tradeoff between economic growth and the environment. If we assume that the social planner acts as the representative agent, using equation (II.8), the first best solution, denoted by (n^{fs}, v^{fs}) will equal to $\text{argmax}_{v,n}\, \rho \log C_0 + (1-\beta)g$, the optimal choices of the representative agent. In contrast, an "environmentally-uncaring" government/social planner will maximize just $\rho \log C_0 + g$. We called this solution the second best solution and denoted by (n^{ss}, v^{ss}). And let denote market equilibrium as n^m, v^m. Both the first best and the second best problems are subject to the physical constraints on human capital and consumption:

$$\begin{aligned} C_0 + n\kappa + \gamma x &= H_F^{1-\alpha} x^{\alpha} \\ H_F + H_R = H_F + n\nu &= H \end{aligned} \qquad (IV.1)$$

We compute the first best growth rate and the second best growth rate as follows:

$$g_s^{fs} = \lambda'(v_s^s)H - \frac{\rho}{1-\beta} \qquad (IV.2)$$

$$g_s^{ss} = \lambda'(v_s^s)H - \rho$$

where $\lambda(v^s_S)/\lambda'(v^s_S)-v^s_S = \kappa_S/\phi(\gamma_S)$ and $\phi' < 0$ $(s=C,D)$. The market equilibrium growth rate is given by:

$$g_s^m = \frac{\alpha\lambda'(v_s^m)H - \rho}{\dfrac{\alpha v_s^m \lambda'(v_s^m)}{\lambda(v_s^m)} + 1} \qquad (IV.3)$$

where $\lambda(v^m_S)/\lambda'(v^m_S)-v^m_S = \kappa_S/w^*(\gamma_S)$ and $w^{*\prime} < 0$ $(s=C,D)$. Like g^m_S, both g^{fs}_S and g^{ss}_S are decreasing with respect to κ_S and γ_S, $(s=C,D)$.

For any v and κ, $g^{fs} < g^{ss}$. With some regularity conditions and without considering the non-negative constraint on consumption $\lim_{\kappa\to 0} g^m < \lim_{\kappa\to 0} g^{fs} < \lim_{\kappa\to 0} g^{ss}$. Given the same v, a small value for γ, we find a κ^{fs}_1, κ^{ss}_1 and κ^m_1, where the optimal choices of n^{fs}, n^{ss} and n^m are zero, such that $\kappa^m_1 > \kappa^{ss}_1 > \kappa^{fs}_1$. This means that the function g^m will cut g^{fs} and g^{ss} at some κ. In turn, this implies that the market equilibrium may have excess growth compared to the social optimum. (The smaller is γ, the larger the gap between the social productivity and market productivity of final goods for a given level of human capital). The market allocates too much human capital to the research and development sector, thereby generating too much growth which is not socially optimal. But in cases where γ is large, the market equilibrium growth rate is lower than the first best growth rate and the second best growth rate. Therefore, a better environment does not necessarily reduce growth if the economy starts out at a sub-optimal market equilibrium. Of course, with small γ, it is likely that the economy will have excess growth. Adding environmental considerations will certainly result in a greater adverse effect on growth.

However, given $\kappa_C \geq \kappa_D$ and $\gamma_C \geq \gamma_D$, $g^{ss}(\gamma_D,\kappa_D) > g^{fs}(\gamma_C,\kappa_C)$. The question is why the government is not implementing the second best policy to reach the fast growth rate in the first place. Any environmental policy may result in lower growth. The remaining

→ interesting to point at other reasons (e.g. environmental) why growth ≠ welfare - why growth can happen here. pt: anything can $\hat{g} \lessgtr 0$ depending on + relative cost of producing new clean vs dirty designs.

choice is between the low growth equilibrium with clean technology and the low growth equilibrium with regulated dirty technology. A higher β, a lower κ_C/κ_D and a lower γ_C/γ_D will increase the ratio of steady state utilities associated with clean and dirty products, and increase the ratio $g^{fs}(\gamma_C,\kappa_C)/g^{fs}(\gamma_D,\kappa_D)$. This makes the move to a clean environment less costly in term of growth even if the economy is starting at a second best equilibrium.

There are two possible cases where the economy can achieve faster growth with clean technology even from a second best equilibrium. The first case is when there is some explicit cost for clearing up the environment. We assume that the clean-up cost is related with the flow of consumption of dirty producer goods, x_D. The resource constraint (IV.1) becomes

$$C_0 + n\kappa + (\gamma + \psi)x = H_F^{1-\alpha}x^\alpha \qquad (IV.4)$$

Even if the social planner does not care about the pollution ($\beta=0$), he/she needs resources to clean up the damage. The total (social and private cost) marginal cost of dirty products increases. If $\gamma_D/\gamma_C < 1 < (\gamma_D+\psi)/\gamma_C$ and $\kappa_C \sim \kappa_D$, the second best equilibrium growth rate with dirty technology can be lower than the second best equilibrium with clean technology: $g^{ss}(\gamma_D,\kappa_D,x_D\neq 0) < g^{ss}(\gamma_C,\kappa_C,x_D=0)$. However, in welfare terms $U^{ss}(\gamma_D,\kappa_D,x_D\neq 0) > U^{ss}(\gamma_C,\kappa_C,x_D=0)$. As a result, an "environment-uncaring" government will not pursue the high growth equilibrium because it is not welfare maximizing. Nevertheless, there are some values for parameters which give $g^{ss}(\gamma_D,\kappa_D,x_D\neq 0) < g^{fs}(\gamma_C,\kappa_C) < g^{ss}(\gamma_C,\kappa_C,x_D=0)$. Thus, an "environment-caring" government (where $\beta\neq 0$) will select the higher growth equilibrium because it is welfare maximizing ($U^{fs}(\gamma_C,\kappa_C,x_D=0) > U^{fs}(\gamma_D,\kappa_D,x_D\neq 0)$).

Another possible case is when the environment is treated as a factor of production. Under such circumstances, environmental degradation would ultimately drive resources out of production and research activities, leading to a lower growth, as the stock of this factor of production diminishes. The simplest way to include the environment in production is to treat it as a public good in final production.

where E is the environment. The environment can also be a source of information for new

$$Y = E\, H_F^{1-\alpha}\, [\int_0^{M_C} x_C(i)^\alpha\, di + \int_0^{M_D} x_D(i)^\alpha\, di] \tag{IV.5}$$

designs,[11] in which case λ is a function of E, $\lambda(M\, E\, h_R)$ say. Suppose that the rate of environment degradation is proportional to the growth of dirty products:

$$\frac{\dot{E}}{E} = -\chi g_D. \tag{IV.6}$$

We calculate the steady state market equilibrium growth rate with dirty products as

$$g_D^m = (1-\chi)\frac{\alpha\lambda'(v_D^m)H - \rho}{\dfrac{\alpha v_D^m \lambda'(v_D^m)}{\lambda(v_D^m)} + 1} \tag{IV.7}$$

where $\lambda(v^m{}_D)/\lambda'(v^m{}_D)-v^m{}_D = \kappa_D/w^*(\gamma_D)$. With a sufficiently high χ, it can be shown that $g^m(\gamma_C,\kappa_C) > g^m(\gamma_D,\kappa_D)$. Similarly even when $\beta=0$, there exists a χ, such that $g^{fs}(\gamma_C,\kappa_C) > g^{fs}(\gamma_D,\kappa_D)$ where

$$\begin{aligned} g_D^{fs} &= (1-\chi)[\lambda'(v_D^s)H - \rho] \\ g_C^{fs} &= \lambda'(v_C^s)H - \rho \end{aligned} \tag{IV.8}$$

and $\lambda(v^s{}_s)/\lambda'(v^s{}_s)-v^s{}_s = \kappa_s/\phi(\gamma_s)$, $\phi' < 0$ $(s=C,D)$.

In general, without any explicit cost of environment damages, taking care of the environment is costly to growth but is welfare improving no matter where the economy starts from. However, we believe that the conservation of the environment is crucial for maintain an economy's production frontier. Moving away from the steady state with dirty products may be both welfare improvement and growth improving. Given the knowledge

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[11] Those assumptions can be supported by the fact that the proponent of biodiversity argues that genetic information, species and ecosystems of the environment provide material and important information in the form of food, fibre, medicine, and inputs into industrial processes.

spillover in the research sector, it is difficult to think of any automatic mechanism for moving from dirty production to clean production. In principle, however a government that commits itself to clean up the environment and abandon all dirty inputs, might change the expectations of designers, such that research activity eventually becomes devoted solely to clean innovations.[12] In the absence of this, market type policies may not be sufficient to establish the clean environment with higher growth. The economy may be stuck with a regulated dirty technology at the expense of our growth.

V. Conclusions

This chapter has presented our preliminary findings on how environmental considerations can affect our standard predictions about growth. In general. it does not appear to be the case that pollution control is necessarily a depressant on growth. There are several important issues ignored in the chapter including (i) the dynamics of moving from the steady state with dirty technology to the steady state with clean technology, (ii) the implications of different elasticities substitution between clean and dirty products, (iii) a complete welfare analysis associated with the optimal growth path and (i) the competition between cost-improvement and environmental quality research activities. These and other issues lie on our agenda for future research.

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12 Krugman (1991) and Matsuyama (1991) have found that both history and expectations are important in determining the steady state of a multiple equilibrium economy like our model.

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CHAPTER 5 GROWTH AND FINANCIAL DEVELOPMENT

Abstract

We develop a theory of growth and financial intermediation. The mechanism of growth is increasing product variety arising from research and development. Research is risky and designers of new products require external capital to finance their research ventures. Problems of moral hazard dictate that an optimal loan contract must involve monitoring which is costly. According to the type of contract, monitoring may be conducted ex ante or ex post. Lenders have the opportunity of establishing a financial intermediary to act on their behalf. We compare the implications of direct and delegated monitoring, and establish the conditions under which the latter is preferred. Our main findings may be summarized as follows: (i) there is a positive, two-way causal relationship between growth and financial development; (ii) different economies may evolve towards different financial systems depending on cross-country differences in the relative costs of these systems; (iii) the market may choose a financial system which does not generate the fastest growth.

I. Introduction

There is overwhelming evidence that the financial regimes of economies matter for growth. The stylized facts are that financial repression impedes the growth process.[1] These facts are important since the extent of financial maturity is, in part, matter of policy choice. Thus, governments have the potential either to retard or promote growth by adopting policies which either restrict or encourage financial innovation through regulation. This chapter presents a theoretical analysis of the causal links between economic growth and financial development.

Our original motivation for the chapter was the view that cross-country convergence (or divergence) in growth rates has as much as to do with similarities (or differences) in

[1] The empirical relationship between growth and financial development has been studied by Fry (1982, 1988), Goldsmith (1969), Jung (1986), Mckinnon (1973, 1986), Roubini and Sala-i-Martin (1991), Shaw (1973) and the World Bank (1989).

national institutions as it has with distribution of human capital and technology across countries. It is the institutional structure of an economy which provides the incentives to engage in education and training, research and development. Economies with similar endowments, similar technologies and similar knowledge may exhibit dissimilar rates of growth because of differences in institutional arrangements which affect growth incentives. by the same token, any single economy may experience changes in its growth rate over time according to developments in its own institutions. The institutional arrangements that we consider in this chapter is the financial arrangements.

We ask the following questions:

1) what is the relationship between economic growth and financial development?
2) how might difference economies evolve towards different financial systems?
3) will the market choose the financial system which generates the fastest growth?

To answer these questions, we develop a model which combines theories of endogenous growth and financial intermediation. The model describes a dynamic stochastic economy in which there are three sources of inefficiency: imperfection competition, knowledge externalities and asymmetric information. The answers we obtain are

1) growth is both encouraged by, and encourages, financial development;
2) different economies may evolve towards different financial systems depending on cross-country differences in the relative costs of these systems;
3) the market may choose a financial system which does not generate the fastest growth.

Before outlining the remainder of the chapter, we indicate how the chapter relates to the existing theoretical literature on growth, finance and trade. Modern accounts of the relationship between growth and financial development emphasize the role of financial intermediation in improving the allocation resources.[2] In Bencivenga and Smith (1991), financial intermediation allows agents to pool idiosyncratic liquidity risk. This has the effect of stimulating capital accumulation and growth through an improvement in the

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[2] Aghion and Bolton (1991) and Tsiddon (1992) introduce other finance considerations (debt overhang and moral hazard) into the theory of growth.

allocation of saving between risky (illiquid and high expected return) investment projects and safe (liquid and low expected return) deposits. In Greenwood and Jovanovic (1990), allocations are distorted because of imperfect information arising from an unobservable shock. Growth performance is improved by the establishment of a financial intermediary which conducts research on the shock and sells its information to agents. Saint-Paul (1992) considers the case in which improvements in growth require the use of more specialized and riskier technologies. Financial development allows this to occur by expanding the opportunities for diversification. A basic insight of this literature is that the relationship between growth and financial development is two-way causal: growth is both encouraged by, and encourages, financial market participation and innovation.

Liquidity, information efficiency and diversification are three important aspects of financial intermediation. A forth, which has yet to be studied in connection with growth, is monitoring. This chapter presents such a study. The theory of monitoring, as developed by Diamond (1984), Gale and Hellwig (1985) and Williamson (1986), is concerned with the efficient resolution of incentive problems between potential creditors and potential debtors who negotiate optimal loan contracts in the presence of asymmetric information. Loan contracting takes place within a hierarchical financial structure which ranges from ultimate lenders to ultimate borrowers. At each point in the hierarchy, lender cannot observe the state that borrowers are in. It is possible, however, for the lenders to spend resources on monitoring borrowers. Problem of costly state verification dictate that any contract must involve monitoring - otherwise, borrowers would always claim to be in a bad state in an attempt to avoid paying back loans. In addition, lenders can always obtain a safe rate of return on some riskless asset. An equilibrium contract must be optimal (minimize the cost of monitoring), incentive compatible (ensure the truthful revelation of private information) and yields an expected return at least equal to the safe rate.

One type of contracting arrangement is for ultimate lenders to monitor directly ultimate borrowers. Another is for a third party - an intermediary - to be delegated this task of monitoring. Direct monitoring may be very costly if there are many ultimate lenders, each whom monitors. By eliminating the duplication of monitoring effort, delegation may be preferred. In this case, lenders write loan contracts with the intermediary which write loan contracts with borrowers. but this means that if lenders cannot observe the state of the intermediary, there are two agency-incentive problems which must be resolved . The contracts between lenders and the intermediary must ensure that the intermediary has incentives to monitor borrowers' information, to make proper use of that information and to make sufficient repayments to lenders. the costs of providing these incentives are referred to as delegation costs and must be netted out of any monitoring cost saving from delegation. If monitoring cost savings exist and exceed the expected delegation costs, then financial intermediation pays.

Diversification within the financial intermediary is the key to understand why delegated monitoring can have a net cost advantage over direct monitoring. Diversification is important even when there is universal risk neutrality. By increasing the probability that the intermediary has sufficient loan proceeds to repay the debt claims of the depositors, diversification among independently distributed risky loans reduces the delegation costs. In the limit. as the number of loans grows without bound, delegation costs approach zero and each ultimate lender is assured a rate of return equal to the safe rate of return. This eliminates the need to monitor the intermediary. With zero delegation costs, the total cost of intermediation is just the (induplicated) physical cost of delegated monitoring which less than the (duplicated) physical cost of direct monitoring.

We believe that the foregoing theory of financial intermediation can be used to yield insights into the relationship between growth and financial development. In all previous studies of this relationship, the mechanism of growth is the Romer (1986, 1987) mechanism of increasing returns to capital due to production externalities, We depart from this by contracting a model of growth based on increasing product variety similar to chapter 3 and 4 of the thesis (modified from Grossman and Helpman 1989; Judd 1985; Romer 1990). Growth occurs through the generation of new ideas which expands the set of intermediate inputs and so increases the efficiency of other inputs in final production.

Designs, or ideas, are created through research activities. Researchers and developers are risk-neutral entrepreneurs who require external funds to finance their risky design projects. Capital is raised from risk-neutral investors, either directly or indirectly through an intermediary. Since all agents are risk-neutral, a complete description of the optimality of any feasible set of loan contracts is given by the sum of expected monitoring costs. we consider two types of loan contract which is differ in their specifications of monitoring activity. The first type prescribes *ex post* monitoring which we shall refer to as verification. This contract is standard debt contract under which the state is observed if and only if the borrower claims bankruptcy. An example of this is when creditors appoint an auditor to investigate a bankruptcy-declared firm. The contract requires that the borrower makes a fixed payment when solvent, that the borrower is declared bankrupt if the fixed payment cannot be met and creditors recoup as much of the debt as possible from the borrower's assets in the event of bankruptcy. The second type contract prescribes *ex ante* monitoring which we shall refer to as just monitoring. This contract also requires the borrower to make a fixed repayment when solvent but does not require lender to wait for bankruptcy to be declared before they investigate the outcome of research. An example of this is when creditors appoint representatives to act as supervisors on a firm's board of control. Both types of contract must depend only on observable variables and offer lenders an expected safe rate of return. In each case, the observable variables are the fixed repayment of borrowers and inputs of the research. The most important difference between the contracts is that the cost of verification is state dependent but the cost of monitoring is state-independent. Verification costs will change if the probability of successful innovation changes which might occur as a result of specific actions taken by an entrepreneur in response to contract negotiations. This feedback effect is generally ignored in the literature which treats the probability of each state occurring as exogenous.

Our model is able to explain the positive relationship between growth and financial development. The explanation draws attention to the two-way causality in that relationship. The model is also to explain why different economies might evolve towards different financial systems. There are five sections in the chapter in addition to this introduction. Section II sets up the model. Section III contain a description of alternative financial arrangements. An arrangement may involve either direct or delegated loan contracting, either with monitoring or verification. Section IV is devoted to the study of alternative balanced growth equilibria. We compare and contrast these equilibria, each of which corresponds to a different financial system. Section V offers some concluding remarks. We represent our main results as a series of propositions. The proofs of these are contained in an Appendix.

II. The Model

The physical set-up of our representative economy builds on the models of Grossman and Helpman (1989), Hung (1993), Judd (1985) and Romer (1990). There is a constant population of infinitely-lived consumers. Productive activity takes in three sectors: a final goods sector in which a single consumption good is manufactured; a producer goods sector in which a range of intermediate goods are produced; and a research and development sector in which designs for new intermediate goods are created. All markets are characterized by price-taking except the market for each producer good which is characterized by monopolistic competition. The price numeraire of the economy is the final consumption good.

1. Consumers

Our preferred way of modelling consumers is to allocate them into two groups.[3] Both groups discount the future at the rate θ, substitute consumption intertemporally with unit elasticity, have access to a competitive capital market in which there is a riskless asset, a_t, paying the safe rate of return, r_t, and representing ownership claims on patent rights. Agents in the first group, of whom there are many, suppliers of a fixed amount of human capital, H, which earns the rate of return, w_t. Agents in the second group, of whom there are J, are risk-neutral investors who are indifferent between investing the riskless and risky assets. The risky asset, A_t, pays the random rate of return, R_t, and represents a loan to

[3] Product development in our model is conducted using the research effort of agents. if agents are able to observe whether a project is successful, and if the same agents are also the investors in product development, then problems of asymmetry information would disappear. Accordingly, we assume that suppliers of research effort are not suppliers of research funding. An alternative to this is to assume that product development requires many suppliers of research effort, each of whom is delegated a particular task and none of whom can observe the outcome of their joint effort.

entrepreneurs engaged in product development.

Given the above, equilibrium in the capital market implies

$$r_{t+1} = E_t R_{t+1} \tag{II.1}$$

$$E_t\left(\frac{C_{t+1} - C_t}{C_t}\right) = g_t \simeq r_{t+1} - \theta \tag{II.2}$$

where C_t denotes consumption and E_t is the expectations operator.[4] Equation (1) is the arbitrage condition between the riskless and risky asset. Equation (2) defines the intertemporal optimality condition for consumption.

2. The Final Goods Sector

Similar to the set up in chapter 3, the representative firm of the final goods sector maximizes its profit, taking the prices of producer goods $p_t(i)$, the wage rate w_t and the number of existing producer goods M_t as given:

$$\max_{x_t(i),\ i=1,2,\ldots,M_t;\ H_t^F} \Pi_t^F = (H_t^F)^{1-\alpha} \sum_{i=0}^{M_t} x_t(i)^\alpha - w_t H_t^F - \sum_{i=0}^{M_t} p_t(i) x_t(i) \tag{II.3}$$

where $x_t(j)$ is the quantity of the j^{th} input in final goods production (we assume away any time-to-build problem in order to avoid dynamics) and $H^F{}_t$ is the amount of human capital services employed in the final goods sector. Given the firm's maximization problem, we can solve for the derived demands for human capital services H_F and each of the inputs $x(i)$ as:

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[4] For simplicity, we use the approximation $\log(1+x) \simeq x$ for small x.

$$H_F = \frac{(1-\alpha)Y}{w}$$

$$x(i) = \frac{\alpha Y p(i)^{-\frac{1}{1-\alpha}}}{P}, \quad \textit{where } P = \sum_{i=0}^{M} p(i)^{-\frac{\alpha}{1-\alpha}} \qquad (II.4)$$

where Y_t is the volume of final goods.

3. The Intermediate Goods Sector

Each producer good is manufactured using the same technology and inputs as in the final goods sector. Thus if $z(j)$ is the total production of intermediate good j, then

$$z_t(j) = (h_t^I(j))^{1-\alpha} \sum_{i=0}^{M_t} x_t(i,j)^\alpha \qquad (II.5)$$

where $h^I_t(j)$ and $x_t(i,j)$ denote, respectively, the amounts of human capital and producer good i employed in the producer good j industry. Cost minimization produces the following derived demands for human capital services $h^I_t(j)$ and each of the inputs $x_t(i,j)$:

$$h_t^I(j) = \frac{\gamma_t(j)(1-\alpha)z_t(j)}{w_t}$$

$$x_t(i,j) = \frac{\gamma_t(j)\alpha z_t(j)\, p_t(i)^{-\frac{1}{1-\alpha}}}{P_t}, \quad \textit{where } \gamma_t(j) = \frac{\left(\frac{w_t}{P_t}\right)^{1-\alpha}}{\alpha^\alpha(1-\alpha)^{1-\alpha}} \qquad (II.6)$$

$\gamma_t(j)$ is the marginal cost.

An intermediate input embodies a design created in the research and development sector. To use a design, a firm must acquire a permit from the owner of it. In other words, there is a patent law which prohibits any firm from manufacturing an intermediate good without the consent of the patent holder of a design. We assume that the patent holder of a design for good j licenses the design to a manufacturer for a fee $q_t(j)$.[5]

Intermediate goods firms are monopolistically-competitive producers of differentiated products which are sold to final goods producers and other intermediate goods firms at the profit maximizing monopoly price $p_t(j)$. Given $q_t(j)$, each of these firms maximize $\pi_I(j)$:

$$\max_{p_t(j)} \pi^I_t(j) = p_t(j)x_t(j) - \gamma_t(j)x_t(j) - q_t(j) \qquad (II.7)$$

s.t. $z(j) = x(j) + \Sigma_i x(j,i)$, (II.4) and (II.6). Since the solution can be found in the appendix of Chapter 3, we omit it here.

4. The Research and Development Sector

Each period, there are N_t risk-neutral firms engaged in research activity. The product of each activity is a design, or blueprint, for a new intermediate good. Research is conducted using human capital and previously accumulated, generally available knowledge. We denote by $h^D{}_t(k)$ the amount of human capital employed in the kth design firm and approximate the currently available quantity of disembodied knowledge by the existing stock of designs, M_t. Each firm then has e_t, *which equals* $M_t h^D{}_t$, efficiency units of input in period t with which to innovate and produce a design in period $t+1$. As in previous chapters, the creation of new designs depends (positively) on both rival and non-rival, excludable and non-excludable inputs. But as we indicated earlier, we depart from those models by assuming a concave, rather than linear, research technology. This technology states that an innovation occurs with some probability which is given by the function $\lambda(e)$ defined on [0,1], where $\lambda'(e_t) > 0$ and $\lambda''(e_t) < 0$.

Each designer is assumed to have zero wealth. consequently, each designer lacks resources to undertake research and development unless he turns to investors for external

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5 The patent, or property right, provides the necessary excludability condition for protecting a designer's monopoly profits and preserving the incentives to innovate.

finance.[6] The decision problem for a designer is to maximize the expected present discounted value of profits from a successful innovation. If investors cannot observe directly whether a project is successful, this problem must be solved as part of the solution to an optimal incentive-compatible loan contracting problem. From our previous discussion, we know that any optimal contract (whether enforced by monitoring or verification) will require the designer to make a fixed repayment to investors if an innovation is successful. Let us denote this fixed repayment by $\eta^m{}_t(k)$ in case of monitoring and $\eta^v{}_t(k)$ in case of verification. Then if $l_t(k)$ is the amount of loans that a designer receives, the expected present discounted value of profits is

$$\pi_t^D(k) = \lambda(e_t)[Q_t(k) - \frac{\eta^i(k)}{1+r_{t+1}}] - w_t h_t^D(k) + l_t(k) \qquad (II.8)$$

for $i=v,m$, and where $Q_t(k) = \Sigma^{\infty}{}_{j=1} \Pi^j{}_{s=1} (1+r_{t+s})^{-1} q_{t+s}(k)$. The designer will maximize equation (II.8) subject to the constraints imposed by the loan contract.[7]

III. Optimal Loan Contracting

Risk-neutral investors lend to risk-neutral designers either directly or indirectly through an intermediary. In each case, either monitoring or verification may be used to enforce the optimal contract.

1. Direct Lending

We assume that each project is financed by $J' \leq J$ investors. Since investors can invest in a riskless asset, they must be convinced that the rate of return on the risky project is at least equal to the safe rate of return. Thus, an optimal loan contract will maximize the

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6 Hall (1992) presents empirical evidence on the importance of internal finance for funding research and development. A potentially rewarding avenue for future research is to model explicitly the link between growth and different methods of financing.

7 Without loss of generality, we set the designer's reservation wage equal to zero.

designer's expected profit, given a minimum expected return to lenders of at least r_{t+1}.

A. Monitoring

Let $\mu^m(k)$ be the per-project monitoring cost incurred by investors. This cost is incurred during the design stage, being independent of the project's outcome. The decision problem for a designer is to maximize equation (II.8) subject to the market constraint which incorporates the cost of monitoring

$$\lambda(e_t(k))\eta^m(k) - (1+r_{t+1})\mu^m(k) = (1+r_{t+1})l_t^m(k) \tag{III.1}$$

At the margin, the designer will equate expected marginal revenue with marginal cost. In addition, dynamic free entry will drive expected equilibrium profit to zero.[8] These two conditions may be written as respectively,

$$M_t\lambda'(e_t(k))Q_t(k) = w_t \tag{III.2}$$

new term

$$\lambda(e_t(k))Q_t(k) = w_t h_t^D(k) + \mu^m(k) \tag{III.3}$$

The appearance of $\mu^m(k)$ in equation (III.3) acts like a fixed cost in research and development. The existence of such a cost has important implications for the potential growth effects of trade policy.[9]

B. Verification

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[8] If expected profits were positive, them new firms would be encouraged to enter the design sector, increasing the competition for human capital. This would increase the wage and attract human capital from manufacturing sector. At the same time, each designer would cut back on human capital, leading to a fall in final output and a fall in the license fee. The equilibrium outcome is that the wage remains at its initial level, that each designer operates at a smaller scale but that the design sector, as a whole, employs more human capital. Positive expected profits implies re-allocations which do not occur in equilibrium.

[9] The relationship between financial development and trade is studied separately in Blackburn & Hung (1993).

Let $\mu^v(k)$ be the per-project verification cost incurred by investors. This cost is incurred only if the designer declares bankruptcy which occurs with probability $1 - \lambda(.)$. The cost of verification and market opportunity cost combine as a constraint

$$\lambda(e_t(k))\eta^v(k) - [1-\lambda(e_t)]\,\mu^v(k) = (1+r_{t+1})\,l_t^v(k) \qquad (III.4)$$

The marginal and zero-profit conditions are, respectively,

$$M_t\lambda'(e_t(k))\,Q_t(k) = w_t - \frac{M_t\lambda(e_t(k))\,\mu^v(k)}{1+r_{t+1}} \qquad (III.5)$$

$$\lambda(e_t(k))\,Q_t(k) = w_t h_t^D(k) + \frac{[1-\lambda(e_t(k))]\,\mu^v(k)}{1+r_{t+1}} \qquad (III.6)$$

The difference between verification and monitoring is reflected in the designer's equilibrium conditions. First, from equations (III.3) and (III.6), we see that the cost of verification is discounted while the cost of monitoring is not discounted. This is because verification takes place *ex post* whereas monitoring takes places *ex ante*. Second, from equations (III.2) and (III.5), we see that the designer's expected marginal cost is lower under verification than under monitoring. This is because of the state-dependency of verification costs. Whichever scheme is adopted, the designer can reduce the probability of bankruptcy by increasing research input. But only under verification does this marginal decision affect the repayment to investors who anticipate a lower probability of the need to verify and who are therefore more willing to accept a lower repayment. In other words, only under verification is the cost of capital affected. We refer to this as verification with feedback.

Now, if the designer was to take the expected verification as given, then the above result would not apply. This would occur when each investor lends to a large number of firms and conditions each contract on the average firm. Under such circumstances, an individual designer expects to make a repayment which depends on the average probability of bankruptcy determined by the average amount of research input. This means that each designer has an incentive to free ride off others. The Nash equilibrium is one in which no action is taken to reduce the probability of bankruptcy so that each designer faces a parametric verification cost. In this case, the marginal condition is equation (III.2) and the zero-profit condition is equation (III.6). We refer to this case as verification without feedback.

2. Financial Intermediation

When investors delegate the task of monitoring or verification, the cost of this task is not duplicated. On the other hand, the delegated institution must, itself, be monitored or verified. For simplicity, we assume that the number of depositors with the intermediary is $J' \leq J$, the same as the number of investors in each project in the case of direct lending. We also assume that depositors enforce loan contracts with the intermediary through verification. let $\mu^{v}{}_{J'}$, be the cost of this verification. Let $\rho^{i}(N_t)(i{=}m,v)$ be the average *net* repayment from designers to the intermediary and $R^{D}{}_{t+1}$ be the average repayment from the intermediary to depositors. Finally, let $F(\rho^{i}(N_t))$ be the cumulative distribution function of $\rho^{i}(N_t)(i{=}m,v)$. Depositors with the intermediary must expect a rate of return equal to the safe rate of return:

$$\frac{(1+r_{t+1})}{N_t}\sum_{k=1}^{N} l_t^i(k) = R_{t+1}^{D}[1-F_N(R_{t+1}^{D})] + \int_0^{R_{t+1}^{D}} x\,dF_N(x) - \frac{\mu_{J'}^{v}F_N(R_{t+1}^{D})}{N_t} \qquad (III.7)$$

where $F_N(x) = \text{Prob}\,[\rho^{i}(N_t) < x]$ for $i{=}m,v$. At the same time, the intermediary must expect average net repayments from designers to cover its own average repayments to depositors:

$$E(\rho^{i}(N_t)) \geq R_{t+1}^{D} \qquad (III.8)$$

for $i{=}m.v$. With free entry to the intermediation market, equality holds in equation (III.8).

A. Monitoring

The per-project cost of delegated monitoring is now $\hat{\mu}^{m}(k) = \mu^{m}(k)/J'$. The average net repayment to the intermediary from designers is

$$\rho^m(N_t) = \frac{\sum_{k=1}^{N_t} \eta_t^m(k)\,\xi(k)}{N_t} - (1+r_{t+1})\frac{\sum_{k=1}^{N_t} \hat{\mu}^m(k)}{N_t} \tag{III.9}$$

where $\xi(k)$ is a Bernoulli random variable with mean $\lambda(.)$. A designer will maximize equation (II.8) subject to equations (III.7), (III.8) and (III.9).

A. Verification

The per-project cost of delegated verification is $\hat{\mu}^v(k) = \mu^v(k)/J'$. The average net repayment to the intermediary from designers is

$$\rho^v(N_t) = \frac{\sum_{k=1}^{N_t} \eta_t^v(k)\,\xi(k)}{N_t} - \frac{\sum_{k=1}^{N_t} \hat{\mu}^v(k)(1-\xi(k))}{N_t} \tag{III.10}$$

and the decision problem of a designer is to maximize equation (II.8) subject to equations (III.7), (III.8) and (III.10).

3. Delegation Dominance and the Efficient Contract

It is possible to establish conditions under which financial intermediation will always be preferred to direct lending and borrowing. To do this, denote by $\psi^i(N_t)$ for $i=m,v$, the expected delegation cost project of providing incentives to the intermediary. This cost is defined by

$$\begin{aligned} \lambda_t(k)\eta_t^m(k) &= (1+r_{t+1})[\hat{\mu}^m(k) + l_t^m(k) + \psi_t^m] \\ \lambda_t(k)\eta_t^v(k) &= \hat{\mu}^v[1-\lambda_t(k)] + (1+r_{t+1})[l_t^v(k) + \psi_t^v] \end{aligned} \tag{III.11}$$

With equation (III.9), ψ^i is equal to

$$\psi^i = \frac{\left[\dfrac{\mu^v_{J'} + (1+r_{t+1})\sum_{k=1}^{N_t} l_t(k)}{N_t}\right] F(R^D_{t+1}) - \int_0^{R^D_{t+1}} \rho^i(N_t)\, dF(\rho^i(N_t))}{[1 - F(R^D_{t+1})](1+r_{t+1})} \qquad (III.12)$$

for $i=m,v$. The first term in the numerator of this expression is depositors' expected verification cost for the intermediary plus expected opportunity cost of the loan. The second term is depositors' expected residual receipts from the intermediary in the bankruptcy state. The discount factor in the denominator includes $1 - F(.)$ because the compensation to depositors can be payed by the intermediary only in the non-bankruptcy state.

The sum $\mu^m(k)/J' + \psi^m(.)$ is the total cost per project of delegated monitoring and the sum $[1 - \lambda(.)]\mu^v(k)/[(1 + r_{t+1})J'] + \psi^v(.)$ is the expected (discounted) total cost per project of delegated verification. Delegation pays if

$$\min\left\{ \frac{\mu^m}{J'} + \psi^m(.)\ ,\ \frac{[1-\lambda(.)]\mu^v(k)}{(1+r_{t+1})J'} + \psi^v(.) \right\} \le \min\left\{ \mu^m(k)\ ,\ \frac{[1-\lambda(.)]\mu^v(k)}{1+r_{t+1}} \right\}$$

Clearly, if $J' = 1$ and $\psi^i(.) > 0$ for $i=m,v$, then delegation will never be preferred since its only effect is to introduce additional delegation costs. For $J' > 1$, however, delegation brings benefits in the form of reduced monitoring or verification costs which are no longer duplicated. Given that $J' > 1$, we can appeal to the following result which establishes the condition for the unambiguous dominance of delegation:[10]

LEMMA 1: $\lim_{N\to\infty} \psi^i(N_t) = 0$ for $i=m,v$.

With the law of large number, the probability of insolvent state of the intermediary is

[10] We assume that contracts written between the intermediary and designers are same type. Given the symmetry assumption, we may even possible to show that it is an equilibrium arrangement.

converging zero. With sufficient large number of independently distributed projects, there is an inverse relationship between the expected delegation cost per project and the number of projects. In the limit, as the number of projects grows without bound, the expected delegation cost approaches zero and the total cost of delegation reduce to just the physical cost of monitoring or verification. This cost is less under delegation than under direct lending because of the elimination of duplication.

The equilibrium arrangement when $N_t \to \infty$ is for all project funding to be provided by a financial intermediary which writes large numbers of contracts with designers, earn zero profits and writes contracts with depositors who are guaranteed a competitive rate of return, that is the safe rate of return. The equilibrium (marginal and zero-profit) conditions for a designer are unchanged from the case of direct lending and borrowing, except that $\mu^m(k)(\mu^v(k))$ is replaced by $\mu^m(k)/J'(\mu^v(k)/J')$. Whether or not delegation dominates, the choice between monitoring and verification is determined according to the same efficiency criterion - namely, min $\{\mu^m(k),[1-\lambda(.)]\mu^v(k)/(1+r_{t+1})\}$.

IV. Balanced Growth Equilibria

A steady state equilibrium of the economy is one in which (a) all participants are optimizing, (b) all markets are clearing and (c) all non-stationary variables are growing at the common rate g. Our first step in computing such an equilibrium prices and quantities will be the same across all firms in each sector. We also define $w^* = w_t/M_t$(the constant growth adjusted wage), $n = N_t/M_t$(the constant ratio of the potential flow of new designs to the stock of existing designs), $H^I = M_t h^I{}_t$ *(the constant* total amount of human capital employed in the intermediate goods sector), $H^D = N_t h^D{}_t$(the constant total amount of human capital employed in the design sector) and $e = M_t h^D{}_t = M_t H^D{}_t/N_t$(the constant total number of efficiency units of inputs in research and development). Our solution then proceeds as follows[11]:

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[11] The constancy of w^*, which is a function of α, the proof can be found in the appendix of Chapter 3.

Using $Z_t = M_t z$ and $P_t = M_t p^{\alpha/(\alpha-1)}$, where $p = \gamma/\alpha$ is the constant mark up of price competition, we can calculate $z = \alpha^2 Y_t/[(1-\alpha^2)\gamma M_t]$. After some manipulation, $H^I = \alpha^2 Y_t/[(1+\alpha)w^* M_t]$ and $q = \alpha Y_t/[(1+\alpha)M_t]$. Using the equation (II.4) and human capital market equilibrium condition ($H = H^F + H^I + H^D$), we obtain the allocation of human capital to research sector and development as $H - ne = q/(\alpha w^*)$. Given that the probability of a successful innovation is independent across designers, the expected flow of new designs is $M_{t+1} - M_t = \lambda(.)N_t$. Thus, since steady state growth occurs at the rate $(M_{t+1} - M_t)/M_t$, we have $g = \lambda(.)n$. Finally, we note that $Q = q/r$.[12]

1. Direct Lending

The balanced growth equilibrium under each type of financial arrangement is summarized in Table 5.1:

LEMMA 2: *Given (i) $\lambda'(e) > 0$ and $\lambda''(e) < 0$, (ii) $\lambda(e) > e\,\lambda'(e)$, (iii) $\lim_{e \to 0} \lambda' \to$ constant $< \infty$ and (iv) an $e^m = e^m(\mu^m) < e^1$, where $\alpha H \lambda(e^1) = \theta$ and e^m satisfying $w^*[\lambda(e^m) - e^m \lambda'(e^m)]/\lambda'(e^m)$. $\exists$ a unique balanced growth equilibrium with growth rate $g^m = g^m(H, \mu^m) > 0$, such that $\partial g^m(.)/\partial H > 0$ and $\partial g^m/\partial \mu^m < 0$.*

LEMMA 3: *Given (i) $\lambda'(e) > 0$ and $\lambda''(e) < 0$, (ii) $\lambda(e) > e\,\lambda'(e)$, (iii) $\lambda'(e) + e\lambda''(e) < 0$ and (iv) $\lim_{e \to 0} \lambda' \to$ constant $< \infty$, (v) Given $f(e) \equiv \alpha H \lambda'(e) + \theta[\lambda(e) - e\lambda'(e)]$, $\lim_{e \to 0} f(e) > \theta$ and (vi)*

$$\lim_{e \to e^1} \frac{w^*[\lambda(e) - e\lambda'(e)]}{\lambda'(e)} > \frac{\mu^v}{1+\theta} \qquad (IV.1)$$

where $f(e^1) = \theta$ such that $\exists$ at least one $e^v = e^v(H, \mu^v)$, where $e^v \in (0, e^1)$. With some regularity conditions, $\exists$ a unique e^v, $\partial e^v/\partial H < 0$ and $\partial e^v/\partial \mu^v > 0$ and a balanced growth equilibrium with growth rate $g^v = g^v(H, \mu^v) > 0$,

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12 The constancies of n, H^I, H^D and e follow from the steady state equilibrium condition.

such that $\partial g^v(.)/\partial H > 0$ and $\partial g^v/\partial \mu^v < 0$.

LEMMA 4: *Given (i) $\lambda'(e) > 0$ and $\lambda''(e) < 0$, (ii) $\lambda(e) > e\,\lambda'(e)$, (iii) $\lambda'(e)+e\lambda''(e) < 0$ and (iv) $\lim_{e\to 0} \lambda' \to$ constant $< \infty$, (v) an $e^m = e^m(\mu^m) < e^1$, where $\alpha H\lambda(e^1) = \theta$ and*

$$\lim_{e\to e^1} \frac{w^*[\lambda(e)-e\lambda'(e)]}{\lambda'(e)[1-\lambda(e)]} > \frac{\mu^v}{1+\theta} \qquad (IV.2)$$

and with some regularity conditions, $\exists$ only one $\tilde{e}^v = \tilde{e}^v(H,\mu^v)$, where $\tilde{e}^v \in (0,e^1)$, $\partial\tilde{e}^v/\partial H < 0$, $\partial\tilde{e}^v/\partial\mu^v > 0$ and a balanced growth equilibrium with growth rate $\tilde{g}^v(H,\mu^v) > 0$, where $\partial\tilde{g}^v/\partial H > 0$ and $\partial\tilde{g}^v/\partial\mu^v < 0$.

As explained earlier the mechanism of growth is the increasing variety of intermediate inputs associated with the increasing number of firms engaged in research and development. Growth is sustainable despite the concave research technology because the number of efficiency units of research input, $e = M_t h^D{}_t$, remains constant. As the economy grows, the increasing number of research firms intensifies competition for human capital in the research sector. This results in each firm, individually, cutting back on its human capital input. The allocation of human capital across sectors remains the same but aggregate research activity increases. As more resources become available to finance research with technological improvement with M_t, the economy can sustain a constant growth rate of new designs. Moreover, An increase of human capital endowment and a decrease of the cost of monitoring or verification can speed up the economic growth.

2. Financial Intermediation

Let $N_t \to \infty$. Then, as indicated earlier, the balanced growth equilibrium under delegated monitoring (verification) is just the balanced growth equilibrium under direct monitoring (verification) with μ^m (μ^v) replaced by $\hat{\mu}^m = \mu^m/J'$ ($\hat{\mu}^v = \mu^v/J'$).

PROPOSITION 1: *Given Lemmas 2,3 and 4, steady state growth is always higher under* *financial intermediation than under direct lending and borrowing.*

The effect of financial intermediation is to reduce the cost in research and development. As design firms begin to operate at a positive profit because of lower cost, new firms are encouraged to enter the research sector. Following the previous argument, this results in each firm, individually, operating at a smaller scale but the economy, as a whole, experiencing an increase in research activity. A more extreme version of Proposition 1 is

PROPOSITION 2: *For each financial arrangement, ∃ a $J'_0 > 1$ such that the growth rate is zero under direct lending and positive under financial intermediation.*

If each project requires a large number of investors, then the costs of direct monitoring or direct verification may be so large as to discourage any research and development. By eliminating duplication,intermediation can resolve this problem.

Proposition 1 and 2 imply that the direction of causality in the positive relationship between growth and financial development runs from the latter to the former. The converse result can also be established and is stated as

PROPOSITION 3: *Let $J' < J'_0$ in an initial equilibrium with direct lending and borrowing. Given lemma 1, ∃ an N_t at which direct lending and borrowing is replaced by financial intermediation.*

As the economy grows, the delegation costs of intermediation fall, Sooner or later, these costs will be more than offset by the monitoring (or verification) cost saving from intermediation.

As implication of the results obtained so far is that some countries could become trapped in a vicious circle of low economic growth and low financial development. In the absence of institutional reforms, economies which are initially stagnant and financially repressed might forever remain in stagnation and repression, reforming the financial sector of an economy is one way of escaping from this trap and establishing a virtuous circle of growth and financial development. Reforming international arrangements is another possibility that are studied in a separate paper.

3. Monitoring Versus Verification

The foregoing analysis related growth to one aspect of financial system - the choice between direct lending and financial intermediation. We now relate growth to another aspect - the choice between monitoring and verification.

LEMMA 5: *Given the same endowment H and $\mu^m > \mu^v$. Economy can have higher growth and less costly with financial arrangement of verification.*

Given the lemma 5, we can show

PROPOSITION 4: *$\exists$ a $\mu^m{}_0$ and $\mu^v{}_0$ such that the growth rate under monitoring is greater than the growth rate under verification but verification is less costly than monitoring.*

In other words, a market economy might choose to be in a relatively low growth equilibrium because of lower cost of verification financial arrangement. Alternatively, an economy might saddle itself with a costly financial system if the objective is to promote growth.

V. Conclusions

This chapter has been motivated by the overwhelming evidence that economic growth depends on the financial regime of economies. The evidence shows clearly that growth is impeded by financial repression. At the same time, there are reasons to believe why the financial arrangement may be affected by the growth process. Thus, cross-country differences in institutions may explain, to be explained by, cross-country differences in growth rates. The structure of institutions cannot be taken as given when considering the dynamic evolution of economies. Rather, one must conduct a general equilibrium analysis of the joint endogenous determination of economic and institutional development.

In this chapter we have sought to construct a theory of economic growth and financial development in order to explain the relationship between these activities. The theory has been based on a cross-fertilization of ideas from the literature on endogenous growth and financial intermediation. Our reading of these literature suggest several other potentially rewarding avenues for future research. Included amongst these are the issues of internal versus external finance for research and development (Hall (1992)), strategic intertemporal price setting and collusion between researchers and developers, and financial intermediation as a form of commitment in funding research and development (Hellwig (1990); Mayer (1988)). We hope to address these issues in future.

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APPENDIX

A. Proof of Lemma 1

Given equations (III.17), (III.18) and (III.19), ψ^i is equal to

$$\psi^i = \frac{\left[\dfrac{\mu^m_{J'} + (1+r_{t+1})\sum_{k=1}^{N_t} l^i_t(k)}{N_t}\right] F_N(R^D_{t+1}) - \int_0^{R^D_{t+1}} x dF_N(x)}{[1-F_N(R^D_{t+1})]\,(1+r_{t+1})} \qquad (A.1)$$

for i=m, v. We omit the time subscript to simply the notation. With symmetric projects, and by using integration by part, ψ^i can be expressed

$$\psi^i = \frac{\left[\dfrac{\mu^m_{J'}}{N} + (1+r)\,l - R^D\right] F_N(R^D) + \int_0^{R^D} F_N(x)\,dx}{[1-F_N(R^D)]\,(1+r)} \qquad (A.2)$$

Since $R^D = E[\rho^i(N)]$, and $\forall\ \rho(N) < E[\rho(N)]$, $\lim_{N\to\infty} F[\rho(N)] = 0$, it implies $\lim_{N\to\infty} \psi^i = 0$.

Q.E.D.

B. Proof of Lemma 2:

Use the expressions in Table 5.1 to to write n as

$$n(H,e) = \frac{\alpha H\lambda(e) - \theta}{\lambda(e) + \alpha e\lambda'(e)} \qquad (A.3)$$

where $\partial n/\partial H > 0$ and $\partial n/\partial e < 0$. Provided $\lim_{e\to 0} \alpha H\lambda'(e) > \theta$, $\exists$ an $e^1 > 0$ such that $\alpha H\lambda'(e^1) = \theta$. With $\lim_{e\to 0} w^*[\lambda(e)-e\lambda'(e)]/\lambda'(e) < \mu^m$ and $\lambda(e) - e\lambda'(e) > 0$. If e^m satisfies $w^*[\lambda(e^m)-e^m\lambda'(e^m)]/\lambda'(e^m) = \mu^m$ and $e^1 > e^m$, $g^m = g^m(H,\mu^m) = \lambda[e^m(\mu^m)]n^m[H,e^m(\mu^m)] > 0$ and $\partial g^m/\partial H > 0$ and $\partial g^m/\partial \mu^m < 0$.

Q.E.D.

C. Proof of Lemma 3:

Use the expressions in Table 5.1 to to write n as

$$n(H,e) = \frac{\alpha H\lambda(e) + \theta[\lambda(e) - e\lambda'(e)] - \theta}{\lambda(e)[1-\lambda(e)+e\lambda(e)] + \alpha e\lambda'(e)} \tag{A.4}$$

where $\partial n/\partial H > 0$. Let $f(e) \equiv \alpha H\lambda'(e)+\theta[\lambda(e)-e\lambda'(e)]$, provided $\lim_{e\to 0} f(e) > \theta$ and given $f(e) < 0$ for $e < \alpha H/\theta$. $\exists$ an $e^1 \in (0,\alpha H/\theta)$ where $f(e^1) = \theta$. Let $g(H,e) \equiv \lambda(e)n(H,e)$, given $\lambda(e) > e\lambda'(e)$ and $\lambda'(e) + e\lambda''(e) \leq 0$, it implies $\partial g/\partial e < 0$. With

$$\lim_{e\to 0} \frac{w^*[\lambda(e) - e\lambda'(e)]}{\lambda'(e)} < \lim_{e\to 0} \frac{\mu^v}{1+\theta+\lambda(e)\,n(H,e)} \tag{A.5}$$

and

$$\lim_{e\to e^1} \frac{w^*[\lambda(e) - e\lambda'(e)]}{\lambda'(e)} > \frac{\mu^v}{1+\theta} \tag{A.6}$$

$\exists$ at least one $e^v = e^v(H,\mu^v)$, where $e^v \in (0,e^1)$, $\partial e^v/\partial H < 0$, $\partial e^v/\partial \mu^v > 0$, which satisfies

$$\frac{w^*[\lambda(e) - e\lambda'(e)]}{\lambda'(e)} - \frac{\mu^v}{1+\theta+\lambda(e)\,n(H,e)} = 0. \tag{A.7}$$

With addition regularity conditions: (i) $\lambda''' < 0$ and (ii) $\forall\ e \in (0,e^1)$, $1+\theta \neq [2g'(e) - g(e)g''(e)]/g''(e)$. With (i), the first term of equation (34) is *convex* in e and with (ii), $\forall\ e \in (0,e^1)$, *there is no point of reflection* in the second term of equatiom (34). As a result, $\exists$ only one e^v satisfies equation (34) within the interval $(0,e^1)$. Since $e^v < e^1$, $g^v = g^v(H,\mu^v) = \lambda[e^v(H,\mu^v)]n[H,e^v(H,\mu^v)] > 0$, where $\partial g^v/\partial H > 0$ and $\partial g^v/\partial \mu^v < 0$. Q.E.D.

D. Proof of Lemma 4:

Use the expressions in Table 5.1 to to write n as

$$n(H,e) = \frac{\alpha H\lambda(e) - \theta}{\lambda(e) + \alpha e\lambda'(e)} \tag{A.8}$$

where $\partial n/\partial H > 0$ and $\partial n/\partial e < 0$. Provided $\lim_{e\to 0} \alpha H\lambda'(e) > \theta$, $\exists$ an $e^1 > 0$ such that $\alpha H\lambda'(e^1) = \theta$. Let $g(H,e) \equiv \lambda(e)n(H,e)$, if $\lambda'(e) + e\lambda''(e) \leq 0$, it implies $\partial g/\partial e < 0$. With

$$\lim_{e\to 0} \frac{w^*[\lambda(e) - e\lambda'(e)]}{\lambda'(e)[1-\lambda(e)]} < \lim_{e\to 0} \frac{\mu^v}{1+\theta+\lambda(e)\,n(H,e)} \tag{A.9}$$

and provided that

$$\lim_{e\to e^1} \frac{w^*[\lambda(e)-e\lambda'(e)]}{\lambda'(e)[1-\lambda(e)]} > \frac{\mu^v}{1+\theta} \qquad (A.10)$$

and with similar regularity conditions from above, $\exists$ only one $\tilde{e}^v = \tilde{e}^v(H,\mu^v)$, where $\tilde{e}^v \in (0,e^1)$, $\partial\tilde{e}^v/\partial H < 0$, $\partial\tilde{e}^v/\partial\mu^v > 0$, which satisfies

$$\frac{w^*[\lambda(e)-e\lambda'(e)]}{\lambda'(e)[1-\lambda(e)]} - \frac{\mu^v}{1+\theta+\lambda(e)n(H,e)} = 0. \qquad (A.11)$$

Since $\tilde{e}^v < e^1$, $\tilde{g}^v = \tilde{g}^v(H,\mu^v) = \lambda[\tilde{e}^v(H,\mu^v)]n[H,\tilde{e}^v(H,\mu^v)] > 0$, where $\partial\tilde{g}^v/\partial H > 0$ and $\partial\tilde{g}^v/\partial\mu^v < 0$. Q.E.D.

E. Proof of Proposition 1:

From Lemmas 2, 3 and 4, $\partial g^m(.)/\partial\mu^m < 0$, $\partial g^v(.)/\partial\mu^v < 0$. Under intermediation, μ^v (μ^v) is replaced by $\hat{\mu}^m = \mu^m/J'$ ($\hat{\mu}^v = \mu^v/J'$). It follows that $g^m(H,\mu^m) < g^m(H,\mu^m/J')$, $g^v(H,\mu^v) < g^v(H,\mu^v/J')$ and $\tilde{g}^v(H,\mu^v) < \tilde{g}^v(H,\mu^v/J')$. Q.E.D.

F. Proof of Proposition 2:

Consider the case of monitoring, Set $g^m = 0$ and use the equation (A.3) which $e = e(\mu^m)$ which is derived from $w^*[\lambda(e) - e\lambda'(e)]/\lambda'(e) = \mu^m$ and $\partial e(.)/\partial\mu^m > 0$. Observe that $g^m = 0$ when $n^m = 0$ and recall that $\mu^m = \hat{\mu}^m J'$. Then provided that $\lim_{J'\downarrow 1} H\alpha\lambda'[e(\hat{\mu}J')] > \theta$, $\exists$ a $J'_0 > 1$ such that $H\alpha\lambda'[e(\hat{\mu}J')] = \theta$, implying $g^m = n^m = 0$. Under intermediation, $\exists$ no such J'_0 since μ^m is replaced by $\hat{\mu}^m$.

A similar proof can applied to the case of verification. Q.E.D.

G. Proof of Proposition 3:

Suppose $\min\{\mu^m/J'+\psi(N_0),[1-\lambda(.)\mu^v/[J'(1+r_1)]+\psi(N_0)\} > \min\{\mu^m,[1-\lambda(.)\mu^v/[J'(1+r_1)]\}$ at time 0. Given $J' < J'_0$, by proposition 2, $g^m(H,\mu^m{}_{J'}) > 0$. Therefore N_t grows. With lemma 1, $\psi^i \to 0$, for $i=m,v$. $\exists$ a $N^0{}_t$, $\forall N_t > N^0{}_t$, such that

$$\min\left\{ \frac{\mu^m}{J'} + \psi^m(.) \;,\; \frac{[1-\lambda(.)]\,\mu^v(k)}{(1+r_{t+1})\,J'} + \psi^v(.) \right\} \le \min\left\{ \mu^m(k) \;,\; \frac{[1-\lambda(.)]\,\mu^v(k)}{1+r_{t+1}} \right\} \tag{A.12}$$

Q.E.D.

H. Proof of Lemma 5:

Define $g_m(H,e) = \lambda(e)n(H,e)$ from $n(H,e)$ of equation (30) and similar for $g_v(H,e)$ from $n(H,e)$ of equation (31).

$\forall\, H, e, g_m(H,e) < g_v(H,e)$. And let $\Lambda(e) = w^*[\lambda(e)-e\lambda'(e)]/\lambda'(e)$, given $\mu^m{}_0 > \mu^v{}_0$ (which g^m and g^v are both positive), $e^v < e^m$ ($\because\ \Lambda(e^m) = \mu^m{}_0 > \mu^v{}_0/(1+\theta+g^v) = \Lambda(e^v)$). Hence with $\partial g_i/\partial e < 0$ $(i=m,v)$, $g_m[H,e^m(\mu^m{}_0)] < g_m[H,e^v(\mu^v{}_0)] < g_v[H,e^v(\mu^v{}_0)]$. Obviously, since $\lambda(e^v) > 0$, $\{1-\lambda[e(\mu^v{}_0)]\}\mu^v{}_0 < \mu^m{}_0$. Q.E.D.

I. Proof of Proposition 4:

$\exists\ \mu^m{}_0$ and $\mu^v{}_0$ which $g_m[H,e^m(\mu^m{}_0)] < g_v[H,e^v(H,\mu^v{}_0)]$, with lemma 5, this implies $\mu^m{}_0 < \mu^v{}_0$. Provided $e^v(H,\mu^v{}_0) > e^1$ defined in lemma 3, $\exists\ H$, such that $\lambda[e^v(H,\mu^v{}_0)]$ is large enough for $\{1-\lambda[e^v(H,\mu^v{}_0)]\}\mu^v{}_0 < \mu^m{}_0$. Q.E.D.

Table 9: Balanced Growth Equilibria Under Alternative Financial Arrangements.

Monitoring

$$g^m = r^m - \theta$$

$$g^m = \lambda(e^m)n^m$$

$$H - n^m e^m = \frac{r^m}{\alpha\lambda'(e^m)}$$

$$\left[\frac{\lambda(e^m) - e^m\lambda'(e^m)}{\lambda'(e^m)}\right]w^* = \mu^m$$

Verification

With Feedback

$$g^v = r^v - \theta$$

$$g^v = \lambda(e^v)n^v$$

$$H - n^v e^v = \frac{r^v}{\alpha w^*}\left[\frac{w^*}{\lambda'(e^v)} - \frac{\mu^v}{1 + r^v}\right]$$

$$\left[\frac{\lambda(e^v) - e^v\lambda'(e^v)}{\lambda'(e^v)}\right]w^* = \frac{\mu^v}{1 + r^v}$$

Without Feedback

$$\tilde{g}^v = \tilde{r}^v - \theta$$

$$\tilde{g}^v = \lambda(\tilde{e}^v)\tilde{n}^v$$

$$H - \tilde{n}^v\tilde{e}^v = \frac{\tilde{r}^v}{\alpha\lambda'(\tilde{e}^v)}$$

$$\left[\frac{\lambda(\tilde{e}^v) - \tilde{e}^v\lambda'(\tilde{e}^v)}{\lambda'(\tilde{e}^v)[1 - \lambda(\tilde{e}^v)]}\right]w^* = \frac{\mu^v}{1 + \tilde{r}^v}$$